Transients analisys in Proton Exchange Membrane Fuel Cells: A critical review

G.A. Rubio*, W. Agila*‡

*Facultad de Electricidad y Computación, Escuela Superior Politécnica del Litoral

(grubio@espol.edu.ec, wagila@espol.edu.ec)

Abstract- When a proton exchange fuel cell operates it produces in addition to electrical energy, heat and water as sub products, which impact on the performance of the cell. This paper analyzes the issue of transients and proposes a model that describes the dynamic operation of the fuel cell. The model considers the transients produced by electrochemical reactions, by flow water and by heat transfer. Two-phase flow transients result in increased the parasitic power losses and thermal transients may result in flooding or dry-out of the GDL and membrane, understanding transient behavior is critical for reliable and predictable performance from the cell.

Abbreviations

PEMFC	*: Proton exchange membrane fuel cell*
GDL	*: Ground diffusion layer*
GFC	*: Gas diffusion channel*

Keywords- Transient PEMFC; two-phase flow; thermal.

1. Introduction

Base on the PEMFC model in a strategic context [1,2], for a better analysis the causes that produce the transients can be grouped into three large groups strongly related, electrochemical reactions, heat transfer and water flow (two-phase flow) [3].

Electrochemical transients are produced by load variations, battery dynamics and variations in the concentration of the reactants. As a first approximation it could be assumed that the transients caused by the electrochemical reactions could be neglected.

Thermal transients are produced by the load changes and the start-up dynamics and shut-down dynamics and can be analyzed by the equation [4]:

$$v_{tn}(t) = V_{tn}e^{-\frac{t}{\tau_t}} \tag{1}$$

Where:

V_{tn} : Voltage due to heat source of PEMFC a t=0

τ_o : Time constant due to thermal effects

Two-phase flow transients are produced by the dehydration of the membrane [5,6], the flooding of the GDLs and the dilution of the reactants in the GFCs [7,8,9].

Since the losses due to membrane dehydration are related to the ohmic losses - the passage of the protons through the membrane - it can be assumed that the natural voltage due to the ohmic losses is [10]:

$$v_{on}(t) = V_{on}e^{-\frac{t}{\tau_o}} \tag{2}$$

Where:

V_{on} : Voltage due to ohmic losses a t=0

τ_o : Time constant due to ohmic losses

Because the flood losses of the GDL are related to the losses by concentration -mass transport-, it can be assumed that the natural voltage by concentration losses (GDL) is [10]:

$$v_{cn(GDL),d}(t) = V_{cn(GDL),d}e^{-\frac{t}{\tau_{c(GDL),d}}} \tag{3}$$

Where:

$V_{cn(GDL),d}$: Voltage variation due to concentration losses in GDL

$\tau_{c(GDL),d} = \tau_{R_{GDL,d}}$: Time constant due to loss of concentration in GDL.

And finally, since the losses by dilution of the reactants in the GFC are related to the losses by concentration - mass transport -, it can be assumed that the natural voltage for concentration losses (GFC) is:

$$v_{cn(GFC),st}(t) = V_{cn(GFC),st}e^{-\frac{t}{\tau_{c(GFC),st}}} \tag{4}$$

Where:

$V_{cn(GFC),st}$: Voltage variation due to concentration losses in GFC

$\tau_{c(GFC),st}$: Time constant due to concentration losses in GFC [10]

Finally, from table 1, transients that produce time constants that are important may be considered.

Table 1: Transient state analysis			
Component/Process	*Time constant*		
	Symbol	*Value [s]*	*Importance*
Electrochemical	$\boldsymbol{\tau_R}$	$\boldsymbol{\rightarrow 0}$	**No**
Load change -Electro-osmosis	⎯	⎯	⎯
Stack Dynamics -Charge/discharge double layer	τ_{dl}	$2.4x10^{-7}$	No
Changes in reactants -Convection	τ_{GFC}	$0.01 - 2$	No
Heat transfer	$\boldsymbol{\tau_t}$	$\boldsymbol{\rightarrow 120}$	**Si**
Thermal	τ_t	40-120	Si
Two-phase	$\boldsymbol{\tau_f}$	$\boldsymbol{\rightarrow 180}$	**Si**
Membrane dehydration	τ_o	$\rightarrow 25$	Si
-Membrane hydration	$\tau_{R^{H^+}_{PEM,h}}$	$5 - 25$	Si
-Back-diffusion	$\tau_{R^{H^+}_{PEM,d}}$	$0.2 - 9$	
- Hydration catalyst layer	$R^{H^+}_{CL_a}, R^{H^+}_{CL_c}$	1	No
- Drying by electro-osmosis	$\tau_{R^{H^+}_{PEM,DEO}}$	$2.4x10^{-7}$	No
GDL wetting -*Diffusion*	$\tau_{R_{GDL,d}} = \tau_a$	10^{-2}	No
Dilution of reactants in GFCs	τ_c	$\rightarrow 180$	Si
- Capillarity (surface tension)	$\tau_{m,p}$	80-180	Si
- Gravity		$\rightarrow 0$	No

2. Conclusion

Electrochemical transients are very fast. Overshoot arises from changes in reactant concentration and undershoot from changes in membrane hydration. Two-phase transients are much longer in duration and consist of changes in membrane hydration. Thermal transients are also over long durations and they are observed during start-up and shut-down conditions.

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