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Design and Modeling of Fuel Cell using Matlab Simulink

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Abstract—*In this paper, a three-phase grid-connected fuel cell (FC) system is presented. Fuel cell can operate either in a grid-connected or islanding mode. In the grid-connected mode, the inverter is able to control the active (P) and reactive (Q) powers using an algorithm based on Power Regulator and Current Regulator a integrator used which provides a fast signal conditioning for three-phase systems. Controlling of gate pulse so that maximum power is delivered to source is analyzed using matlab software. It has been seen that the fuel cell work good under grid connected and island mode.*

Index Terms*: Distributed Generation, Fuel cell, Microgrid, Smart Grid*

1. INTRODUCTION

To overcome the environmental issues and rapidly increasing Power demand various renewable and non renewable energy sources getting attention. The fuel cell is an important pollution free and high efficiency technology for power grid distribution systems [1]. For power distribution, whenever any distributed source of energy is coupled with main grid it increases the reliability of power but spikes and surges in voltage can be seen in the system [2]. Therefore a smart way should be used to interconnect the distributed generation with the main grid. Distributed generation should be able to adjust the frequency and voltage of the bus so that it can synchronize with the main grid. A synchronizer switch is used to grid interconnection. Isolation transformer is preferable for power grid distribution systems in terms of surge protection and noise reduction. Ripple current reduces the lifetime of fuel cell that must be minimized therefore, in order to extend the lifetime; the fuel cell ripple current must be reduced in the grid interconnection converter . However, Pulse width-modulated (PWM) inverter is used for grid connection system, the power ripple is twice the frequency of the power grid [3].

The slow dynamics of the FC must be taken into account when designing FC systems. This is crucial, especially when the power drawn from the FC exceeds the maximum permissible power, as in this case, the FC module may not only fail to supply the required power to the load but also cease to operate or be damaged [6]. Therefore, the power regulator needs to ensure that the required power remains within the maximum limit.The objective of this paper is to propose results of a grid-connected and islanding mode of three-phase FC system using a inverted which is Gated by current regulator so that ripples can be minimized. In particular, the proposed system, based on the current regulator inverter. The gate triggering stage responsible for both the power regulation as well as the current [8]. The single energy conversion stage provides high power conversion efficiency, reduced converter size, and low cost. The proposed three-phase grid-connected FC system can operate either in grid-connected or island mode. In the grid-connected mode, the inverter is able to control the active (P) and reactive (Q) powers through the grid by the proposed PQ control algorithm using fast signal conditioning for three-phase systems.

2. FUEL CELL ENERGY SYSTEM

A fuel cell is an electrochemical cell that converts a source fuel into an electrical current. It generates electricity inside a cell through reactions between a fuel and an oxidant, triggered in the presence of an electrolyte. The reactants flow into the cell, and the reaction products flow out of it, while the electrolyte remains within it. Fuel cells can operate continuously as long as the necessary reactant and oxidant flows are maintained. Fuel cells are different from conventional electrochemical cell batteries in that they consume reactant from an external source, which must be replenished – a thermodynamically open system [3].

There are many combinations of fuels and oxidants are possible. Commonly used hydrogen fuel cell uses hydrogen as its fuel and oxygen (usually from air) as its oxidant. Hydrogen can be taken from various sources and performing chemical reaction. Other fuels include hydrocarbons and alcohols. Other oxidants include chlorine and chlorine dioxide there are many varieties of fuel cell ; however, their general operation method is same. There is mainly three segments which are sandwiched together: the anode, the electrolyte, and the cathode. Two chemical reactions occur inside the fuel cell. The net result of the two reactions is that fuel is consumed, water or carbon

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dioxide is created, and an electrical current is created, At the anode a catalyst oxidizes the fuel, usually hydrogen, turning the fuel into a positively charged ion and a negatively charged electron. The electrolyte is a substance specifically designed so ions can pass through it, but the electrons cannot. The freed electrons travel through a wire creating the electrical current [6].

The ions travel through the electrolyte to the cathode. Once reaching the cathode, the ions are reunited with the electrons and the two react with a third chemical, usually oxygen, to create water or carbon dioxide. Main block diagram fuel connected to grid is

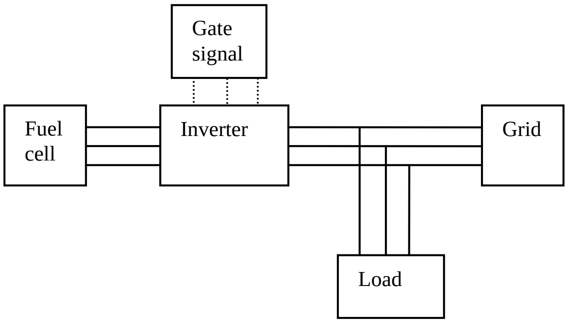

Fig. 1: Block Diagram Of Energy System

A. Fuel cells

Fuel cells are also well used for distributed generation applications, and can essentially be described as batteries which never become discharged as long as hydrogen and oxygen are continuously provided. The hydrogen can be supplied directly, or indirectly produced by reformer from fuels such as natural gas, alcohols, or gasoline. Each unit ranges in size from 1-250 kW or larger MW size. Even if they offer high efficiency and low emissions, today's costs are high. Phosphoric acid fuel cell is commercially available in the range of the 200 kW, while solid oxide and molten carbonate fuel cells are in a pre-commercial stage of development. The possibility of using gasoline as a fuel for cells has resulted in a major development effort by the automotive companies. The recent research work about the fuel cells is focused towards the polymer electrolyte membrane (PEM) fuel cells. but residential size fuel cells are unlikely to have any significant market impact any time soon [3].

Moreover, the scalability of fuel cells has allowed for applications in almost every field. Fuel cell systems can be easily placed at any site in a power system for grid reinforcement, thereby deferring or eliminating the need for system upgrades and improving system integrity, reliability, and efficiency.

The performance of FCs is affected by several operating variables, as discussed in the following. Decreasing the current density increases the cell voltage, thereby increasing the FC efficiency. One of the important operating variables is the reactant utilization, Uf, referring to the fraction of the total fuel (or oxidant) introduced into a FC that reacts electrochemically:

$$U_f = \frac{q_{H_2}^{in} - q_{H_2}^{out}}{q_{H_2}^{in}} = \frac{q_{H_2}^{r}}{q_{H_2}^{in}} \qquad (1)$$

Where qH2 is the hydrogen molar flow.

High utilizations are considered desirable (particularly in smaller systems) because they minimize the required fuel and oxidant flow, for a minimum fuel cost and compressor load and size. However, utilizations that are pushed too high result in significant voltage drops. The SOFC consists of hundreds of cells connected in series and parallel. Fuel and air are passed through the cells. By regulating the level, the amount of fuel fed into the fuel cell stacks is adjusted, and the output real power of the fuel cell system is controlled. The Nernst's equation and Ohm's law determine the average voltage magnitude of the fuel cell stack [18]. The following equations model the voltage of the fuel cell stack:

$$V_{fc} = N_0 (E_0 + \frac{RT}{2F} (\ln(\frac{P_{H_2} P_{O_2}^{0.5}}{P_{H_2O}})) - rI_{f0} \qquad (2)$$

where:

N_o is the number of cells connected in series;

E_0 is the voltage associated with the reaction free energy; 3

R is the universal gas constant;

T is the temperature;

If 0 is the current of the fuel cell stack;

F is the Faraday's constant.

PH_2, PH_2O, PO_2 are determined by the following differential equations:

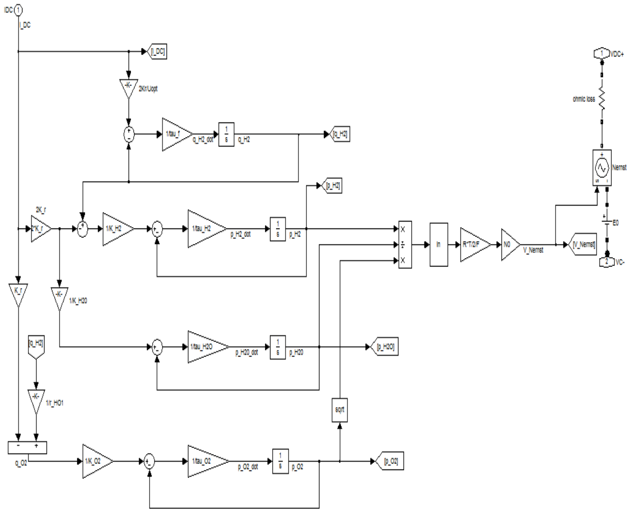

Fig. 2: Fuel Cell Based On Nernst Equation

$$P'_{H_2} = -\frac{1}{t_{H_2}}\left(P_{H_2} + \frac{1}{K_{H_2}}(q^{in}_{H_2} - 2K_r I_{fc})\right) \quad (3)$$

$$P'_{H_2O} = -\frac{1}{t_{H_2O}}(P_{H_2O} + \frac{2}{K_{H_2O}} K_r I_{fc})) \quad (4)$$

$$P'_{O_2} = -\frac{1}{t_{O_2}}\left(P_{O_2} + \frac{1}{K_{O_2}}(q^{in}_{O_2} - K_r I_{fc})\right) \quad (5)$$

Where, in Hq 2 and in Oq 2 are the molar flow of hydrogen and oxygen.

3. INVERTER

Two level three phase voltage source Inverter is used to convert the dc output of the fuel cell into a ac supply, the ac output from the inverter should be in such a way so that it can be connected directly with the main grid that is the output of inverter should be in synchronism with the grid. For synchronism with the grid it should have the same voltage same, same phase and same frequency any of the above condition leads to malfunctioning of grid or damage the equipment. The output of inverter is controlled by controlling the gate pulse of inverter PWM technique which analyzes the grid output and produces the firing gate pulse so that the output of inverter is exactly same as grid. Switching of inverter switches causes high harmonics in the output waveform which should be minimize. To minimize the harmonics passive filters of appropriate value of inductance and capacitance is used. The output from the inverter is pure sinusoidal without any harmonic distortion.

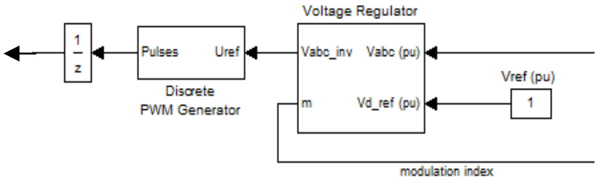

Fig. 3: Gate Pulse Generator For Inverter

4. SIMULATION AND RESULT

Fig. 4 shows the complete simulink diagram in grid connected mode.

The inverter uses hysteresis switching and controls active power by manipulation of direct-axis current while holding reactive power at 0MVar . The measurement blocks are rated at 50kW. Therefore, an active power reference of 1pu =50kW. Ode23tb solver with the configuration parameter discrete sampled at 1e-005s is used. This model assumes the following: The fuel cell gases are ideal ii. Only one pressure is defined in the interior of the electrodes iii. The fuel cell temperature is invariant. There is reverse in pressure of all the reactants after 0.4s.Due to which reactive power output of the fuel cell also increases. Simulation can be extended for dynamic study of fuel cell. After 0.4 s fuel cell able to provide the 50kw Active Power. It can be seen in Fig. 5(a) that there is small disturbance in active power flow before 0.4s it can be eliminated by the use of series inductor as shown in Fig. 5(b).

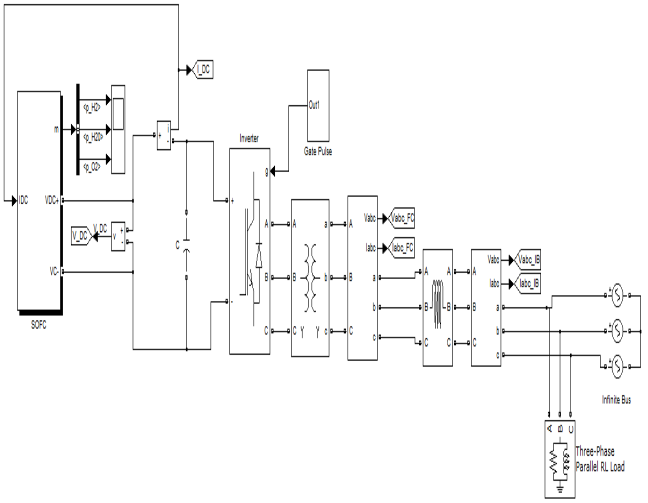

Fig. 4: Simulink Diagram Of Fuel Cell Connected To Grid

Fig. 6 shows the DC power output from the fuel cell standard potential of one cell is 1.14 volt such 450 cells are connected in series which produces nearly 420volt. Fig. shows voltage drop after 0.4 s and correspondingly current increases up to 200 ampere.

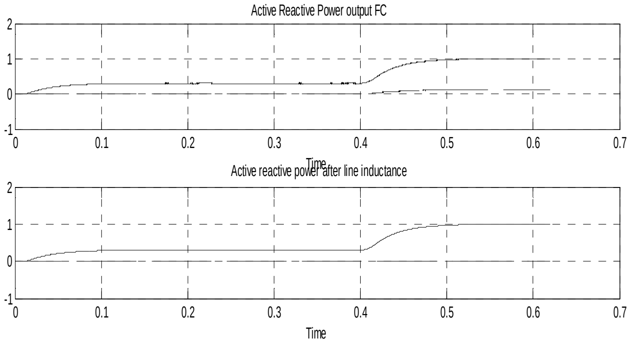

Fig. 5: Active And Reactive Power Of Fuel Cell

Fig. 5 shows the injected reactive power is zero all the time that is inverter doesn't produce any reactive power.

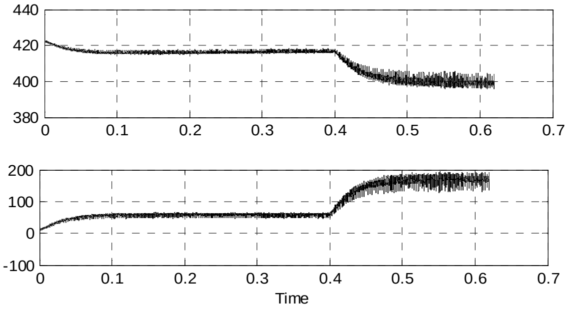

Fig. 6: DC Voltage and Current Of Fuel Cell

There is fluctuation in the DC output voltage due to slow dynamic of chemical reaction takes place inside the fuel cell. The output can be smoothen using capacitor in parallel with output of the fuel cell. It can be analyzed that there is 20 volt reduction in voltage after 0.4 second but current changes from 100 Ampere to 200 Ampere. Due to which the Active Power produced by the fuel cell also increases.

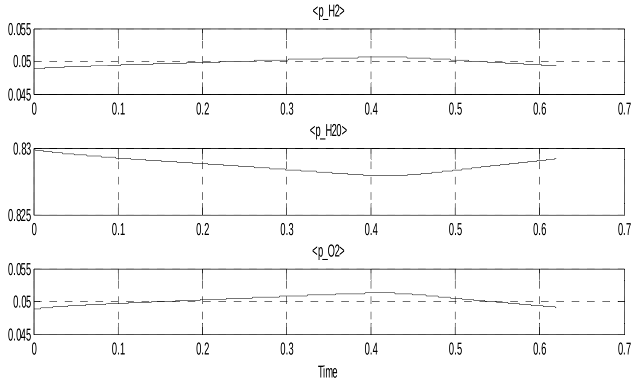

Fig. 7: Partial Pressure Of O_2,H_2O,H_2 respectively

It can be seen that as the partial pressure of oxygen and hydrogen increases the partial pressure of water decreases and as soon as the partial pressure of oxygen and hydrogen starts decreasing partial pressure of water starts increasing. This shows the relation between the various pressure of reactants.

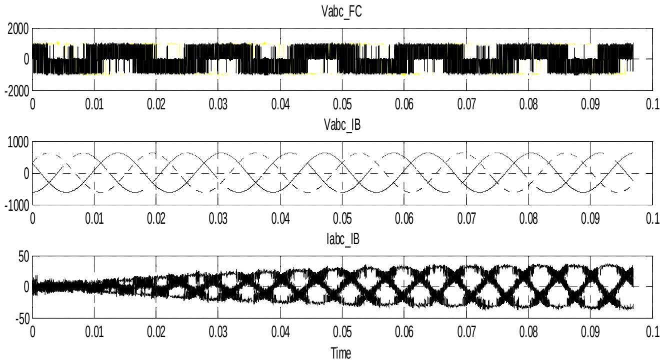

Fig. 8: Inverter output voltage, output voltage after LC filter, Current output

Fig. 8 shows the inverter output voltage and the voltage after LC filter and current drawn by the load from the inverter. The distortion in the current due the harmonic.

5. CONCLUSION

This paper presents a approach for active power control in a fuel cell distributed generation system. Modeling, control, and simulation study of a SOFC system are investigated in this paper. A validated SOFC dynamic model is used to model the fuel cell power plant. The state space models for the boost DC/AC three-phase inverter are also discussed. The proposed control method is insensitive to the parameter variation of the distribution system, because it is adaptive in nature. This is an absolute necessity in distribution systems, since there is no dependence on the parameters of the electrical network.

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