

Design and Simulations of Solid Oxide Fuel Cell Power System using Three Phase Inverter for Grid Applications

Inderjeet Singh¹, Vivek Kumar², Devendra Parmar³

¹ M. Tech (EEE), B.R.C.M College of Engineering Bahal, Haryana, India

Assistant Professor, EEE Department of B.R.C.M college of Engineering Bahal, Haryana, India

³M. Tech. Rajasthan Technical University of Rajasthan. Institute of Engineering & Technology, Alwar, India

Abstract: Fuel cell technology is a relatively new energy-saving technology that has the potential to compete with the conventional existing generation facilities. Among the various Distributed Generation or onsite generation or localized generation technologies available, fuel cells are being considered as a potential source of electricity because they have no geographic limitations and can be placed anywhere on a distribution system. Modeling of SOFC is done by using by using Nernst equation. In that the output power of the fuel cell can be controlled by controlling the flow rate of the fuels used in the process. The three phase PWM inverter to get the suitable form three phase output voltages for the grid connected applications. In this paper, design and modeling of Solid Oxide Fuel cell (SOFC) is discussed for the distributed generation applications. Modeling and simulations are carried out in MATLAB Simulink platform.

Keywords: ELF-extremely low frequency, Amplifiers, loop antennas, magnetic field measurement, magnetometers.

1. Introduction

Distributed generation is referred in general to small generators, starting from a few kW up to 10 MW, whether connected to the utility grid or used as stand-alone at an isolated site. Normally small DGs, in the 5-250 kW range serve households to large buildings (either in isolated or grid-connected configuration) [1], [2]. 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) [1], [2].

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. Fossil fuel-based DGs are not considered sustainable power generation sources as their energy source will not renew. They include: Internal combustion engine (ICE), Combustion turbine, Gas turbine, Micro turbine and Fuel cells (using some type of fossil fuel, e.g. natural gas to generate hydrogen) [2,3]. Both types of DGs (renewable and nonrenewable) are popular and widely used around the world. The downside of renewable resource DGs is the intermittent nature of their renewable energy source; and the disadvantage of fossil fuel-based DGs is that generate environmentally polluting, and in some cases poisonous exhaust gases, such as SO₂ and NO_x, which are similar to the pollutants from conventional centralized power plants. However, considering the increasing need for electricity, the benefits of the nonrenewable DG technologies with low emission of polluting gasses exceed their disadvantages and are expected to be used in the foreseeable future. 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. Through careful design, selected fossil fuel driven DGs can be built to oxidize some of the fossil fuel (by combining with oxygen) to produce heat. Such operation modes, whether in electromechanical (rotational) or electrochemical (fuel cell) systems, are referred to as combined heat and power (CHP) operation mode. Most of the new DG technologies include power electronic devices to provide usable output power. These DGs are often referred to as power electronically interfaced DGs. Enormously improved power control of these generation sources has become possible by controlling their power electronic interfacing units. In a common approach the output voltage of these generation devices whether dc or ac is converted to a controlled output voltage. Fuel cells are being considered as a potential source of electricity among the various Distributed Generation technologies available. Fuel cells have numerous benefits which make them superior compared to the other technologies.

The integration of the fuel cell system is to provide the continuous power supply to the load as per the demand. In the fuel cell energy system which is used for the distributed generation applications, the source is integrated with the DC – DC boost converter to stabilize the voltage from the fuel cell. The output of the boost converter is then fed to the three phase PWM inverter to get the three phase ac voltage for the grid connected applications. The overall block diagram of the fuel cell energy system is shown in figure 1 [1], [2].

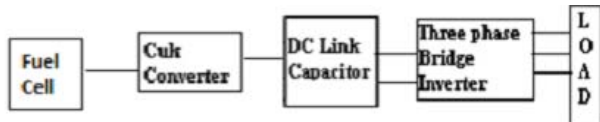


Figure 1: Block diagram for Fuel cell base Energy System

2. Design Fuel Cell for System

The structure and the functioning of a fuel cell are similar to that of a battery except that the fuel can be continuously fed into the cell. The physical structure of a fuel cell consists of two porous electrodes (anode and cathode) and an electrolyte layer in the middle. The Schematic of individual fuel cell is shown in figure 2. Fig.2 shows the basic workings of a fuel cell with positive ion flow through the electrolyte, which is based on electro chemical principles. Hydrogen and oxygen molecules combine to form water. The process is caused by the fact that charged particles migrate toward regions of lower electrochemical energy. The charged hydrogen and oxygen particles move toward each other and bond to one another because the final product of this reaction has a lower overall electrochemical energy. Electrical energy is generated as a result of the movement of the charged hydrogen and oxygen particles, which is essentially the controlled movement of electrons [5], [6].

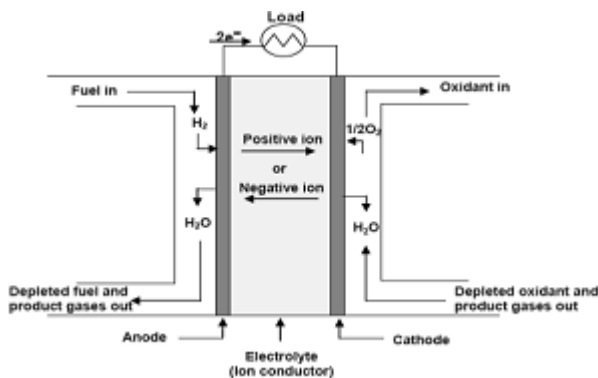


Figure 2: Schematic of individual fuel cell

By breaking the hydrogen molecules to electrons and positive ions (protons), with the help of a catalyst to facilitate faster reaction, the protons move from the cathode to anode through the membrane (electrolyte), but the electrons cannot. The electrons travel through an external electrical circuit (load) to recombine with the hydrogen protons and oxygen molecules at the cathode (again, with the help of the catalyst) to produce water. The actual chemical reaction inside a hydrogen fuel cell can be broken down into two half reactions, the oxidation half reaction and the reduction half reaction [3], [4]. An individual fuel cell produces less than a volt of electric potential. A large number of cells are stacked on top of each other and connected in series (with bipolar connects) to produce higher voltages. Figure shows cell stacks which consists of repeating units, each comprising an anode, cathode, electrolyte and a bipolar separator plate. The number of cells depends on the desired power output [4], [5]. 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%. 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. The electrolyte used is a ceramic oxide (yttrium stabilized zirconium) [6].

The anode used is nickel-zirconia cermets and the cathode is a strontium doped lanthanum magnetite. 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. 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 [5]. Figure.3 shows the typical volt-amp characteristics of SOFC. Fuel cells have drooping voltage characteristics: an increase in the load current causes a decrease in the stack voltage. The number of cells is taken to be 450 and the standard cell potential is 1.18V.

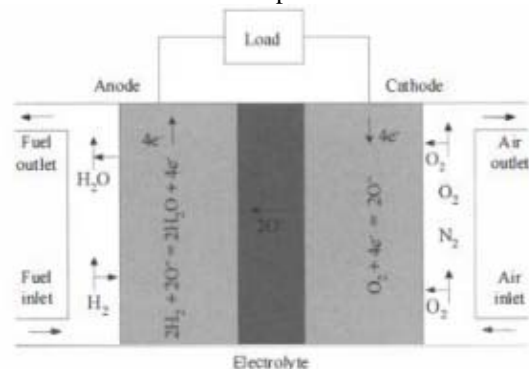


Figure 3: Schematic of solid oxide fuel cell [5]

3. Design 3-Ø Inverter System

A Inverter power circuit has to Convert DC to 3 phase AC voltage. Inverter requed two power supply for Inverter power circuit. SMPS power supply input DC requirement. Input power supply for Drive and protection circuit Consiting of 12-0-12 transformer/ used (IN 4007,1.5A,240V) diode bridge rectifer. Circuit and 470uf 25v capacitor we required but we have used fixe 12v dc supply so I have used voltage controller IC LM 78012. In protection circuit also used 12-0-12 transformer, 1.5 amper and (IN 4001, 1A, 50V) diode module, 220uf, 16v capacitor used and variabel 12volt dc to conver (voltage controller IC LM7812) fix 12 volt. A power circuit in Inverter I have requered 110 volt DC supply for convert three phase AC supply [8], [9]. we have requered smps supply for some practicat experiment results. A power circuit is 3 phase bridge inverter using IGBTs. LCL filter with load or grid current is 2 Ampere and supply voltage is 440 volt.

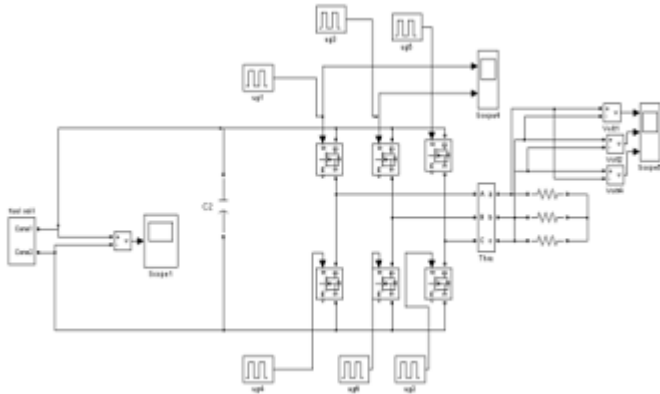


Figure 4: Overall Fuel cell modal

Current = Max current * safety factor
 = 2 * 2 = 4 Ampere
 $PIV = 2 * 415 / \sqrt{2} = 586$ volts

IRG4PH50U has breakdown voltage of 1200 volt and 50 ampere current rating, so it is selected as a switching device [7].

4. Modeling System in MATLAB

The modeling of SOFC is carried out based on the assumptions made that the fuel cell temperature is made to be constant; the fuel cell gasses are ideal and the Nernst's equation applicable to the cell. By Nernst's equation output fuel cell dc voltage V_{fc} across stack of the fuel cell at current I is given by the Simulink Models of Fuel Cell System. The fuel system designed in this work for distributed generated grid connected applications consists of the solid oxide fuel cell, CUK converter, three phase inverter and the load. The three phase inverter is selected because most of the loads are three phases in general. The overall simulink model diagram is shown in figure 4 and followed by the model Designs of the individual blocks of SOFC, converters. Now we design and this fuel cell used in our power system modal and find all wave forms in figure in shown in Figure 5 and Figure 6, Figure 7. and Figure 8 is final Our MATLAB Modal results for current and voltage in grid systems [9], [10]

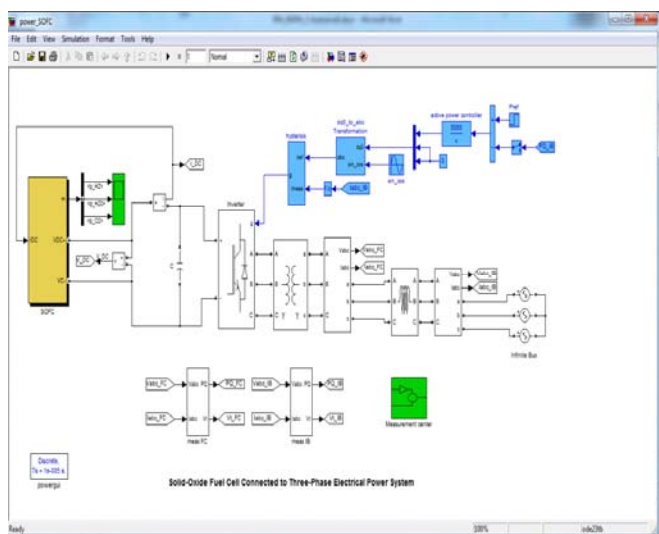


Figure 5: MATLAB Modal in Power system

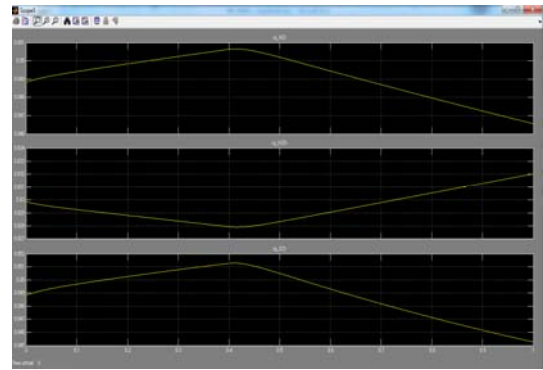


Figure 6: Matlab modal Results PH and PO2 Energy waveform

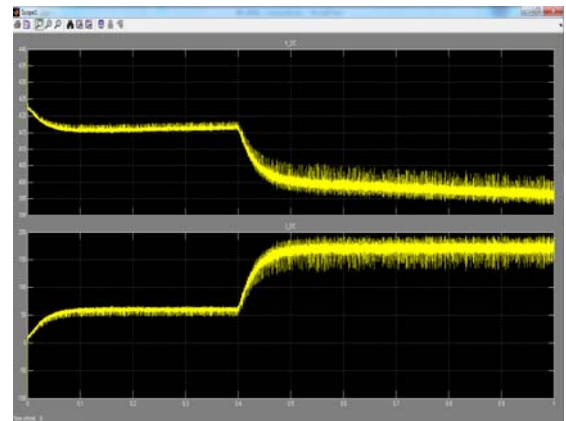


Figure 7: DC Voltage and DC Current Waveform

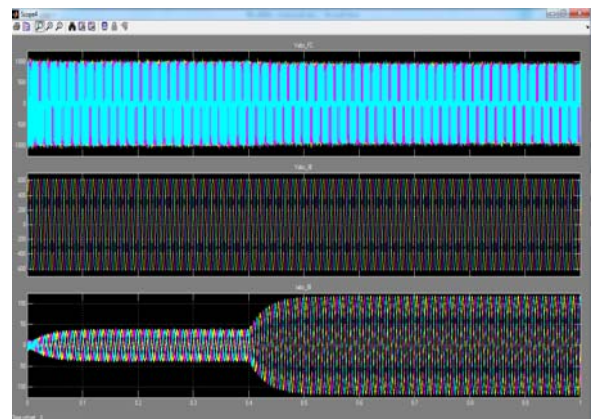


Figure 8: Grid Voltage A, B, C and grid Current A, B, C

From the above simulation results it can be identified to meet the load changes in the power system can be effectively be controlled by incorporating the FC system as they are fed constant output voltages. The FC output can be controlled by controlling the internal parameters of the fuel cell.

5. Conclusion

Dynamic modeling of solid-oxide fuel cell with three phase inverter has been performed to analyze its load behavior as distributed generator in a grid connected power system. The response of the system to step changes in load demand are presented along with the analysis of the simulated results. It has been observed that the fluctuations in the output voltages in the power system due to load variations are taken care of by the SOFC very closely. An efficient dynamic model of Solid Oxide Fuel Cell has also been developed which can

supply active power maintaining inverter voltage as desired. The combined system reduces the cost of power generation as well as the level of pollution reducing the fuel consumption enables comprehensive quantitative and qualitative analysis

6. Acknowledgment

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Author Profile



Inderjeet Singh did M. Tech in EEE specialization in instrumentation and control from B.R.C.M College of Engineering, Bahal, Haryana.



Professor **Vivek Kumar** did M. Tech (gold medalist) in power electronics from R.G.P.V, Bhopal. He is working as Assistant Professor in EEE Department of B.R.C.M college of Engineering Bahal, Haryana.



Assistant Professor **Devendra Parmar** received his B.E degree from Sauvrastra University in 2007, and did M. Tech. from Rajasthan Technical University of Rajasthan Institute of Engineering & Technology, Alwar in 2013. The major fields of study were Power System respectively. Since 2008, he joined as Faculty of Engineering and Technology, C U Shah Technical Institute of Diploma Studies, Gujarat Technical University, Gujarat, India. He was appointed as Lecturer, Assistant Professor in 2010 respectively. He is working in R&D/project with national / International Company.