Thermodynamic analysis of Gas Turbine Based Hybrid Power Cycle – “A State of Art”

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Abstract—this paper presents an extensive review in the field of hybrid gas turbine system. In order to make gas turbine hybrid thermal integration of fuel cell is considered as the best practice in the present scenario. Various integration of Gas turbine cycle with fuel cell has been presents with the potential of gas turbine based power cycle with fuel cells for fuel flexibility, which could expand the prospective for sustainability and profitability in energy conversion systems. The impact of various thermal integration and their performance parameters has been present in terms of energy efficiency, exergy efficiency and economical analysis. In gas turbine based power plant exhibits high content of waste heat which cannot been utilized which leads to lower thermal efficiency, but due to advancement in the technologies various integrations are available which improves the performance of the cycle. Such as HRSG, HAT cycle, SOFC, gasification system, refrigeration system, photovoltaic system, etc..

Keywords—Hybrid Gas Turbine, SOFC, SOFC-GT

I. INTRODUCTION

Solid oxide fuel cells (SOFC) are the high temperature fuel cell, which is most valuable in the field of power generation hybridization with thermal-based generator systems as contrasted to other fuel cell technologies due to their high operating temperatures. For instance, SOFCs can be integrated with a bottoming gas turbine based cycle to make use of the benefits of high quality waste heat and fuel recovery from the fuel cell stacks for further power generation [1, 2]. Direct-fired solid oxide fuel cell gas turbine (SOFC/GT) hybrid systems shown in Fig. 1 also offer some benefits in terms of air pressurization as a result of turbo-machinery pressure ratio consequence on fuel cell Nernst potentials, and heat recovery of gas turbine exhaust. Mutually high pressure and heat recuperation openly assists the total system efficiency.

Figure 1. Basic flow diagram of a SOFC/GT hybrid system

II. LITERATURE REVIEW

Nor et al. 2017 investigated an open and closed loop transient response of solid oxide fuel cell (SOFC) gas turbine (GT) hybrid system using experimental approach in cyber-physical fuel cell
system. A transition from methane lean syn-gas to methane rich gases with no turbine speed control was studied. The distributed performance of the fuel cell was analyzed in detail with temporal and spatial resolution across the cell. They observed that changing syn gas to lower LHV fuel increases the initial turbine speed. Moreover, the effects of fuel composition were strongly coupled to cathode air flow variations.

![Figure 2 Turbine speed and cathode air mass flow responses for open loop and closed loop [3]](image)

Choudhary and Sanjay 2017 present a novel integration of SOFC with cooled gas turbine. In their work the 1st law thermodynamic analysis has been carried out along with the effect of various performance parameters such as turbine inlet temperature, pressure ratio, fuel utilization ratio, recirculation ratio, etc. They observed that increase in TIT and pressure ratio the performance of their hybrid system increases, moreover they also plot a unique performance map which reveals the system specific work and hybrid efficiency for wide range of TIT and pressure ratio and efficiency of 73.46% has been achieved.

![Figure 3 Performance map of SOFC-cooled gas turbine [4]](image)

Jamasb et al. 2017 present an optimal configuration for solid oxide fuel cell-gas turbine hybrid systems based on thermo-economic modeling. They present a four different configuration SOFC-GT
hybrid system. They found that hybrid system with one pressurized fuel cell hybrid system is superior to the other. The benefits of this system take account of having lower irreversibility rate, low purchase, low installation and startup costs, and the enough price of its generated electricity. Results reveals that the hybrid system with one atmospheric fuel cell has a low electrical efficiency, high irreversibility rate; and also the price of its generated electricity is higher than that of the other proposed systems.

Nor et al. 2016 present a dynamic study of fuel cell gas turbine (SOFC/GT) hybrid systems, concentrating on the drastic transient response of an anode fuel composition for constant turbine speed operations. Their work is motivated by the potential of fuel cells for fuel flexibility, which could expand the opportunities for sustainability and profitability thermal integration of energy conversion systems. A arrangement of hardware and numerical models in a hybrid simulator has been adopted to examine the transient profile of fuel cell performance parameter in addition to the subsequent influences of fuel cell thermal effluent on the integrated gas turbine engine.
Penyarat 2015 presents a detailed thermodynamic model of SOFC and gas turbine hybrid system which is simulated in MATLAB. Few configurations of the combined or hybrid cycles are proposed and analyzed. A comparative study based upon performance parameters, such as SOFC power and turbine inlet temperature is used to select the better configuration. Simple thermodynamic models for the compressor and turbine are used during the configuration selection.

**Figure 6 Configuration 1 sensitivity studies of different air flow rates (kg/s) on the cycle efficiency (%)**[7]

Mehdi et al 2016 presents an exergetic-economic-environmental analysis of an SOFC-GT-ST plant. The model of SOFC selected has internal reforming therefore, no external reformer has been used. The exergetic efficiency and total cost rate of the plant were considered as main objectives. To obtain optimal solution Multi-objective optimization has been performed. The exergy destruction rate and capital cost of components of the plant has also been evaluated and found that the Rankine bottoming cycle enhanced the exergetic efficiency of the plant by 8.84%.

**Figure 7 Annual power enhancement and CO2 emissions saved by integration of a Rankine bottoming cycle to the SOFC-GT plant [8]**

Chinda and Brault 2012 developed the hybrid solid oxide fuel cell and gas turbine power system model. Two models has been prose on the basis of simple thermodynamic expressions. The simple
models are adopted in the preliminary part of the study and a more realistic based on the performance maps. A comparative study of the simulated configurations, based on an energy analysis is used to perform a parametric study of the overall hybrid system efficiency.

![Figure 8 Performance map of the modeled turbine, based on the radial turbine map NASA-CR-174646 (a) The relation between the pressure ratio and efficiency (b) The relation between the pressure ratio and corrected mass flow rate.][9]

Choudhary and sanjay computationally examined the transient response, structural integrity, flow dependency of internal reformed SOFC. They found that the recirculation ratio adversely affects cell performance with higher carbon deposition. To maintain uniform temperature distribution air ratio has been varied and observed that increasing air ratio tends do decrease thermal stress. Comparative temperature profiles, electrochemistry, and species transport has been studied for counter and co flow configuration.
Choudhary et al. 2016 CFD modeling of Solid oxide fuel cell (SOFC) which is coupled with cogeneration system. The SOFC cogeneration system is a low emission and energy efficient combined heat and power (CHP) is a most promising candidate in the field of electric and thermal energy generation technology for execution in future commercial buildings. Using finite volume approach CFD modeling of SOFC has been carried out by using commercial software COMSOL 4.3.1. The performance characteristic of an SOFC has been examined by performing parametric analysis. The effect of fuel utilization factor, recirculation ratio, operating temperature significantly affects the cell performance. It has been observed that, internal reforming is advantageous over the external reforming system in terms of thermo-economics and power supply.

Khani et al. 2016 conducted an Multi-objective optimization of an indirectly integrated solid oxide fuel cell-gas turbine cogeneration system. The exergy efficiency and sum of the unit costs of the products are the main objective functions. Using Pareto front plot the result of multi-objective optimization has been presented the result shows that the optimal design point has an exergy efficiency of 55.11% and the cost of produced power and heating are 24.68 and 145.8 $/GJ, respectively.
Lv et al. 2016 proposed a novel IT-SOFC/GT hybrid system fueled by gasified biomass gas. Their proposed approach is capable to determine the safe operation zone for hybrid system. Using this approach a characteristic map of safe operation zone of hybrid system has been plotted which helps in operating the system under safety measures. They found that the system has a characteristic of high efficiency and low load with low rotational speed, vice versa. In other words, the powers and load adjustment ranges both decrease with decreasing rotational speed whereas the efficiency increases, which peaks at 63.43%.

A comprehensive literature survey on different types of SOFC hybrid systems modeling is presented. These models are categorized based on the classification scheme discussed earlier. In this paper, a hybrid cycle could be any combination of SOFC and gas turbine, steam turbine, coal integrated gasification, and application in combined heat and power cycle. In order to make this review comprehensive, wide range of models are considered, including but not limited to, design and off-design, steady state and dynamic, and multidimensional models. Also, systems with various applications, fuel types, and configurations are considered. Moreover, models with different
objectives such as parametric, exergetic, and thermo-economic analysis as well as optimization are reviewed.

From the above review some key conclusion has been drawn are as follows

- SOFC is the most promising candidate for the utilization of the waste heat.
- Thermal integration of this fuel cell enhances the performance of the cycle and makes it hybrid by utilizing waste heat.
- Increase in pressure and temperature the performance of SOFC integrated system increases significantly.
- Wide range of fuel can be used in the SOFC integrated system therefore, it has various application is CHP, aerospace application, power generation utilities, etc.

REFERENCES


