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Research paper

A Study on the Optimization of Water Balance Control in the Intermittent PEM Fuel Cell

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Abstract : One of the water management goals in PEM fuel cell is to avoid flooding and drying in the membrane, therefore the air humidification process is required. In order to increase water removal out of the membrane, the water management system may require the dehumidification process and it also requires a large space for application, moreover the process time is slow. In conformity with this fact, this present study proposes an advanced dynamic fuel cell water management which can be an intermittent optimization control using air flow rate instead of the air humidity as an variable in the optimization process. The results of this study have shown that the membrane flooding and drying can be avoided after being assisted by air velocity controlling method.

Key Words : Fuel cell, Water management, Flooding, Optimization, Control

— Nomenclature —

$\dot{m}$: Mass flow rate [g/s]
C_d : EOD coefficient
ρ : Density [kg/cm]
M_r : Relative molecular mass [kg/mol]
k : permeability ㎡
S : liquid saturation level
ε : Porosity
μ : Dynamic viscosity [㎡/s]
T : Temperature [℃]
δ : Membrane thickness [m]
λ : Latent heat [kJ/kg]
h : Heat transfer coefficient [W/m^2K]
α : Acceleration [m/s]
v : vehicle velocity [m/s]
I : Current density [A/m^2]
A : Cross section area [m^2]
F : Faraday constant, [C/mol]
ϕ : Humidity ratio [g/kg]
m : Mass [kg]
γ : Specific volume [m^3/kg]
V : Volume [m^3]
Q : Flow rate m^3/s
W : Power, Watt

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1. Introduction

In PEM Fuel cell, a membrane hydration is required to promote the passage of protons through the membrane[1]. The hydrogen and the air entering the flow channels must be humidified to prevent the membrane from drying out. However, If water enters the fuel cell in droplet form, the catalyst sites will be flooded. As a result, it will inhibit the electrochemical reactions. Thus, the water contents of the membrane and the reactant gases affect directly the fuel cell performance. The water addition and the water removal in the fuel cell membrane should be balanced to avoid membrane's flooding or membrane's drying[2]. The water balance should be managed well to get higher performance by keeping the balance of ratio between the water addition and the water removal.

The water management method in a dynamic system has been developed by many researchers. Bakthiar & Choi have created a novel water management technology using and intermittent air humidification control as on of improving ways from many researcher's previous results.[3~4] In this study, the variables are the temperature and the humidity of that input air. In fact, method controlling the temperature is relatively easy but controlling technic of the humidity is very difficult especially for the dehumidification step process. Dehumidification device requires large space for its application, moreover the dehumidification process takes a lot of time to be done. According to this fact, this present study proposes an improving technology of the intermittent control by using air flow rate variable instead of the air humidity in the optimization process.

2. Control method and modelling technic

This present study is dealing with a kind of improving control method which was devised already by Bakhtiar & Choi.[2] Hence, the control method used in this study is adopted from Bakhtiar & Choi method that is an intermittent control based on the load patterns. The controlled operating variables are the air temperature and the air velocity and the sampling time of pattern is 50 seconds. The sample of patterns are given by international standard driving cycles. The optimization method to get the optimum control parameter values are obtained by the genetic algorithm theoretical background that is done every 50 seconds.

Representation of the dynamic load fuel cell is given by running the vehicle under the driving cycle velocity patten. Therefore the dynamic load of the fuel cell is given by simulate the vehicle model.[5] as given by Eq. (2). In these equations, the driving cycles as shown in Table 1 and the vehicle parameters given by Table 2 are supposed to be used for the simulation.

$$W_{vehide} = W_{roll} + W_{resist} + W_{kinetic} \tag{1}$$

$$W_{vehide} = mgC_{rf}|v| + \frac{1}{2}\rho_a|v|^3 c_{drag}A + mv\frac{dv}{dt} \tag{2}$$

Table 1 Driving cycle

Driving cycles	Vmax (m.s-1)	Time (s)
EUDC	33.3	400
JP 10-15	19.4	660
FTP72	25.3	1369

Table 2 Vehicle parameters

Parameters	Value
m	1000 kg
c_{rf}	0.02
ρ_a	1.177 kg.m-3
c_{drag}	0.4
A	1.5 m2

The Control method takes the following process as same as the flowchart indicated by Fig. 1 The optimization method is taking the genetic algorithm theory and the fitness function consists of the PEM fuel cell water balance model as described in Eq. (3) to Eq. (9).

The water management target is to keep the balance between water addition and water removal based on the dynamic load condition. The indicator of the water balance is a liquid saturation level S that is the ratio of the accumulated water in the fuel cell membrane pore to the membrane void fraction.

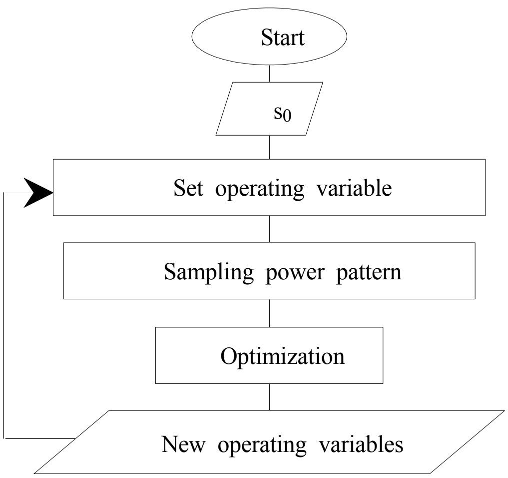

Fig. 1 Flowchart of the intermittent optimization control

The Water additons as a produc of oxygen reduction reaction (ORR) and the electro osmotic drag (EOD) will be given by Eq. (1) and the water addition from input air is given in Eq. (2) respectively. On the other hand, the change of S as a result of the water additions is taken up by Eq. (3). and the liquid saturation difference will be defined by Eq. (4).

$$\dot{m}_{add} = \frac{M_r(c_d+1)IA}{2F} + \frac{\phi_a Q}{\gamma_a} - \frac{\phi_s Q}{\gamma_s} \quad (3)$$

$$\triangle s_{add} = \frac{\dot{m}_{add}}{\rho V_{void}} \quad (4)$$

The mass flow rate as an effect of the capillary transport and evaporation are obtained by Eq. (5) and Eq. (7) respectively[2~4), 6)]. In addition, the changes of S as the outcome of the capillary transport and evaporation are also given by Eq. (6) and Eq. (8). The total change of S as the outcome of the water addition and removal will be generated by Eq. (9) and the fuel cell water management parameters is given by Table 3.

$$\dot{m}_{cap} = s^4(1.417 - 4.240s + 3.789s^2) \times \frac{A\sigma\cos\theta_c(\epsilon\kappa)^{0.5}}{\mu\delta} \quad (5)$$

$$\triangle s_{cap} = \frac{\dot{m}_{add}}{\rho V_{void}} \quad (6)$$

$$\dot{m}_{evap} = \frac{h(4s+2)(\varepsilon\delta A)^{2/3}|\triangle T|}{\lambda} \quad (7)$$

$$\triangle s_{add} = \frac{\dot{m}_{evap}}{\rho V_{void}} \quad (8)$$

The final liquid saturation becomes as the following Eq. (9).

$$\triangle s_{total} = s_0 + \triangle s_{add} - \triangle s_{cap} - \triangle s_{evap} \quad (9)$$

Table 3 Fuel cell water management parameters

Parameters	Value
N	448
S0	0.1
c_d	0..5
ϵ	0.6
θ_c	120°

3. Result and discussion

When the vehicle needs to be accelerated, the power demand must be high Fig. 2shows the results of the simulation concerning on the vehicle power demand using EUDC driving cycle. This means that the fuel cell needs to compensate the power demand by producing the same amount of energy as the energy demand. Then the electrochemical reaction produces the energy and water. The water addition and the water removal, however, need to be controlled to reach the water balance.

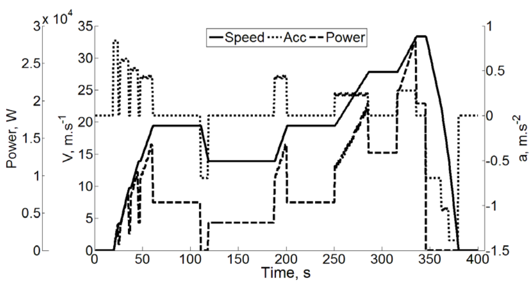

Fig. 2 The EUDC power demand

Intermittent optimization control keeps handing the air input and flow rate periodically every 50 seconds to reach the minimum deviation between target liquid saturation and current liquid saturation level. The values of the operation variable are also tabulated as shown in Table 4.

Table 4 Operation variable values

I (50s)	T (°C)	Flow rate (LPM)
1	25.00	0.12
2	26.27	4.57
3	25.39	1.72
4	33.47	1.16
5	25.18	3.14
6	25.90	6.36
7	25.00	9.20
8	25.04	0.12

The comparisons of the liquid saturation level with the uncontrolled operation variable has been shown in Fig. 3. The solid continuing line reveals that the saturation level increased gradually. This result indicated that the liquid water accumulated in the pore continuously without being compensated with membrane flooding took place. The value of S suggests the flooding level.

The water balance control has been executed by being changed the air temperature and flow rate periodically every 50 seconds, and those operation variable are obtained from the genetic algorithm optimization. This result of the optimization is reaction of the adaption of the operation variable obtained from the driving cycle using the water balance model as the fitness function in the genetic algorithm. That is, the optimization requires increasing either flow rate or temperature, or both of them to reduce the flooding level as the values of the operation variable. The flooding level as the result of the intermittent optimization control is like the dotted line as shown in Fig. 3. This Fig. 3 shown the optimization result controls the flooding level by controlling the operation variables in the EUDC driving cycles. Table 5 also shows the final flooding level target deviations from all driving cycles.

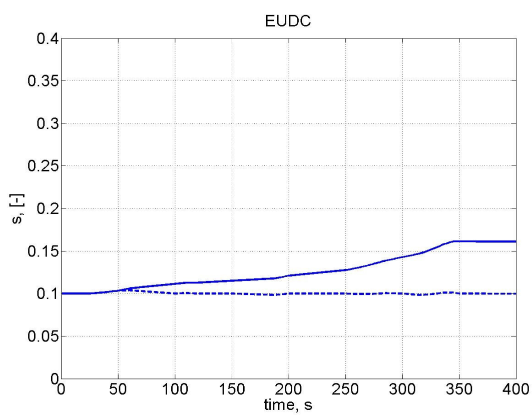

Fig. 3 Optimization results of the EUDC case

Table 5 Flooding level difference

Driving cycle	△s
EUDC	0.06
JP 10-15	0.03
FTP72	0.08

4. Conclusions

The present study is related with one of the improving way of the PEM fuel cell intermittence optimization water management. The improvement in the genetic algorithm of the intermittence optimization control was executed by conducting the air flow rate control instead of the humidification or dehumidification process as the operation variables. Throughout this study, the results has informed that the flooding level can be controlled when the air temperature and the air flow rate are handled properly on the purpose of their target.

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