AC 2008-1919: AN OPTIMIZED HUMIDITY AND TEMPERATURE CONTROL SYSTEM FOR FUEL CELLS

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An Optimized Humidity Control System for PEM Fuel Cells

Abstract

Hydrogen Fuel Cells require humidity to function efficiently and cost effectively. There is an optimum range of humidity for any given load condition and cell design. Hydrogen Fuel Cells inherently produce water, thus creating some of the necessary humidity for the cell to function. However, this self humidification through the back diffusion from the cathode side provides a limited range of operation for the fuel cells.

Without external control of the humidity, fuel cells do not operate at optimum condition. They generally have a warm up time lasting many minutes, in which they operate at limited output power. During operation, flooding could occur when there is an excessive amount of moisture built up in the fuel cell when the cell temperature is relatively low and inlet reactant gases are externally humidified. The humid air could condense to water inside the cell. The water then limits the flow of air through the reactant flow conduits and isolates the catalyst surface from the reactant gases and the electrolyte. Air carries oxygen to the active sights in the Membrane Electrode Assembly (MEA). Oxygen flow should be adjusted at the exact stoichiometric ratio otherwise the fuel cell will starve for its reactant fuel, thus the output power efficiency is reduced to unsatisfactory levels.

As the temperature of the fuel cell rises to 50 ºC or higher, another phenomenon occurs that limits a hydrogen fuel cell's output power. The internal heat generated by the fuel cell electrochemical reaction is enough to evaporate any water or moisture built up. This dries the conductive membranes, which in turn reduces their ionic conductivity thus curtailing the output power. This condition does not allow fuel cells to reach maximum allowable operating temperatures.

This paper presents an optimized humidity control system, which monitors vital data from humidity sensors and makes necessary adjustments to the external humidification apparatus at all given load conditions. This method ensures maximum power efficiency at all load and operating conditions.

1. Introduction

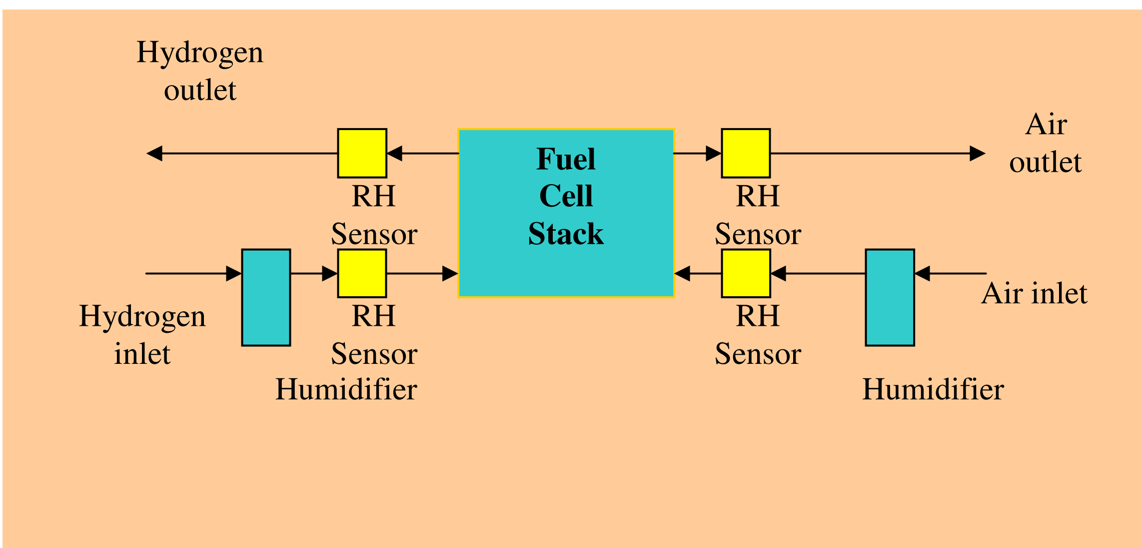
Humidity is one of the critical parameters which affect the performance of the fuel cells. Humidity is often referred to as a water management problem. Properly hydrated membranes maximize the performance and extend their lifetime, but poorly dehydrated ones can reduce the performance dramatically and shorten the life of the membranes. However, excessive humidity causes water flooding inside the fuel cell that blocks the flow of gases and covers the catalyst as a result. Most of the research work related to relative humidity is analyzed in fuel cell stacks. Various approaches are addressed to understand the phenomena of water management inside the fuel cell.

Understanding the transport phenomena of water inside the membrane and exploring the characteristics and affecting factors were investigated by some researchers[1-4]. Channel designs have been developed to maintain the humidity of the membranes[5-6]. Several types of humidifiers have been designed and analyzed to enhance the stack performance[7-10]. Humidifier design and analysis considering dynamics changes for automotive applications have been researched[11]. Specifically, ~~a~~ research work shown in reference[12] has closely estimated the humidity of stacks. For better performance, humidity must be managed and controlled. Different control schemes were used to run the fuel cell more efficiently and easily[13-15].

In this paper, the effect of gases relative humidity on the performance of the fuel cell was studied with the experimental data.

2. Fuel Cell stack System

A five single fuel cell stack made of graphite bipolar plate with straight channel flow pattern which distributes the reactant gases homogenously with 50 cm^2 active area; acquired with MEA (1 mg/cm^2 Pt loading and Nafion Membrane).and two end plates are made of aluminum 6061 as shown in Fig, 1. The hydrogen and air streams are connected to a two humidifiers to humidify the hydrogen and air and relative humidity sensor developed from Advanced Micro Power (AMP) Corp. as show in Fig. 2 to measure the relative humidity. Hydrogen with 99% purity was used as received from a commercial supplier and the air was pumped through an industrial compressor. The hydrogen gas entered the system at a pressure of 10 psi while air simultaneously entered the fuel cell at 10 psi and a flow rate of 6 SCFH. All experiments were run at room temperature: $22^\circ C \pm 2^\circ C$.



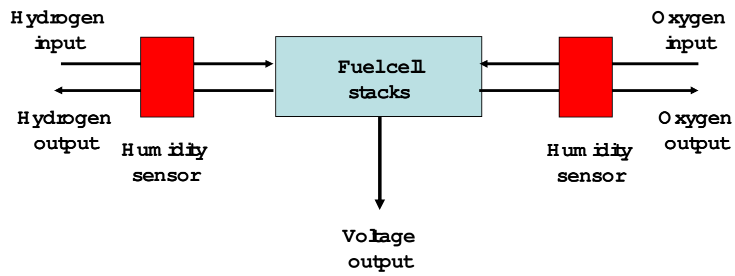


Figure 1 fuel cell system.

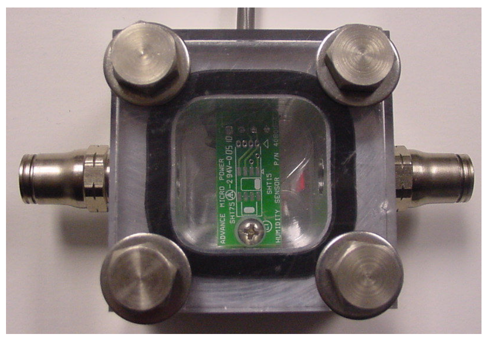


Figure 2 Sensor used for measuring relative humidity of gases.

3. Experimental Results

The experimental data for the fuel cell was gathered by first testing the fuel cell without any introduction of external humidity to the stream of hydrogen and air gases for the inlet side of the stack. Initially there is no load applied to the fuel cell, load current is equal to zero, however the output voltage in this condition is at its theoretical maximum. If the load current is increased gradually, there is a linear increase of power output from the fuel cell stack. This power curve is limited to a small percentage of the fuel cell's theoretical maximum power. If one considers the theoretical maximum current output, again the output is much less than optimum. Under this mode of operation there is output power but no guarantee of performance.

If the cell is first loaded with minimal current and the cell is allowed to generate its own water to hydrate the gas diffusion layer, the fuel cell will have a potential of increase in output power as compared to the power available after initial turn on.

After providing a sufficient time for the membranes to hydrate, the fuel cell will provide increased output in current. From the above statement it is easy to conclude that if current load is gradually increased, the fuel cell will be able to provide enough hydration to self hydrate the membranes. This is not the case. When load current is increased, the demand for hydrogen is also increased. Hydrogen gas stored in commercially available cylinders for use has a moisture content of less than 1% of humidity. As the load demand increases, so does the consumption of hydrogen. Any moisture that was on the hydrogen side of the membrane-electrode assembly (MEA) begins to migrate toward the air (oxygen) side, thus causing a decrease in hydration on the hydrogen side. This results in loss of electrical and thermal conductivity of the MEA.

The air side has a non uniformity in moisture distribution. The membrane area closer to inlet ports is drier than the membrane area closer to the outlet port. Since moisture content effects current conduction, majority of load current will pass through the membrane area closer to the exit port. The passage of current over a smaller surface area will yield localized heating of the bipolar plates and gas diffusion layer. Increasing the load current will eventually begin to heat the water to the point of boiling. Once this condition occurs, the MEA will experience a reduction of hydration, thus causing loss of current and further heating due to increase in resistively.

Operating a fuel cell without external introduction of moisture or control of such parameters is possible but the output power is limited to a small percentage of the fuel cells optimum performance. Furthermore life expectancy of the MEA is unpredictable. Uneven hydration resulting in non-symmetrical heating creates exaggerated mechanical stresses on the membrane. This in turn can cause premature failure of the fuel cell. In all instances the MEA experienced ruptures which resulted in hydrogen gas leaking to the air side. The life expectancy without introduction of humidity or a controlled humidification system under load can be as low as few minutes.

Having a system that monitors moisture content of inlet and outlet gasses with a controlled feedback loop reduces the heat stress associated with turning a fuel cell on rapidly at maximum power. The feedback system also allows the fuel cell stack to reach stable operation faster.

At system turn on the controller assesses ambient start up conditions by first accruing temperature data. Next the Hydrogen gas and air have to be turned on. When the gases have begun to flow, their humidity content information is acquired. In a control system setup adjustments can be made during turn on to protect the membranes from potentially extreme conditions. Once the fuel cell has gas flow, there will be output power. The output power will start to increase as the gases make their way through the internal channels of the bipolar plates. As the output power is approaching its required level, the controller will monitor power and compare it to stored performance data and begin to adjust humidity of inlet gases. The inlet temperature can be adjusted to minimize time necessary for the fuel cell to reach its optimum operating temperature. The above process will continue until a sensor data is out of its normal range. The detailed control algorithm is shown in figure 3.

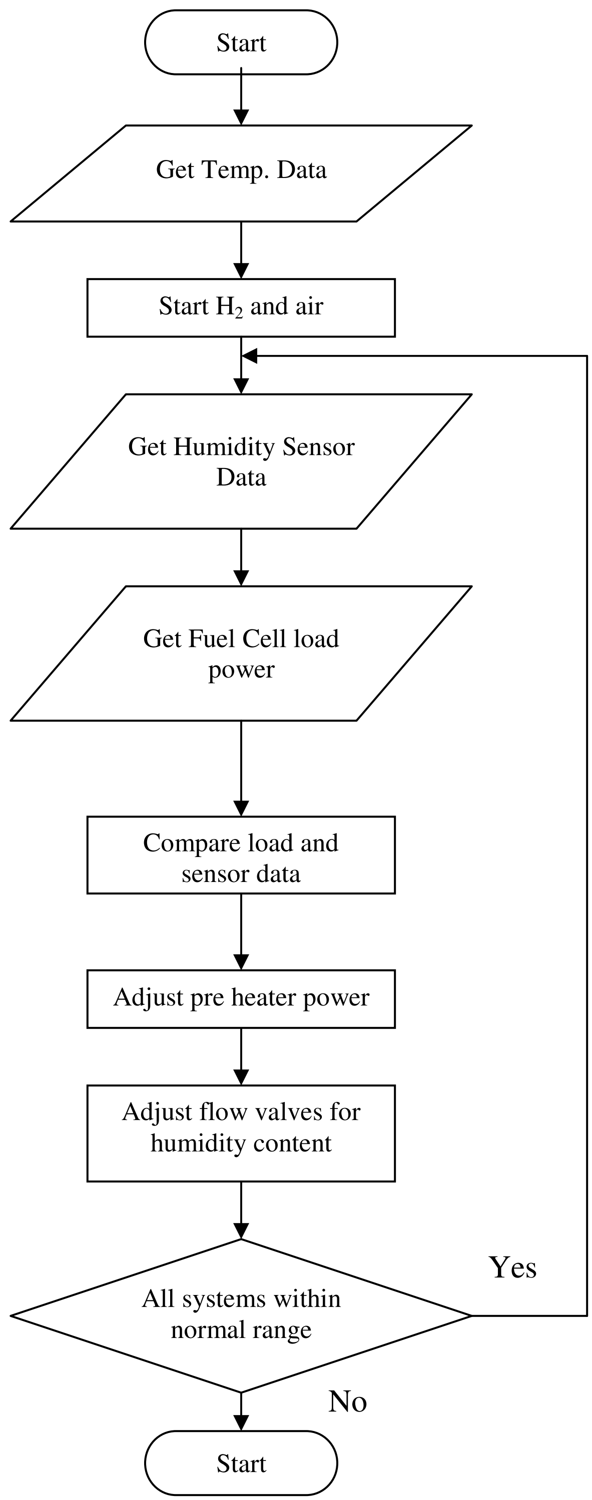


Figure 3 Flow chart for the feedback control algorithm.

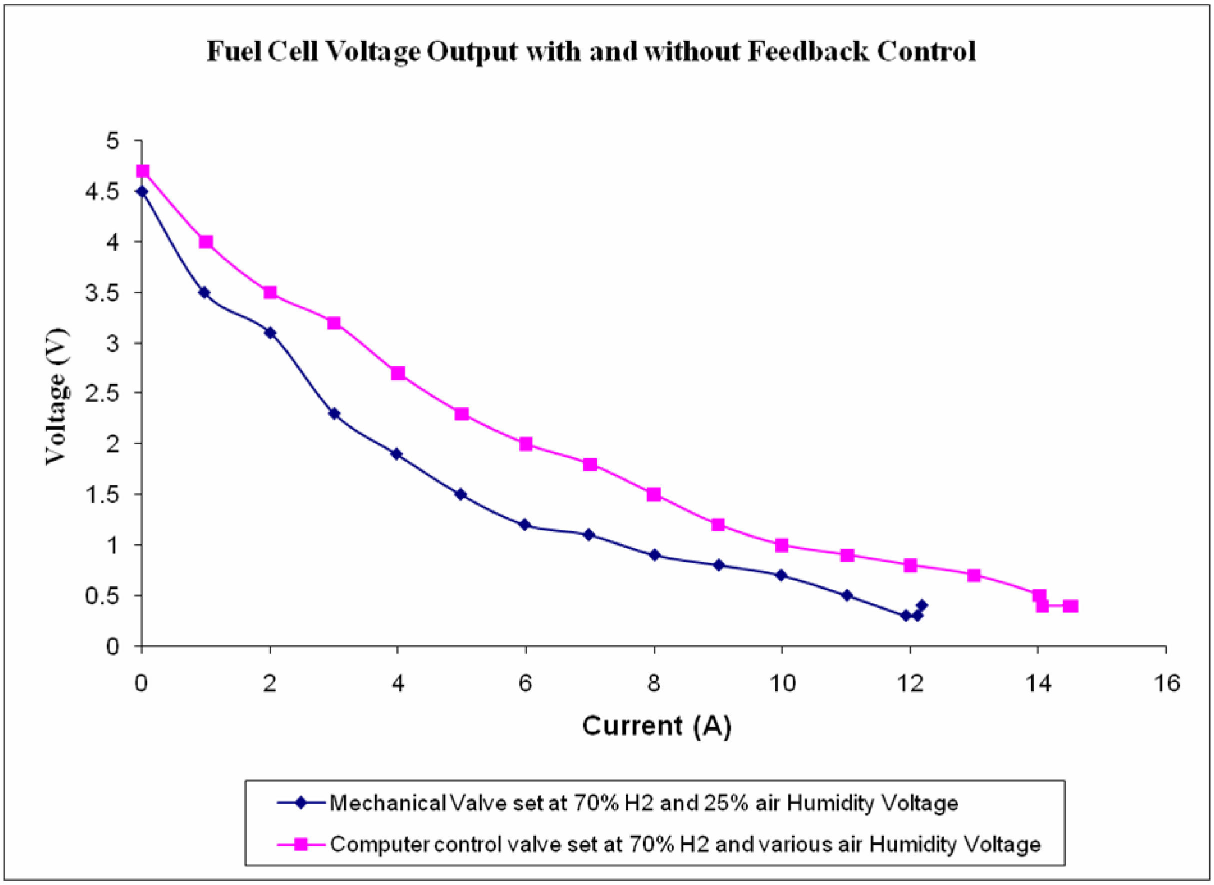


Figure 4 Fuel Cell Voltage Output with and without Feedback Control

Figure 4 shows the fuel cell voltage output under a mechanical valve without control versus a computer controlled valve, which constantly adjusts itself under the influence of the feedback system to provide optimum voltage. The blue curve shows the mechanical valve condition preset at 25 percent of air humidity and the purple curve shows solenoid valves control by computer through NI data acquisition (DAQ). The curve is higher in value due to the control of dry and humid solenoid valves.

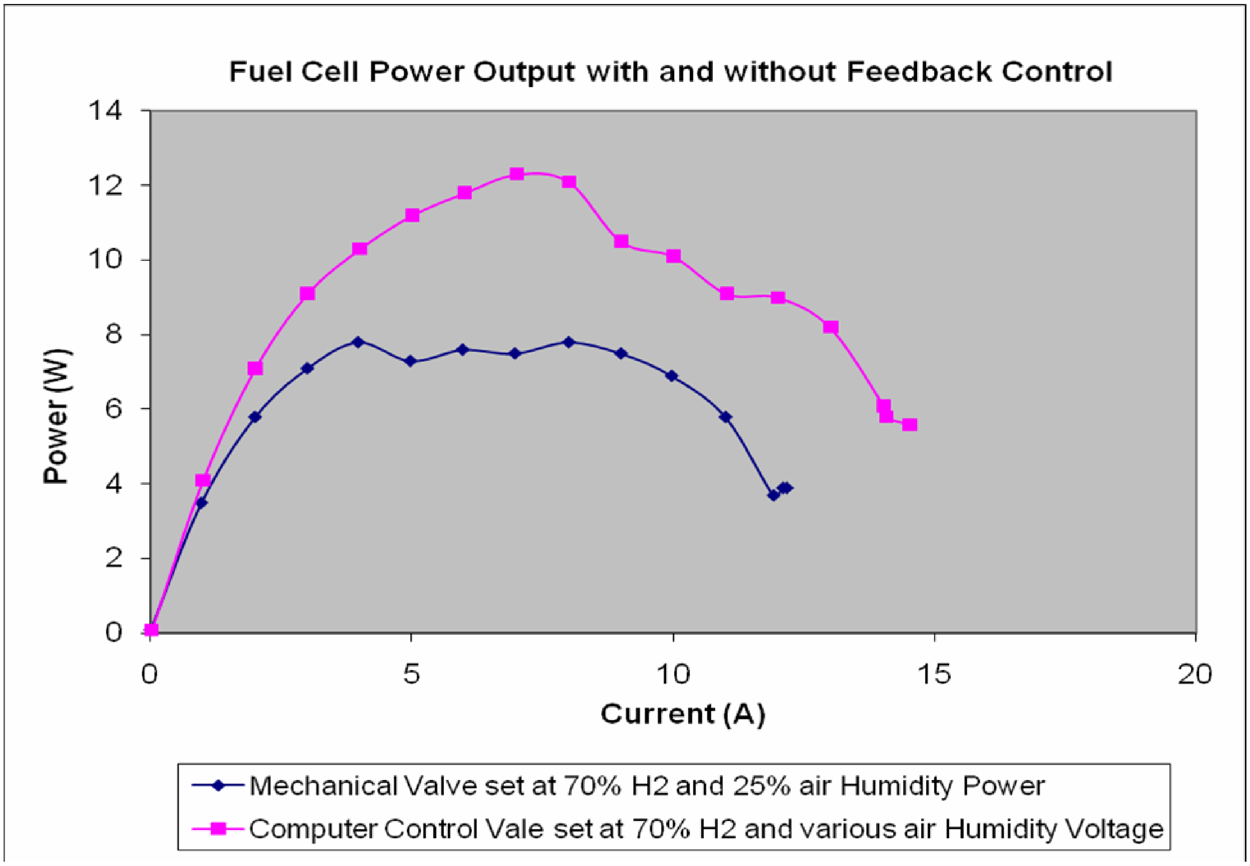


Figure 5 Fuel Cell Power Output with and without Feedback Control

Figure 5 shows the fuel cell power output curves. As with voltage output under a mechanical valve versus a computer controlled valve, the output power is consistently much higher with feedback system. The blue curve shows the mechanical valve condition preset at 25 percent of air humidity and the purple curve shows solenoid valves control by computer through NI data acquisition (DAQ). Use of the solenoid vale to control input gas flow and humidity allows the fuel cell to reach maximum possible power over the entire range of operation.

4. Conclusion

In this paper, the effect of the relative humidity to the power output of the fuel cell is experimentally investigated. A simple control method was applied to find the desired humidity for the maximum power of fuel cells. Finally a humidity control loop was developed for the relationship between the desired value and the error which led to finding the relationship between the humidity of the gases.

5. Impact in Engineering Technology Education and Future Works

Emerging technologies such as those involving alternate forms of energy are expected to play a major role in modern engineering technology curricula. The results presented in this paper involve expertise from multidisciplinary teams in our school of engineering technology; in particular, technology of fuel cells, control systems, fluid mechanics, thermodynamics, and software applications. Major parts of this work were performed as student projects by the first two authors who are students in the school of engineering technology. Namely students were involved in setting up the fuel cell system, developing code for control algorithm and data acquisition, and running the experiments. It is expected that this lab setup will be used in future undergraduate senior projects for students in the departments of mechanical engineering technology and electrical engineering technology. In addition, interdisciplinary courses in alternate forms of energy, fuel cells, solar energy systems, and control mechanisms could be developed in the future as outgrowth of these experimental setups and activities. Parts of the algorithms developed have also been used as examples in existing courses.

The performance of the fuel cell is influenced by many different parameters. In this paper we analyzed the relationship between humidity and the maximum power. Temperature is also another important parameter to the maximum power and the humidity. We will continuously investigate the relationship between temperature, humidity, time and power. For real life applications, we need to develop a more sophisticated control algorithm to consider many parameters in the extended running of fuel cells.

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