Fuel Cell Stack Simulated Analysis

MENG 3211 LABORATORY REPORT

031-Fri1-Group6

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We certify that the narrative, diagrams, figures, tables, calculations and analysis in this report are our own work.

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ABSTRACT

Fuel cells are electrochemical cells that convert chemical reactions to electricity. They consist of three things that allow it to work the anode, cathode, and electrolyte. This is done by anode, which oxidizes the fuel, hydrogen, which allows the charged ion to pass through an electrolyte and keep negatively charged electrons out and have them pass through a wire producing a current. The ions that were now separated by the electrolyte can pass through the cathode where another reaction occurs of hydrogen uniting with the oxygen residing in the cathode producing water. This basic premise is what allows the fuel cell to operate. In this experiment, a simulated model of “6 KW 45 Vdc Fuel Cell Stack” [1] is analyzed using parametric values and simscape simulated values. When first starting to calculate the values of voltage and current based on the parameters the utilization and partial pressure being implemented in the fuel cell is calculated based on the pressure, flowrate, and temperature of the hydrogen and oxygen. A graph of Voltage versus Current is made with a slope of -.1527. Next running the simulation the following data points for flowrate, pressure, utilization percentage, voltage, and current are taken by scope components model being used for the simulation. Based on the data given the following values of Voltage versus Current with a slope of -.1734. The reason for the difference in slope in the calculated values based on the parameters and the simulated values is impart by having a different partial pressure and flow rate of hydrogen and oxygen into the system.

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INTRODUCTION

A fuel cell is an electrochemical cell that takes in chemical energy for fuel, such as hydrogen and oxygen, and converts it into electrical energy. Fuel cells are all consisting in three things that allow it to work the anode, cathode, and electrolyte. This is done by anode, which oxidizes the fuel, hydrogen, which allows the charged ion to pass through an electrolyte and keep negatively charged electrons out and have them pass through a wire producing a current. The ions that were now separated by the electrolyte can pass through the cathode where another reaction occurs of hydrogen uniting with the oxygen residing in the cathode producing water. This basic premise is what allows the fuel cell to operate.

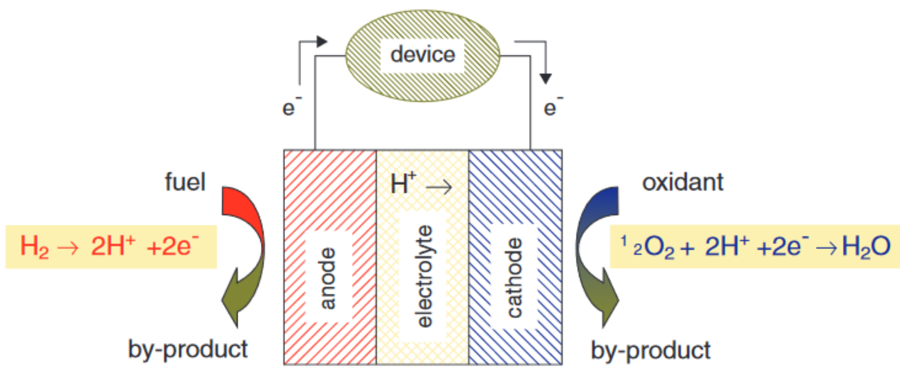

Fig 1. A diagram that shows how a fuel cell generates electricity [1].

In order to know if a fuel cell is successful in converting chemical energy to electrical energy to a notable degree, a goal must be made of producing energy efficiently. This is done by first identifying the output characteristics of the fuel cell such as the voltage and current which are influenced by flowrate temperature and pressure.

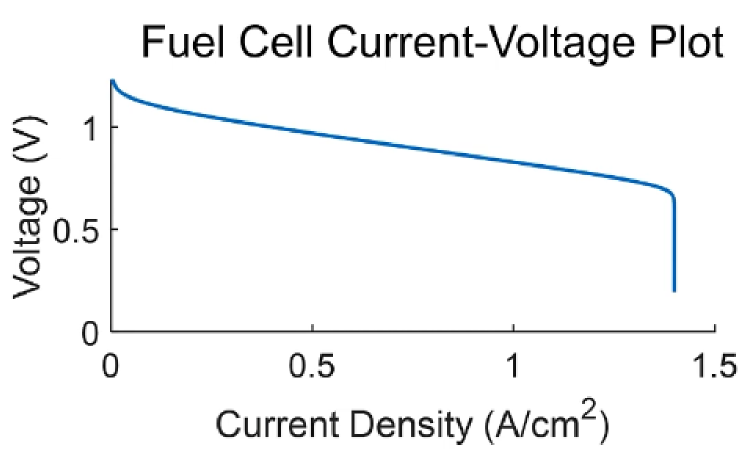

Fig 2. A graph that would characterize the output is shown below [2].

To find rates of conversion being utilized the following two equations for hydrogen and oxygen are shown below. The following equations used the terms: Pfuel = Absolute supply pressure of fuel (atm), Pair = Absolute supply pressure of air (atm), Vlpm(fuel) = Fuel flow rate (l/min), Vlpm(air) = Air flow rate (l/min), x = Percentage of hydrogen in the fuel (%), y = Percentage of oxygen in the oxidant (%), and N = Number of cells. The 60000 constant comes from the conversion from the liter/min flow rate used in the model to m3/s (1 liter/min = 1/60000 m3/s).

$$U_{fH_2} = \frac{60000TNi_{fc}}{zFP_{fuel}V_{ipm(fuel)}x\%}$$

$$U_{fO_2} = \frac{60000TNi_{fc}}{2zFP_{air}V_{ipm(air)}y\%}$$

The following equations allow for partial pressures to be calculated using the prior found values of rates of conversion, P_{H2O} = Partial pressure of water vapor inside the stack (atm), and *w* = Percentage of water vapor in the oxidant (%)

$$P_{H_2} = (1 - U_{fH_2})P_{fuel}x\%$$

$$P_{O_2} = (1 - U_{fO_2})P_{air}y\%$$

$$P_{H_2o} = (w + U_{fO_2}2y\%$$

To find the following voltage from the system being designed the following equations are used where E = the standard cell potential, T = temperature in Kelvin, R = 8.3145 J/(mol K), F = 96485 A s/mol, K is voltage under constant nominal condition, and P is the partial pressure inside the fuel cell stack.

$$V_{Nernst} = 1.229 + (T - 218)\frac{-44.43}{2F} + \frac{RT}{zF}ln\left(P_{H_2}P_{O_2}^{1/2}\right)$$

$$V = KV_{Nernst} \qquad (2)$$

To find current of the system the following equation below is used. F = 96485 A s/mol, z = Number of moving electrons, h = Planck's constant = 6.626 × 10–34 J s, Δv = Activation barrier volume factor (m3). The size of activation barrier (ΔG) is computed assuming Δv = 1 m3. ΔG = Size of the activation barrier which depends on the type of electrode and catalyst used (J/mol), and T = Temperature of operation (K).

$$i_0 = \frac{zFk\left[P_{H_2} + P_{O_2}\right]\Delta v}{Rh}e^{-\frac{\Delta G}{BT}}$$

Now to demonstrate the principals stated above for the fuel cell a computer software tool known as Simulink can be used. Simulink is a software in which block diagrams can be used to dynamically simulate a model. In this experiment the simulation will be derived from a previous design.

METHODOLOGY

Experimental Apparatus

The experiment as stated will be using Simulink for its environment. The experiment will be using a previously designed Simulink file in which the analysis will be done. Its description is as follows, first starting is placing a fuel cell stack which will contain a anode, cathode, and electrolyte. Next for the anode to take in hydrogen for fuel, a link is placed in which flow rate will be controlled to make sure a certain pressurized volume will come into the system. Similarly, on the other side of the fuel cell the cathode will also have a link placed in a determined flow rate for intaking air which will allow for oxygen to be obtained. Next scopes, data acquisition, will be used to identify how much energy is being produced from the fuel cell stack. Finally, regulators will be placed so a threshold of how much a flow rate for the hydrogen or air intake for the system can be determined based on the outputted energy.

The simulation of the fuel cell will have present parameters, which are conditions that it will be going through to analyze the affects it will have on the fuel cell.

Table 1. Shows the parametric data for the simulated fuel cell.

Preset Model	PEMC - 6 KW - 45 Vdc				
Voltage	65 Volts	Current	0 Amps		
Voltage	63 Volts	Current	1 Amps		
Nominal Operating point	45 volts	Current	133.3		
Maximum Operating Point	37 Volts	Current	225		
Number of Cells	65				
Nominal Stack efficiency	55%				
Operating Temperature	65	Celsius			
Nominal Air flow rate	300	L/min			
Nominal Supply Pressure	Hydrogen	1.5 bar	Air	1 bar	
Nominal Composition	Hydrogen	99.95%	Oxygen	21%	H2O 1%

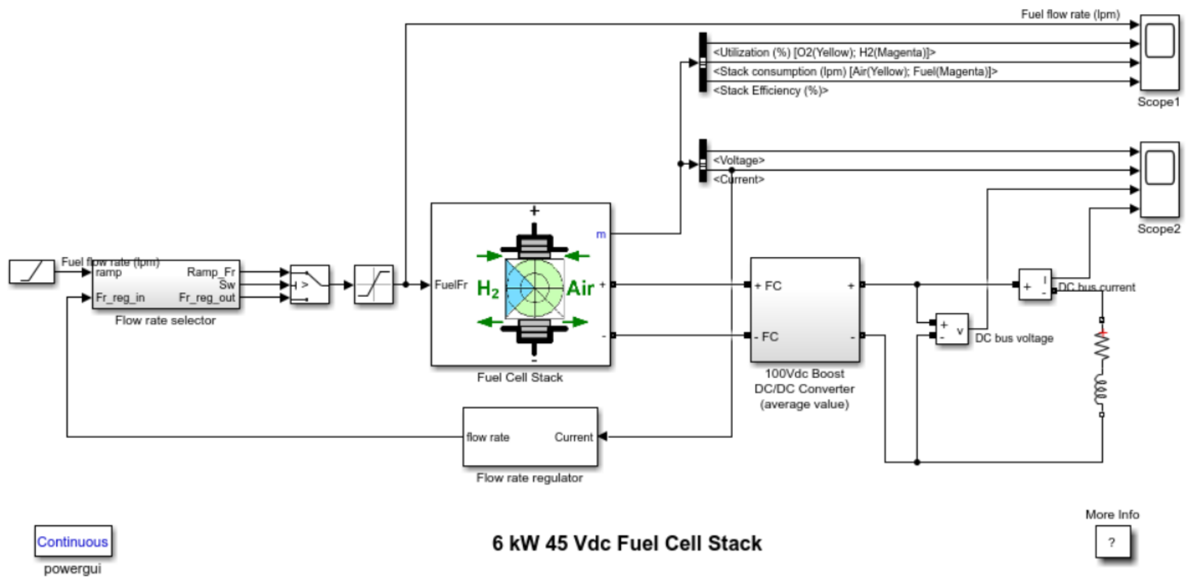

Fig 3. Shows the configuration of the experiment taken from the MathWorks website [2].

Experimental Procedure

The procedure can now start after the configuration is setup. It is data acquisition using the scopes by having the simulation run for a determined time with set parameters. The simulation will run at first by starting with a minimum flow rate from both hydrogen and air intake to the fuel cell stack. The simulation will end after 20 seconds.

RESULTS

The results for this simulation are derived from the two scope components of the simulation. The first scope shows 4 graphs of fuel flow rate of hydrogen, utilization percentage of oxygen and hydrogen, consumption of hydrogen and oxygen in liters per minute, and efficiency of stack. The second scope shows 4 graphs of the voltage, current, bus voltage, and bus current. The next portion of the data is obtained are the current vs voltage graphs.

Table 2. Shows the data from the first scope.

Time	Fuel Rate	Utilization O2	Utilization H2	Consumption Air	Consumption Fuel	Efficiency
0	0	59.3	100	0	0	0
5	49.56	59.3	99.56	176.1	49.35	55.15
10	50.07	59.3	99.56	178	49.85	55
15	85	59.3	48.33	146.6	41.08	32.41
20	85	59.3	48.31	146.6	41.07	32.4

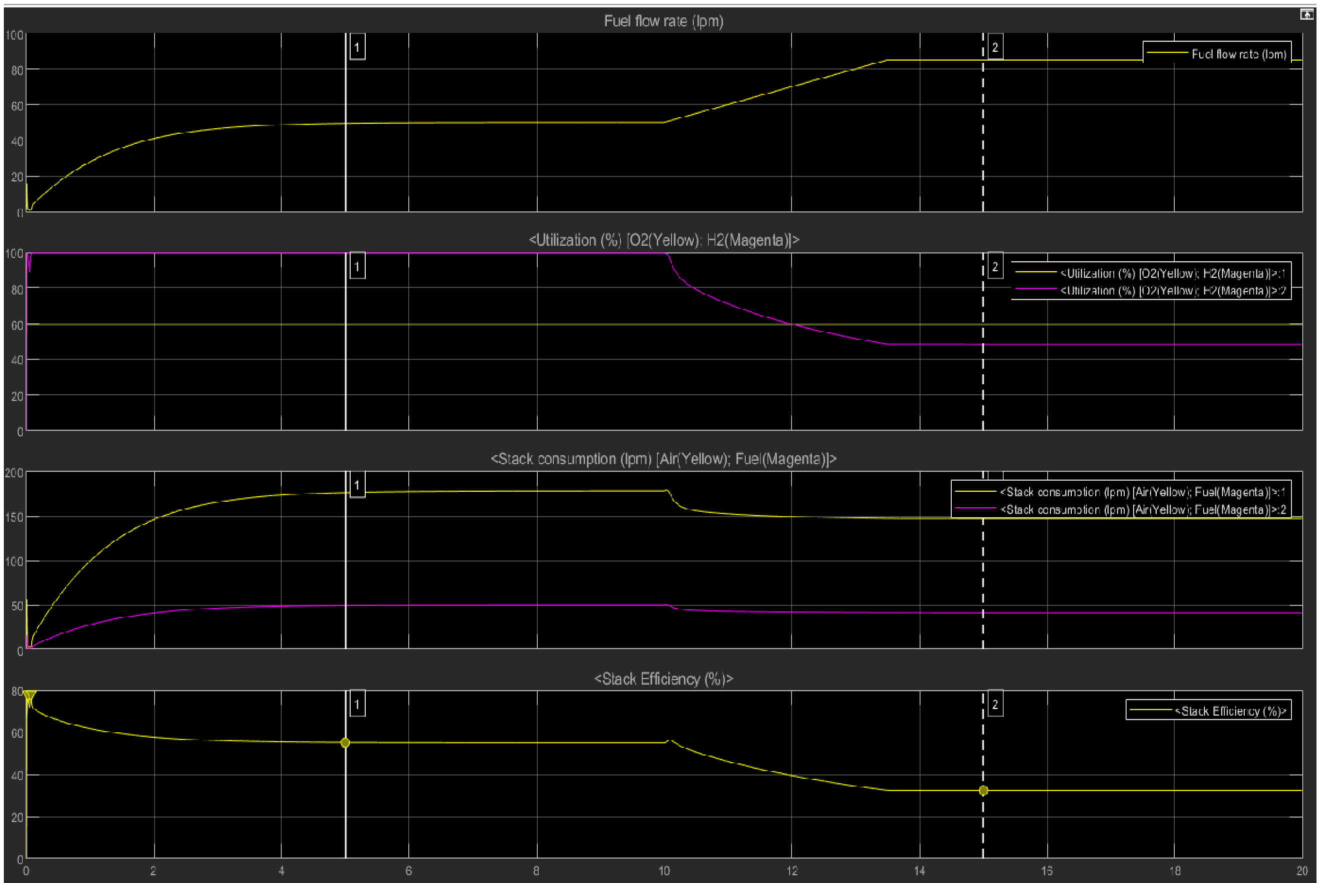

Fig 4. Shows the graphs for the first scope.

Table 3. Shows the data from the second scope.

Time	Voltage	Current	Bus Voltage	Bus Current
0	69.55	0	100	0
5	45.12	132	99.98	59.56
10	45	133.3	100	60
15	54.62	109.9	100	60.02
20	54.62	109.8	100	60

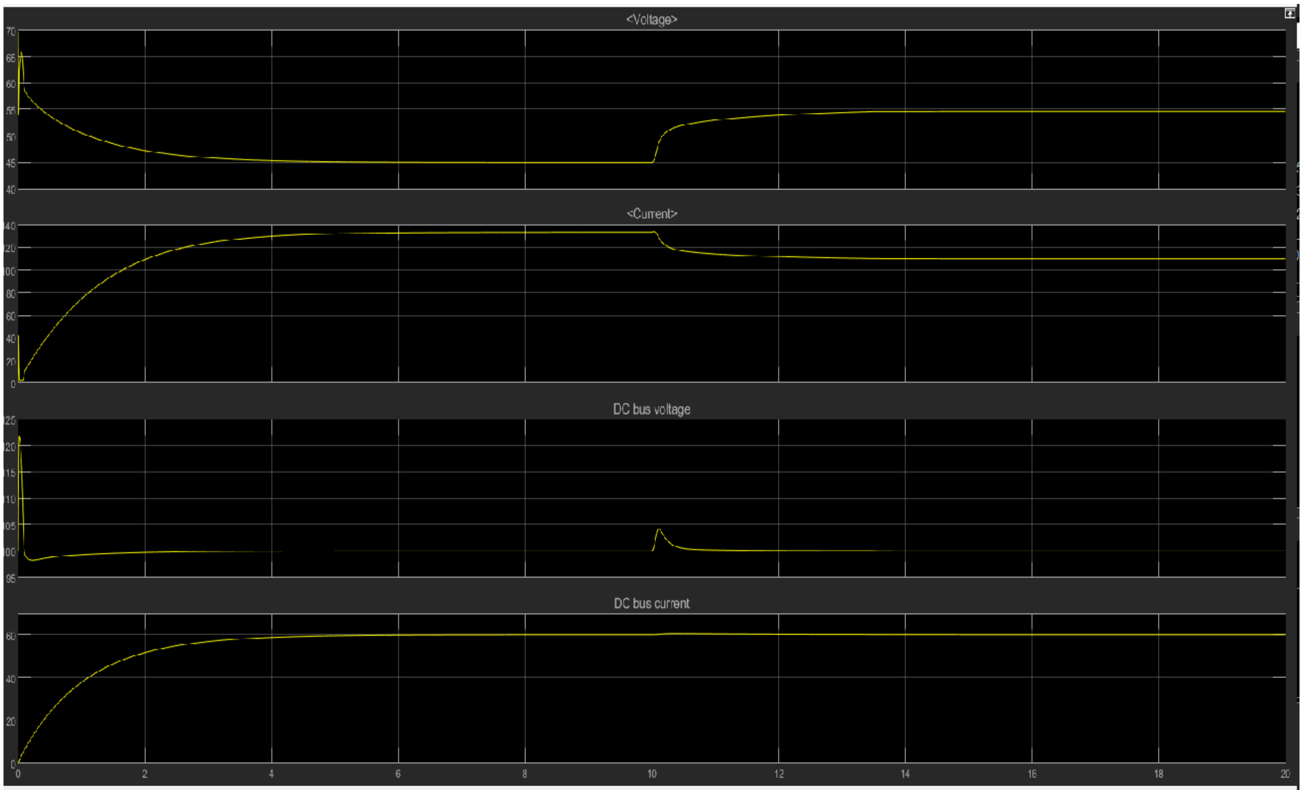

Fig 5. Shows the graphs for the second scope.

Discussion

The analysis for this simulation can be compared to calculated results that would find what differences are taken into account when using this simulated model.

Calculated Results

Using the parametric values the following graph can be constructed from the fuel cell prior to the simulation start for Voltage versus Current.

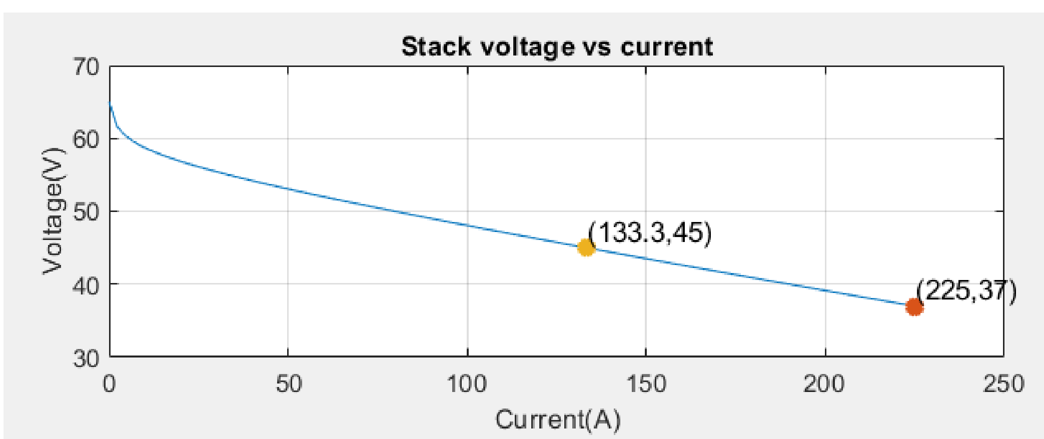

Fig 6. Shows the graphs for the Voltage vs. Current based on raw data found in Appendix B.

Simulated Results

Using **Table 3.** the following can be used construct a graph for Voltage versus Current. The graph then can be compared to the calculated resulted graph based on the parameters set prior to running the simulation.

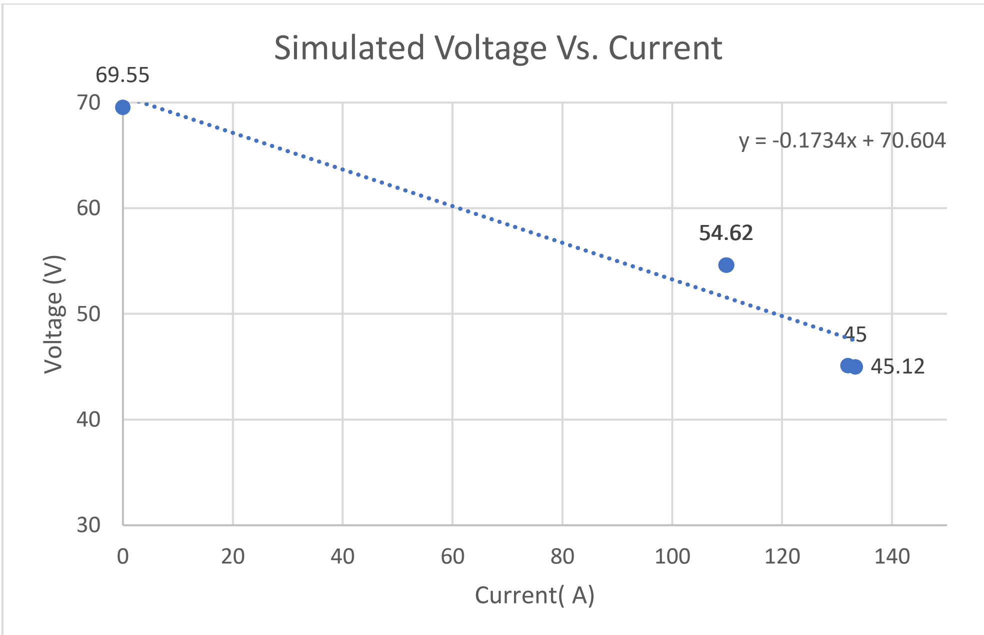

Fig 6. Shows the graphs for the Simulated Voltage vs. Current.

Comparison

In order to compare both graphs the slope of the parametric valued Voltage vs. Current has to be found. This can be found by using the mid and end point as highlighted in the graph from **Fig 6.**

$$\frac{31-45}{225+133.3} = -.1527$$

When comparing the slope for the parametric values -.1527 to the slope of the simulated values -.1734, the difference is shown to be caused by the difference in initial voltage values. This is impart by having a different partial pressure and flow rate of hydrogen and oxygen into the system.

Upon further inspection of the model used for the simulation the reason for there being a difference in the simulated values versus the calculated values is due to there being model limitations. Some of the model discrepancies can be due to not taking into consideration the stack output power being influenced by the limited fuel and flow rates for both of the fuel and air. This can cause the partial pressure to be impacted which further impacts the calculations for the current and voltage.

Conclusion

In conclusion a fuel cell uses hydrogen and air to generate voltage and current based on the flow rate, pressure, and temperature. In this experiment however the temperature is constant at 65 degrees Celsius, meaning the variables that are impacting the power generated are the flow rates and the pressures. The simscape model of “6 KW 45 Vdc Fuel Cell Stack is used to demonstrate the difference between calculated and simulated values for analysis. The calculated Voltage and Current are based on the parameters that are set prior to starting the simulation was found to have a slope of -.1527. The simulated Voltage and Current are the analysis done with the values taken from the scope devices that take into account the pressure, flow rate, and utilization of hydrogen and oxygen was found to give a Voltage versus Current slope of -.1734. The differences are due to difference in nominal values given from the parameters set prior to the simulation compared to the values obtained from the simulation itself. Although the curve is very close this simulation still has model limitations due to it not taking into account of stack output power is limited due to fuel and flowrate at initial start of simulation causing a jump in fuel needed for simulated data. This contrasts the calculated data based on parameters that don’t take into account initial fuel needed to start.

REFRENCES

[1] “6 KW 45 Vdc Fuel Cell Stack.” *6 KW 45 Vdc Fuel Cell Stack - MATLAB & Simulink*, www.mathworks.com/help/physmod/sps/ug/6-kw-45-vdc-fuel-cell-stack.html.

[2] “Fuel Cell Stack.” *Implement Generic Hydrogen Fuel Cell Stack Model - Simulink*, www.mathworks.com/help/physmod/sps/powersys/ref/fuelcellstack.html.

[3] Haile, Sossina M. "Fuel Cell Materials and Components." Acta Materialia 51.19 (2003): 5981-6000. Web.

Appendix

Appendix A

The link to our zoom meeting presentation which has a PowerPoint and simulation of the Fuel Cell with

https://uttyler.zoom.us/rec/play/Rkx128J5evYuhLiwrjCafr36Q8f44JOM41cS_OE-RnL2Ku9ozt1aDzpzuRPlnJZoR_84xHaaojsZ7aBq.ZK338ErKUcfKO7W0?startTime=1619229529000

Appendix B

All Raw Data Pertaining to the parameters set prior to the experiment and simulated results

Preset Model	**PEMC - 6 KW - 45 Vdc**					
Voltage	**65 Volts**	**Current**	**0 Amps**			
Voltage	**63 Volts**	**Current**	**1 Amps**			
Nominal Operating point	**45 volts**	**Current**	**133.3**			
Maximum Operating Point	**37 Volts**	**Current**	**225**			
Number of Cells	**65**					
Nominal Stack efficiency	**55%**					
Operating Temperature	**65**	**Celsius**				
Nominal Air flow rate	**300**	**L/min**				
Nominal Supply Pressure	**Hydrogen**	**1.5 bar**	**Air**	**1 bar**		
Nominal Composition	**Hydrogen**	**99.95%**	**Oxygen**	**21%**	**H2O 1%**	
Time	**Fuel Rate**	**Utilization O2**	**Utilization H2**	**Consumption Air**	**Consumption Fuel**	**Efficiency**
0	**0**	**59.3**	**100**	**0**	**0**	**0**
5	**49.56**	**59.3**	**99.56**	**176.1**	**49.35**	**55.15**
10	**50.07**	**59.3**	**99.56**	**178**	**49.85**	**55**
15	**85**	**59.3**	**48.33**	**146.6**	**41.08**	**32.41**
20	**85**	**59.3**	**48.31**	**146.6**	**41.07**	**32.4**
Time	**Voltage**	**Current**	**Bus Voltage**	**Bus Current**		
0	**69.55**	**0**	**100**	**0**		
5	**45.12**	**132**	**99.98**	**59.56**		
10	**45**	**133.3**	**100**	**60**		
15	**54.62**	**109.9**	**100**	**60.02**		
20	**54.62**	**109.8**	**100**	**60**		

Appendix C

Shows the times we all meant on zoom and worked on our project on through teams. We all went through each section together during the meetings.

	31-Mar	1-Apr	2-Apr	3-Apr	4-Apr	5-Apr	18-Apr	19-Apr	20-Apr	21-Apr	22-Apr	23-Apr
Jonathan Gonzalez	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Mohammed Alhulaimi	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Mohammed Waheed	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Vasuhans Goswami	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Hamed Amiri	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Luis Rosario	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.
Luis Rosario	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.	9:00 P.M.- 9:30 P.M.