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A STATCOM Controller for Grid Interfaced Fuel Cell Generation System

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Abstract

This paper presents the concepts of grid interconnection of non-conventional energy sources such as solar, wind plants, fuel generation systems that will give signifying moment in near future. Generally, these energy generating stations are interconnected at PCC for continent consumer applications and due to this the system has high economical, more complex and less reliability in efficiency point of view. The Generated power is transmitted through transmission lines from source to load. It will have some power quality problems like current unbalances and harmonics because of usage in non-linear load due to which the system will lose the reliability. This paper mainly concentrates on the reduction of ripples in line current. For this, we introduced a concept called shunt active filter. This improves the power quality from source to load by using P-Q control through shunt active filter from the output energy of PEM fuel cell in MATLAB Simulink environment.

Keywords: Coordination Control Operations, Fuel Cell Power Generation, Micro Grid

1. Introduction

In present scenario, a large number of mathematical Proton Exchange Membrane (PEM) fuel cell models exist whose purpose spreads from fuel cell designing; describing static and dynamic behavior up to operation analysis in complex systems[6], where fuel cells have to meet specific work conditions. Most of the dynamic models are dealt with temperature and fluid pressures because these variables are known to have time constants that can last even few seconds, while influence of parasitic capacitances on output cell voltage is often neglected. Models that take into account this effect[4] usually use highly evolved fuel cell equivalent electrical circuits composed of resistance-capacitance parallels connected in series. These complex structures describe high frequency electric effects very precisely, but determination of their capacitance values demands additional electric measurement on a real fuel cell, and presents severe problem. That is the reason why simplified model, which has only one time constant was used in this case to describe electric dynamic of PEM[1]. In this model, all parasitic capacitances are represented with one connected in parallel with activation and concentration resistances of fuel cell. As far as power converters are concerned, papers can be found that focus on power converters whose characteristics and regulation techniques have been customized to suit PEM fuel cells[2]. As these models are often customized for certain purpose (for instance automotive applications), they are neither suitable for studying of fuel cell operation effects on power converter operation nor for analyzing effects caused by different controllers. Hence, appropriate boost power converter dynamic model is used here, which when connected to a fuel cell model gives stack current, stack voltage and converter output voltage responses in short simulation execution time. In that way, a system suitable for interaction between PEM fuel cell and power converter was obtained[8].

Generally, voltage source inverter based current controlled type is extensively used for interfacing the intermittent in distribution energy systems. For compensation of the load current harmonics both load and inverter current sensing are used in this strategy.

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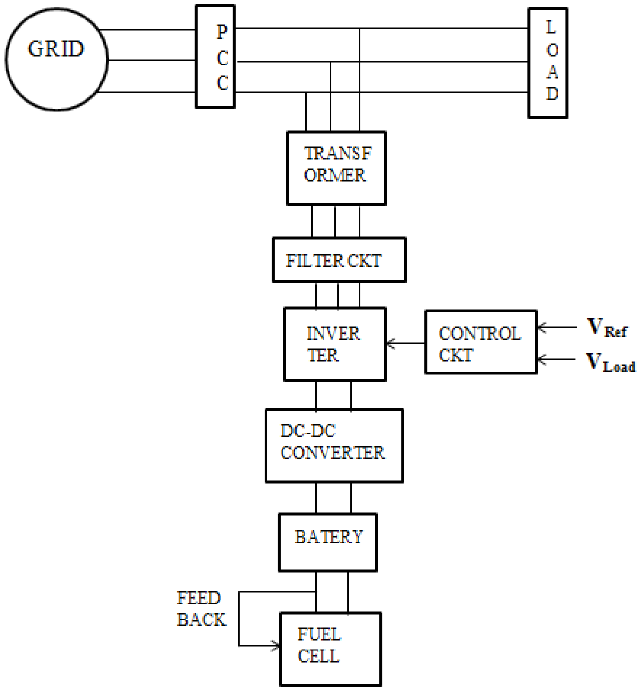

Figure 1. Block diagram of micro grid.

2. Modeling of Fuel Cell Model

For fuel cells, the electrochemical process starts at anode side. At the anode side, flow plate channels brings H_2 molecules. Catalyst in anode separates hydrogen on protons H^+ through membrane that proton travel to cathode and over external electrical circuit the electrons that travel to cathode. By using of catalyst at the cathode, oxygen is combined with hydrogen protons and electrons for formation of H_2O and heat. This reaction is expressed in below equations[9]

$$H_2 \rightarrow H_2O + 2e^-(Anode)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O(Cathode)$$

$$\Delta g_g = \Delta g^o{}_f \; - RT_{fc}[\ln(PH_2) + 0.5\ln(PO_2)]$$

Where, at basic standard pressure the Gibbs free energy is expressed as $\Delta g^0{}_f$, T_{fc} PEM temperature and p_{O2}, P_{H2} are gas pressures and R universal gas constant. The expression for the electrical work done by the fuel cell system with respect to releasing of chemical energy is

$$E = -\left(\frac{\Delta_{gf}}{2F}\right)$$

Electron-proton chemical bonds formation and breaking are the result by Cathode and anode activation losses, at zero current through membrane hydrogen proton migration is caused by the parasitic electrochemical reactions. The fuel cell voltage drop is expressed as

$$V_{act} = V_0 + V_a(1 - e^{-C_1 i})$$

Based on fuel cell temperature the voltage at zero current density v_0 is based on the cathode pressure, pressure due to water saturation Va=f(T_{fc}, P_{ca}, P_{sat})Voltage drop v_a inserts in above equation correlation with current density as Va=f(T_{fc},P_{o2},P_{sat}) and c_1 is activation voltage constant.

2.1 Fuel Cell Equivalent Electric Circuit

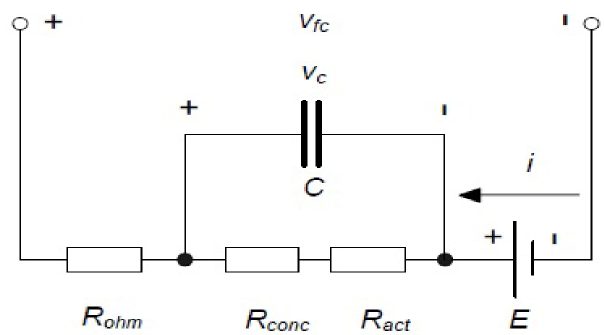

Figure 2. Equivalent circuit for fuel cell system.

$$V_{fc} = E - V_c - iR_{ohm}$$

$$C\frac{dV_C}{dt} + \frac{V_C}{R_{act} + R_{conc}} = i$$

$$V_{fc} = E - \left(\frac{R_{act} + R_{conc}}{\left(sc\left(R_{act} + R_{conc} + 1\right)\right)} + R_{ohm}\right)i$$

3. Dynamic Modeling of Boost Converter

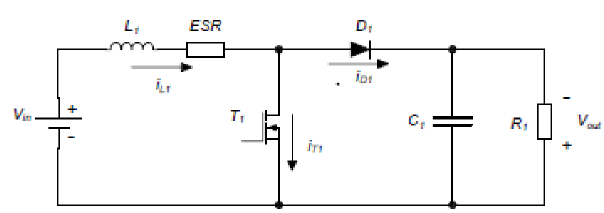

Figure 3. Boost Converter.

The power voltage characteristic curve regulates the terminal voltage across fuel cell; the regulated fuel cell terminal voltage used to obtain the maximum power from the fuel cell is the main objective of the boost converter[5].

$$Vin - L\frac{di_1}{dt -}(1-D)V_C - ESRi_1 = 0$$

$$i_{D1} = i_{C1} + i_{L1}$$

$$\begin{bmatrix} \dot{i}_{L_1} \\ \dot{v}_{C_1} \end{bmatrix} = \begin{bmatrix} \frac{-ESR}{L_1} & \frac{-(1-D)}{L_1} \\ \frac{1-D}{C_1} & \frac{-1}{R_1C_1} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ v_{C_1} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \end{bmatrix} [V_{in}]$$

$$[V_{Out}] = [0 \quad 1] \begin{bmatrix} i_{L_1} \\ v_{C_1} \end{bmatrix} + [0][V_{in}]$$

4. Modeling of Battery

In this project the battery uses both induction generator and fuel cell for charging and it is acting as a constant voltage load line on the fuel cell. The battery is modeled as nonlinear voltage source.

$$V_b = V_O + R_b i_b - K\frac{Q}{Q + \int i_b dt} + A\exp(i_b dt)$$

5. P-Q Theory Power Components

The control strategy used in PQ theory is Clark's transformation. Clark's transformation is nothing but transferring the stationary reference system coordinates a-b-c in[7] to a system with coordinate's α-β-*0*. The α-β-*0* coordinates of voltages and currents are calculated as follows:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = T\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}, \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = T\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

$$T = \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix}$$

5.1 Zero-sequence Power Component (p_0)

$$p_0 = v_0 i_0 = \bar{p}_0 + \tilde{p}_0$$

In 3-ø systems only the zero-sequence power exists with neutral wire. It is important to notice that without the presence of $\tilde{p}_0$, $\bar{p}_0$ cannot exist in a power system[8].

5.2 Instantaneous Real Power

$$p = v_\alpha i_\alpha + v_\beta i_\beta = \bar{p} + \tilde{p}$$

5.3 Instantaneous Imaginary Power

$$q = v_\beta i_\alpha - v_\alpha i_\beta = \bar{q} + \tilde{q}$$

$$q = \frac{[(v_a - v_b)i_c + (v_b - v_c)i_a + (v_c - v_a)i_b]}{\sqrt{3}}$$

The above expression is used in power system under balanced case i.e the system has no harmonics and distortions.

Orthogonal coordinate system for the three-phase instantaneous power ($p3$) and stationary frame coordinates such as a-b-c and α-β-*0*, by assuming the same value

$$p_1 = v_a i_a + v_b i_b + v_c i_c = p_a + p_b + p_c$$

$$p_1 = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 = p + p_0$$

It is necessary to compensate the alternating power components p_0 and $\tilde{p}_0$.

6. P-Q Theory Applied to Shunt Active Filter through Inverter

For controlling the shunt active filters the PQ theory concept plays a key role. $\bar{p}$ is usually the only desirable p-q Theory power component.

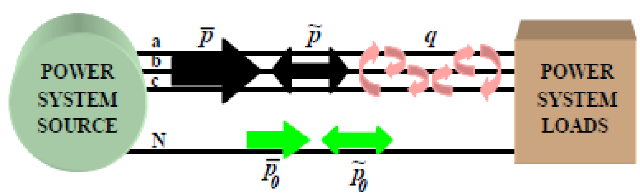

Figure 4. P-Q theory power components.

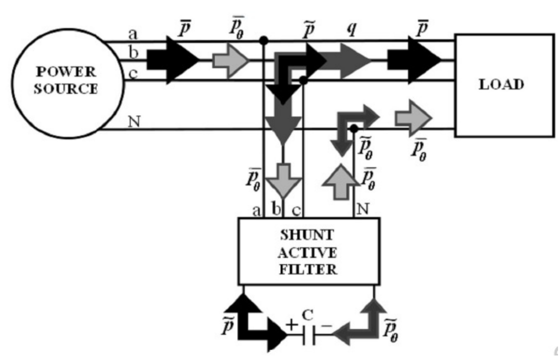

Figure 5. Diagram for Power Flow Directions.

For calculating the reference current we express the equations in the "α" and "β" coordinates, the expression is inversed, and the power to be compensated ($\tilde{p}$ - $\bar{p}_0$ and q) are used.

$$\begin{bmatrix} i_{c\alpha}{}^* \\ i_{c\beta}{}^* \end{bmatrix} = \frac{1}{\left(v_\alpha{}^2 + v_\beta{}^2\right)} \begin{bmatrix} v_\alpha & -v\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} - \bar{p}_0 \\ q \end{bmatrix}$$

Since the component for zero sequence must be compensated with the component of reference compensation coordinate i_0

$$i_{c0}{}^* = i_0$$

The inverse parks transformation for obtaining the reference currents for compensation in a-b-c coordinates can be expressed as,

$$\begin{bmatrix} i_{ca}{}^* \\ i_{cb}{}^* \\ i_{cc}{}^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & 1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c0}{}^* \\ i_{c\alpha}{}^* \\ i_{c\beta}{}^* \end{bmatrix}$$

$$i_{cn}{}^* = \left(i_{ca}{}^* + i_{cb}{}^* + i_{cc}{}^*\right)$$

7. Closed Loop Control Diagram for Statcom

Figure 6 shows the closed loop control diagram 3-ø 3-wire grid interfaced system. Neutral current of load is compensated by the fourth leg of inverter.

The gating signals for the statcom controller is varied such that it shows the effect on load and injected powers to the grid system. Hence, the output voltage across the Direct Current (DC) link capacitor produces the effects in active component current (I_m) the magnetic current component (I_m) with the balanced voltage vectors across

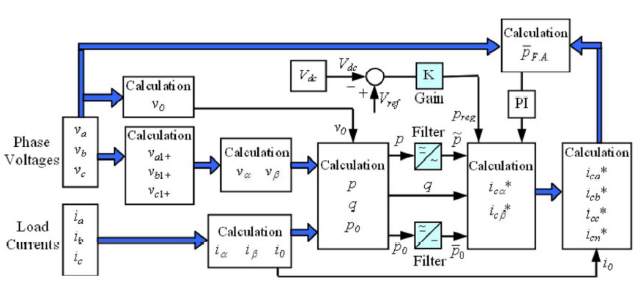

Figure 6. Control Diagram for SAPF.

grid (V_a, V_b, and V_c), these vectors generates the reference currents in grid as ($I_{ca}{}^*$, $I_{cb}{}^*$,and $i_{cc}{}^*$).

8. Simulation Diagram and Results

Figure 7 shows the simulation diagram for the proposed 3-phase 3-wire fuel cell based grid connected system controlled by statcom.

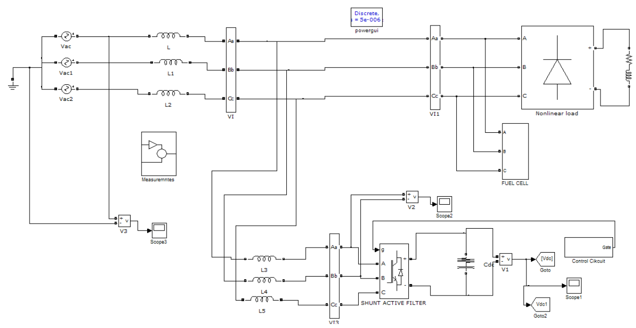

Figure 7. Simulation Diagram for Proposed System.

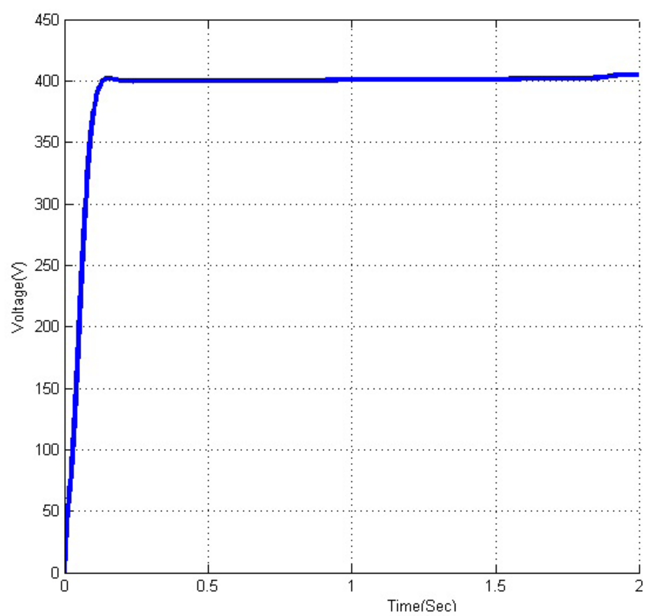

Figure 8. Output voltage of the fuel cell system.

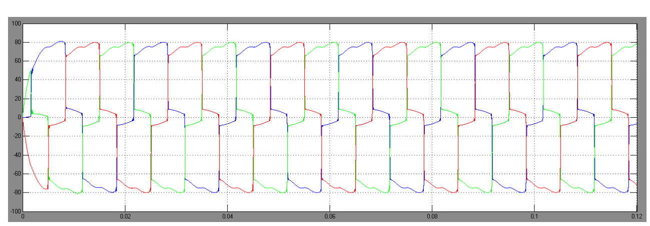

Figure 9. Three phase output currents at load.

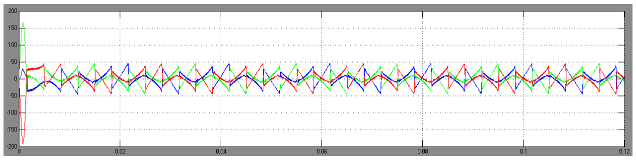

Figure 10. Injected currents to the load under fault conduction.

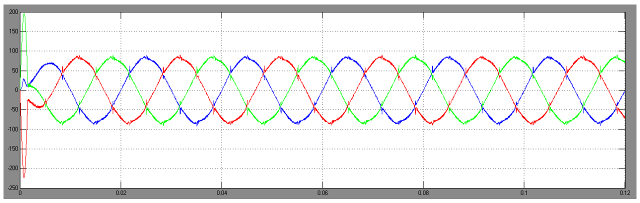

Figure 11. Three phase Source currents after Compensation.

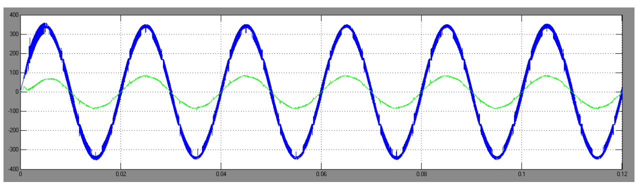

Figure 12 Three phase output voltage and current showing power factor.

Figure 8 shows output voltage of fuel generation corresponding to chemical reaction of the system. Initially generation voltage is low; based on the chemical reaction done there is a corresponding increase in the voltage, and after certain point, this voltage will become constant.

Figure 9 shows the load currents due to non-linear load. Due to this faults the three phase currents will be unbalanced.

Figure 10 shows injected currents. Due to this injected currents there will be compensated faults at particular period

9. Conclusion

The hybrid grid interfaced system is proposed in this paper. This hybrid system, is generally, composed of a fuel cell system Proton Exchange Membrane Fuel Cells (PEMFC). In order to improve the power quality for a 3-ø three wire system, this paper presents a novel control strategy for grid interfacing inverter. The shunt active filter converter showed an effective performance for maintaining the power quality without effecting its normal transferring power. Because of this controller there is no need for external power conditioning devices for power quality improvement. This is implemented in MATLAB/Simulink simulation.

10. References

1. Peng. Fuel cell power system controlling. Springer-Verlag London Limited; 2005. doi: 10.1007/978-1-4471-3792-4.
2. Hoogers G. Fuel Cell Technology Handbook. CRC Press LLC; 2003.
3. Hartkopf Th, Mancher H. Simulation of dynamic modelling of fuel cell system and its application. Journal of Power Sources. 2006; 154: 386–93.
4. Garnier J, Pera M-C, Hissel D, Harel F, Candusso D, Glandut N et al. Dynamic PEM Fuel Cell Modeling for automotive applications. 2003 IEEE 58th Vehicular Technology Conference; IEEE. 2003; 5:3284–8. doi: 10.1109/VETECF.2003.1286265.
5. Balog R. Economical based Inverter for Medium-Power Fuel Cell Sources. IEEE. 2002; 1:321–6. doi:10.1109/PSEC.2002.1023889.
6. Won C, Yoo D. A novel power conversion circuit for cost-effective battery-fuel cell hybrid systems. Journal of Power Sources. 2005; 152:245–55.
7. Anderson M, Carr D. Battery energy storage technologies. Proceedings of IEEE. 1993 Mar; 81(3):475–9.
8. Lynch W. A mathematical model for lead acid batteries. IEEE Trans Energy Convers. 1992 Mar; 7(1):93–98.
9. Rai G. Non-Conventional Energy Sources. Khanna Publishers; 2011.