Energy Management of an Electro-Hydrostatic Actuator Hybridizing with Storage and Fuel Cells Supply

Date: 23/10/2015

Developed by:

Prerana Shamsundar Punjabi

Table of Contents

1 Introduction

A fuel cell is a device that generates electricity by a chemical reaction. Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution– much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless by-product, namely water. A single fuel cell generates a tiny amount of direct current (DC) electricity (0.6V – 0.7V). The fuel cell can be used in many applications such as to generate power.

The aim of the lab session was to study the supply system of an electro-hydrostatic actuator (EHA) and to evaluate the interest of hybridizing supply sources.

For achieving this goal, first the power mission profile of EHA is studied, then a fuel cell stack capable to provide the required power to supply is designed. For the purpose of this lab the peak voltage required by EHA is as displayed in the mission profile i.e. 2200W and a fuel cell generates a voltage of 0.6-0.7V, this implies if a stack of 100 cells is used voltage of 60-70V will be generated. A power converter with a typical step-up ratio of 4-5 will be used to reach 270V.

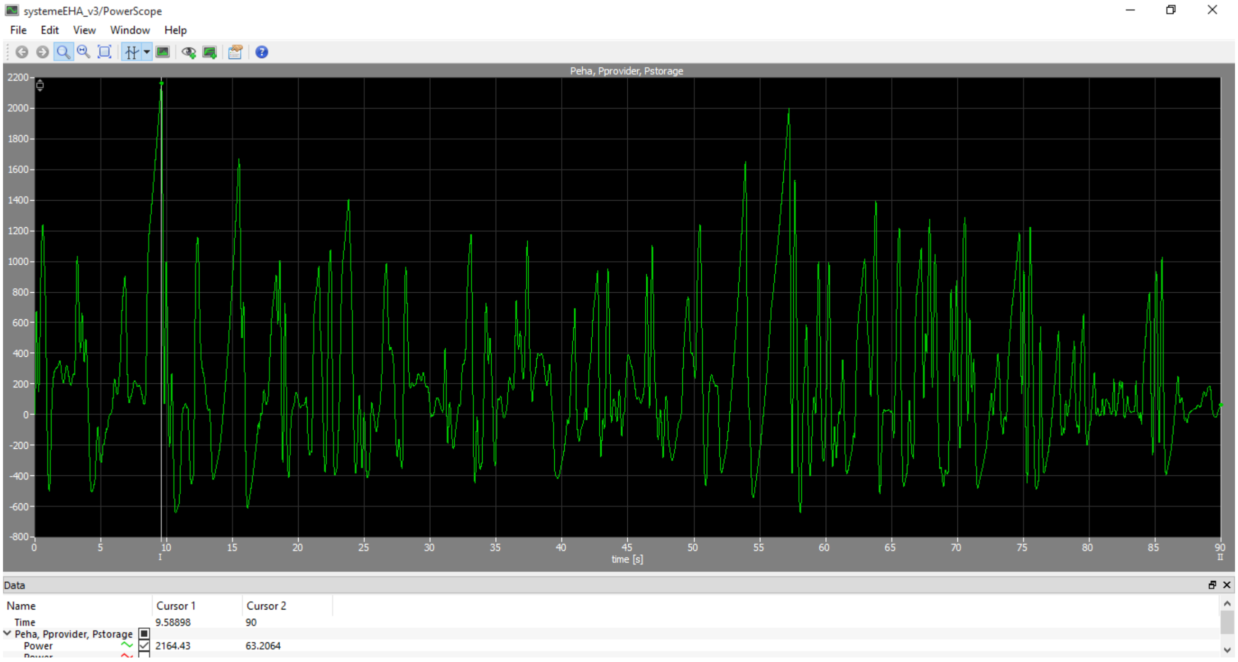
Next an evaluation of Hybridization potential is done. In case the system has to be hybridized: a corresponding storage component is added to the system. The storage component is designed using power-frequency sharing concept.

Lastly considering the new constraints on the fuel cell stack, a new fuel cell is designed and its new weight is evaluated.

2 Design of Fuel Cell Stack

The power mission profile to be generated using the fuel cells is as shown below, the maximum (peak) power observed is 2164W. The fuel cell stack shall be designed to provide a maximum power of 2200W.

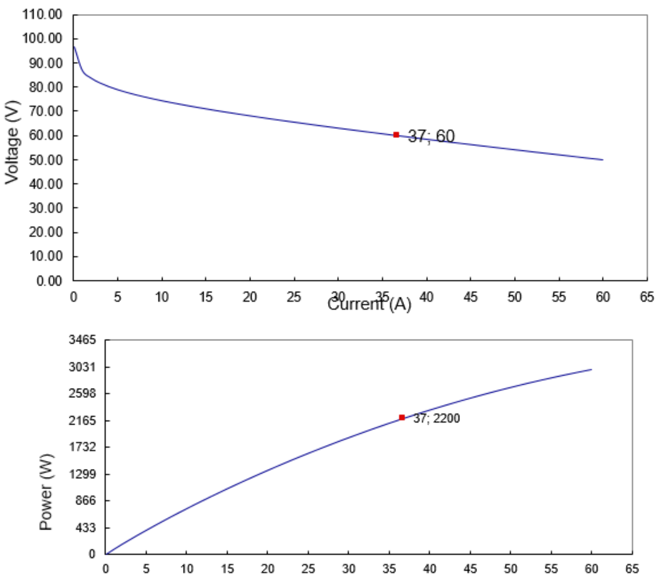
Pmax = 2200W



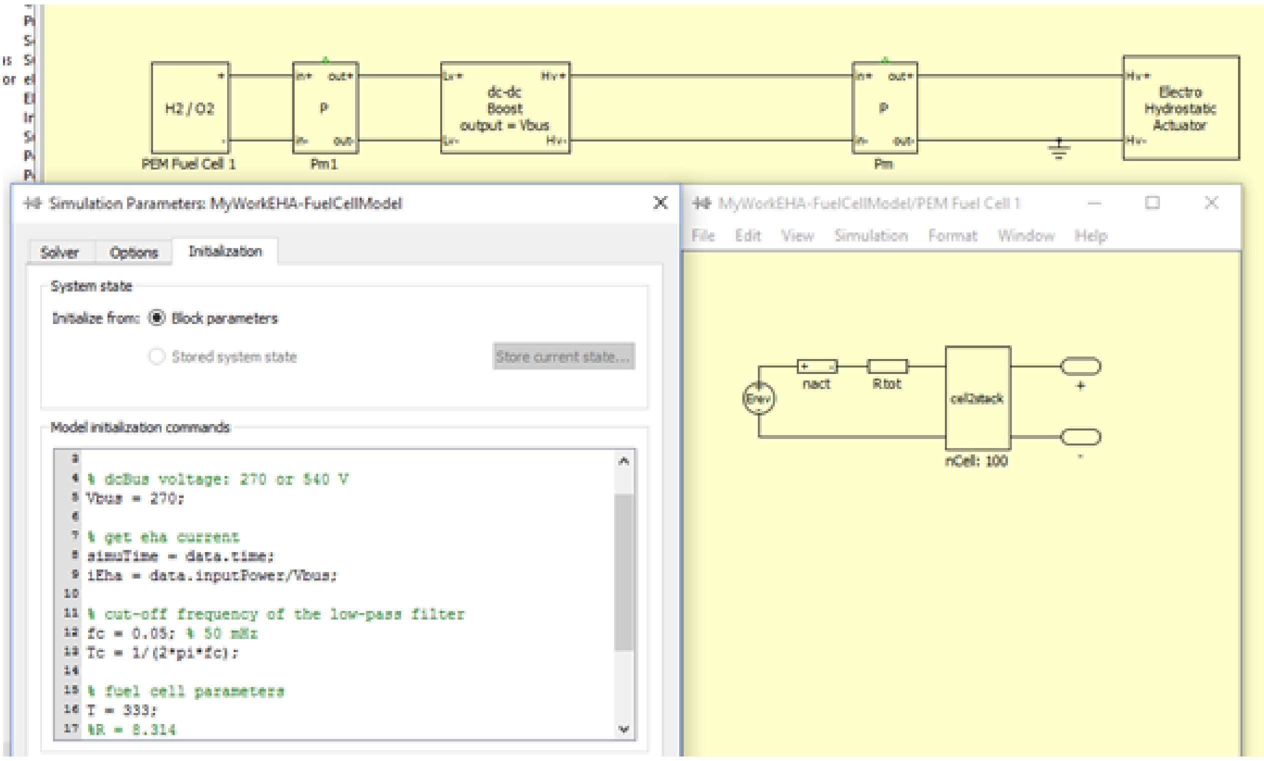
Using the excel sheet "*FuelCellDesign.xls*", the fuel cell stack parameters are designed - the required power for the EHA system and the surface area for each fuel cell is entered to get the apt values for the model.

Design from the output power and the output voltage

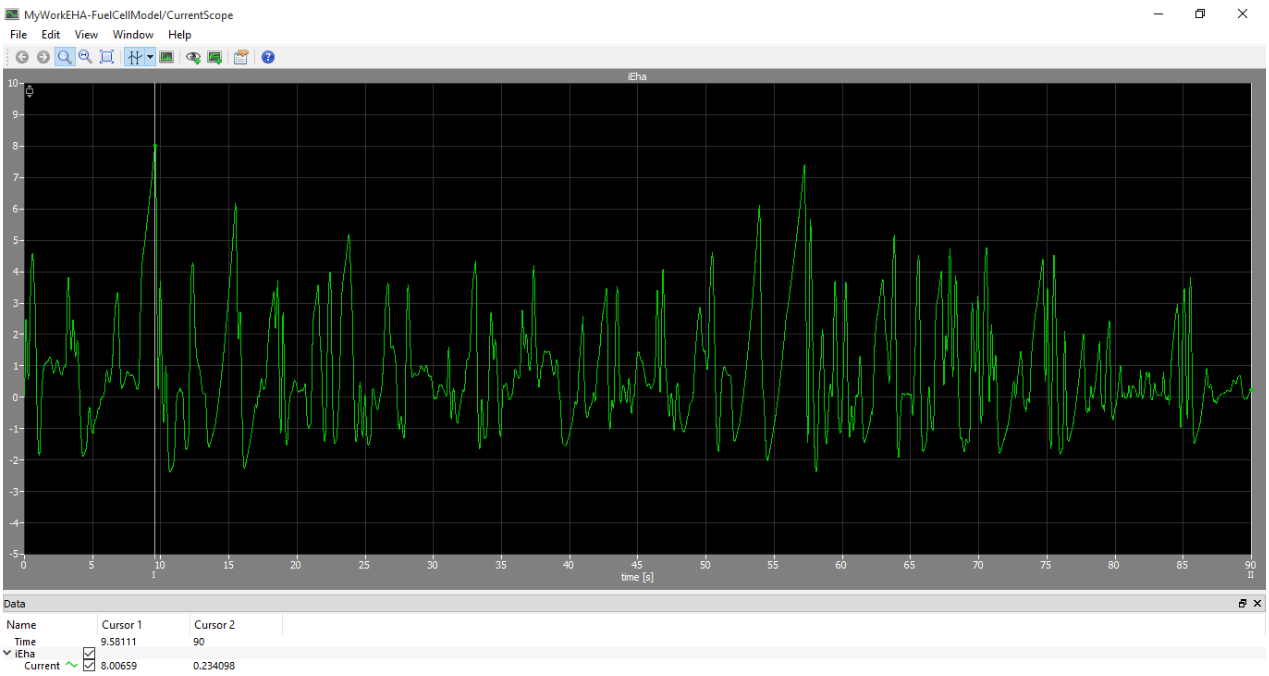
Input Data		
Stack power	2200	W
Cell number	100	cells
Stack number	1	
Cell voltage	0.6	V
Parameter		
active surface	**58**	**cm2**
Output data: electric characteristics		
Current	37	A
Current density	0.632	A/cm2
Stack voltage	60	V
Output data: model parameters		
Temperature	333.0	K
Transfer coefficient (alpha)	0.350	
Activation current density	3.0	µA/cm²
Activation current (Io)	174.0	µA
Rtot	0.0034	ohms
Fuel cell weight	***11.37***	***kg***
Hydrogen consumption	***62.707***	***moles***

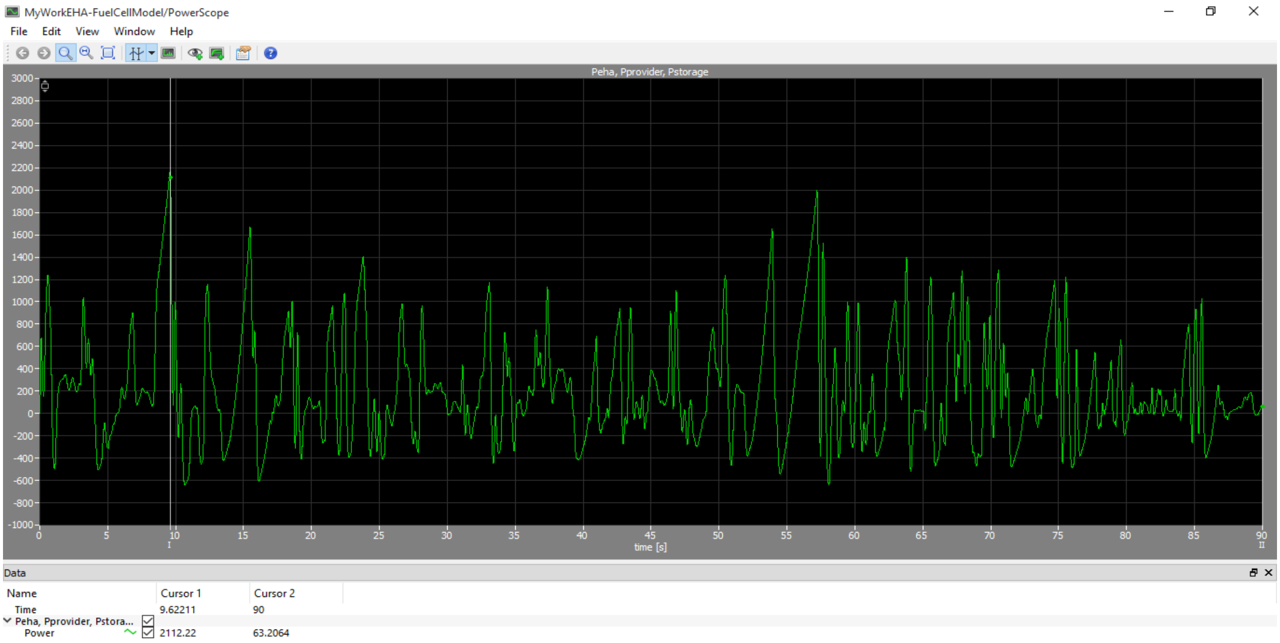


The weight of the fuel cell stack is around 11.37kg and the surface area of each fuel cell is designed to be 56cm2 to get maximum efficiency. The above parameters are used to design the fuel cell stack.



The achived Fuel Cell stack - Energy and Power profile are shome below:

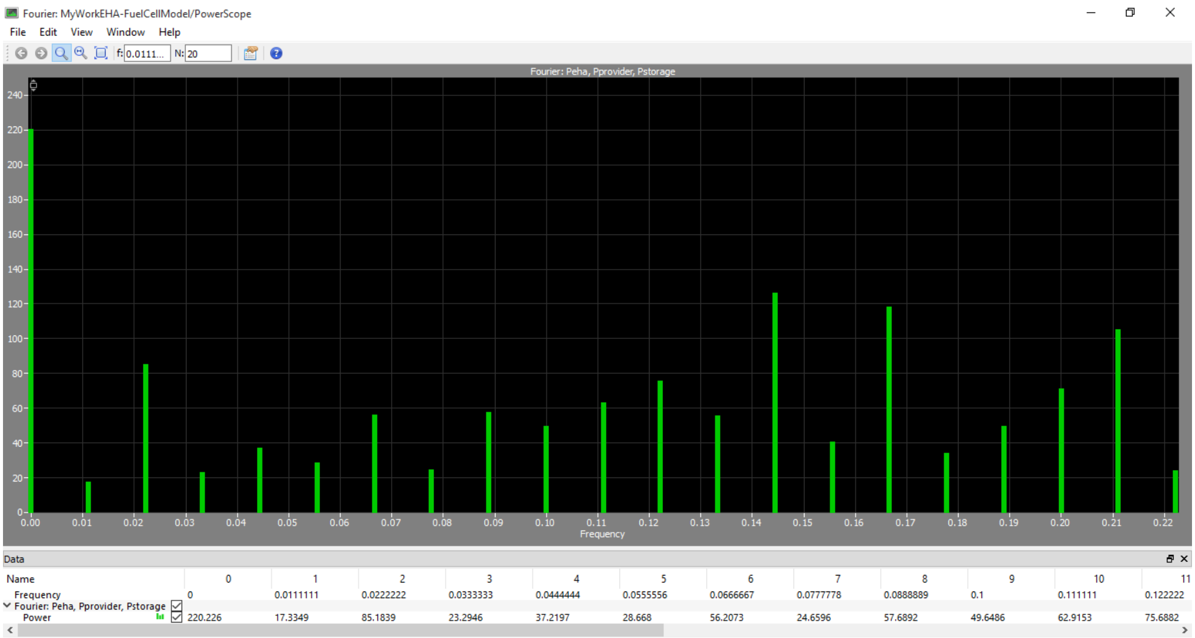




For improving the systems overall efficiency the system is checked for the necessity for Hybridization. By hybridizing the system we can optimize the component size and control various parameter (power management and current dissipation etc.). Additionally, the fuel cell stack power load can be stabilized in order to provide power at higher frequencies.

Obtain the average power of the system from the frequency graph (220.226W)

The average power is derived from Fourier Transform of the power profile (i.e. 220.226V).



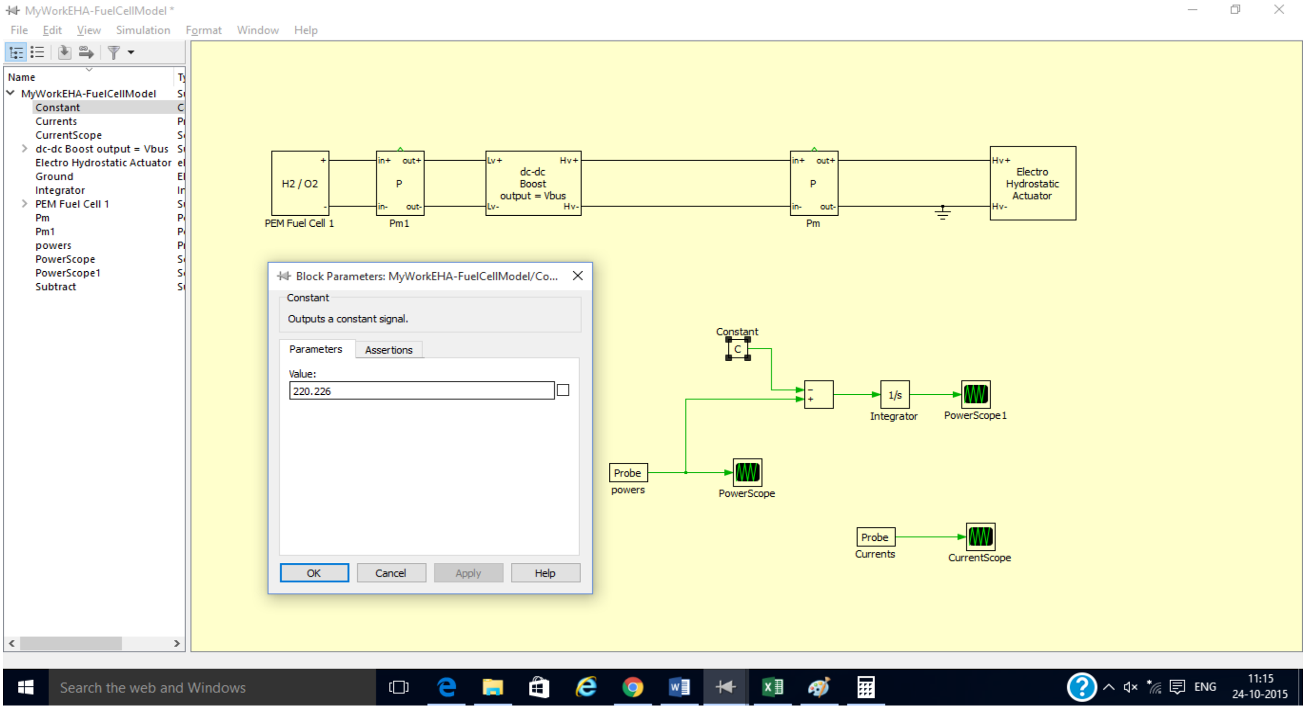
Power hybridization potential

Ratio between P_{avg} and P_{max}

$$PHP = 1 - \frac{P_{avg}}{P_{max}}$$

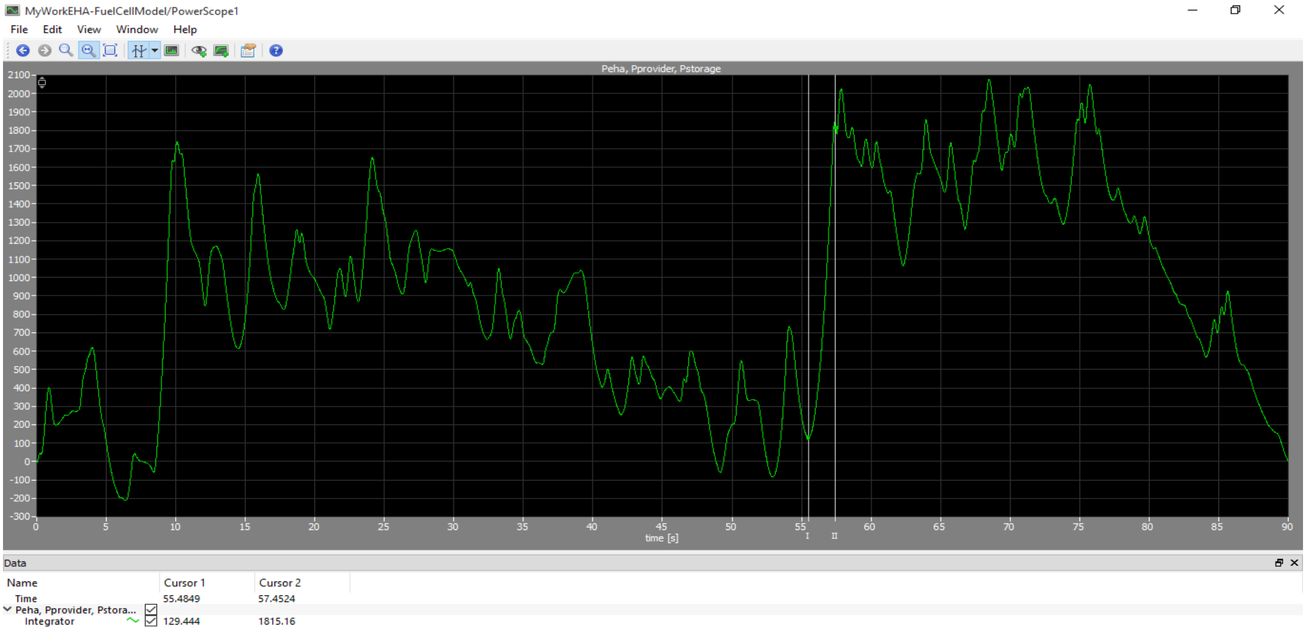
PHP = 1- (220.226 / 2164.81) = 0.8982700

Next an Energy Hybridization is determined by subtracting the maximum power and the average power, and integrating the result.



From the power profile that has been obtained below the maximum variation in the profile is measured.

Eu = 1.815 s-1 = 1.815 Hz



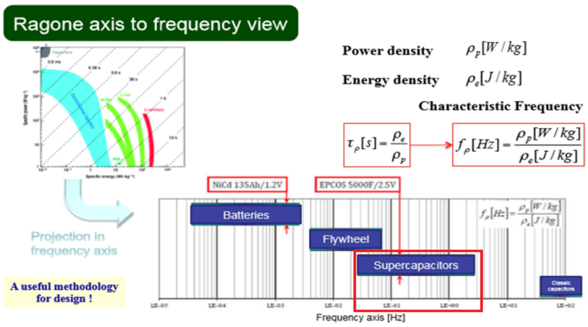
Energy hybridization potential

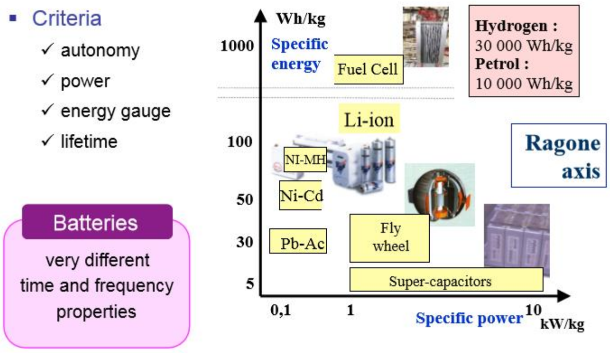
Ratio between P_{max} and E_u ≈ characteristic frequency

$$PHE = \frac{P_{max}}{E_u}$$

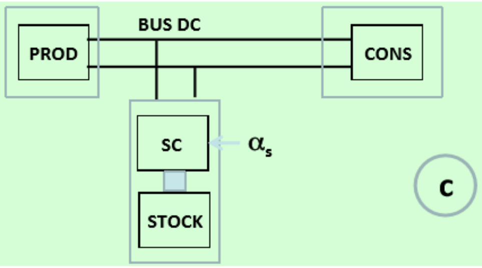
PHE = 2200 / 1.815 = 1.21 Hz

From the "*Ragone Axis to Frequency View*" at ≅1.0Hz Super capacitors may be used as the storage devices for hybridizing the system.





Now calculate the super capacitor value to integrate into the system.



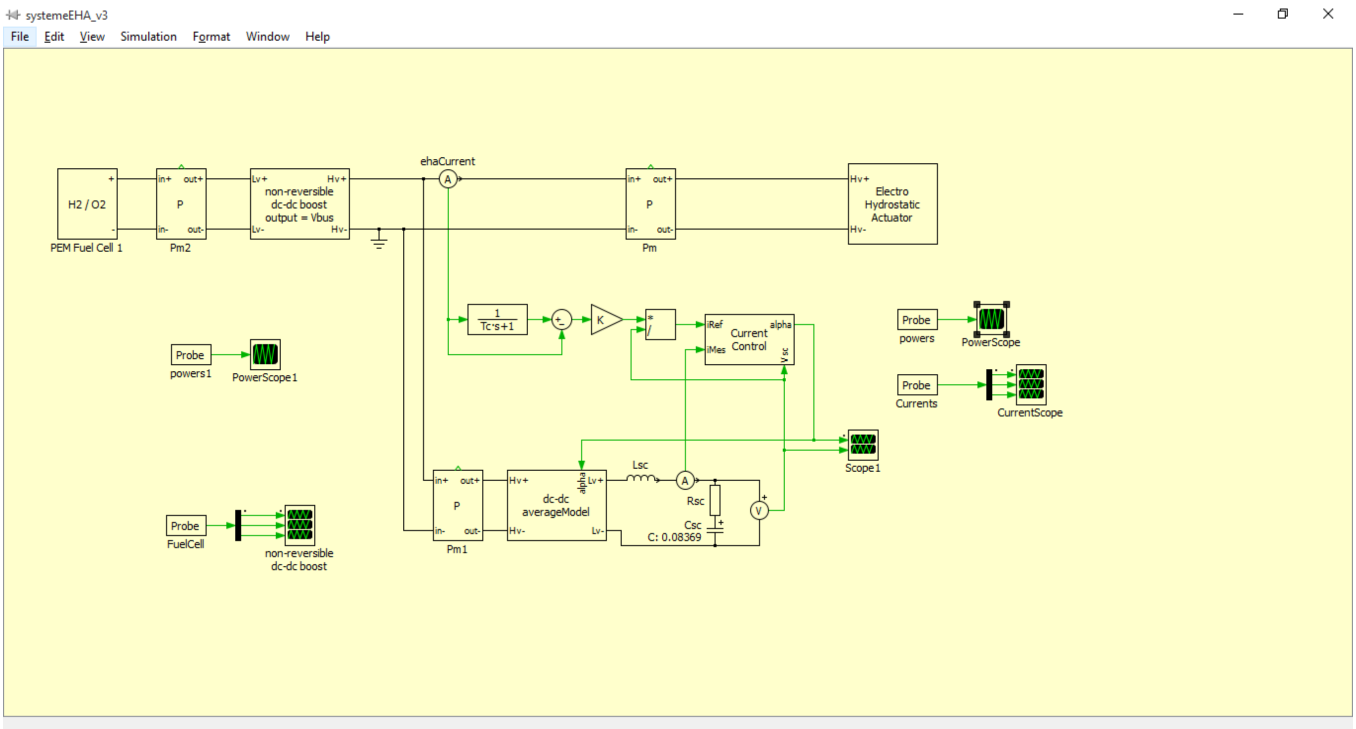
$$-E_{sc} = \frac{1}{2}C\left(V^2_{SC\max}\ \Delta V^2_{SC\min}\right)$$

Vsc = α. Vbus   0 ≤ α ≤ 1

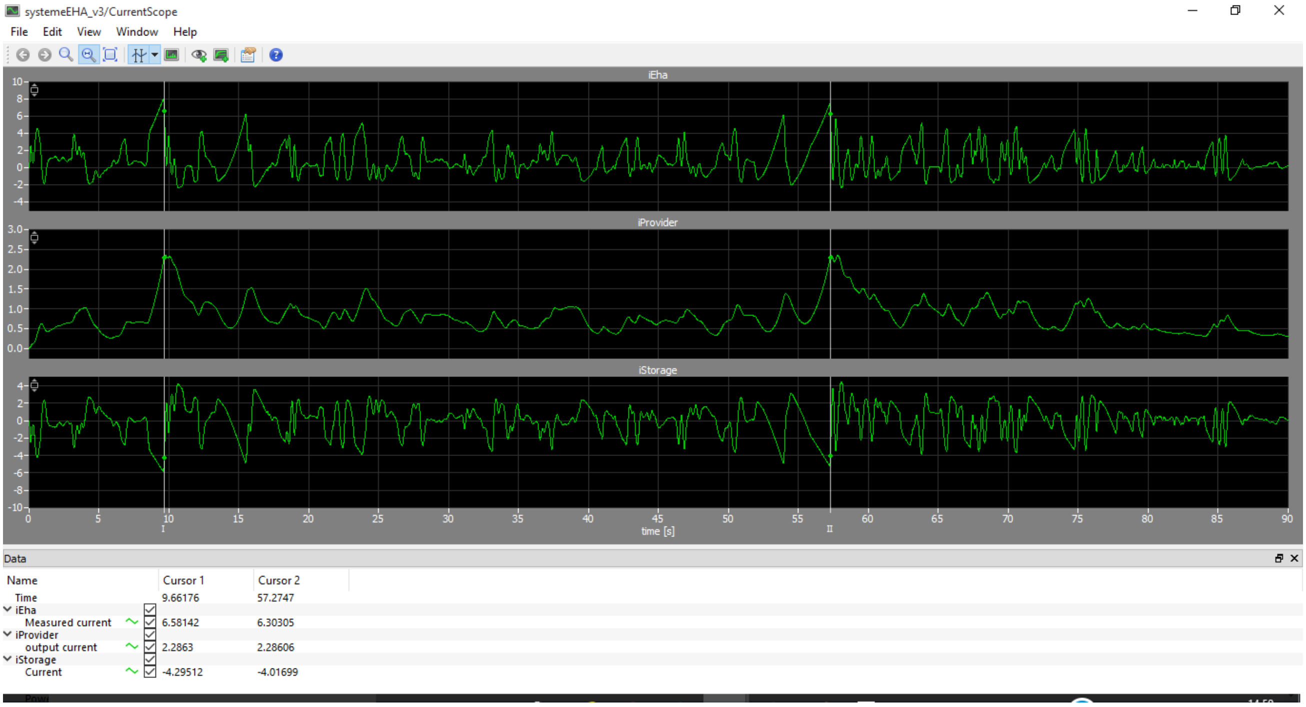
ΔESC = ½ (Vsc^2 – Vsc^2)

C = 0.08369 F

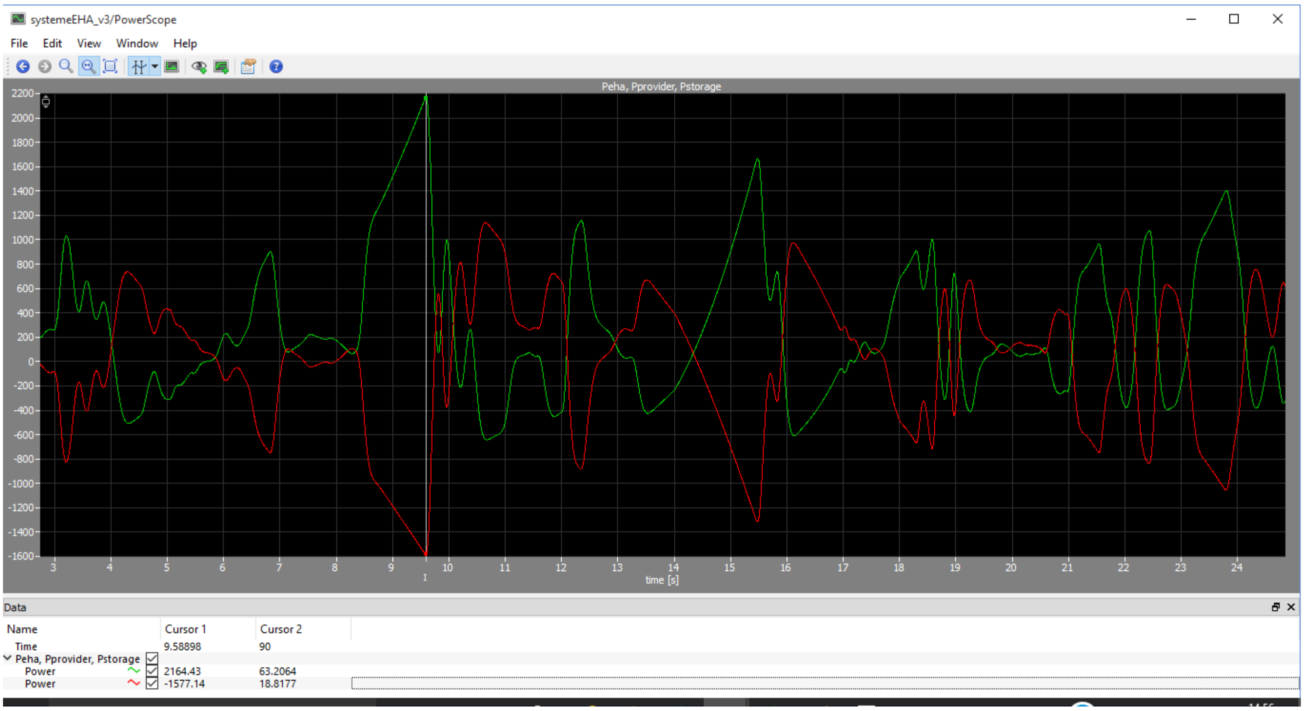
Finally integrate the Super Capacitor into the system.



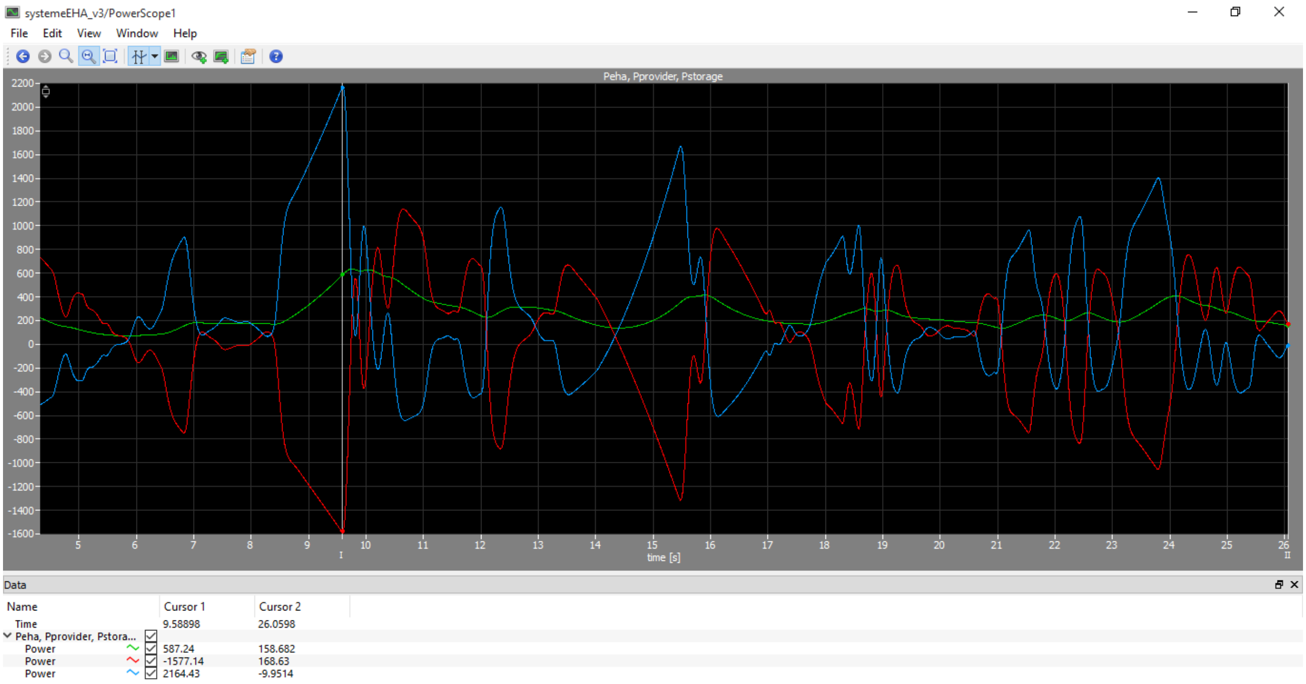
The final output for the engery, current and power profiles is as shown below:



The capacitor power vs the final mission power profile.

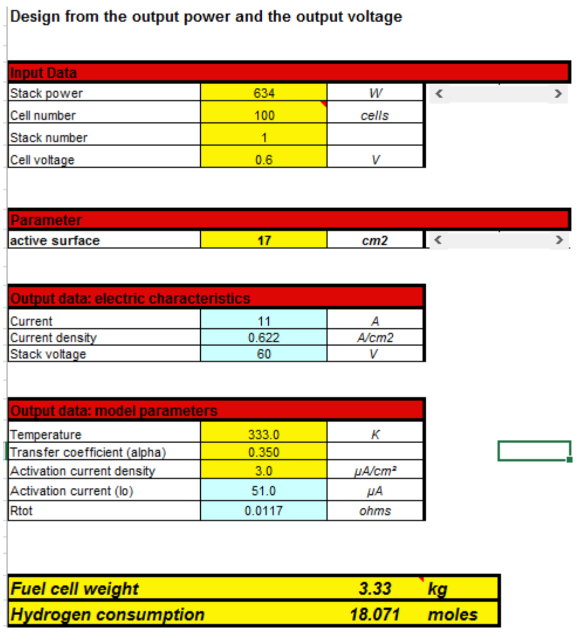


The comparison of the power generated from the fuel cell stack, the capacitor and the final power is as shown below.



From the above profile we can see that the maximum power has been generated using the fuel cell stack and super capacitor.

Now, the above profile was achieved by considering the maximum stack power as 2200W, but from the above graph we can see the power generated by the fuel cell stack is about 634W and the rest of the power is compensated by the super capacitor, hence now the new fuel cell stack can be established to reduce the weight of the fuel cell stack.



Design from the output power and the output voltage

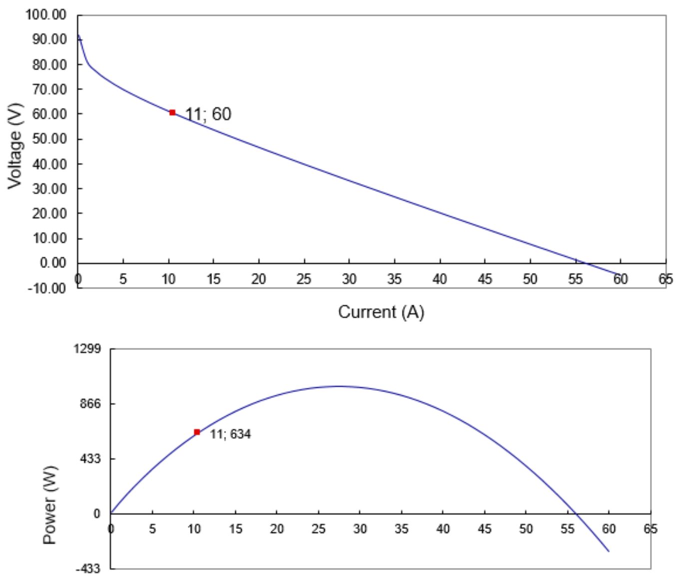
Input Data		
Stack power	634	W
Cell number	100	cells
Stack number	1	
Cell voltage	0.6	V

Parameter		
active surface	17	cm2

Output data: electric characteristics		
Current	11	A
Current density	0.622	A/cm2
Stack voltage	60	V

Output data: model parameters		
Temperature	333.0	K
Transfer coefficient (alpha)	0.350	
Activation current density	3.0	µA/cm²
Activation current (Io)	51.0	µA
Rtot	0.0117	ohms

Fuel cell weight	*3.33*	*kg*
Hydrogen consumption	*18.071*	*moles*



The Fuel cell weight has been reduced to 3.3 kgs.

3 Conclusion

From the above lab we observe that fuel cell stack can be used for generating power at high frequencies. In case only fuel cell stack are used, the weight of the system is considerably high which is not desirable. To reduce the weight of the system and to increase the efficiency of the system by bringing-in stability in the power that is generated at high frequencies, the system is hybridized. This is done by adding an appropriate storage device into the circuit.

It is also observed that the weight of new hybridized fuel cell stack system that was designed was reduced over 70%.

If the weight and packaging constraints are taken into account, the optimizing techniques yield lesser weight, higher frequency output and controlled power load management.

Hence the objective of the system that was to obtain overall efficiency, the hybridised system is shown to be more efficient in comparison to the non-hybridised system.

The drawback of using hybridised fuel cell stack system is the initial cost of the system is very high at the expense of higher efficiency and lesser weight.