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Stirling based fuel cell hybrid systems: An alternative for molten carbonate fuel cells

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ABSTRACT

This paper presents a new design for high temperature fuel cell and bottoming thermal engine hybrid systems. Now, instead of the commonly used gas turbine engine, an externally fired – Stirling – piston engine is used, showing outstanding performance when compared to previous designs.

Firstly, a comparison between three thermal cycles potentially usable for recovering waste heat from the cell is presented, concluding the interest of the Stirling engine against other solutions used in the past.

Secondly, the interest shown in the previous section is confirmed when the complete hybrid system is analyzed. Advantages are not only related to pure thermal and electrochemical parameters like specific power or overall efficiency. Additionally, further benefits can be obtained from the atmospheric operation of the fuel cell and the possibility to disconnect the bottoming engine from the cell to operate the latter on stand alone mode. This analysis includes on design and off design operation.

1. Introduction

The main research and development areas in the electricity production industry are efficiency enhancement and pollutants reduction, especially carbon dioxide. Developing huge capacity facilities at one single location, in the range from 1 to 2 GW, is not a concern anymore as the scenario is shifting towards a more distributed scheme where electricity and heat are produced close to the final user. Additionally, conventional gas and steam combined cycle plants are currently producing around 1.5 GW, where needed, with off the shelf technology.

Advances in the suggested directions shall address the main concerns of today's society. First of all, some agents and observers of international politics along with scientists, mainly geologists, are claiming that a peak oil production rate is due to be reached in the following years, after which a reduction in oil production will have to be faced [1–3]. Consensus on the precise date does not exist but it is agreed that this situation shall take place in the first quarter of the present century. Despite the fact that coal seems to be abundant [4], high fuel to electricity conversions must be sought after if fuel consumption is to be reduced. This efficient production of electricity is profitable also in terms of emitted pollutants like carbon dioxide. If low temperature systems are developed, nitrogen oxides will be cut down as well.

In such a scenario, high temperature fuel cells have been regarded as very attractive power systems for small and even medium scale facilities of up to 1 MW rated capacity, showing a 50% stand alone efficiency. When coupled to gas turbine bottoming cycles, the efficiency of the resulting fuel cell – gas turbine hybrid system increases to 60% [5]. This concept has been applied to both solid oxide fuel cells and molten carbonate fuel cells with either open or closed bottoming cycles [6].

Hybrid systems have been researched for the past 15 years and, lately, they have approached the commercial phase [5,7,8]. Fuel Cell Energy (USA) has already completed field testing of its sub-megawatt proof of concept plant DFC/T, based on a 300-kW atmospheric MCFC coupled to an indirectly fired Capstone micro gas turbine. Ansaldo Fuel Cells (Italy) has also tested a hybrid MCFC/GT system successfully, based on two 250 kW 2TW pressurized cell modules coupled to an indirectly fired micro gas turbine. Finally, for the case of SOFCs, Siemens Westinghouse holds long experience with 220 kW and 300 kW demonstration units of directly fired gas turbines coupled to tubular cells.

Nevertheless, in spite of this previous experience with test plants, some problems regarding transient performance of hybrid systems seem to be still unresolved [9]. High temperature fuel cells require that air and fuel mass flows and temperatures be very precise in order to avoid undesirable situations like overheating or fuel/oxygen starvation. Thus, when they are coupled to bottoming gas turbines, and due to the very fast and sensitive transient performance of such engines, the control system turns out to be crucial in terms of operability and reliability. This concern is even more

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