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TURBOCHARGED SOLID OXIDE FUEL CELL SYSTEM: DESIGN AND EMULATION

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***Abstract* - This paper presents a design model of a turbocharged solid oxide fuel cell system fueled by biogas. The aim of this plant layout is the development of a low-cost solution considering the coupling of the solid oxide fuel cell (SOFC) with a low-cost machine such as a turbocharger (instead of a microturbine). The whole system model calculates the operational conditions and realizes the coupling between the turbocharger, the recuperator and the solid oxide fuel cell system (comprising SOFC, air pre-heater, fuel compressor and pre-heater, reformer, off-gas burner and anodic ejector). This model also supports the design of an emulator test rig in which a burner, located inside a thermal insulated vessel, replaces the solid oxide fuel cell system. The emulator test rig will be useful to study the matching between the turbocharger and the fuel cell to validate simulation models, design innovative solutions and test the control system of the whole plant.**

***Index Terms* - Solid oxide fuel cell, turbocharger, low-cost layout, emulator rig.**

I. NOMENCLATURE

OGB	Off-Gas Burner
REF	REFormer
SOFC	Solid Oxide Fuel Cell

II. INTRODUCTION

SOFC based systems are promising for high efficiency near-zero emission power generation [1]. However, they are not ready for a wide commercialization for cost issues and not completely solved technological problems [1]. For this reason, plant layouts based on standard commercial devices are interesting to decrease component costs. These options could be significant for the system future even in case of efficiency decrease in comparison with the high performance layouts [2]. So, in this work attention is focused on an SOFC stack pressurized with a commercial turbocharger. Even if this layout is not able to maximize the plant efficiency (the machine is not equipped with the generator), it is a low-cost solution for exploiting the SOFC pressurization benefit [2].

An initial analysis was carried out with a validated design system model [3]. This was necessary to define the system design and the operative possible conditions for such innovative SOFC based plant. Moreover, it was an essential preliminary modelling activity for the sizing of an experimental rig able to emulate the system.

Finally, special attention is devoted to the design of the experimental rig for performing further analysis on this promising SOFC based system. It is an emulator test rig based on the coupling of a turbocharger with a vessel. This component will be essential to emulate the SOFC behaviour (the cathodic side) including a properly controlled combustor and ceramic material. Moreover, the plant layout includes bypass lines and a bleed duct for tests devoted to dynamic operations, control issues, surge prevention, etc. The emulation approach with rigs not including a real fuel cell was demonstrated [4,5] to produce significant experimental results for such complex innovative systems.

III. PLANT LAYOUT

The SOFC system is based on the coupling of an SOFC with a turbocharger (Fig.1). The compressed air flow is pre-heated with a recuperator using the exhaust thermal content. Then. the air flow reaches the fuel cell cathodic side through the pre-heating system. On the anodic side the bio-gas fuel (50% CH_4, 50% CO_2 - molar fractions) is compressed and used in the primary duct of an anodic ejector [3]. This device is necessary to generate an anodic recirculation to feed the reformer (upstream of the anodic side) with a significant steam amount. Finally, the SOFC exhaust flows are mixed in the Off-Gas Burner (OGB) located just upstream of the turbine.

IV. DESIGN MODEL

The system design model was developed in Matlab-Simulink using component tools previously validated in other SOFC system works [3] considering tests on existing experimental facilities [5] and on the turbocharger. The plant complete model includes the following components: turbocharger (compressor, turbine and shaft), recuperator, reformer, SOFC stack, air pre-heater, off-gas burner, fuel compressor and pre-heating system and anodic ejector for flow recirculation. The system model is based on the following main aspects: performance map interpolation for the turbocharger, Number of Transfer Units for the recuperator, reforming and shifting equations for the reformer, the electrochemistry equations (including losses) for the stack, combustion process calculation for the OGB, and mass/momentum/energy equations for the ejector [3]. Although it is a design model, the performance maps are necessary because the turbocharger coupling is not obtained at its standard operative conditions.

V. MODEL RESULTS

The model was used to evaluate the design main property values (Fig.1). The simulation was carried out considering the bypass valve opened at 1.8% (necessary margin for control reasons) and the SOFC fuel utilization at 0.8. Bleed and wastegate valves were fixed in the fully closed position.

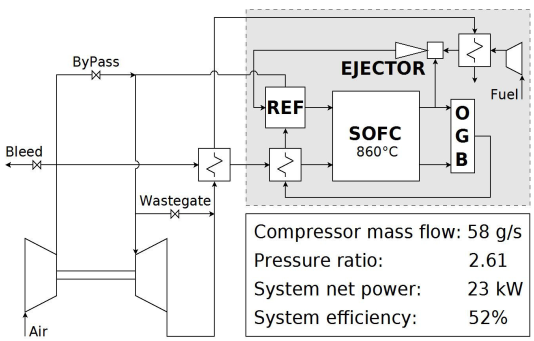

Fig. 1. SOFC turbocharged system: plant layout and main design values.

Since the fuel cell temperature was considered fixed at 860°C, the model calculated the matching with the turbocharger considering a 14.6 m^2 cell area (for the electrochemical reactions). For future research activities, this model can simulate the behavior of the whole system in the off-design and at different ambient conditions.

VI. EMULATOR TEST RIG

On the basis of the system design data presented in the previous paragraph, an emulator test rig (Fig.2) was developed considering the coupling of a turbocharger with a cathodic vessel. The vessel is including a burner (CCM in Fig.2) followed by inert ceramic materials to emulate the SOFC thermal behavior. The rig is also equipped by a recuperator for air pre-heating, a start-up combustor (CCS in Fig.2), bypass lines for control reasons and to emulate different operative conditions (e.g. different SOFC inlet temperatures), a bleed line and an air/water heat exchanger for ambient temperature control. Moreover, the plant includes also three inlet lines for the start-up air (managed by the VSU valve), compressor intake humidification (managed by the VWI valve) and a CO_2 injection (managed by VCO2 valve).

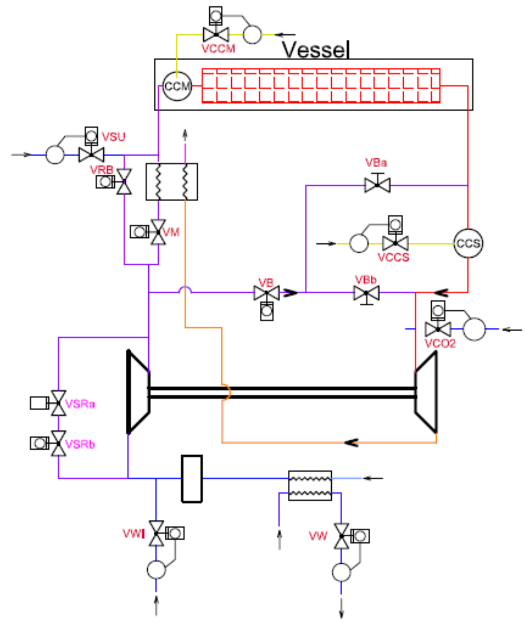

Fig. 2. Emulator rig layout.

VII. CONCLUSION

The model presented in this work allowed to define the design property values of the turbocharged SOFC system. These data (mainly the pressure ratio and the mass flow rate) were used to develop an emulator test rig. This will be an essential facility for tests on SOFC/turbocharger coupling, risk prevention, development of control system tools, model validation, and innovative solutions.

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