International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 03 Issue: 05 | May-2016 www.irjet.net p-ISSN: 2395-0072

A SIMULATION APPROACH FOR FUEL CELL POWER BASED GENERATION IN GREEN BUILDING

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Abstract-
The assessment of solid oxide fuel cell (SOFC) combined heat and power (CHP) system configurations for request in residential lodgings are explored through modelling and simulation of cell-stacks. Active system concepts and key concert parameters are identified. The SOFC stack act is based on anode-supported planar geometry. A cell model is scaled-up to forecast voltage–current performance features when aided with either hydrogen or methane fuel gas sources. The measured SOFC-CHP model is intended based on the mathematical equations and established using Matlab/Simulink. The results displayed the better enactment of the system and thereafter it is connected to a building load entailing of both balanced/unbalanced nonlinear loads. All the appropriate results were obtained in Simulink after bearing in mind all the parameters associated and the estimated economics for the developed model are also shown.
Keywords: SOFC-Solid oxide fuel cell, CHP-Combined Heat and Power, Green Building, economics, mathematical.

INTRODUCTION

Fuel cell systems turn out to be significant in energy production research. They are reflected to be identical attractive power generation systems, gifted, highly efficient electricity generation and very little environmental impact. The Fuel Cell Power (FC Power) Model examines the technical and economic features of high-temperature fuel cell–based dispersed energy systems through the purpose of providing consistent, transparent, analogous results [1]. This sort of energy system would offer on-site-generated heat and electricity to great end users such as hospitals and office campuses or any other green buildings. The hydrogen formed could be cast-off for fueling vehicles or kept for later conversion to electricity. In the FC Power Model, manipulators select which know-how are secondhand in the system (see Figure 1) — such as hydrogen fuel cells, electrolysis—besides defining each technology's cost and performance limitations. Consumers also choice fuel costs and demand priority (i.e., whether the system surveys electricity or heat demand) and can receive default FC Power Model financial parameters or enter custom constraints. Hourly electricity, heat, and hydrogen demand outlines and renewable energy supply outlines can become in or selected [2]. The model customs the inputs, default principles, calculations, and a typical discounted cash flow, rate of return procedure to regulate the rate of delivering energy, with situation to a specified after-tax inner rate of return. Further, they're also a provision to govern the amount and type of energy input and output and the related greenhouse gas emissions.

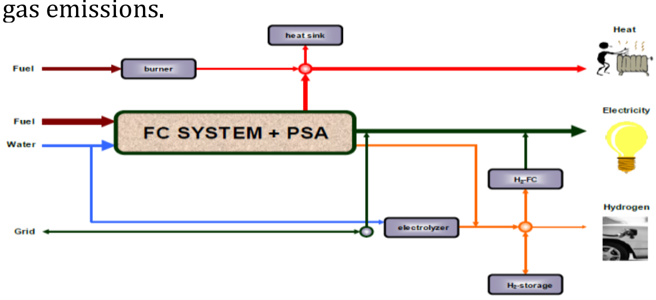

Figure **Error! Bookmark not defined.** Layout of Fuel cell arrangement

Now this paper is based on the suitability and for simplicity a simple combined model of fuel cell and CHP model using SOFC is calculated in Matlab/Simulink and it is tested for various loads commonly used in the buildings. Furthermore a procedure is also explained to utilize the heat developed by SOFC.

2. MODELING TO CONSIDER

In this segment, dynamics of reformer and voltage-current polarization curve of a fuel cell stack drive be discussed in detail.

a. Dynamics of Reformer

Intended for dynamic showing of the fuel cells, the reformer and stack, which fix the dynamic response of the fuel cell system, are additional descriptions. Figure 2 demonstrations a thorough block diagram of the fuel cell scheme to exemplify its operation.

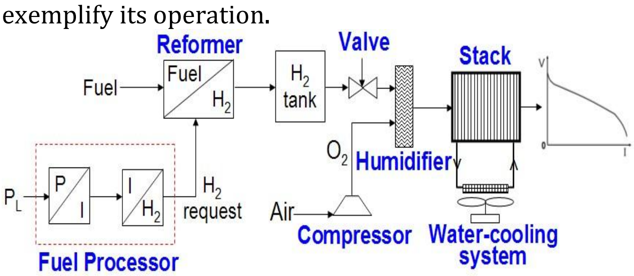

Figure 2. Detailed block diagram of the fuel cell system

As portrayed in this figure 2, the fuel cell system contains of a fuel cell stack and supplementary systems such as a fuel processor regulator to appeal the hydrogen gas, a reformer, an air compressor to deliver pressurized oxygen flow over the cathode, a valve to switch the hydrogen flow through the anode, a humidifier to enhance moisture to the hydrogen plus oxygen gases, then a water-cooling system to eliminate heat from the stack.

b. Voltage-Current Polarization Curve of a Fuel Cell Stack

The comeback of the stack that harvests electric DC power from hydrogen and oxygen is ample faster than that of the reformer. A voltage-current polarization curve of a fuel cell stack characterized in Figure 3 also wants to be measured in the practical model of the fuel cell. That is, cell voltage declines as the stack current rises [3]. Figure 3 demonstrations a static voltage-current typical curve of a single fuel cell intended to obtain the static V-I characteristics. As illustrated in the figure, there exist three regions: area of activation polarization, area of ionic polarization, and region of concentration polarization. Laden, in an area of activation polarization, the cell voltage drops rapidly with even the slightest current rise. Additional, in the area of ionic polarization, the cell voltage linearly cuts as current rises, and the fuel cell normally operates in this area. The latter, in region of concentration polarization, the voltage failures sharply when currently surpass the upper limit of safe operation, and as a significance, action in this area should be circumvented because the fuel cell may be damaged due to the primarily famine of the hydrogen [4].

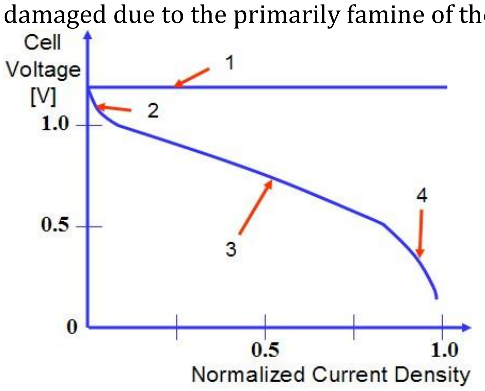

Figure 3: V-I polarization curve of a single fuel cell

4. COMBINED HEAT AND POWER (CHP) OF FUEL CELL

In some domicile as shown in Fig 4, fuel cell systems not only essential to afford electricity but also essential to provide heat. After receiving electricity from fuel cell systems, the electricity is transported into heat when heat is required. In this instance, the energy efficiency is very low. Perhaps the heat can originate from the waste heat after the fuel cell system in its place of from electricity. So the CHP is a very well-organized method to use the energy in fuel cell systems, when the electricity and heat both are wanting. Colella [6] concentrated on a fuel cell systems not only about electrical productivity, but also about thermal productivity. If the electricity is altered as heat to be used, the productivity would be very low. So it is healthier to deliver heat directly from fuel cell systems by the exhaust heat. They established the fuel cell systems which can attain a heat-to-power ratio that can be quickly changed in a CHP. Colella [8] passed out a case study of the United Kingdom for implications of electricity liberalization aimed at CHP fuel cell organisations. The undesirable significances were analyzed for the UK's liberalized model with current embedded generators. On the extra hand, the potential positive possessions were discussed for the liberalizing trend. Finally, assumptions about design strategies for CHP fuel cell systems as future embedded generators were given out. Colella [6] focused on the successfully capturing heat from a CHP fuel cell system. Some intrinsic potentials were given to CHP fuel cell arrangements:

(1) A facility to contrast their electrical load rapidly,
(2) An ability to contrast their heat to power ratio during operation, and
(3) An ability to deliver their waste heat to a useful thermal sink.

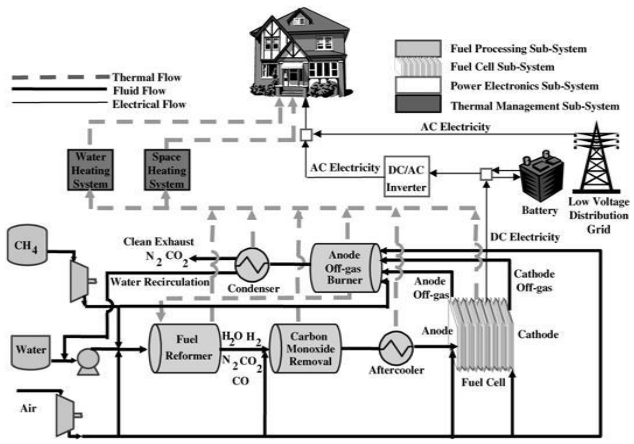

Figure 5: Schematic diagram of one of type of combined heat and power (CHP) fuel cell system

5. DESIGN OF CONSIDERED SOLID OXIDE FUEL CELL MODEL IN BUILDINGS

Solid oxide fuel cells practice an electrolyte self-possessed of a solid, non-porous metal oxide, typically $Y2O_3$-stabilized ZrO_2 [1]. They function at 600°–1,000°C, at which temperatures ionic conveyance by oxygen ions take place. Naturally, the anode is a Ni-ZrO_2 cermet, besides the cathode is Sr-doped $LaMnO_3$. Since the SOFC electrolyte is solid, here are no material corrosion or electrolyte-management problems related to liquid electrolytes. Nevertheless, the high functioning temperatures place stringent supplies on the materials. A widespread range of fuels, counting various hydrocarbon fuels, can be transformed by SOFCs. The high functioning temperatures let for high-efficiency power conversion, interior reforming, and high-quality by-product heat for cogeneration or usage in a bottoming cycle. Simple-cycle and hybrid SOFC systems have established efficiencies that are amongst the highest of any power generation system in adding to minimal air pollutant emissions and low greenhouse gas emissions. These competences make SOFCs a good-looking emerging technology for stationary power generation ranging after 2 kW to 100s of megawatts of capacity. In more recent times, planar SOFC systems with high power densities working at lower temperatures (700°–850°C in its place of the previous norm of 900°–1,000°C) have been industrialized, which allows the use of less-expensive materials. This could recover the economics of SOFC applications reaching from small-scale stationary supremacy (dejected to ~2 kW) to auxiliary power units for vehicles and mobile generators. SOFCs could eventually be used to supply part of the prime power in vehicles. The key technical challenge is to produce robust, high-performance SOFC stack technologies using suitable low-cost materials and fabrication methods. Derivatives of SOFC technology, such as automobile oxygen sensors, are already in widespread commercial use.

The following description of SOFC operation is occupied after the *Fuel Cell Handbook*, 7th edition [1]. Realize that reference for additional details. Figure is a schematic of an SOFC operating configuration. The following are the half-cell electrochemical reactions:

$H_2 \rightarrow 2H^+ + 2e^-$ (at the anode) ………………. (1)

½$O_2 + 2H^+ + 2e^- \rightarrow H2O$ (at the cathode)…….. (2)

The following is the overall cell reaction:

½$O_2 + H_2 \rightarrow H_2O$………………… (3)

6. MODEL OF SOFC-CHP SYSTEM

The SOFC-CHP system established in this paper uses fuel and air inputs to produce electricity and heat. Some of the key development steps are described below, numbered to resemble with the numbers in Figure 6.

1. Fuel input and water content: Fuel (e.g., Natural gas) arrives the system. Anode exhaust recycles around 65% achieves an H_2O-to-CH_4 ratio of 2.5–3.0, which is characteristic of current industry performs. The feedstock is gutted of contaminants that can damage the system, such as sulfur (from the fuel) and salts (from the water). The cleanup subsystems remained not modeled since multiple technologies could be used, and many of them do not touch the mass and energy balance of the system suggestively.

2. Steam-methane reforming: The SMR somewhat (20%) reforms the fuel (CH4) to harvest CO and H_2. The reforming reaction temperature in the prototypical is 700°C. As this reaction is endothermic, the anode exhaust gas is cast off to preheat the steam and fuel mixture up to a enough temperature for the catalytic reactor. Partial pre-reform is done to frontier the temperature gradient in the fuel cell as of the endothermic reforming of CH_4 and the exothermic electrochemical reactions.

3. **Cathode air supply**: Air is abounding to the cathode at a stoichiometric ratio of 3.2 (i.e., ~3 times as ample O_2 is fed than stoichiometric ally wanted to react to the quantity of H_2 consumed). The additional air is cast off to cool the fuel cell and bound the temperature rise in the fuel cell stack to around 150°C. The air is preheated to a favorable catalytic reaction temperature by restoration with the cathode exhaust (depleted-O_2 air). The cathode exhaust is then cast-off as an oxidant for the tail gas combustion.

4. SOFC electricity production: Hydrogen is abounding to the anode at a stecometric ratio of 1.77 (i.e., 77% more H_2 is contemporary than can react to the amount of O2 present). The anode finish recycles about 65% brings the total fuel cell fuel operation up to 78% (i.e., The total proportion of fuel converted to electricity by the fuel cell is 78% via the reactions labelled in Equations 1–3). The polarization curve is distinct by a linear relationship with cell voltage of 0.78 V at supreme power (1,000 kW) and 0.84 V at minimum power (250 kW). The exhausted reformat from the anode exhaust is fed to the burner after heat recuperation.

5. Building heating system: Extra heat—after the fuel cell and from the combustion of idle fuel in the anode tail gas with the air from the cathode exhaust—is second-hand for heat generation. In the classic, water arrives the fuel cell heat recovery subsystem at 60°C and is animated to 80°C before returning to the facility.

6. Power electronics: The inverter converts DC electricity shaped by the fuel cell into AC electricity. An efficiency of 93% is expected for this conversion; higher efficiencies are conceivable for large applications. In addition, the power electronics naturally supply the power required by the fuel cell blowers, pumps, and valves. Inside the model, some power is used for fixed electrical draws such as control systems, cabinet aeration, solenoids, and fixed rapidity auxiliaries. These additional factors are accounted for by an extra 5% power loss.

7. Pressure swing adsorption (PSA): Around 85% of the hydrogen in the gas stream is healthier via PSA before being compressed to 6,250 psi for storage and supply. The residual gas stream (including unrecovered hydrogen) is nursed to the burner.

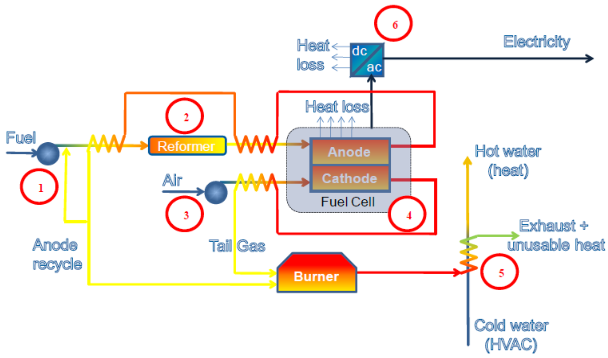

Figure 6 Schematic model of considered SOFC-CHP model

Figure 7 portrays a configuration of a single SOFC-CHP unit using a building load. It contains of a fuel cell unidirectional and bidirectional lonely full-bridge DC to DC power converters, a three-phase DC to AC inverter, an L-C output filter, a three-phase building load, and two controllers to make the performance of the fuel cell more efficient.

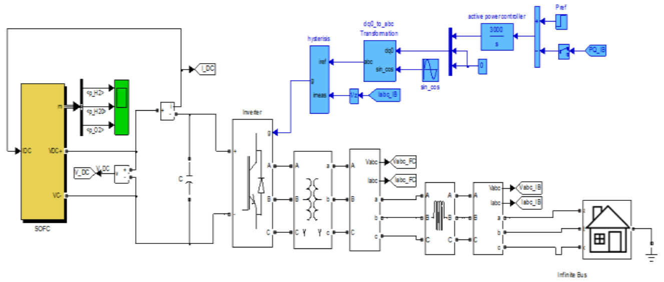
Figure 7: SOFC-CHP system connected to the building

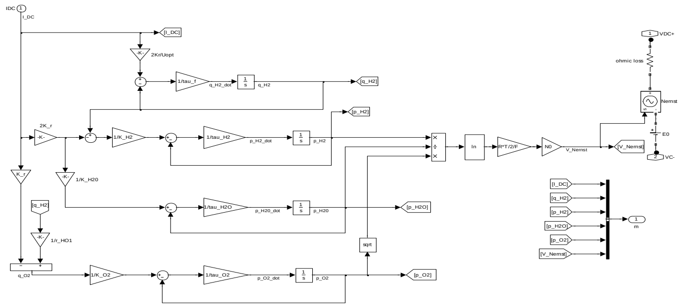
Figure 8: Simulink model of SOFC-CHP system

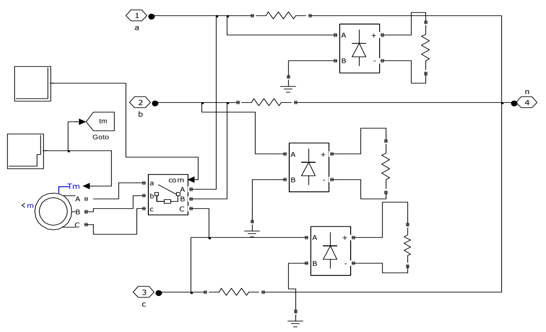
Figure 9: Considered balanced and unbalanced non-linear loads in a building

The above shown figure (8) gives the design of fuel cell founded on the equations 1, 2 and 3 and as the loads in a building can be of different types here we chose a combination of both balanced and unbalanced nonlinear loads which is shown in figure (9)

6. SIMULATION RESULTS

Based on the overhead design, a simulation model was developed in Matlab/Simulink and tested. The simulation results shown are of accurate values and the results are plotted below.

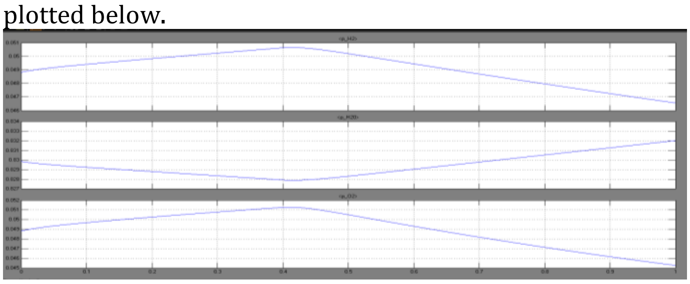
Figure 10 By products of Fuel cell

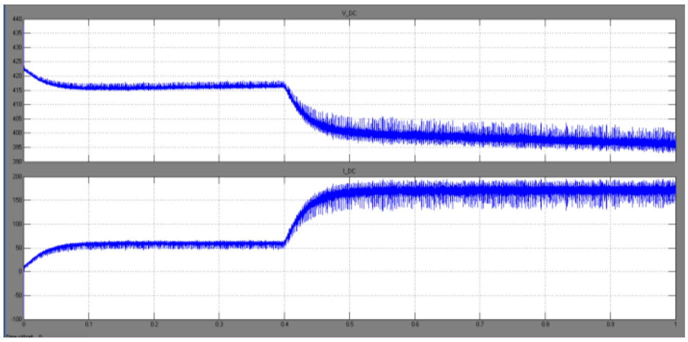
Figure 11 Fuel Cell Voltage and Current

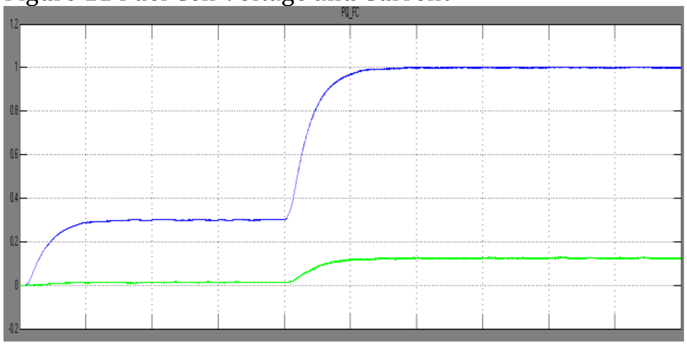
Figure 12 Active and Reactive power of Fuel cell

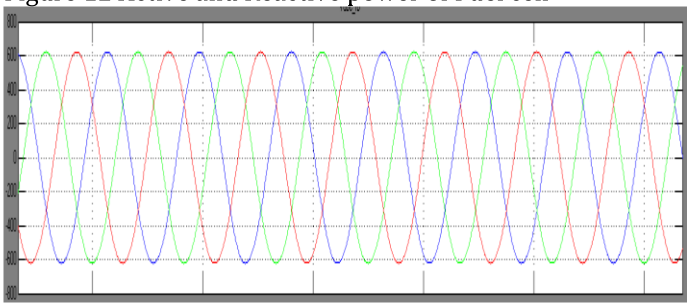
Figure 13 Inverter output voltages

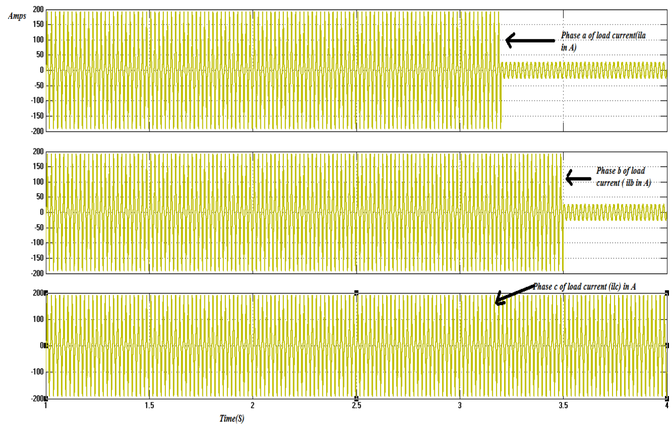
Figure 13 Inverter output currents due to balanced/unbalanced loads

7. ESTIMATED COST OF UNIT

Fuel cell	
Rated power (kW)	6.5
Efficiency (%)	50
Lifetime of individual cells (yrs)	5

Capital cost ($)	37350
Replacement cost ($)	2550
Electrolyser	
Rated power (kW)	6.5
Efficiency (%)	74
Lifetime of individual cells (yrs)	5
Capital cost ($)	37350
Replacement cost ($)	2550
Total capital cost of hydrogen tanks ($)	2000
Power converter	
Rated power (kW)	7
Efficiency (%)	95
Capital cost ($)	14000
Battery	
Voltage (V)	12
Capacity (kWhr)	1.35
Roundtrip efficiency (%)	85
Minimum charge (%)	30
Capital cost ($)	130
Lifetime (yrs)	5
Total capital cost of fuel cell unit($)	94800

8 .CONCLUSION

The basic physical process of fuel cell model for a building has been modeled using MATLAB/SIMULINK software.

Here a process is designed and explained for a combined SOFC-CHP system which offers more advantages. It is shown that the SOFC system is modeled using Matlab/Simulink and the unit is connected to a building load consists of balanced/unbalanced loads. The control used for the unit shows the better performance of fuel cell and maintenance of constant voltages for all the load conditions. The estimated economics were provided such that even a normal consumer will be aware of the total cost of unit.

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