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Reactant Control System for Proton Exchange Membrane Fuel Cell

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Abstract

The Proton Exchange Membrane Fuel Cell (PEMFC) has been a focus in many fuel cell studies for tremendous commercialization. It generates an efficient and reliable power with a suitable system to ensure its electrochemical reaction operates well. In this paper, a reactant system is being discussed. Significant parameters such as reactant pressure, flow rate and stoichiometric ratio are the major factors for a reliable performance. A fuel cell owning a complex structure with traditional reactant requirement generally gives an unsatisfactory performance when facing dynamic loading instances. Fuel starvation usually occurs especially during transients where the reactants consumed are higher than being supplied. This in turn causes a problem to the MEA components such as platinum particles agglomeration, carbon corrosion and even cell reversal problem that lead to degeneration of fuel cell. Hence, excess stoichiometric ratio need to be supplied to prevent this issue and ensure a dynamic operation at the same time avoid the wastage issues. A development of a system identification and control strategy for reactant system is significant to ensure a reliable performance of power production and longer life span of the fuel cell. Hydrogen was controlled according to the load variation and the reactant control system compensates the loading transient variation that meets the design requirements and produces a reliable performance. The Mass Flow Controller (MFC) meter used with the current input range between 0.004 to 0.020 A and was changed for the suitable supply of fuel flow accordingly. A Zigler-Nicholes method used to tune the PID controller using a parameter of Kc = 23,385, Ti = 0.011 and Td = 0.002. An optimum consumption of hydrogen observed with an average error from the overall reaction is 0.000423 A. From the result shown, the reactant control system build is competence to fulfill the loading demand.

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Keywords: PEM fuel cell; on-line; non-linear dynamics; self tuning control; flow rate control; PID Controller

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1. Introduction

Fuel cell converts energy from chemical and produces electrical energy efficiently as a result from the electrochemical reaction between fuel (hydrogen) and oxidant (oxygen or air) as the reactant. They require a minimum maintenance due to their less moving parts [1]. There are various types of fuel cell being studied today and the most reliable fuel cell for stationary, portable electronics and vehicle applications is proton exchange membrane fuel cell (PEMFC). This is due to its low operational temperature, low noise, light weight, low corrosion, small volume and fast start-up capability which results in high energy density and quick start.

The amount of pressure and flow rate to be applied in the system is very complicated. Wherein an increase in flow rate will boost the kinetics of electrochemical reaction that result in higher power density and stack efficiency, but in the contrary this will also reduce the net available power from the fuel cell system. Usually, fuel is supplied in fixed amount but problem will arise during load variation where the fuel cell output power and current will increase [2, 3]. This problem needs a serious attention especially in vehicle or load variation applications as less hydrogen supply will cause power transient issue that leads to performance degradation, and subsequently poor response at higher load demand and also damaging MEA [4]. An excess hydrogen supply will issue the hydrogen wastage at lower current demand [5]. In order to overcome this problem, a controller needs to be implemented to control the flow rate of hydrogen being supplied to the fuel cell in the system.

In order to produce an efficient performance, the fuel cell needs a reactant management system where it functions to deliver the correct amount of supplies to generate power on demand [6]. There are many studies being done towards the control of fuel cell system, initiated by the complexity of the fuel cell. Reactant controls reported by many other researchers resulting in better performance where they presented an application of online self-tuning PID controller to prevent momentary drop during transient response caused by load variation [7]. This paper is focusing on the implementation of a reactant controller which is a design of feedback control system manipulating the flow rate of reactants being supplied into the fuel cell in order to improve the system response during load change. This will contribute to an increase of the fuel cell durability, capability and prevent the reactant waste.

2. Experimental Procedure

The single cell PEMFC used consists of a 25cm² of active area, graphite plate, silicone gasket, o-ring, MEA, current collector, and an aluminium end plate. The single cell was fueled by high purity hydrogen (99.99%) that being stored in a compressed gas cylinder which is reduced to 0.5 bar using a pressure regulator. The oxidant from purified air was also compressed in a gas cylinder reduced to 0.5 bar. The mass flow controller (MFC) used in this experiment was controlled by a PID type controller for an effective fuel supply at loading variation conditions. LabVIEW program with National Instrument (NI) devices was used to measure and record the values of the fuel cell performance on a real time basis. A programmable electronic load was used to generate a pulse current load profile. There are four flows of control algorithm, starting from fuel cell system, DAQ hardware tools (read), LabVIEW programme and DAQ hardware tools (write). These sequences keep running and analyzing as the system is powered. DAQ hardware tools were used to acquire data so that the signal can be sent out (control) and coming in (feedback). The setup of fuel cell testing was shown in Fig. 1.

3. Result & Discussion

Reactant pressure value is very much related to the flow rate [8]. When pressure was applied at constant value, the flow rate of gas proceeds into the graphite channel at fixed values, unless there is another controller that determines the value that flows through it. A controller is frequently used to ensure proper usage of the reactants and the power generated, in the sense that there is sufficient reactant flow rate during operating to improve the system efficiency. Fig. 2 shows the performance of the PEMFC with two levels of hydrogen flow rate at the pressure of 0.5 bar. Both conditions were tested with an increase of current periodically using DC electronic load. The polarization curves demonstrate that the load requirement can only be fulfilled if the fuel cell was supplied with a sufficient amount of hydrogen. In this case it was achieved at the maximum flow rate (10 liter/minute). On the other hand, the voltage decreases rapidly when the load current demand is high at low hydrogen flow rate (1 liter/minute). This is due to the amount of hydrogen which is insufficient for electrochemical reaction to occur entirely at higher loads.

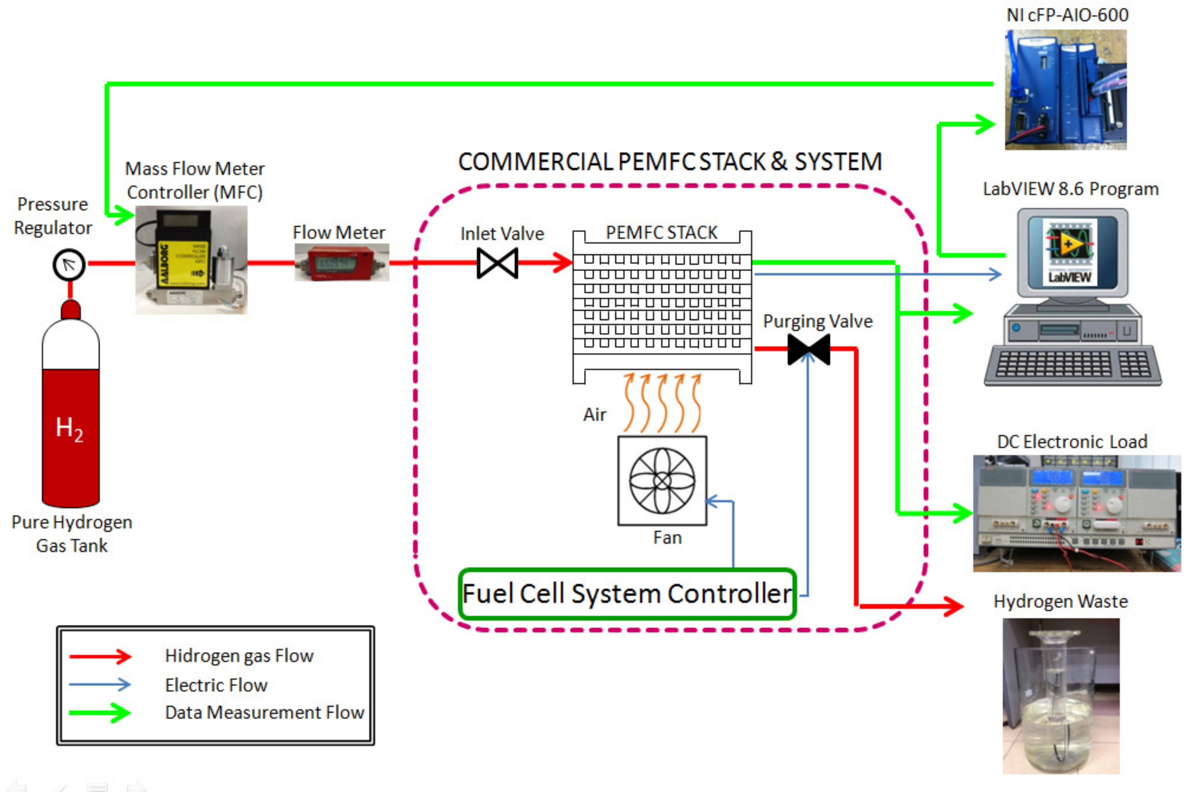

Fig. 1. Test bench of PEMFC system

The reactant starvation issue may occur during this operation due to improper gas supply, transient loading demand or even an improper start-up/shut-down process [8-10], and can cause accelerated and permanent damage to the electro-catalyst of the PEMFC [11, 12], such as loss in surface area of the catalyst [13-15], corrosion of the carbon-based catalyst support, and even cell failure [16]. As observed by Yu *et al.* [17], the existence of a mixture of hydrogen and air on the surface of the catalyst layer under hydrogen starvation will result in a more heterogeneous distribution of the current. Therefore, it is important to study the effects of reactant starvation and to take the corresponding measures to develop fuel cells that are durable.

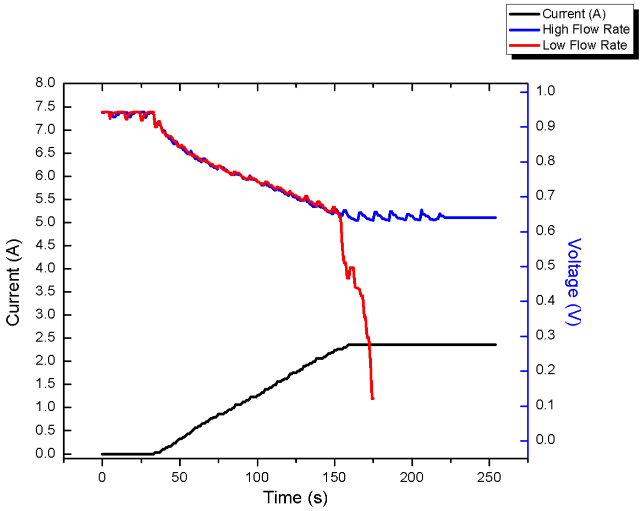

Fig. 2. Polarization curve with different hydrogen flow rate

Tuning procedure was done to determine the suitable parameter values to be used in PID controller. In this procedure, the parameter values of proportionality gain, integral gain and differential gain were determined to get the optimum value for the desired control response. Different control system has a different behavior depending on the needs and applications of each. There are several methods for tuning PID parameters and the model that frequently used are manual tuning, Ziegler-Nichols method, Cohen-Coon method or using software tools [18]. In this study, the PID parameters for the hydrogen control system were determined using automatic tuning Ziegler-Nichols methos as shown in Fig. 3. The tuning program determines the appropriate parameters to be used according to the set point changes that occur.

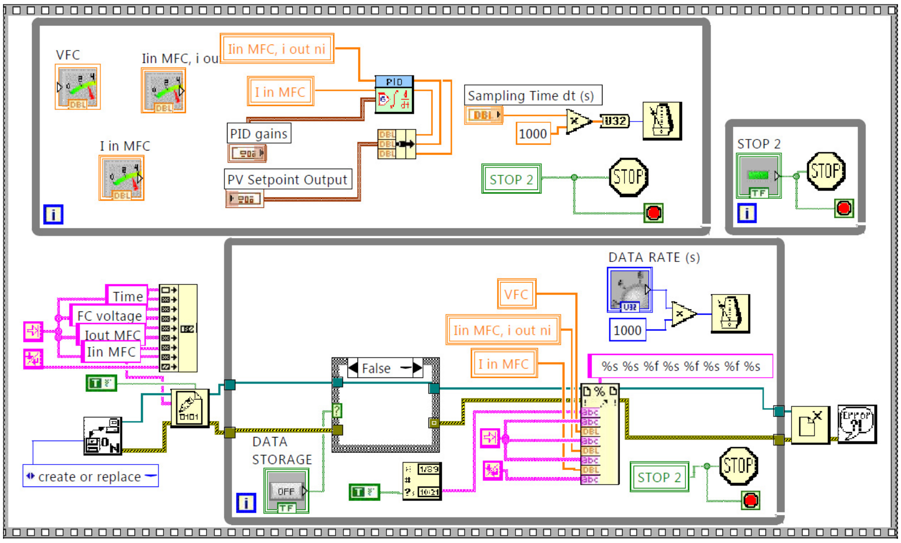

Fig. 3. Block diagram of PID auto tune program

In this study, hydrogen mass flow rate that enter the system was controlled automatically with a desired set point. The gas pressure was set using a pressure regulator to reduce the complexity of the system. These changes were made directly with the changes in voltage readings while the system is operating. This is to ensure that the voltage drop does not occur which subsequently reducing the use of hydrogen fuel as the control was made according to current demand. The MFC valve opening was controlled using the current analog system, with the range of 0.004 to 0.020 A and was changed for the suitable supply of fuel flow accordingly. The value of 0.02 was selected as the set point and automatic tuning program was used to determine an appropriate coefficient. Once the tuning process was completed, the parameter values recommended for PID was Kc = 23,385, Ti = 0.011 and Td = 0.002. These parameter values determined from the automatic tuning are suitable for the use of the system to achieve the desired set point.

It is found that the hydrogen flow rate control system designed using MFC as the manipulated tool performs a good result. This result is shown in Fig. 4, which is obtained from the study of the controller system construction using PID control. It is observed that when the voltage changes occur as the result of changes in load demand, the flow rate of hydrogen required by the fuel cell to operate will also change. This is a very favorable impact in terms of optimal use of the source of hydrogen, as the flow rate supplied varies according to MFC and the valve opening response time less than two seconds is needed to change prevailing trends.

In Fig. 4, an example of the change in the flow rate is marked by a green circle. The stability of controller is achieved for flow rate control using PID controller where at each change of set point, output current change does not suffer so much disturbance to reach steady state. The result showed that an average error resulting from the overall reaction is 0.000423 A, observed in the rise time of each change of current with a frequency of 0.2 seconds up to the maximum of 3 seconds. This occurs when the flow was changed dramatically causing delayed controller to interact in order to achieve the set point as seen in red circle.

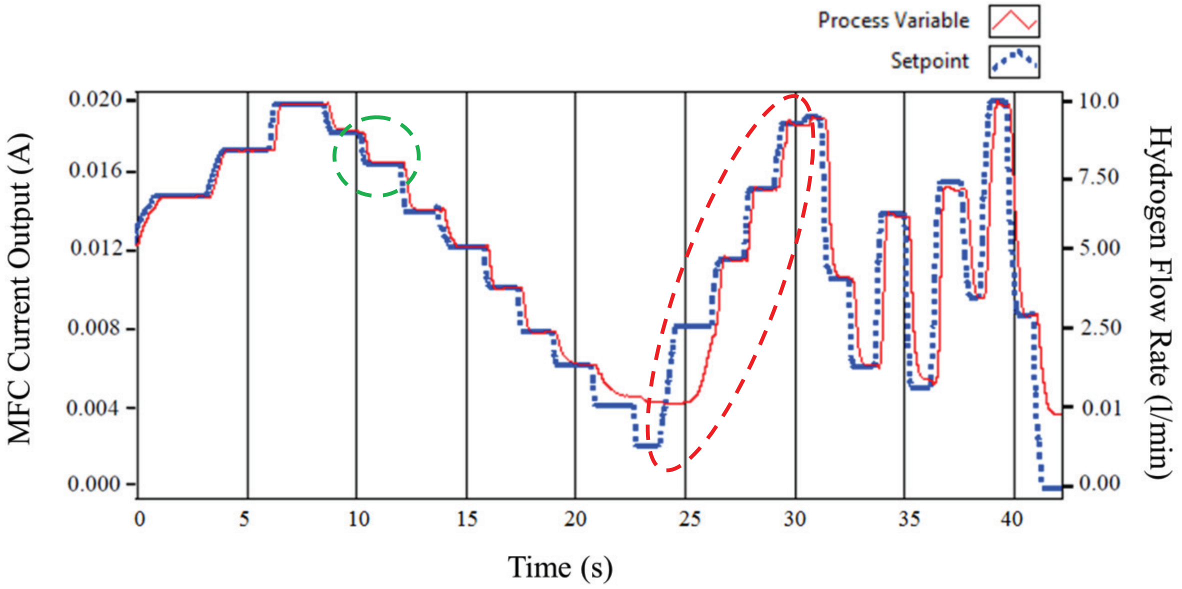

Fig. 4. Flow rate changes in dynamic response between current set point and current output using PID controller

4. Conclusion

The reactant control system is competent to follow the load demand even in transient response. In which with the sufficient amount of hydrogen, the fuel cell performance is improved, the fuel wastage is reduced and the MEA damage can be prevented. The implementation of PID controller is very effective to control the hydrogen flow for active current load variation. Although this experiment is conducted in a small-scale with short time of operation, it is signified that the design has improves the fuel cell hydrogen efficiency and cost effectiveness by reducing hydrogen waste, which constitute a significant benefit to the commercial fuel industry. The proposed fuel cell control system is also capable of accommodating transient load demands. This implementation can be widely used in many applications with large load variation such as fuel cell vehicle where the power demand is impulsive rather than constant.

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