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Effect of Temperature on the Efficient of Solid Oxide Fuel Cell

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ABSTRACT:Solid oxide fuel cells (SOFCs) are gaining prominence as power sources amongst other types of fuel cells due to their high electric energy efficiencies, their ability to integrate with other energy cycles in a hybrid system, fuel choice flexibility and low pollutant emissions. In the research work SIMULINK based dynamic modelling of solid oxide fuel cell is carried out. Various experiments were performed to evaluate the performance of the deigned SOFC model.The result from the developed models shows that the SOFCs give the best cell performance when operated at high temperatures. The study on the effect of integrating the SOFC in a three phase system showed high electrical efficiency.

KEYWORDS: SOFC, Dynamic, Temperature, Power, Current, Voltage.

I.INTRODUCTION

One of Renewable Energy Sources engender a modicum of greenhouse gases, and there is plenty of energy emanating from the sun, rivers or geothermal waters to cover human needs. There are, however, additionally some quandaries and inhibitions connected with these sources – the sun does not shine every day and its vigor is different depending on location, wind does not blow with the same vigor during the year and there is circumscribed accessibility for hydro and geothermal power depending on the location. An energy carrier is needed to store the electricity during excess engenderment so that it is yare to be used when the peak comes [1-5].

Solid oxide fuel cells (SOFC) are electrochemical devices that convert chemical energy of a fuel and oxidant directly into electrical energy. Since SOFCs produce electricity through an electrochemical reaction and not through a combustion process, they are much more efficient and environmentally benign than conventional electric power generation processes. Their inherent characteristics make them uniquely suitable to address the environmental, climate change, and water concerns associated with fossil fuel based electric power generation [7].

A planar SOFC consists of three bonded layers: a cathode, an anode, and an electrolyte separating the electrodes. Each electrode is a thin, porous, electronic (e-) conductor. Electrode porosity is required for gaseous diffusion between the electrode's outer surface and the electrode/electrolyte interface. The electrolyte is a thin, fully dense oxygen ion (O=) conductor, but not an electronic conductor. The electrolyte needs to be fully dense to prevent gaseous fuel from contacting air and burning [8-10].

The SOFC is a high-temperature operating fuel cell which has high potential in stationary applications. The efficiency of SOFC is in the range of 45-50% and when integrated with a gas turbine, it reaches a high efficiency of 70-75%. It is a solid-state device that uses an oxide ion-conducting non-porous ceramic material as an electrolyte. Since the electrolyte is a solid, the cells do not have to be constructed in the plate-like configuration typical of other fuel cell types. Corrosion is less compared to MCFC and no water management problems as in PEMFCs due to the solid electrolyte. High temperature operation removes the need for a precious-metal catalyst, thereby reducing the cost. It also allows SOFCs to reform fuels internally, which enables the use of a variety of fuels and reduces the cost associated with adding a reformer to the system [11-15].

Two different geometries which are being developed are tubular and planar. Tubular designs are more costly and advanced compared to the planar designs and is closer to commercialization. The electrolyte used is a ceramic oxide

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(yttria stabilized zirconia). The anode used is nickel-zirconia cermet and the cathode is a strontium doped lanthanum manganite. The use of ceramic materials increases the cost of SOFCs. High operating temperature requires stringent materials to be used which further drives up the cost. Research is being carried out to reduce the operating temperature and use less stringent materials.

Reduction of temperature improves the starting time, cheaper materials can be used, durability and robustness can be increased. Intermediate-temperature SOFCs cannot be used for all applications. Higher temperature is required for fuel cell micro-turbine hybrid systems. However, for smaller systems intermediate temperature SOFCs would be ideal [57-58].

Since SOFCs have fuel-flexibility, the input to the anode can be hydrogen, carbon monoxide or methane. Hydrogen or carbon monoxide may enter the anode. At the cathode, electrochemical reduction takes place to obtain oxide ions. These ions pass through the electrolyte layer to the anode where hydrogen is oxidized to obtain water. In case of carbon monoxide, it is oxidized to carbon dioxide [16-20].

$$O_2 + 4e^- \rightarrow 2O^{2-}$$

$$H_2 + O^{2-} \rightarrow H_2O + 2e^-$$

$$CO + O^{2-} \rightarrow CO_2 + 2e^-$$

$$H_2 + O_2 + CO \rightarrow H_2O + CO_2$$

Hydrogen is the fuel that has been used in this analysis. Operating voltage (Vfc) ofthe fuel cell at a current I is obtained by applying the Nernst’s equation and taking thelosses into account is shown in equation

$$V_{fc} = E - V_{act} - V_{conc} - rI$$

$$E = N(E^o + \frac{RT}{2F}\left(\frac{pH_2 . pO_2^{1/2}}{pH_2O}\right)$$

E – Reversible open circuit voltage (V)

Eo – Standard reversible cell potential (V)

pi – Partial pressure of species i (Pa)

Vact – Drop due to activation loss (V)

Vconc – Drop due to concentration loss (V)

r – Internal resistance of stack (Ω)

I – Stack current (A)

N – Number of cells in stack

R – Universal gas constant (J/ mol K)

T – Stack temperature (K)

F – Faraday’s constant (C/mol)

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Typical values for the above parameters are shown in Table A.1 of the Appendix. Activation loss is due to the slow rate of the electrochemical reaction between the fuel and the oxidant. A part of the voltage generated is lost in initiating the electrochemical reaction. Concentration loss results from the change in concentration of the reactants at the surface of the electrodes as the fuel is used. When the reactants are being consumed at the respective electrode, there will be a slight reduction in the concentrations. This change in concentrations leads to a drop in the partial pressures which results in a reduction in the voltage [47]. In this analysis, a reduced model of the fuel cell has been taken into account, neglecting the activation and concentration losses as well as the double charging effect. The loss due to internal resistance of the stack is basically due to the resistance to the flow of ions in the electrolyte as well as the material of the electrode [21-22]

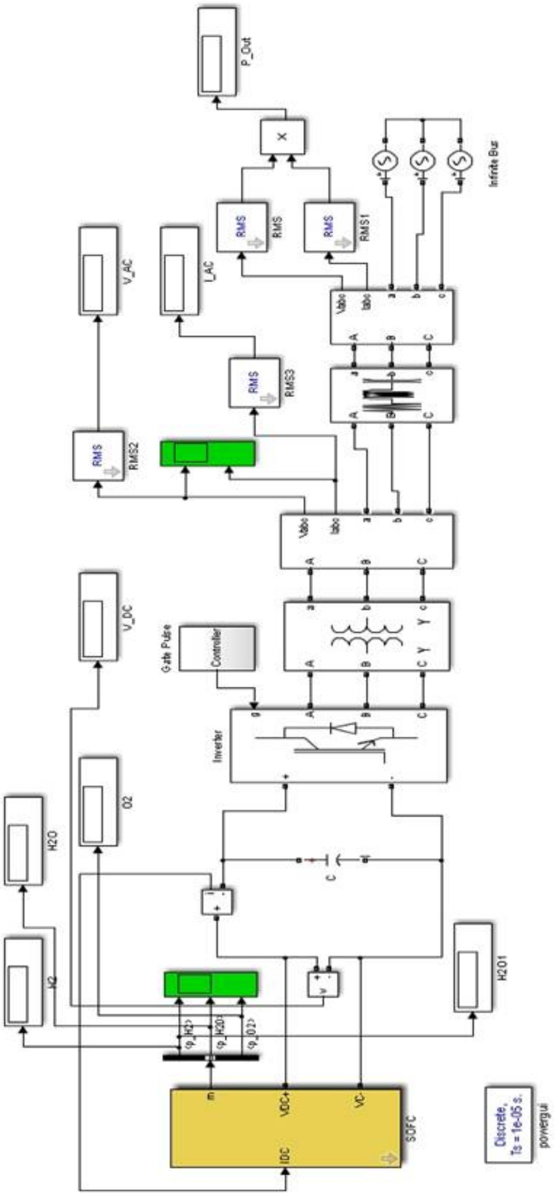

Fig. 1 Designed Simulink model for three phase solid oxide fuel cell.

Table 1 Effect of temperature on electrical parameter with RLC type impedance

Temperature (K)	DC Voltage (V)	AC Voltage (V)	AC Current (A)	Power Across Load (W)
323.15	669	1204	0.08321	36.61
373.15	663.9	1195	0.08229	36.21
423.17	658.8	1186	0.08136	35.8
473.15	653.7	1176	0.08043	35.39
523.15	648.7	1167	0.0795	34.98
573.15	643.6	1158	0.07857	34.57
623.15	638.5	1149	0.07764	34.16
673.15	633.4	1140	0.07672	33.76
723.15	628.3	1131	0.07579	33.35
773.15	623.2	1122	0.07487	32.94
823.15	618.2	1112	0.07394	32.54
873.15	613.1	1103	0.07302	32.13
923.15	608	1094	0.0721	31.72
973.15	602.9	1085	0.0718	31.32
1023.15	597.9	1076	0.07025	3091
1073.15	592.8	1067	0.06933	30.15
1123.15	587.7	1058	0.06841	30.1
1173.15	582.7	1048	0.0675	29.7
1223.15	577.6	1039	0.06658	29.29
1273.15	572.5	1030	0.06566	28.89

II.METHODOLOGY

The centralized and regulated electric utilities have always been the major source of electric power production and supply. These are small generating units which can be located at the consumer end. Fuel cell shows potential application as they are portable. In this research work dynamic model of fuel connected to three phase load is to be modeled and various effect of temperature. The fuel cell stack is connected to the utility load via the IGBT inverter. The fuel cell and DC-AC inverter are modeled in SIMULINK. Figure 4.18 shows the block diagram representation of the fuel cell system connected to the utility load through the three phase transformer and the IGBT based inverter.

The designed model in SIMULINK is shown in Fig. 1. Simulink have a graphical user interface with 5 levels of capabilities. In terms of implementation of the models and accuracy in the results, it is highly suitable. SIMULINK was developed primarily for power system analysis. Another feature of SIMULINK that makes it an ideal choice for modeling is its data import and export facilities. Data can be exchanged between the main system and the subsystems without having any connection between them. Various simulations has been carried out to investigate the fuel cell stack effect on power generation, effect of temperature on power generation capability of fuel cell, and finally the effect of load on the fuel cell. In experiment I, numbers of fuel cells were varied from 50 to 600 with RLC and RL load connected to the output. In experiment II, temperature of the fuel cell was varied and the output power was measured and finally in experiment III, load was varied and the output current and power were measured.

III.RESULTS AND DISCUSSION

The simulation results consist of the fuel cell and dependencyon temperature of the system.Temperature is an important factor that determines the efficiency of the solid state devices performance. In this experiment temperature was varied with 600 fuel cell stack and contact load at the output. Table 1 shows the tabulated output electrical parameter. Figure 2 to 5 shows the dc output voltage obtained at fuel cell, ac converted voltage, ac current passing through load and power delivered to the load respectively. It can be observed for the tabulated that the trend line in the values of electrical parameters decreases as the temperature is increases. But the deviation in the voltage levels are not that much prominent as the SOFC model is stable at high temperature also which can visualize from the graphs. The maximum value of electrical parameter obtained at 373 K are dc voltage of 669 V, rms ac voltage of 1204 V, rms ac current of 0.08321 A, and output power of 36.61 W. Minimum value of electrical parameter obtained at 1273 K are dc voltage of 572.5 V, rms ac voltage of 1030 V, rms ac current of 0.06566 A, and output power of 28.89 W.

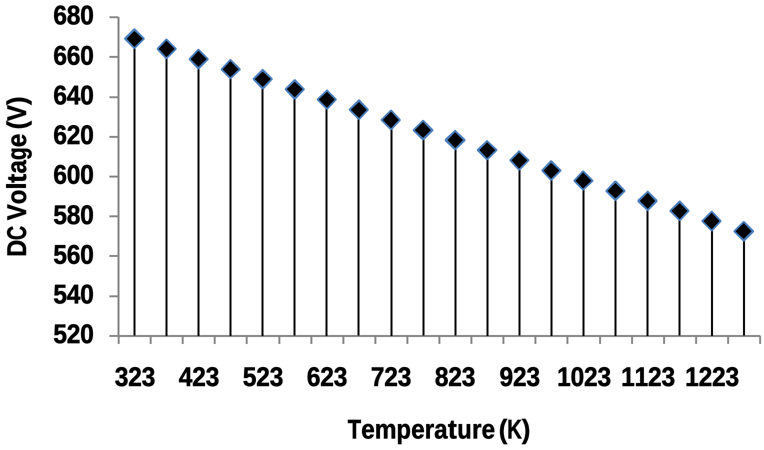

Fig. 2 variation in dc voltage with change in temperature.

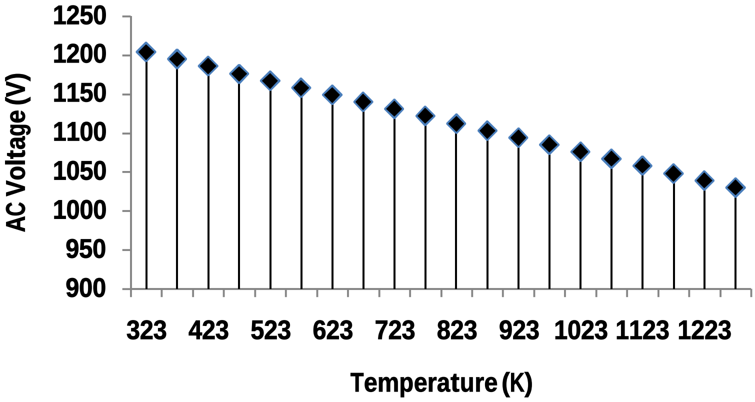

Fig. 3 Variation in output RMS ac voltage with change in temperature.

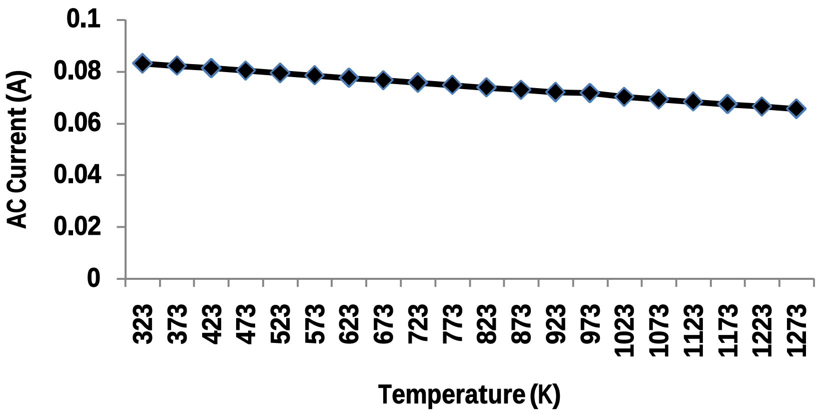

Fig. 4 Variation in output RMS ac current with change in temperature.

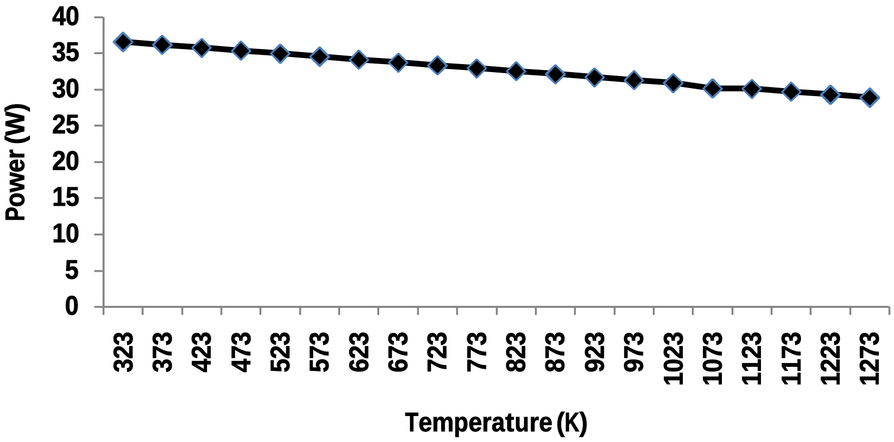

Fig. 5Variation in output power with change in temperature.

IV.CONCLUSION

The main contribution of this thesis to the field of the design and operation of SOFC systems. The presented design and system components demonstrated to be technically feasible and can be utilized in the future to develop commercial systems. Various experiments were carried out to effectively demonstrate the variation in electrical parameters such as dc voltage, ac voltage, ac current, and power with change in system temperature.In second set of experiment effect of temperature was computed on the electrical parameters. Since the semiconductor electronic components depends upon the temperature and with each one degree Celsius rise in temperature voltage also varies thus the output parameters of the system decreases as the temperature is increased.

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