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Study of Flooding Prevention on Cathode Gas Diffusion Layer for Dynamic Load Fuel Cell

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Abstract

Water management is important in proton exchange membrane fuel cell because the water balance has a significant impact on the overall fuel cell system performance. In fuel cell vehicle, the vehicle's power demand is dynamic; therefore, the dynamic water management system is required. This present study proposes a method to control the humidity of the input air in cathode side of the fuel cell vehicle. The simulation using several driving cycles shows the proposed air humidification control obtains a relatively good result. The liquid saturation level is seen constant at the target level although still there are small deviations at driving cycles which having averagely high power demands.

Keywords : Fuel cell, Water management, flooding prevention, Control system

1. Introduction

Using fuel cell in automobiles, replace its energy source from fossil fuel into renewable and clean energy, furthermore it reduces the pollution from the point of global protection. Among several types of fuel cells, Proton Exchange Membrane (PEM) fuel cell is one of the most promising candidate, especially for automobile applications. It is because there are its high-energy density at low operating temperature, quick start-up and zero emission [1-2].

Water management is important in PEM fuel cell because the water balance has a significant impact on the overall fuel cell system performance. A flooding level in PEM fuel cell can be seen from the accumulated liquid water in a porous medium and it can indicates the level of the liquid water saturation. Hence this present study proposes an inlet air humidification control system of fuel cell for a vehicle to reach the water balance.

2. Modelling

The vehicle power is modeled as the total powers for rolling resistance, air resistance and kinetic given by Eq. (1) [3].

$$W_v = m\,g\,C_{rf}|v| + \frac{1}{2}\rho_a|v|^3 c_{drag} A + mv\frac{dv}{dt} \quad (1)$$
$$(roll) \quad (airresist) \quad (kinetic)$$

The water liquid saturation level (s) is the flooding or drying indicator and it can be defined as the volume fraction of the total void space of porous medium occupied by the liquid phase. It means that the higher the value of s, the greater the flooding level is, and vice versa..

$$s = \frac{V_{liq}}{V_{tot}} \quad (2)$$

The present liquid water in a cathode catalyst layer (CCL) is a function of the difference between the water addition and the removal [4] as given in Eq. (5).

$$\dot{m}_{rct} = M_r(c_d + 1)\frac{IA}{2F} \quad (3)$$

$$\dot{m}_{air} = \frac{\phi\, Q}{\gamma} \quad (4)$$

$$\dot{m}_{liq} = \dot{m}_{rct} + \dot{m}_{air} - \dot{m}_{sat} \quad (5)$$

The change of the liquid saturation level is given by Eq. 6. V_p is the volume of porous medium occupied by the gas phase that depends on the degree of its porosity.

$$\triangle s_{rct} = \frac{\dot{m}_{liq}}{\rho V_p} \quad (6)$$

Many studies were already investigated about the characteristics of the steady state water transportation in gas diffusion layer (GDL) of PEM fuel cell [5,6]. In those researches, it was seen that the capillary transport is the dominant factor in the process to remove the water from the flooded GDLs. The mass flow rate transported by capillary process is given by Eq. 7. The liquid saturation change affected by this capillary process is also given by Eq. 8.

$$\dot{m}_{cap} = s^4(1.417 - 4.240s + 3.789s^2) \times \frac{A\,\sigma\cos(\theta_c)(\varepsilon\kappa)^{0.5}}{M_r\,\mu\,\delta_{GDL}} \quad (7)$$

$$\triangle s_{cap} = \frac{\dot{m}_{cap}}{\rho V_p} \quad (8)$$

In general, the evaporation rate can be calculated by Eq. 9 and the liquid saturation change affected by this evaporation process can be given by Eq. 10. Furthermore the final liquid saturation is defined as Eq. 11.

$$\dot{m}_{evap} = \frac{h(4s+2)(V_p)^{2/3}|T_{liq} - T_{air}|}{\lambda} \quad (9)$$

$$\triangle s_{evap} = \frac{\dot{m}_{evap}}{\rho V_p} \quad (10)$$

$$s_x = s_0 + \triangle s_{rct} - \triangle s_{cap} - \triangle s_{evap} \quad (11)$$

3. Control system

The intermittent control system is used to handle the input air properties. The setting of the input air becomes flexible by every designed control interval. The control interval in this study was set already on 50s. Therefore, the control system started by measuring the current density of the fuel cell within first 50s. This measured data was then used as the control reference on the optimization process using genetics algorithm (GAs). The fitness function used in this GAs was the water transportation model given by Eq. 11. The outcome of this fitness function also means the difference between the predicted liquid water saturation level and the controlled level as given in Eq. 12.

$$s_{fit} = |s_{target} + s_m| \quad (12)$$

This s_{target} is the controlled liquid saturation level and s_m is the liquid saturation level obtained from the model. The fitness value is the absolute difference between the model result and the target. The smallest s_{fit} value is able to be target of the GAs.

4. Simulation

In order to evaluate the performance of the alternative control algorithms, it is useful to take a standard usage pattern against which to test them. Nine driving cycles were used in this simulation [7] as shown in Table 1.

Table 1. Driving cycles

Driving cycle	Max Velocity ($m \cdot s^{-1}$)	Time (s)
NYCC	12.3	599
EUDC	33.3	400
JP 10-15MODE	19.4	660
ECE	13.8	195
FTP72	25.3	1369
FTP75	25.3	1874
NEDC	33.3	1180
SC03	24.4	596
US06	35.8	596

5. Results and discussions

By applying the driving cycle data, the vehicle power can be calculated using Eq. 1. The simulation results revealed that the different ambient air condition reaches different fuel cell's liquid saturation level profiles as shown in Fig. 2. When the fuel cell is operated under the low temperature and humidity (10°C and 10% RH), the drying tends to happen in almost driving cycles. However, if the humidity increases, some of driving cycles start to get flooding. This is the reason why the inlet air properties should be controlled dynamically to avoid flooding or drying in the process.

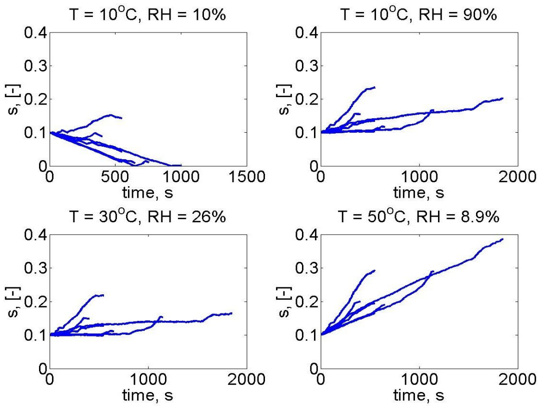

Fig. 2. Simulation result for all driving cycles in varying air condition without control system

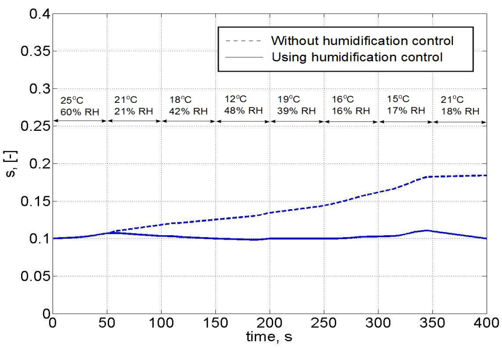

Fig. 3 Intermittent humidification

The proposed intermittent control system for the air humidification in cathode side is then used to maintain the liquid saturation at constant level. The given set point of the liquid saturation level in this study is 0.1 and the given interval is 50s. Therefore, the humidification is changed every 50s with the target of the final liquid saturation level is 0.1. The first 50s power pattern is used by GA as the reference to get the optimum air properties. And then, this optimum setting is used for the next 50s unknown power pattern. Fig. 3 shows the control result for EUDC driving cycle at ambient air condition at 25°C and RH 60%.

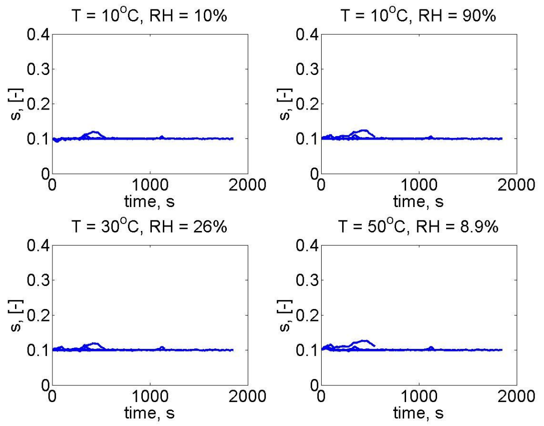

Fig. 4 Simulation result of control system for all driving cycles in varying air condition

The control results for all driving cycles were shown in Fig. 4 against every ambient air condition as shown in Fig. 2 . It was clear that the liquid saturation level of every driving cycles were controlled to the target level 0.1. But for high average power demands, the results have shown the greater deviations.

6. Conclusions

In dynamic system, different inlet air condition in cathode side have given different liquid saturation level at cathode. Therefore the dynamic inlet air control system is necessary to be applied to a dynamic fuel cell system. The inlet air condition can not be changed rapidly due to the air conditioning system limitation. Hence, the intermittent control is preferred for simple use. This study presents about simulations of the control system with nine driving cycles to investigate the flooding and drying. The simulation was done with and without air humidification control system under the different ambient air condition. The simulation of the intermittent air humidification control system in several driving cycles has shown a relatively good result. The liquid saturation level was kept as seen constant at 0.1 although there are still small deviations at high average power demands.

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