Study on Thermo-Electric Generator and hydrogen recirculation on Solid Oxide Fuel Cell

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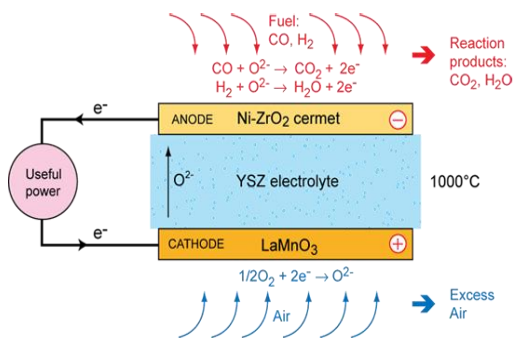
ABSTRACT

In todays modern world growing power demand has not been diluted the need for alternate power source. Thus producing clean power from the renewable source of fuel has been a interesting and serious debate over the impacts on environment in a positive way as green energy-fuel cell comes into picture using Hydrogen as a fuel makes the pollution free power generation. Hence improvements such as waste heat recovery and combined power generation makes the technology more efficient and reliable. The analysis has been approached through MATLAB – Simulink and various conceptual ideas has been implemented on simulation. Additionally the efficiency using waste heat recovery system has been studied for an solid oxide fuel cell using MATLAB – Simulink coding tab and the results were analyzed.

Key words: Fuel cell, Solid Oxide Fuel Cell (SOFC), Thermo-Electric Generator, Electrolysis, hydrogen recirculation, Seebeck Generator, waste heat recovery system (WHRS).

1. INTRODUCTION

The fuel cell technology has been recognized as the green energy as it does not release toxic soot particles, or any such harmful emissions, as it cleaner while generating power. The principle behind the fuel cell technology is the chemical reaction turns into an electrical energy, thus the chemical reaction gives the byproducts such as water, carbon monoxide, carbon dioxide, etc.., because of the absence of combustion process the system does not liberate any harmful emissions, in simple terms the working of the fuel is the reverse reaction takes place in the electrolysis process. Here the anode of fuel cell collects the hydrogen, cathode collects the atmospheric oxygen, the use of electrolyte is to allow the hydrogen ions to pass through and makes the reaction continuous, the main drawback of the fuel cell is the storage of hydrogen in its pure form due to low volume density and its melting point its hard to store at room temperatures.



1.1 EXISTING FUEL CELL TECHNOLOGIES

The existing fuel cell types are in research are SOFC [Solid Oxide], AFC [Alkali], DMFC [Direct Methanol], MCFC[Molten Carbonate], PAFC[Phosphoric Acid], PEMFC [Polymer Electrolyte Membrane]. These fuel cells has an merits and demerits based on the operation temperatures, fuels used, catalyst used to ionize the hydrogen etc.., these fuel cells while operating as a single stage power generator the efficiencies are around [50%-65%]. as the remaining energy has been liberated as a waste heat and the byproduct from the fuel cell has not been utilized properly. thus the over all efficiency is poor, which leads to the research on waste heat recovery and , hydrogen [fuel] re-circulation comes into picture to make the system more efficient on working.

1.2 MODEL APPROACHED:

As we discussed earlier the problem identified in the conventional methods has been analyzed and the various solutions has been discussed in the later part.

1. Using Thermo-Electric Generator[TEG] ,
2. Hydrogen recirculation,
3. Multi stage power generation.

The above listed are the key areas where the improvements in the solid oxide fuel cell has been analyzed and the working has been studies in the following stages.

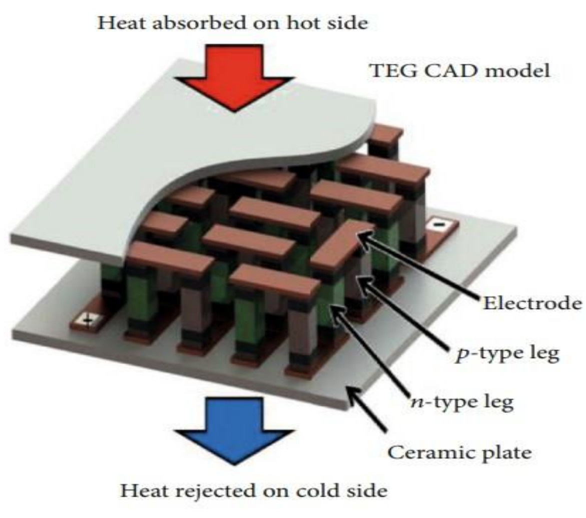
The multi-stage power generation and waste heat recovery management using Seebeck generators[TEG], and the process of hydrogen circulation into the fuel cell back from the hydrolysis of water which is the byproduct of fuel cell. such that the overall efficiency will be improved so that cost can also be saved because of the usage of reproduced hydrogen from the water.

1.2.1 USING TEG

When we use TEG in the fuel cell the waste heat of fuel cell has been utilized to the maximum extend and provides sufficient cooling and optimum temperature for the working of fuel cell[18]. The TEG are then connected in series to produce the necessary voltage and supplied for auxiliary power system which helps the efficient functioning of the fuel cell and it helps to find the alternate solution for the production of hydrogen from this useful power

1.2.2 HYDROGEN RECIRCULATION

As discussed the by product of the most common fuel cells are water and carbo-di-oxide., as the water from the fuel cell has a high temperature due to exothermic reaction of water and hydrogen the same water is recirculated as the source for hydrogen by further electrolysis using the power from the TEG.,



1.2.3 MULTI STAGE POWER GENERATION

The concept of multi stage power generation is helpful when we need to increase the over all system efficiency by utilizing the stage 1 as input for stage 2 as we can have a different configuration of fuel cell either a SOFC as stage 1 and PEMFC as stage 2 due to higher heat production capacity of SOFC fuel cell the TEG works better in SOFC and the power from TEG of SOFC(stage 1) can be utilized to produce hydrogen from the water from the same SOFC stack and the hydrogen is recirculated to the PEMFC and the combined power output has been achieved.

2. WORKING

The fuel cell [SOFC] has been preferred due to its cost of operation and the amount of heat produced while operating is much higher compared to other efficient fuel cell such that the heat from the SOFC stack has been utilized for power generation using seebeck generator such that the effective voltage produced is used to electrolyze the byproduct hot water from the fuel cell. And the hydrogen from the electrolysis has been recirculated into the anode so that the system overall efficiency will be improved.

In SOFC stack the yttrium stabilized zirconia has been used as a solid electrolyte which enables oxygen ion conduction while blocking the electronic conduction. To achieve the sufficient ion conduction, an SOFC with a YSZ electrolyte must be operated at high temperature between 800oC - 1000oC, the main advantage of using SOFC is its cheap operating cost and the cheap electrolyte used the efficiency of SOFC is around 60-65% the commercial manufacturer of SOFC stack is bloom energy[31].

There are commercial fuel cell plants where multi-layer SOFC stack has been used to generate power out of it nearly to 50KW. Hence further improvement and research helps to increase overall efficiency and produce high power density SOFC stack.

The main advantage of using SOFC is the cost where the anode, cathode and electrolyte cost is bearable compared to other fuel cells further utilization of the waste heat recovery and anode gas (hydrogen) recirculation will help to increase the efficiency and reduce the cost per watt generation. By using the power from the Thermo-Electric Generator[TEG] the voltage has been generated and the power from the multiple TEG where coupled and the electrical power generated has been utilized to carry out the electrolysis process from the hot water which is the byproduct of the fuel cell. The main advantage of using hot water is that the electrolysis voltage is much lower when compared to the electrolysis required to carry out in room temperature. The resulting product from electrolysis will liberate hydrogen and oxygen the hydrogen recirculated back into the same SOFC stack or the other low power producing fuel such that the waste heat management has been carried out and the overall power produced will also be improved.

Table -1: Fuel cell types and its working characteristics

Type of fuel cell	Applications	Core temp. efficiency	Advantages	Limitations
Proton Exchange Membrane (PEMFC)	Portable, stationary and automotive	50–100°C; 80°C typical; 35–60% efficient	Compact design, long operating life, quick start-up, well developed	Expensive catalyst; needs chemical grade fuel; complex heat and water control
Alkaline (AFC)	Space, military, submarines, transport	90–100°C; 60% efficient	Low parts and, operation costs; no compressor; fast cathode kinetics	Large size; sensitive to hydrogen and oxygen impurities
Molten Carbonate (MCFC)	Large power generation	600–700°C; 45–50% efficient	High efficiency, flexible to fuel, co-generation	High heat causes corrosion, long startup, short life
Phosphoric Acid (PAFC)	Medium to large power generation	150–200°C; 40% efficient	Good tolerance to fuel impurities; co-generation	Low efficiency; limited service life; expensive catalyst
Solid Oxide (SOFC)	Medium to large power generation	700–1000°C; 60% efficient	Lenient to fuels; can use natural gas, high efficient	High heat causes corrosion, long startup, short life
Direct Methanol (DMFC)	Portable, mobile and stationary use	40–60°C; 20% efficient	Compact; feeds on methanol; no compressor	Complex stack; slow response; low efficiency

Table -2: Fuel cell efficiency with waste heat recovery

Absolute temperature	1273K
Initial current	100A
Universal gas constant J/(kmol K)	8314
Faraday's constant (C/kmol)	96.487e6
Ideal standard potential (V)	1.18
Number of cells in series	450
Maximum, minimal and optimal fuel utilization	[0.9 0.8 0.85]
Valve molar constant for hydrogen, water and oxygen (kmol/(s atm)	[8.43e-4, 2.81e-4 ,2.52e-3]
Ohmic loss per cell (ohms)	3.2813e-004
Ratio of hydrogen to oxygen	1.145
Fuel processor response time (s)	5
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Table -3: SOFC stack parameters

FC type	**Operating temperature**	**Efficiency**	**Heat percentage waste**	**Power generation increase**	**Final efficiency**	**Efficiency improvement**
LT–HT PEM FC	80-180° C	40%	60%	9.6%	49.6%	24%
Alkaline FC	65-220° C	60%	40%	6.4%	66.4%	11%
Phosphoric acid FC	205° C	37-42%	60%	9.6%	49.6%	24%
Molten carbonate FC	650° C	45%	55%	8.8%	53.8%	20%
solid oxide	600-1000° C	45-65%	45%	7.2%	62.2%	13%

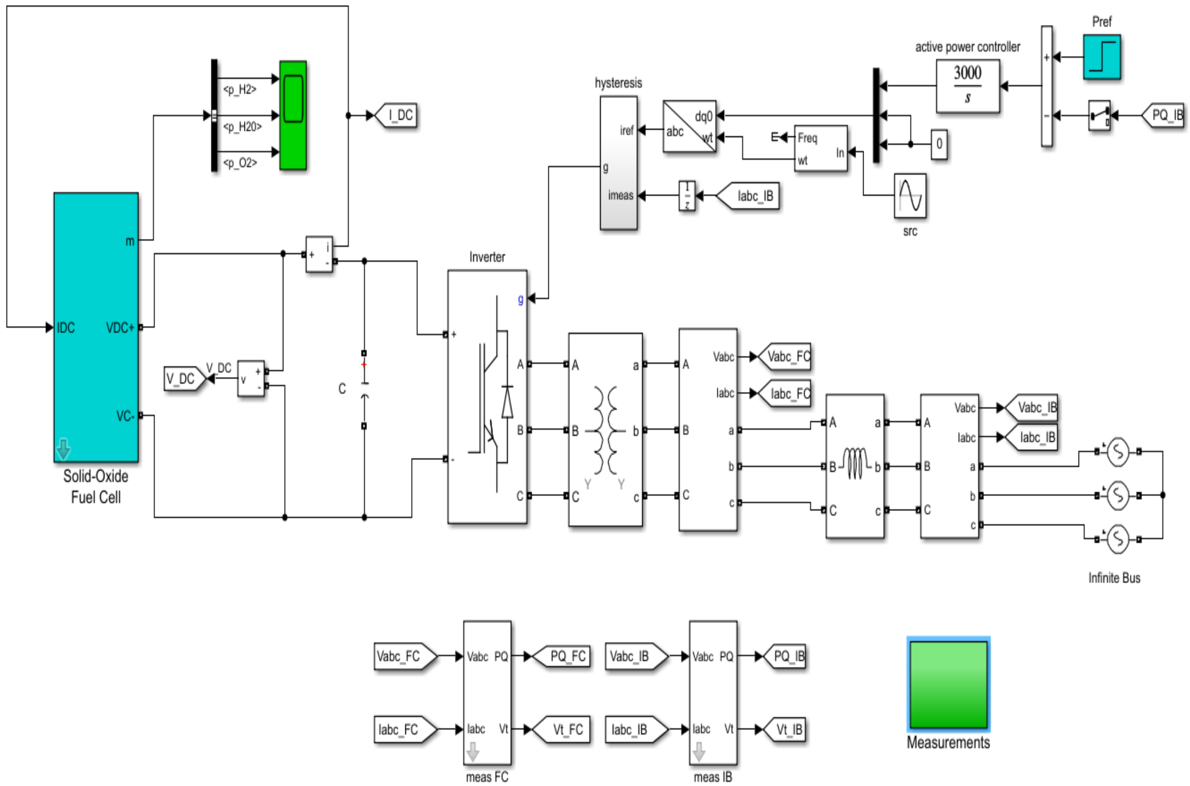

Fig -1: SOFC power generation unit

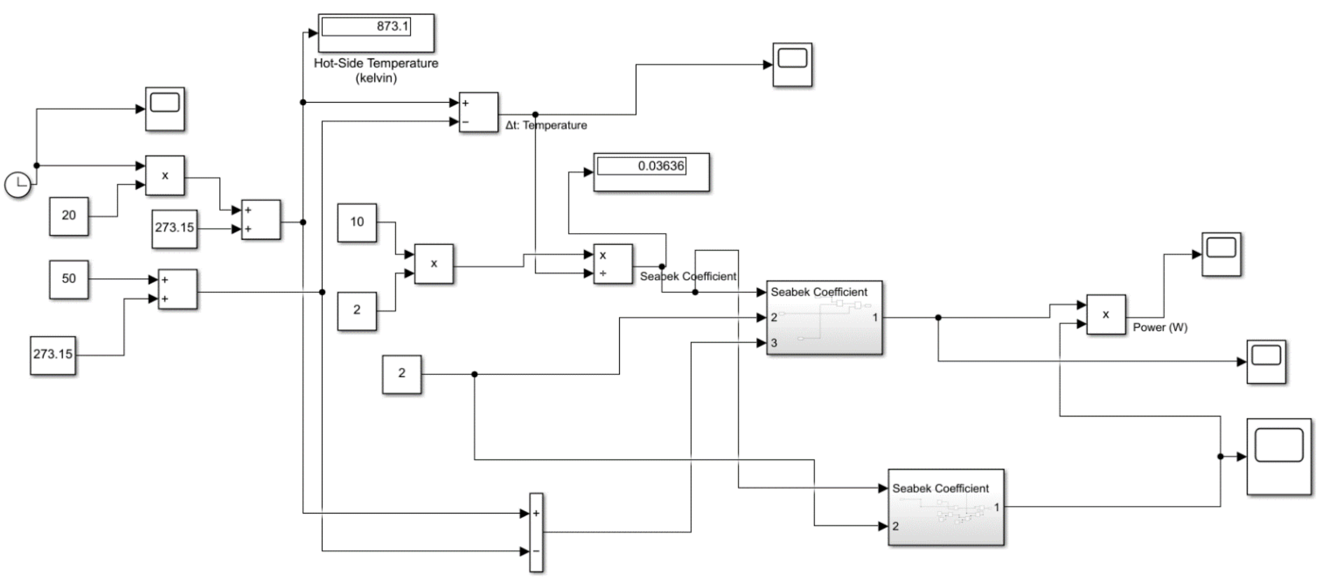

Fig -2: TEG model for an fuel cell stack

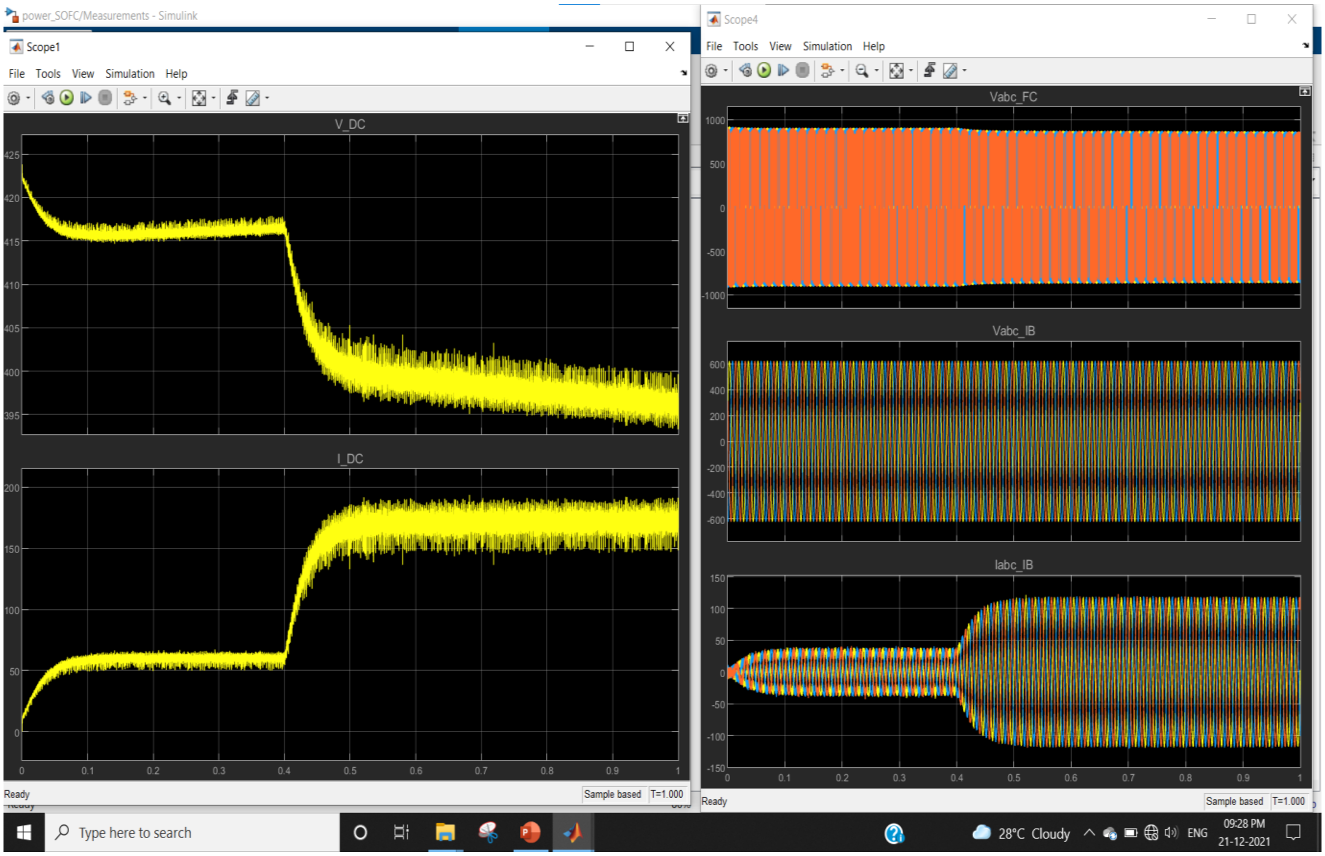

Fig -3: power characteristics of a SOFC fuel cell

3. CONCLUSION

Thus the multi-stage fuel cell with waste heat recovery and anode gas(hydrogen) recirculation using TEG improving the overall system efficiency using the waste heat of fuel cell stack and the hot water which is the byproduct of fuel cell has been utilized and the model has been proposed on various ideology and working have been discussed.

4. REFERENCE

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