

Solid Oxide Fuel Cell Connected to Load

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ABSTRACT

In this paper fuel cell technology can belong to either of the above categories. If the hydrogen fuel needed to power the fuel cell is generated from a renewable source, the fuel cell power generating unit is considered a renewable energy technology. i.e., wind and solar energy used to generate hydrogen to fuel a fuel cell stack. On the contrary, if hydrogen is produced from a fossil fuel source (e.g., natural gas or methane), the fuel cell is considered a nonrenewable energy technology. Fuel cells have numerous benefits which make them superior compared to the other technologies.

Keywords-- SOFC, Hydrogen, Fuel cell

I. INTRODUCTION

The depleting fossil fuel resources and increasing pollution are leading to the research and development of alternate energy generation techniques like fuel cells and solar cells. Fuel cell systems have a high efficiency and use easily available hydrocarbons like methane thus alleviating the fuel shortage. Moreover, since the by-product is water, they have a very low environmental impact. The fuel cell system consists of several subsystems and a lot of effort in diverse areas is required to make it a popular choice for power generation. An introduction is provided describing the working of the fuel cell, its applications and the use of fuel cell for power generation. A SOLID OXIDE fuel cell (SOFC) converts chemical energy into electrical energy at high temperature. The SOFC is a promising technology for distributed power generation with high efficiency and no moving parts. Fuel cells typically utilize hydrogen as the fuel and oxygen (usually from air) as the oxidant in the electrochemical reaction. It generates electricity, and its by-products are water and heat. DG technologies can be categorized to renewable and nonrenewable DGs. Renewable energy technologies are in general sustainable (i.e., their energy

source will not run out) and cause little or no environmental damage; they include: Solar photovoltaic, Solar thermal, Wind, Geothermal, Tidal, Low head (small) hydro, Biomass and biogas and Hydrogen fuel cells (hydrogen generated from renewable resources). Nonrenewable energy technologies are referred to those that use some type of fossil fuel such as gasoline, diesel, oil, propane, methane, natural gas, or coal as their energy source. Fuel cell technology can belong to either of the above categories. If the hydrogen fuel needed to power the fuel cell is generated from a renewable source, the fuel cell power generating unit is considered a renewable energy technology. i.e., wind and solar energy used to generate hydrogen to fuel a fuel cell stack. On the contrary, if hydrogen is produced from a fossil fuel source (e.g., natural gas or methane), the fuel cell is considered a nonrenewable energy technology. Fuel cells have numerous benefits which make them superior compared to the other technologies. Fuel cells eliminate pollution caused by burning fossil fuels; the only by product is water. Since hydrogen can be produced anywhere where there is water and electricity, production of potential fuel can be distributed. Most fuel cells operate noise less, compared to internal combustion engines. However, they are attributed to some of the drawbacks; Fuelling fuel cells is still a problem since the production, transportation, distribution and storage of hydrogen is difficult, Reforming hydrocarbons via reformer to produce hydrogen is technically challenging and not clearly environmentally friendly. Fuel cells are in general slightly bigger than comparable batteries or engines. However, the size of the units is decreasing fuel cells are expensive.

A Applications of Fuel Cells Fuel cells have been used extensively and successfully in spacecrafts and now efforts are on to commercialize the fuel cell. They have a wide range of applications which are listed below.

1. Stationary power

- Power generating stations

- Auxiliary units
- Distributed power generation
 - Residential use as combined heat and power (CHP) generation systems

2. Transportation

- Buses and cars
- Airport intra-terminal vehicles

3. Portable electronics

- Laptops
- Cellular phones

1.1 Working of a Typical Fuel Cell

Fuel cell is an electrochemical device that continuously converts the chemical energy of a fuel and oxidant into electrical energy and heat as long as the fuel and oxidant are supplied to the electrodes. A fuel cell is similar to a battery as it operates on the electrochemical

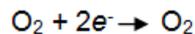
energy conversion principle but there is an important difference; a fuel cell does not store fuel like a battery, but runs on a continuous supply of fuel. This makes it similar to engines, but unlike engines it does not combust the fuel giving out gases, it galvanically burns the fuel and the output is water. However, the efficiency of a heat engine is limited by the Carnot efficiency but since a fuel cell works on an electrochemical principle it is not similarly limited and thus can achieve a efficiency higher than a heat engine. Thus, a fuel cell achieves the continuous energy transformation from chemical to electrical form with very low pollution and high efficiency making it an excellent choice for power generation.

The electrochemical reactions that occur in an SOFC that utilize fuel (hydrogen) and air (oxygen) are as follows.

Anode:



Cathode:



Overall reaction:

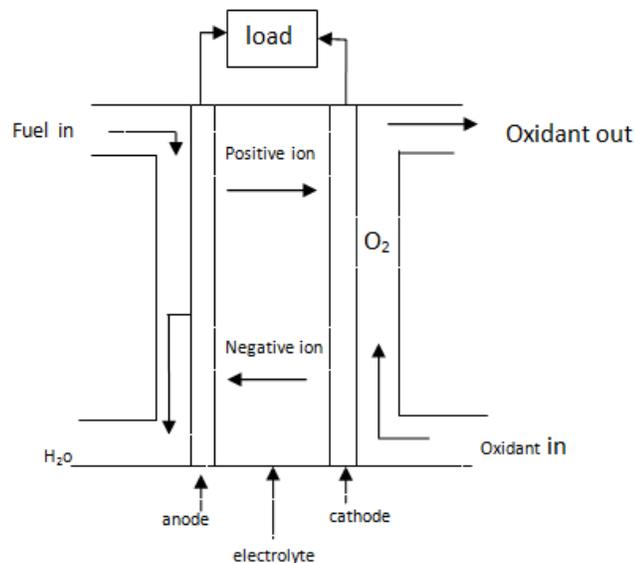
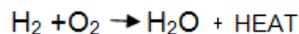


FIG.1 FUEL CELL

A fuel cell consists of a fuel electrode (anode) and an oxidant electrode (cathode), separated by an ion-conducting electrolyte. The electrodes are connected externally through a load, thus completing the electronic - ionic circuit. A basic fuel cell with hydrogen as the fuel and oxygen as the oxidant is considered. The hydrogen is ionized at the anode to give hydrogen ions and electrons. The electrolyte allows only the ionic flow and resists the electronic flow. Hence the electrons flow through the electrical circuit and reach the cathode after supplying power to the load whereas the hydrogen ions flow through the electrolyte to reach the cathode. Oxygen at the cathode reacts with the electrons and the hydrogen ions to form water. The overall reaction is the sum of the anodic and the cathodic reactions producing water. In high temperature fuel cells, the ionic carriers are carbonate ions

for molten carbonate electrolyte fuel cells and oxide ions in the case of solid oxide fuel cells.

1.2 TYPES OF FUEL CELL

There are mainly four types of fuel cell :-----

- Alkaline fuel cell
- Phosphoric-acid fuel cell (PAFC)
- Solid oxide fuel cell (SOFC)
- Molten carbonate fuel cell (MCFC)

Alkaline fuel cell (AFC)

This is one of the oldest designs. It has been used in the U.S. space program since the 1960s. The AFC is very susceptible to contamination, so it requires pure hydrogen and oxygen. It is also very expensive, so this type of fuel cell is unlikely to be commercialized.

Phosphoric-acid fuel cell (PAFC)

The phosphoric-acid fuel cell has potential for use in small stationary power-generation systems. It operates at a higher temperature than PEM fuel cells, so it has a longer warm-up time. This makes it unsuitable for use in cars.

Solid oxide fuel cell (SOFC)

These fuel cells are best suited for large-scale stationary power generators that could provide electricity for factories or towns. This type of fuel cell operates at very high temperatures (around 1,832 F, 1,000 C). This high temperature makes reliability a problem, but it also has an advantage: The steam produced by the fuel cell can be channeled into turbines to generate more electricity. This improves the overall efficiency of the system.

Molten carbonate fuel cell (MCFC)

These fuel cells are also best suited for large stationary power generators. They operate at 1,112 F (600 C), so they also generate steam that can be used to generate more power. They have a lower operating temperature than the SOFC, which means they don't need such exotic materials. This makes the design a little less expensive.

1.3 Fuel Cell Power Plant

Since the fuel cell has a low environmental impact in terms of negligible air and noise pollution and requires low maintenance, it is an excellent choice for power generating systems and can also be placed in residential areas. A typical fuel cell power system consists of the following components.

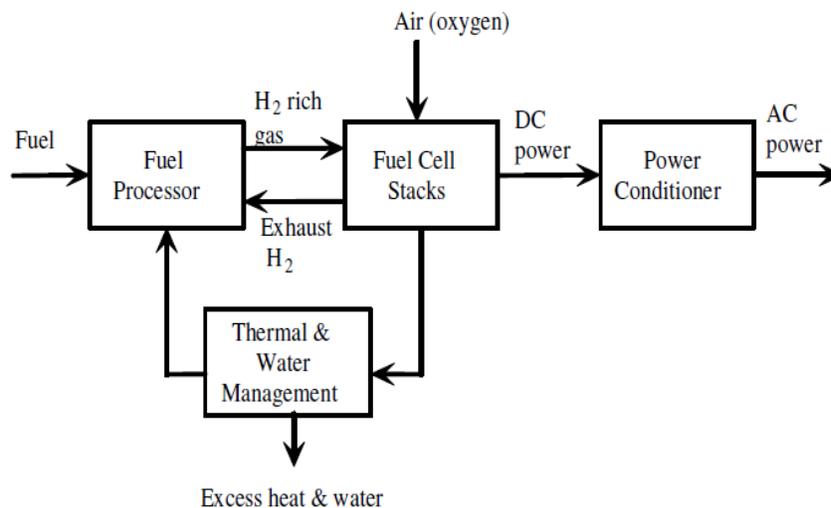


FIG.2 BLOCK DIAGRAM FUEL CELL POWER PLANT

1. Fuel processor:

The fuel needs to be treated and purified before it can be used in the fuel cell. Fuel processors (also called a fuel reformer) is used to pre treat the fuel and boost the hydrogen concentration before it is fed into the fuel cell.

2. Fuel cell stack:

This forms the heart of the fuel cell power system. A fuel cell stack is made up of individual fuel cells connected in series to increase the output DC voltage.

3. Power conditioner:

The fuel cell output is a DC low voltage. Most applications use AC voltage. The power conditioner provides the interface between the fuel cell output and the load and thus regulates or converts the DC power to AC power. It also provides the control and grid interface.

4. Thermal and waste management:

The heat and waste generated in the fuel cell and the fuel processor is dissipated or recovered (cogeneration) by the thermal and waste management system. Simulate the behavior of the fuel cell it can greatly aid the

development of the fuel cell technology, the control systems and the power electronics required for fuel cells.

II. FUEL CELL ELECTRICAL CHARACTERISTICS

In order to design a simulator, a mathematical model of the fuel cell needs to be developed. The internal working of the fuel cell needs to be studied and the effects of various parameters need to be known. In this chapter, the electrochemical and thermodynamic principles of fuel cells are described and the effect of various parameters such as temperature, pressure and reactant composition on the fuel cell power output are studied.

2.1 Energy Conversion Efficiency

Since a fuel cell burns the fuel galvanically the enthalpy change (ΔH) during combustion is not converted entirely to heat. Instead of hot molecules in random motion, a stream of electrons is given out whose maximum total energy is equal to the change in free energy (also

called Gibbs energy, ΔG) for the reaction. In an ideal fuel cell, all the free energy change is available in the form of electrical energy. The efficiency of the energy conversion is based on energy output produced relative to change in thermal energy between reactants and products given by the enthalpy change for the process. Thus the maximum energy conversion efficiency (Efficiency max,ec) of a fuel cell

$$\text{Efficiency max}_{,ec} = \Delta G_T / \Delta H_o$$

where ΔG_T is the Gibbs energy at cell operating temperature T and ΔH_o is the thermal energy at the standard temperature (298.15 K) and pressure (100 kPa)(STP). It is important to note that for fuels containing hydrogen the value for thermal energy(ΔH) varies depending on whether the output is liquid water or vapor.

Form of Water Product	Temperature (°c)	Max V rev (v)	Efficiency Limit (%)
Liquid	25	1.23	83
Liquid	80	1.18	80
Gas	100	1.17	79
Gas	200	1.14	77
Gas	400	1.09	74
Gas	600	1.04	70
Gas	800	0.98	66
Gas	1000	0.92	62

Maximum Reversible Cell Potentials V_{rev} And Maximum Efficiency limit for hydrogen Fuel cell two values are called the higher heating value (HHV) and the lower heating value (LHV) respectively and the latent heat of vaporization accounts for this difference. The maximum efficient limit and maximum reversible open circuit voltage for a hydrogen fuel cell for various temperatures. It appears from the ideal case that low temperature fuel cells have higher efficiency and voltages, however, in actual fuel cells the losses are higher at low temperatures as compared to losses at high temperatures. The high temperature fuel cells can be used in combined heat and

power (CHP) systems and show a higher system efficiency.

2.2 Efficiency and the Fuel Cell Voltage

It is seen that there is a connection between the maximum efficiency and the maximum voltage. For a hydrogen fuel cell, the thermal energy of the reaction (ΔH) is 285.8 kJ/mole and the Gibbs free energy (ΔG) is 237.1 kJ/mole, it follows the maximum thermal efficiency at STP is 0.83. Using the LHV for hydrogen, the ideal voltage is 1.229 V for hydrogen fuel cell operating reversibly at STP. The actual efficiency of a fuel cell can be expressed as a ratio of the actual fuel cell voltage to the ideal voltage as

$$\eta = \frac{\text{useful energy}}{\Delta H}$$

It come out

$$\eta = 0.675 * V_{cell}$$

2.3 Fuel Cell Losses

An actual fuel cell has a lower efficiency than the ideal one because of the irreversible losses in the cell reaction. The fuel cell terminal voltage drops from the open circuit voltage and this drop in voltage is proportional to the current drawn by the electric circuit. This phenomenon is known as polarization. There are three main types of polarization: activation polarization, ohmic polarization and concentration polarization.

1. Activation polarization:

This occurs due to slow charge transfer reaction at the surface of the electrodes. Some of the electrode potential is used to drive the electron transfer to match the current demand and thus the potential at the fuel cell terminal is reduced. Activation polarization depends on the nature of type of electrode, ionic interactions, ion-solvent interactions and the electrode electrolyte interface. Increase in temperature reduces the loss due to activation polarization. Using a catalyst to speed up the charge

transfer and increasing the active surface area of the electrode improves the cell performance.

2. Ohmic polarization:

This occurs due to resistance to the flow of ions in the electrolyte, resistance to the flow of electrons through the electrodes and the contact resistance at the cell terminals. These losses can be reduced by using electrolytes with high ionic conductivity, electrodes with high electronic conductivity and reducing the space between electrodes to minimize electrolyte resistance.

3. Concentration polarization:

This occurs due to a decrease in the concentration of the reactants at the electrode-electrolyte interface. A steady supply of the reactants is required at the electrode-electrolyte interface to maintain the flow of electric current. Due to diffusion or convection problems in the electrolyte, the concentration of the reactants is not maintained at the initial level. Reaction product accumulation can also cause dilution of reactants. The

concentration gradient thus formed, causes a drop in electrode activity and the terminal voltage is reduced. The ideal and the practical fuel cell electric characteristics. In a practical fuel cell, the voltage drop is significantly more at low and high current densities. At low current densities, the activation polarization is predominant and at high current densities, the concentration polarization is a

major cause of losses. The ohmic polarization is nothing but cell resistance and hence with increase in cell current the voltage drop increases proportionately. Low temperature fuel cells exhibit high activation polarization at low current densities. On the other hand, high temperature fuel cells have a low activation losses and ohmic polarization is the most important cause for losses.

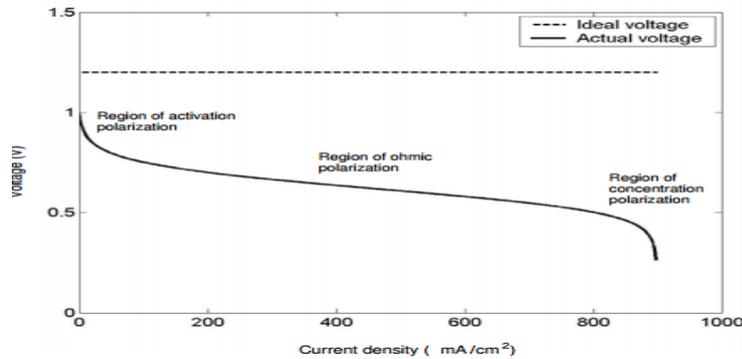


FIG 3: FUEL CELL ELECTRICAL CHARACTERISTICS

2.4. Fuel Cell Performance Parameters

Fuel cell performance is affected by design parameters such as cell size, power level, cost and by operating variables such as temperature, pressure, fuel composition and current density. Many of these parameters have opposing influences and a compromise has to be arrived at based on constraints dictated by the application.

1. Temperature

Its seen that with increase in temperature the reversible voltage for a hydrogen fuel cell decreases. But for an actual fuel cell the effect of temperature is different. The cell voltages of PEFCs, PAFCs, and MCFCs show a strong, positive dependence on temperature. PEFCs show increase in voltage till a point and suddenly the voltage drops with further increase in temperature. This is due to

water management problems at temperatures above 100°C. SOFCs are operated at about 1000°C because the ohmic resistance of the electrolyte increases rapidly with decrease in temperature. The improvement in performance at higher temperatures is due to decrease in polarization losses. An increase in temperature leads to an increase in reaction rate, higher mass transfer rate and lower cell resistance due to improved ionic conductivity of the electrolyte. For low-temperature fuel cells the CO tolerance of electrolytes increases with rise in temperature. However, material problems related to corrosion, electrode degradation, electro catalyst sintering and re-crystallization and electrolyte loss due to evaporation are accelerated at higher temperatures

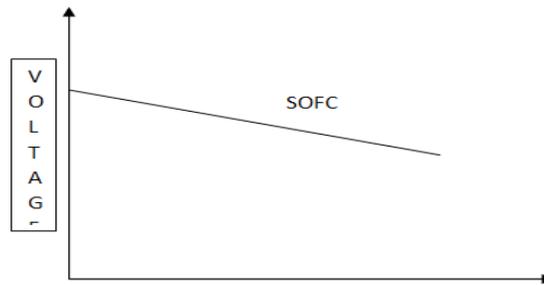


FIG.5 TEMPERATURE

2. Pressure

The change in Gibbs free energy due to pressure can be studied by the Nernst equation. It shows the effect of pressure on cell voltage as follows.

$$E = E_0 + \frac{RT}{2F} \ln \frac{\alpha \beta^{1.2}}{\delta} P^{1.2}$$

where E_0 is the EMF at standard pressure (100 kPa), F is the Faraday constant (96485 C), α , β are constants depending on molar masses and concentrations of the reactants, δ is a constant depending on molar mass and concentrations of the product and P is the system pressure. The pressure on both the cathode and anode are assumed same to simplify the equation. It is seen that increasing the operating pressure of the fuel cell has a positive impact on the cell voltage. Increase in pressure implies that the re partial pressure, gas solubility and mass transfer rates are higher. Additionally, electrolyte loss by evaporation is lower at a high pressure. But this is offset by the extra power required to compress the reactants and the financial cost required to improve the structural strength of the fuel cell to withstand the higher pressure.

III. FUEL CELL MODELLING

The mathematical modeling of the Fuel Cell is a complex task and still need more investigation. The single components of the system interact with each other in a complex form, where the electrical, chemical, and thermodynamic processes are strongly non-linear in nature. These processes are accomplished at high efficiency, as the fuel cell has no moving parts. The parameters of such complex models are difficult to estimate. A model developed for dynamic power

simulation of Fuel Cells available has been used in this work as a starting point. The assumptions for the model are as follows.

- The gases are ideal
- The fuel cell is fed with hydrogen and air
- The pressure drop across the electrode channels is negligible
- The ratio of pressures between the inside and outside of the electrode channels is large enough to assume choked flow
- The fuel cell temperature is stable
- The Nernst equation applies
- The losses are as follows: Ohmic, Activation, Mass Transport.

By Nernst's equation output fuel cell dc voltage across stack of the fuel cell at current I is given by the

$$E = E_0 + \frac{RT}{2F} \ln \frac{p_{hydrogen} * p_{oxygen}}{p_{water}}$$

Where – Operating dc voltage (V), E_0 – Standard reversible cell potential (V), P_i – Partial pressure of species i (Pa), - Number of cells in stack, R – Universal gas constant (J/mol K), T – Stack temperature (K), F – Faraday's constant (C/mol),

The main equations describing the slow dynamics of a SOFC can be written as follows.

$$\begin{aligned} \frac{dq_{H_2}}{dt} &= \frac{1}{\tau_f} \left[-q_{H_2} + \frac{2K_r}{U_{opt}} I_{DC} \right] \\ \frac{dp_{H_2}}{dt} &= \frac{1}{\tau_{H_2}} \left[-p_{H_2} + \frac{1}{K_{H_2}} (q_{H_2} - 2K_r I_{DC}) \right] \\ \frac{dp_{O_2}}{dt} &= \frac{1}{\tau_{O_2}} \left[-p_{O_2} + \frac{1}{K_{O_2}} \left(\frac{1}{r_{HO}} q_{H_2} - K_r I_{DC} \right) \right] \\ \frac{dp_{H_2O}}{dt} &= \frac{1}{\tau_{H_2O}} \left(-p_{H_2O} + \frac{2K_r I_{DC}}{K_{H_2O}} \right) \end{aligned}$$

q_{H_2} – Fuel flow (mol/s),

q_{O_2} – Oxygen flow (mol/s),

K_{H_2} – Valve molar constant for hydrogen (kmol/satm),

K_{O_2} – Valve molar constant for oxygen (kmol/s atm),

K_{H_2O} – Valve molar constant for water (kmol/s atm),

τ_{H_2} – Response time for hydrogen (s),

τ_{O_2} – Response time for oxygen (s),

τ_{H_2O} – Response time for water (s),

τ_f – Fuel response time (s),

U_{opt} – Optimum fuel utilization,

r_{HO} – Ratio of hydrogen to oxygen, K_r – Constant (kmol/s A).

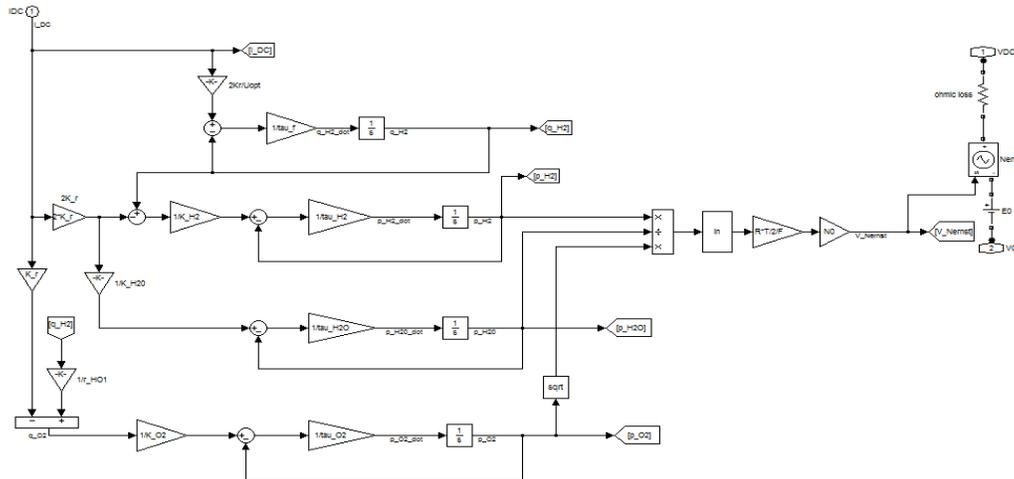


FIG 6 SOLID OXIDE FUEL CELL MODEL

- Absolute temperature= 1273 k
- Universal gas constant= 96.487e6 c/kmol
- Ideal standard potential=1.18V
- Number of cell in series= 450
- Optimal fuel utilization = 0.85
- Valve molar constant for hydrogen, water and oxygen=8.43e-4, 81e-4, 2.52e-3 kmol/atm
- Response time for hydrogen,water and oxygen flow = 26.1,78.3,2.91
- Ohmic losses per cell = 3.2813e-004s
- Electrical response time=0.8s
- Fuel processor response time=5s
- Ratio of hydrogen to oxygen=1.145

IV. SYSTEM UNDER CONSIDERATION

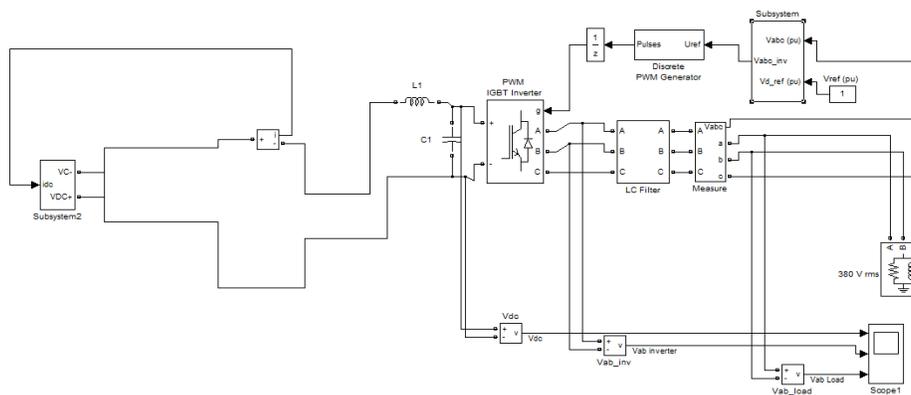
SIMULINK MODEL

The system consists of a SOFC which is connected to a three-phase load through an IGBT inverter. The filtered DC voltage is applied to an IGBT two-level inverter generating 50 Hz. The IGBT inverter uses Pulse Width Modulation (PWM) at a 2 kHz carrier frequency. The circuit is discretized at a sample time of 2 us. The Discrete 3-Phase PWM Pulse Generator is available in the Extras/Discrete Control Blocks library. The voltage

regulator has been built from blocks of the Extras/Measurements and Extras/ Discrete Control libraries

The load voltage is regulated at 1 pu (380 V rms) by a PI voltage regulator using abc_to_dq and dq_to_abc transformations. The first output of the voltage regulator is a vector containing the three modulating signals used by the PMW Generator to generate the 6 IGBT pulses.

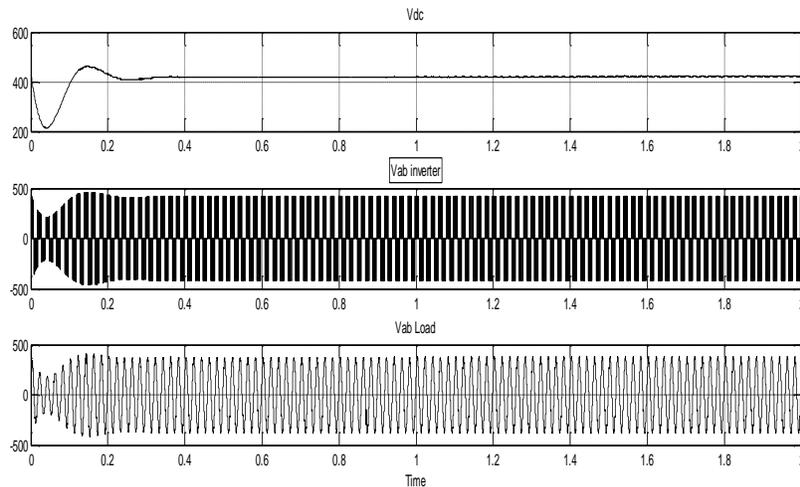
V. MATLAB SIMULINK MODEL



VI. RESULTS AND DISCUSSION

The output results of the Simulink model has been obtained and the are shown in the waveform. Output

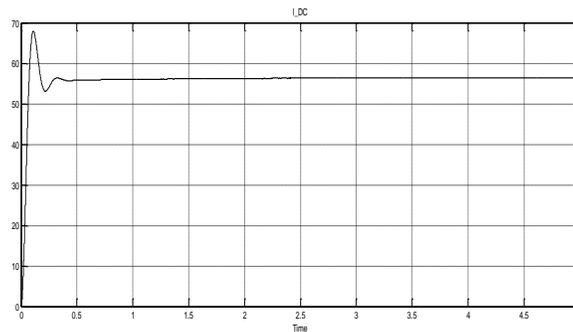
dc voltage comes out near 420V dip in output voltage due to inductor and capacitor charging. Load phase to phase voltage is 381 rms.it takes 0.2 sec to settle output.



OUTPUT CURRENT OF SOLID OXIDE FUEL CELL

Output current from the solid oxide fuel cell is near 55 ampere as shown in figure. It takes 1 sec to

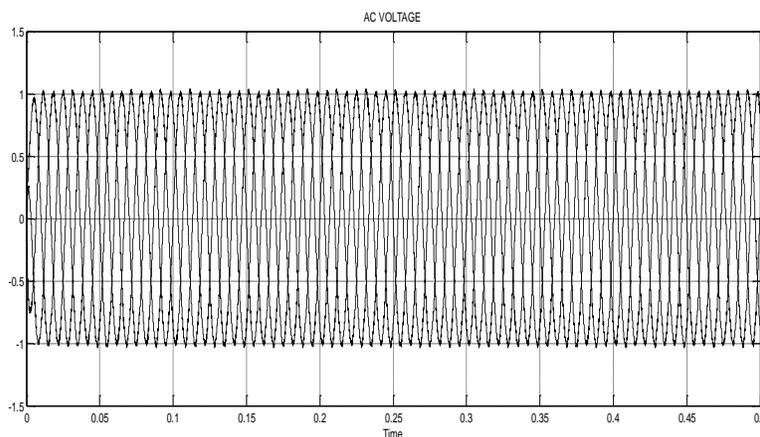
become constant. In shown figure current is filtered using LC filter to remove the distortion.



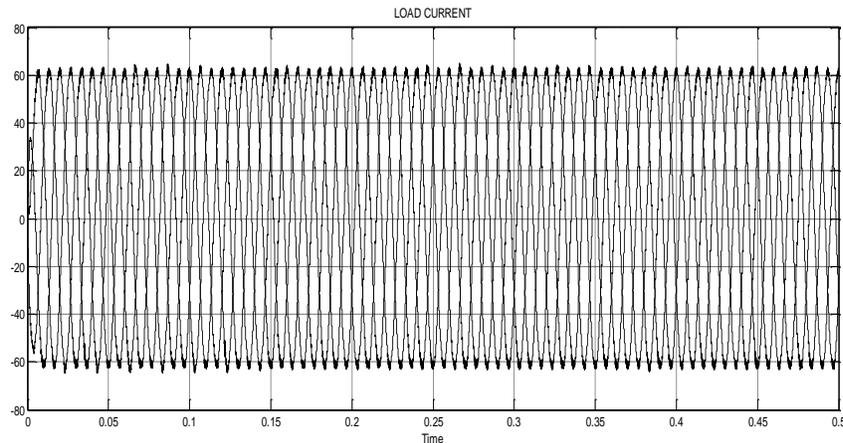
THREE PHASE VOLTAGE

It can be clearly observed from the below figure that the load voltage is settled at 1 p.u. as desired. which

can be regulated by changing the base voltage in measurement block.



THREE PHASE AC LOAD CURRENT



VII. CONCLUSION

The dynamic model of the solid oxide fuel cell (SOFC) is developed using MATLAB. A DC–DC boost converter can be used to boost up the voltage, the three phase voltage source inverter and a closed loop control structure are modelled using MATLAB. The inverter control scheme uses a PWM and PI control strategy to control the output voltage. The power conditioning unit including DC–AC inverter implemented in MATLAB. The DC characteristic of SOFC is analysed with a constant load. The AC characteristics of SOFC model are tested under an AC load. The simulation results show that the SOFC model and the power conditioning unit, which are developed by MATALB, can be used for power system applications.

VIII. FUTURE SCOPE OF WORK

As of today, a detailed study of electrode and electrolyte materials for SOFC that is compatible with LTCC has been demonstrated. There is plenty of scope for further work in this area. Although SOFC device development was also taken up in this work, it was not studied in great details. Again, there is a plenty of scope for optimizing the fabrication process and design of such integrated SOFC. Thus, the further developmental work can be taken up in these two directions, as elaborated below:

SOFC materials development:

In this work, the development of glass-ceramic material for oxygen ion conductor electrolyte has been almost completed. The next work in this area, therefore, is to take the laboratory scale work to a pilot and production scale and develop the related batch processes. Work is required to be done to develop tapes, these materials in tapes and paste format that is necessary for integration with the LTCC technology.

Once the full set of LTCC compatible materials is available, much closer look at the physical properties of these materials is needed to improve for co-firing capability with LTCC materials. This would facilitate fabrication of SOFCs in using LTCC process flow. Again, up-scaling and bringing the materials in LTCC compatible forms of tapes or pastes would be required. Completion of the above identified work would surely lead to a significant breakthrough in commercialization of this new SOFC technology.

Miniaturization of the device using LTCC:

The SOFC cell development work presented in this Thesis has been only in its initial stages. There is a need to look into the flow channel design, current collector designs, fuel and oxidant supply and the rest of the integration aspects (which works together with materials processing constraints) needs to be solved. The cell fabrication process and design needs to be optimized to achieve high efficiency and ease of operation. This work was also looking forward to miniaturize SOFC devices by lowering their physical dimensions. Even if the cell miniaturization is achieved, methods of fuel supply and removal of byproducts needs to be developed that will allow continued advantage of miniaturization. The next goal of this work needs to be achieving such miniaturization, which would lead to opening of new applications of SOFC in mobile and hand-held devices, automobiles *etc.*

REFERENCES

- [1] Abraham Gebregergis, Pragasen Pillay, Debangsu Bhattacharyya, Raghunathan Rengaswemy "Solid Oxide Fuel Cell Modeling" IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 56, NO. 1, JANUARY 2009.
- [2] Lee T. Jacobsen, Benjamin J. Spivey, John D. Hedengren "Model Predictive Control with a Rigorous

Model of a Solid Oxide Fuel Cell” 2013 American Control Conference (ACC) Washington, DC, USA, June 17-19, 2013.

[3] Seyfullah Fedakar, Serkan Bahceci, Tankut Yalcinoz “Modeling and Simulation of SOFC using PSCAD” EuroCon 2013 • 1-4 July 2013 • Zagreb, Croatia

[4] Yutong Qi, Biao Huang and Jingli Luo “Nonlinear State Space Modeling and Simulation of A SOFC Fuel Cell” Proceedings of the 2006 American Control

Conference Minneapolis, Minnesota, USA, June 14-16, 2006.

[5] Y.H. Liu, N. P. Brandon, Minhua. Liu “Electrical models of SOFC for Power Generation” 978-1-4577-0547-2/12/\$31.00 ©2012 IEEE.

[6] Bariya Ketan Ratanbhai, H.B Patel “Modelling and Simulation Of Grid Connected Fuel Cell” IJSR - INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH.