Modeling and Analysis of a Combined Power Generation System Performance Equipped with Three Electrical Energy Generators

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ABSTRACT: The purpose of this paper is thermodynamic modeling of a new hybrid system to provide electrical power. The new hybrid system consists of a solid oxide fuel cell and gas turbine cycle equipped with a Stirling engine. For all components of the cycle, a thermodynamic analysis and for utilized fuel cell, electrochemical and thermal analysis have been performed. Then, with a parametric study of hybrid system, effects of compressor pressure ratio, turbine inlet gas temperature, type of fluid used in the Stirling engine and number of cells in fuel cell are studied on the efficiency and net power output of the hybrid system. The results show that the electrical efficiency of the new hybrid system will increase by increasing the compressor pressure ratio and turbine inlet gas temperatures up to about 81 percent. Also, in the case of using helium in Stirling engine, its weight will reduce and efficiency will increase about 15 percent. The results also show that increasing the number of cells in fuel cell causes enhancement in electrical power and overall efficiency of the hybrid system.

1- Introduction

Due to the growing trend of energy consumption in the world, using new methods and systems for power generation with high efficiency and low emissions have been prioritized. Today, with the proliferation of different systems of energy production, different techniques such as the use of solar energy, wind energy, fuel cells, micro turbines, Stirling engines, diesel generators are considered each having its own advantages and disadvantages. Fuel cells convert chemical energy into electrical energy converters that are considered today as a new technology in energy production [1]. Physically, the Stirling engine is an external combustion engine more efficient than gasoline and diesel engines. Its energy can be from any external heat source (solar energy, waste heat power generation system, etc) for mechanical power production [2]. Ideally, Stirling engines consists of two types of processes: constant volume and constant temperature. Gases that are used within the Stirling engine are always inside the engine. The new hybrid system used in this study, implements energyexhaust of gas turbine as a heat source for the Stirling engine. Hybrid system combines a gas turbine, Stirling engine and a solid oxide fuel cell. This combination is introduced for the first time as we know.

2- Composition of the hybrid system

In these study hybrid system components are shown in Fig. 1. The proposed system consists of a mass of solid oxide fuel cells, combustion, gas turbines, Stirling engines, air compressors, pressure relief valves, fuel tank and five recoveries. Hydrogen is used in fuel systems and air contains 21 % oxygen gas and 79 % nitrogen gas.
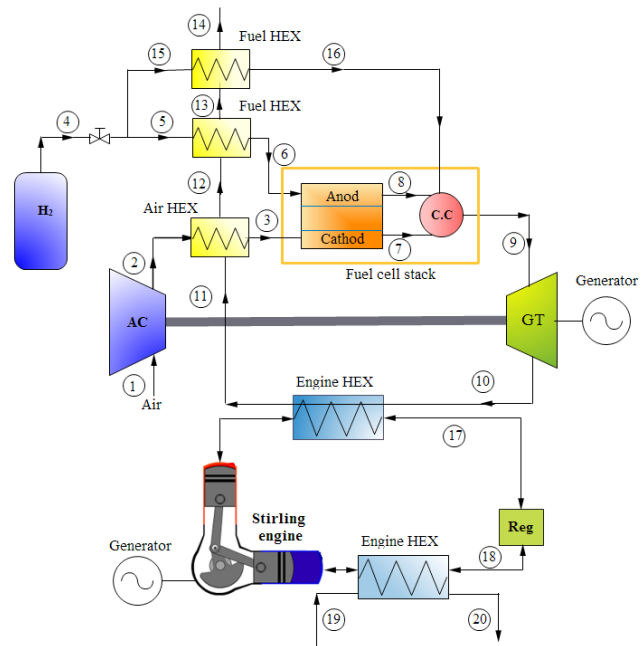

Figure 1. Composition of the proposed hybrid system

3- Governing equations

In this section we use existing relations governing the performance of all the components used in the proposed separately under steady state conditions. For this purpose, a computer code written in EES software is developed and thermodynamic performance of the system is analyzed by changing some key operational parameters such as pressure ratio of the compressor, the temperature of gas turbine inlet, the number of cells, fuel cells and fluids used in the Stirling. On the whole cycle and hybrid systems by considering the

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entire system as a control volume, electrical efficiency can be obtained by using Equation 1.

$$\eta_{ele} = \frac{\dot{W}_{net}}{\dot{n}_f \times LHV} \tag{1}$$

Net power output of the system of is calculated through Equation 2.

$$\dot{W}_{net} = \left(\dot{W}_{AC}\right)_{gt} + \left(\dot{W}_{AC}\right)_{sofc} + \dot{W}_{ST} - \left(\dot{W}_{C,a}\right) \tag{2}$$

$$\left(\dot{W}_{AC}\right)_{gt} = \left(\dot{W}_{DC}\right)_{gt} \times \eta_{inv,gen} \tag{3}$$

$$\left(\dot{W}_{DC}\right)_{gt} = \dot{W}_{gt} \tag{4}$$

4- Validation
Ford 4-215 is the engine used in this study, invented by scientists at the Dutch Philips, was later developed and built by Ford Motor Company. In order to validate the developed code for Stirling engine in this study, a comparison is made between results of present study and Uriel and colleagues study [4] in Table 1. Close match between these results prove the validity of our method.

Figure 1. Comparison of the present model with Uriel and colleagues study [4]

Parameter	Urieli et al. [4]	Present work	Error (%)
Heat transferred to the cooler Q_k (J/cycle)	1901	1840	3.2
Heat transferred to the Heater Q_h (J/cycle)	5572	5485	1.56
Power output (kW)	212.9	207.88	2.4
Thermal efficiency (%)	67.1	66.08	1.52

5- Results
In this section the performance of the proposed hybrid cycle is analyzed from a thermodynamic point of view.
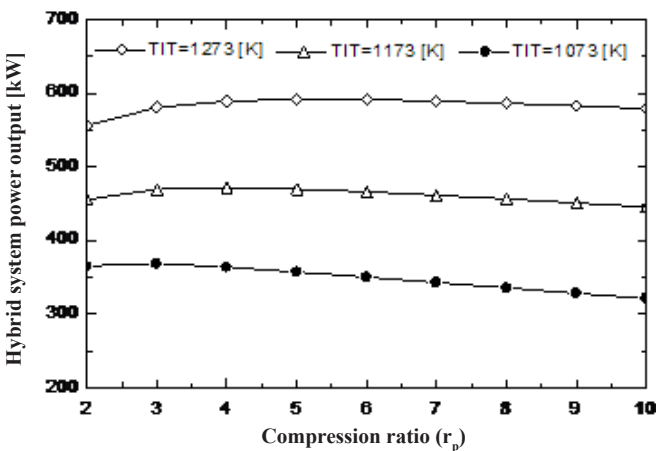

Figure 2. Effect of system compression ratio on hybrid system power output

The results show that by increasing the compressor pressure ratio, production capacity increases first, then it is reduced. Fig. 3 changes in the electrical efficiency of the hybrid system are shown as a function of compression ratio.
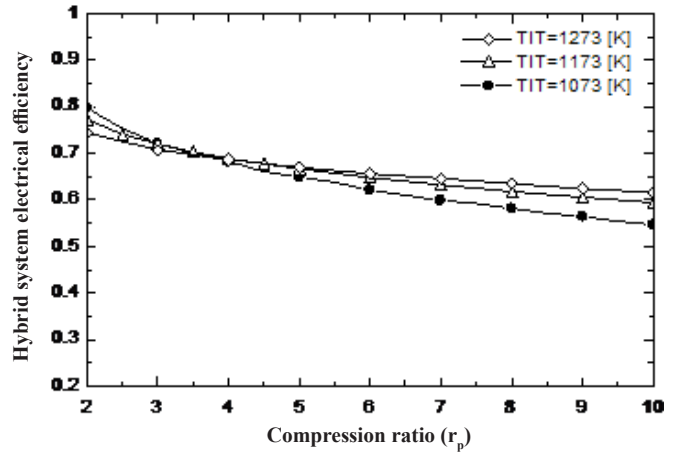

Figure 3. Effect of system compression ratio on hybrid system electrical efficiency

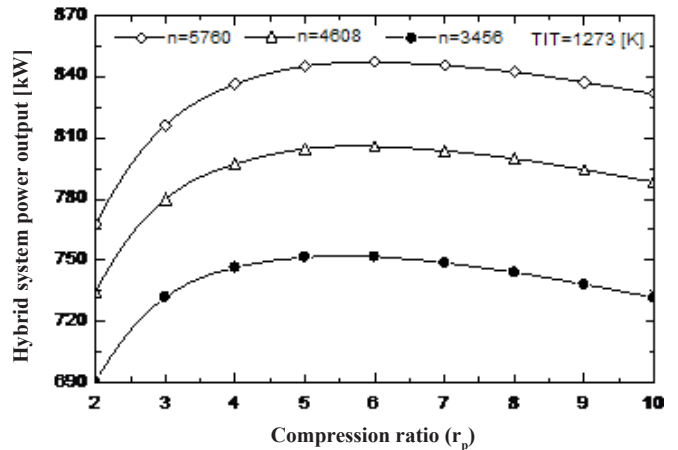Fig. 4, shows that increasing the number of cells increases hybrid system power output.

Figure 4. Effect of system compression ratio on hybrid system power output with different number of cell

With increasing the compressor pressure ratio, maximum point of net power production will occur in higher pressures. On the other hand, if one changes the type of fluid from H_2 to He, net power production system enhances (Fig. 5).

6- Conclusion
The purpose of this paper is thermodynamic modeling of a new hybrid system to provide electrical power. The new hybrid system consists of a solid oxide fuel cell and gas turbine cycle equipped with a Stirling engine. The results show that the electrical efficiency of the new hybrid system will increase by increasing the compressor pressure ratio and turbine inlet gas temperatures up to about 81 percent. Also, in the case of using helium in Stirling engine, its weight will reduce and efficiency will increase about 15 percent. The results also show that increasing the number of cells in fuel cell causes enhancement in electrical power and overall efficiency of the hybrid system.
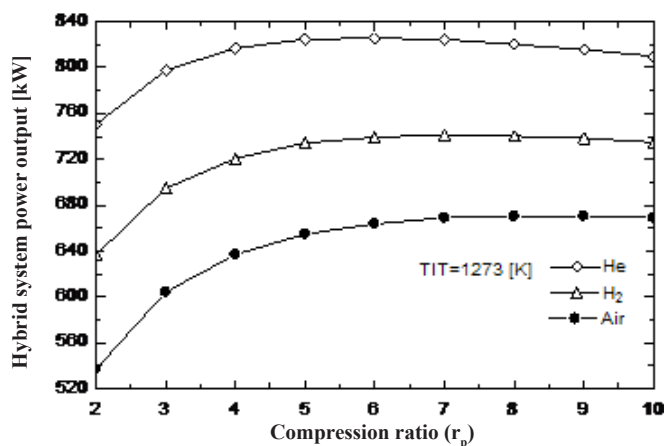
Figure 5. Effect of system compression ratio on power output with different working fluids

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