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

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Objectives

- Optimization of the Siemens DELTA-N solid oxide fuel cell (SOFC) and scale-up of its dimensions.
- 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) of lesser multi-MWe capacity.

Approach

- Analytical modeling to optimize the DELTA-N cell geometry.
- Develop a viable cell manufacturing process 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.

Accomplishments

- Evaluated multiple proof-of-concept and baseline system candidate cycle concepts.
- Developed a figure-of-merit system with which the candidate systems are to be compared.
- Redefined the reference cycle concept for the baseline power system to a less complex technology basis that should provide for more reliable implementation.
- Identified a preferred cycle configuration for the proof-of-concept system.
- Optimized the high power density (HPD) DELTA-N cell geometry for the air feed tube and axial fuel flow configuration.
- Successfully extruded and sintered HPD DELTA-N tubes.
- Completed the conceptual design of the most critical stack components.
- Completed shakedown of the pressurized cell test facility.

Future Directions

- Optimize baseline cycle configuration.
- Update and initiate conceptual design of proof-of-concept system based on optimized baseline system configuration.
- Execute cell and stack performance test.
- Optimize atmospheric plasma spray (APS) operating parameters.
- Continue the conceptual design for the module.

Introduction

Siemens Power Generation SFC will develop a MWe-class solid oxide fuel cell power system to operate on coal-derived synthesis gas and demonstrate operation at greater than 50% electrical efficiency (basis higher heating value [HHV] 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 SOFC 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 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 was redeveloped as the gas turbine and the ion transport membrane (ITM), respectively, were removed from the cycle, the SOFC system is now at atmospheric pressure, and a steam turbine bottoming cycle has been integrated into the heat recovery system. The reference cycle includes an oxygen-blown gasification system with conventional cleanup and scrubbing to produce a syngas rich in hydrogen and carbon monoxide. After shifting, the CO_2 is removed from the syngas via a low-temperature polymer membrane. Oxygen for the gasification process is supplied by a cryogenic air separation unit.

This reference cycle SOFC/steam turbine (ST) configuration is less complex than its predecessor and should provide for more reliable implementation at the POC level. Operating at ambient pressure, the SOFC system is composed of multiple, identical SOFC modules that receive preheated air from the heat recovery system. The SOFC modules are based upon the high power density DELTA-N cell geometry, developed within this project. Cell and stack performance and durability will be verified via performance testing of single and multiple cells (bundles).

Approach

The baseline SOFC/ST power system is fueled by coal-derived syngas. The overall objectives are high electrical efficiency and CO_2 separation capability. The baseline system power capacity is to exceed 100 MWe whereas the proof-of-concept system is to be in the 10 MWe-class range. Several candidate cycle configurations were identified that could be implemented at the >100 MWe level. These configurations were 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 the 10 MWe-class capacity. The efficiency target for the POC is 50% (net AC/coal HHV).

SFC is developing 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 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 SOFC/gas turbine (PSOFC/GT) hybrid power system. Further innovation will be required, particularly in 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 will be characterized via a series of single and multi-cell tests.

Results

A number of cycle configurations 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 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.

A seal-less module configuration that features an air feed tube and an axial fuel flow was developed, a result of an investigation evaluating numerous stack configurations. Also, as a result of numerous finite element analyses (FEA), the dimensions of the DELTA-N cell were optimized. Based on these dimensions, an optimization of the various layers of the cell to minimize electrical performance losses and internal stresses was initiated. The validation of the optimized cell geometry commenced via the successful extrusion and sintering of a number of DELTA-N tubes. These tubes are now being used to optimize the APS operating parameters.

Conclusions

Systems analysis indicate the performance objectives (>50% electrical efficiency, net AC/coal HHV) can be achieved and exceeded with the successful implementation of improvements in SOFC module and balance-of-plant component technologies, in cell and module efficiencies, and advanced materials and fabrication processes for the DELTA-N cell.

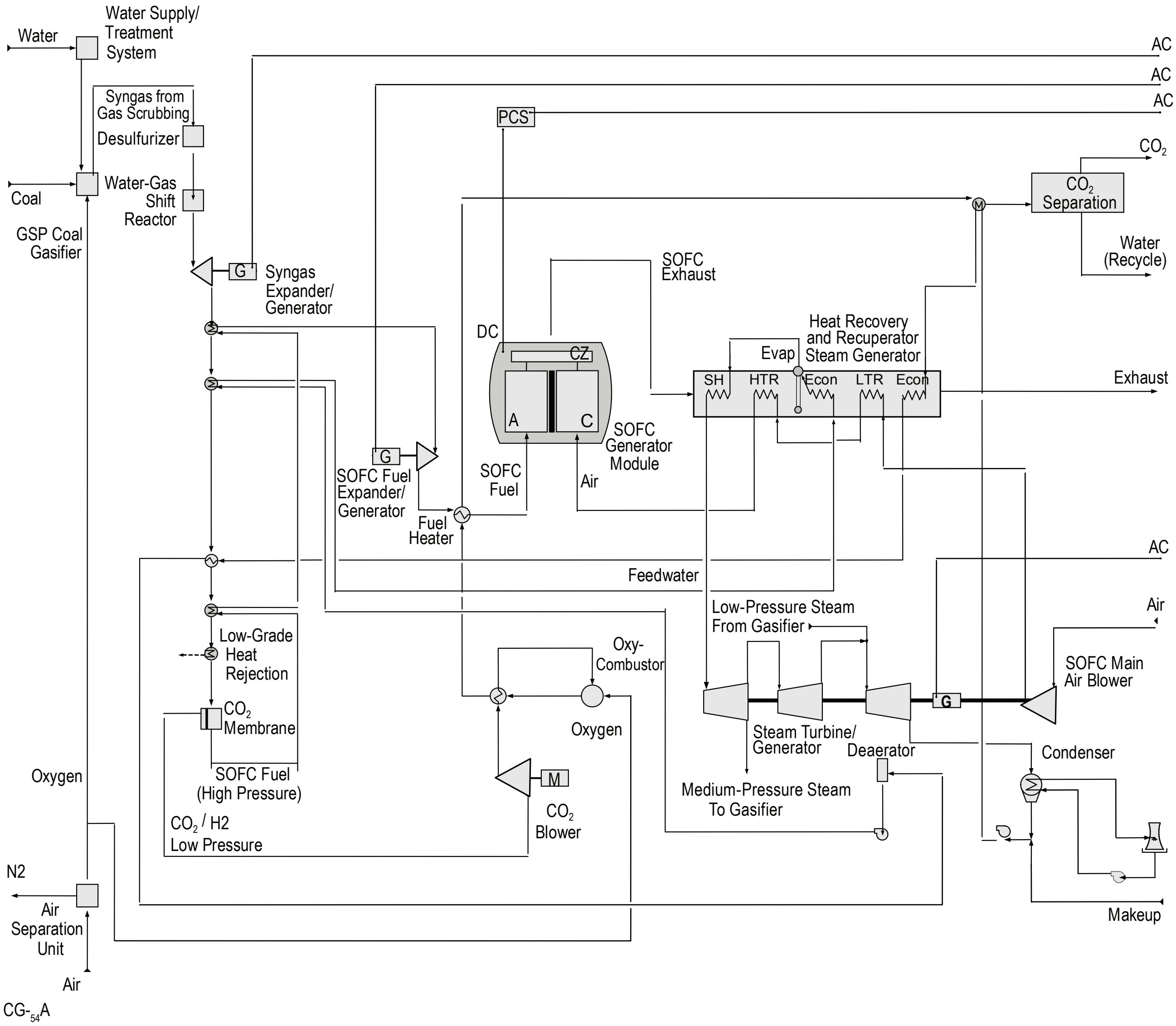

FIGURE 1. Baseline SOFC/ST Power System, Reference Cycle