Appendix A

Fuel Cell operating principle

A.1: Chemical reaction on the electrodes:

The reaction below shows the chemical reactions for hydrogen as fuel:

$$Anode: H_2 \rightarrow 2H + \; 2e^-$$

$$Anode: O_2^- \; + 2H^+ \rightarrow H_2O$$

$$Cathode: \frac{1}{2}O_2 + 2e^- \; \rightarrow O^{-2}$$

$$Overall: H_2 + \frac{1}{2}O_2 \; \rightarrow H_2O$$

A.2: fuel cell thermodynamics

$$\Delta G = \Delta G_{products} - \Delta G_{reactants}$$

Where:

ΔG: is the Gipps free energy

$$\Delta G_o : E_o * n_e F$$

Where:

ΔG_o: is the Gipps free energy at start

E_o :cell voltage at start

n_e:number of electrons

F: faraday’s constant (F=1)

$$E_{CELL} = \frac{\Delta G_O}{neF} + \frac{RT}{neF} \ln\left[\frac{P_{H_2} P^2{}_{O2}}{P^2{}_{H2O}}\right]$$

Where:

R: idle gas constant.

T: tempreture.

P_{H2}: partial pressure for hydrogen.

P_{O2}: partial pressure for oxygen.

P_{H2O}: partial pressure for water.

A.3: Voltage loss

$$V_{\mathbf{cell}} = E_{\mathbf{cell}} - \eta_{\mathbf{act}} - \eta_{\mathbf{ohmic}} - \eta_{\mathbf{con}}$$

Where:

η_{act}: Activation polarization loss.

η_{ohmic}: Ohmic loss.

η_{con}: concentration/diffusion loss.

A.3.1: Activation loss (η_{act})

$$\eta\ act = \frac{RT}{\beta neF} \ln \frac{i}{i_o}$$

Where:

β : Butler-Volmer Constant.

i: Current density.

i_o: Exchange current density at an electrode/electrolyte interface.

$$i = 2 * i_o, k \sinh\left(\frac{neF\eta act, k}{RT}\right) \rightarrow \eta act, k = \frac{2RT}{neF} \sinh^{-1}\left(\frac{i}{2i_o, k}\right)$$

Where:

k: Cp/Cv

A.3.2: Ohmic loss (η_{ohmic})

$$\eta_{Ohmic} = i * R_{ohm}$$

Where:

i: Current density.

R_{ohm}: ohmic resistance.

$$R_{ohm}=R_a+R_e+R_c+R_i$$

Where:

R_a: Anode resistance.

R_e: Electrolyte resistance.

R_c: Cathode resistance.

R_i: Interconnector resistance.

A.3.3: Concentration/diffusion loss (η_{con})

$$\eta con = me^{(ifc)}$$

Where:

m: mass.

ifc: current per unit area for fuel cell.