Large Scale Hybrid SOFC Power Generators from Rolls-Royce Fuel Cell Systems

Gerry D. Agnew, Stephen H. Pyke, Michael B. Jorger, Rowland P. Travis
Rolls-Royce Fuel Cell Systems Limited, Loughborough, Leicestershire, UK

Growing demands for energy in the modern world require increased efficiency in the use of resources to generate power. This paper identifies the opportunity for technology development in this space, and the requirements for a solution to this issue. Solid oxide fuel cells (SOFCs) at megawatt scale offer a potential solution at high (60+%) efficiency and benefit from a fuel flexibility not enjoyed by other types of fuel cell. This paper presents the Rolls-Royce Fuel Cell Systems Limited (RRFCS) technology to deliver a SOFC system at this scale and address the inherent challenges.

1. Introduction

International Energy Agency (IEA) projections point to a growth in global energy demand of over 50% by 2030, with more than 80% of this growing energy requirement continuing to be met by fossil fuels [1]. Global energy-related CO₂ emissions are likely to grow at an even faster rate due to the use of more carbon-intensive fuels. More than half of these emissions will come from the power generation sector. The need for more efficient means of generating power is therefore clear if a reduction in the growth of CO₂ emissions is to be achieved. Further CO₂ emissions reductions can be achieved if transmission losses associated with centralised power generation can be lessened.

Re-regulation of electricity markets has already led to a reduction in the investment in large-scale power plants. Allied to the increasing cost and planning difficulties of installing new power lines, this clearly favours the installation of distributed generation close to the point of use. This has created potential markets that fuel cell systems should be ideally placed to meet. One such market opportunity is for units in the 1-10 MW power range, which are well-matched to, for example, hospitals, industrial sites, educational establishments and other medium-sized clusters of buildings. At this power level hybrid solid oxide fuel cell systems operating on pipeline natural gas potentially offer an electrical power generation efficiency of 60+ % [2].

2. Rolls-Royce Fuel Cell Systems Limited

Rolls-Royce, the world-leading provider of power systems and services for use on land, at sea and in the air, operates in four global markets - civil aerospace, defence aerospace, marine and energy. It is investing in core technology, capability and infrastructure that can be applied across these sectors to take a competitive range of products to market.

The company has established strong positions within programmes that will shape the power-systems market for many years to come. In the energy markets, Rolls-Royce is investing in new products and capabilities for the oil and gas industry and for distributed electricity generation.

Rolls-Royce has been developing a SOFC system since 1992 (see for example ref. 3, 4, 5, 6, 7). Since 2004, the development has been conducted by RRFCS, a majority-owned subsidiary of Rolls-Royce plc, and the focus has been megawatt-scale power generation. As can be seen from Figure 1 this is naturally complementary to other aero-derivative power generation technologies that the company produces.

3. The RRFCS Fuel Cell System

The essential concept for the RRFCS fuel cell system is shown in Figure 2. The basic building block of the RRFCS stack is a bought-in flat ceramic “tube” which contains internal channels for fuel flow and is porous to allow diffusion of the fuel to the active anode layer. On the outer faces of the tube, the electrochemical layers of the fuel cell are printed using state-of-the-art screen-printing and sintering processes. Additional processes apply a gas-tight layer to seal the remaining exposed areas of the tube. The cells are...
The system operates at a nominal temperature and pressure of 900 °C and 7 bar respectively. At this temperature it ensures high ionic conductivity of a standard yttria stabilized zirconia (YSZ) electrolyte. It also allows conventional choices for the other electrochemical materials within the stack. However, it does require a ceramic support for the fuel cell, and RRFCS has adopted a Magnesia Magnesium Aluminate (MMA) material to operate in this environment. The support structure of the stack can be seen in Figure 5.

One of the important considerations in the choice of electrolyte type and operation temperature for a fuel cell is the fuel required. Generally, the lower the temperature of operation, the greater the restriction of fuel – typically the cell must see hydrogen below 600 °C. Similarly the purity of the fuel is of paramount importance at lower temperatures. However, by choosing an operating temperature of 900 °C, hydrocarbons can be introduced to the cell, and reformed within a heat recuperating environment within the system. This ensures that natural gas is a realistic initial choice of fuel for the RRFCS system. In the longer-term, further fuel flexibility can be implemented – propane, butane, alcohol and ultimately diesel are all within reach of such a technology.

The stacks are built into a pressure vessel (see Figure 6) and are thermally integrated with the other high temperature components of the system, which is shown schematically in Figure 7. The system is pressurized to its nominal operating pressure of 7 bar by means of a purpose-designed turbogenerator. Operating at power conversion. The system operates at a nominal temperature and pressure of 900 °C and 7 bar respectively. At this temperature it ensures high ionic conductivity of a standard yttria stabilized zirconia (YSZ) electrolyte. It also allows conventional choices for the other electrochemical materials within the stack. However, it does require a ceramic support for the fuel cell, and RRFCS has adopted a Magnesia Magnesium Aluminate (MMA) material to operate in this environment. The support structure of the stack can be seen in Figure 5.

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Figure 2. The RRFCS concept for manufacture of a SOFC system.

Figure 3. A schematic showing that electro-chemical layers are printed on top of a ceramic supporting component known as a “tube”.

Figure 4. Building the RRFCS fuel cell stack.

Figure 5. The design and reality of the RRFCS stack.

Figure 6. A Generator Module pressure vessel in a test configuration at RRFCS.
this pressure and a temperature of 900 °C enables a compact and highly efficient system to be realized. The cycle design includes two gas flow loops – an anode flow loop and a cathode flow loop. Both the anode and cathode loops involve partial recirculation, by means of ejectors, of the exhaust flows from the stack. This means that no external water requirement exists for fuel reforming – this is provided by the steam in the recycled anode gas – and inerting atmospheres, if required for the fuel cell under operational transients, are generated from the fuel and air sources, see Figure 8. The cathode side recycle loop minimizes the requirement for large inlet fresh air flows and also provides the necessary pre-heat so that a large airside heat exchanger – a potential weakpoint of other SOFC systems – is not necessary and the recycle loop further contributes to the compact system design.

A requirement of a fuel cell system is to be able to follow a demanded load. High temperature systems such as SOFC systems can be ideally configured for a constant load, but this limits the application potential. The RRFCS system has been investigated for its performance under part load, and the typical response for loads of 50% design point and above are shown in Figure 9. The figure shows that there is only a small efficiency loss for significant power reductions from the design point. Also, the figure indicates that on hot days the efficiency is slightly improved from cold days – this is perhaps slightly counter-intuitive because the value of the heat exiting from the system has lower differential to ambient conditions.

Figure 6 shows a generator module pressure vessel. A typical 1MW product will contain four such generator modules, as shown in Figure 8. The system is designed to give individual access to each vessel for operational and maintenance functionality.

4. System Progress

The individual subsystems of the RRFCS design have been successfully developed and demonstrated, including the stack (Figure 5), the fuel reformer, the ejectors, the off-gas burner, the turbogenerator (Figure 7) and the external fuel processor. Many of these have required innovative design solutions such as the ejectors.

Successful demonstration has been shown during recent years including operation of the stack block as shown in Figure 5. Currently, demonstrations of the complete system are on-going with on-site demonstration scheduled at an electrical utility company later in the year.

Two further measures of progress of design and demonstration are given in Figure 10. Power density has increased since the early days of this project, achieved by design optimisation, growing understanding and experience of operation requirements and improvements in manufacturing processes, such as screen printing. Further significant advances are anticipated in coming years.

In parallel, part count has been reducing, driven by functional and cost requirements and by manufacturing simplification.

5. Conclusions

RRFCS has been developing a design of large
scale hybrid SOFC system for over 15 years, and is currently demonstrating complete systems. The proposed solution is well matched to the opportunity in high efficiency power generation, and in particular the distributed market.

References