Concepts on PEM Fuel Cell

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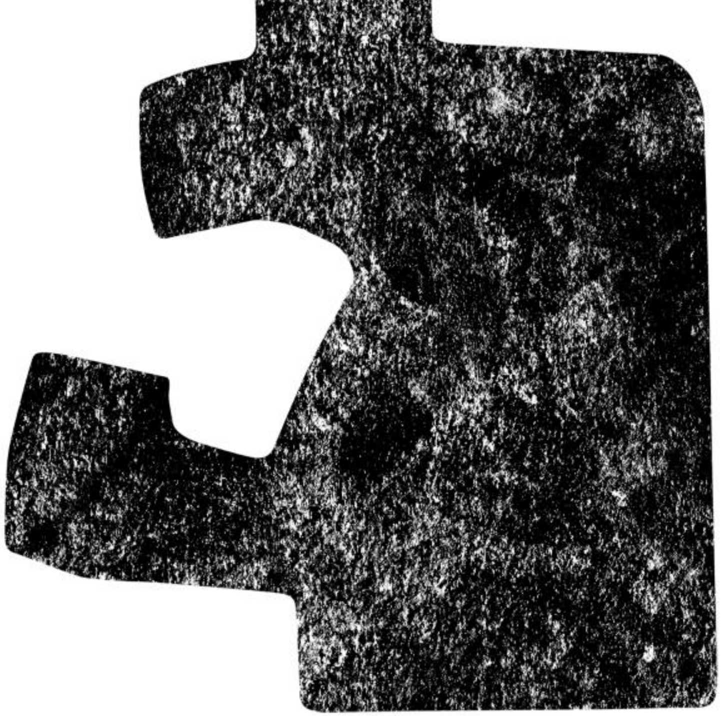

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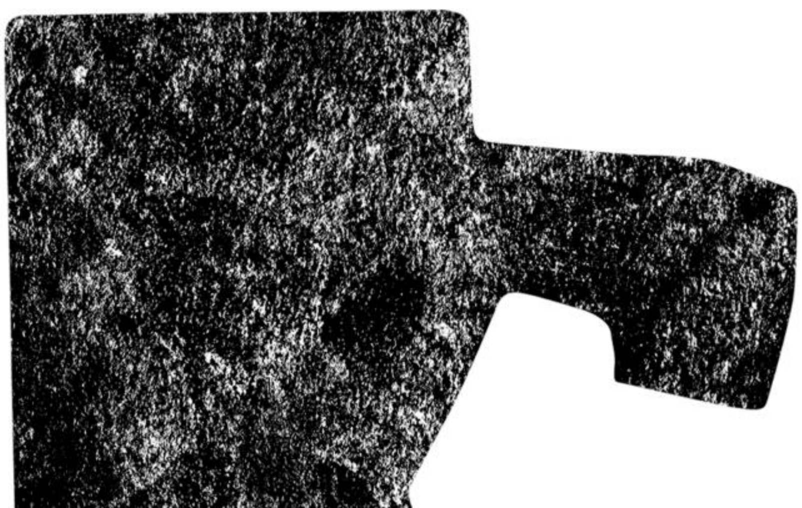
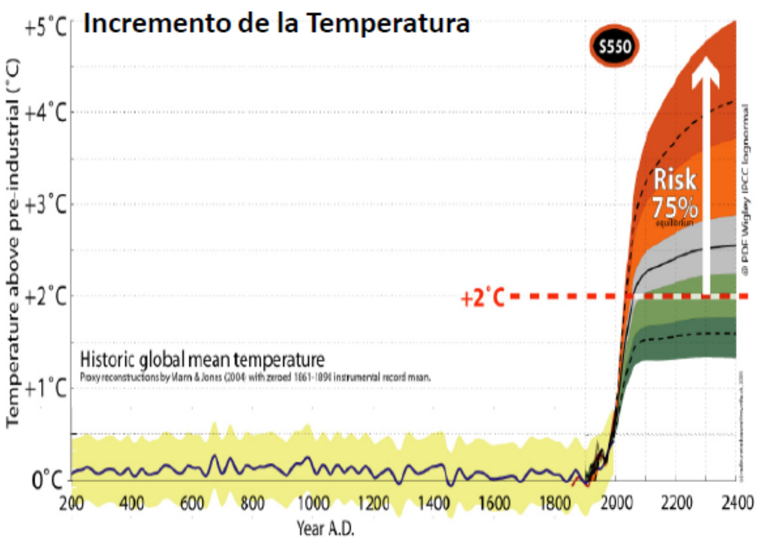


PEM Fuel Cell

BASIC CONCEPTS

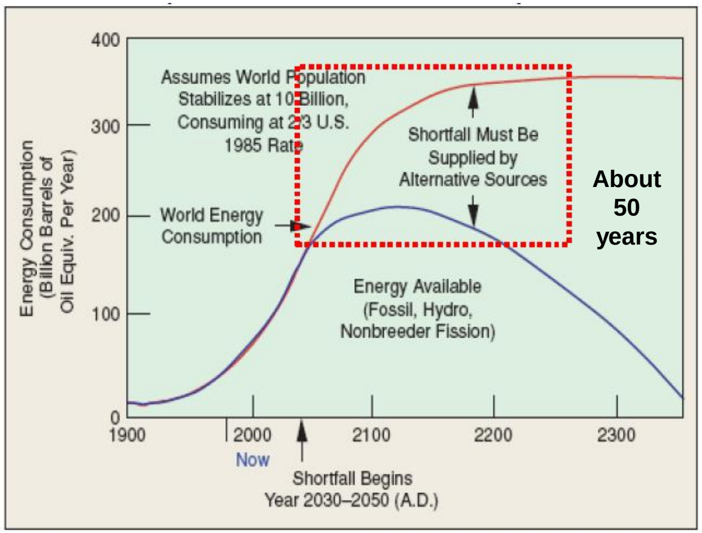
Introduction | Global warming



Last Decades
- We have to use fossil fuel to obtain electricity

Problem
- Greenhouse effect gases grow up
- Global warming

Solution
- Find new energy sources to obtain the electricity
- One solution using Fuel Cell.



Last years
- The electricity demand is growing up

Problem
- Energy Available is not enough for the demand

Solution
- Growing down the consumption
- New energy sources

- Advantages:
  - It Don’t produce CO2
  - Efficiency around 60 %
  - It Don’t produce contaminants

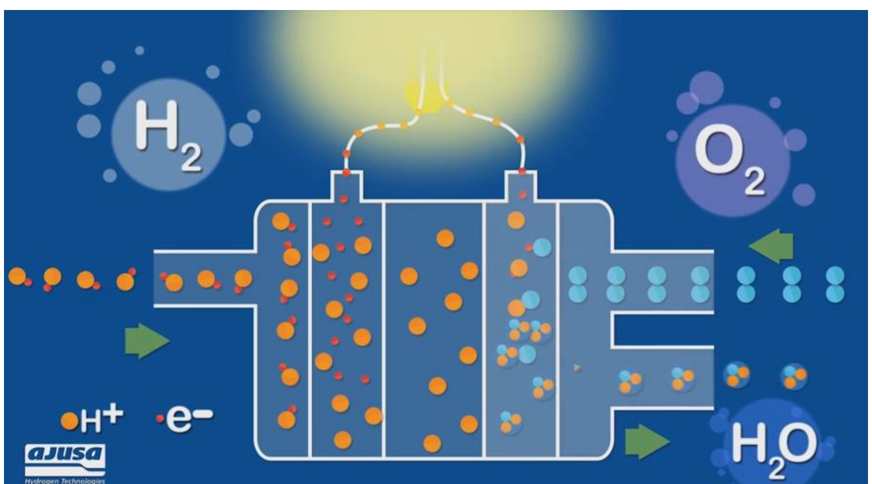
- Disadvantages:
  - Normally hydrogen extract from fossil fuels.
  - It is really expensive to obtain hydrogen from water
  - Problems to conserve in a tank -> Can blow up

Introducción | How it Works

Aim idea
- Chemical reaction

Reactants
- Fuel -> Hydrogen
- Oxygen

Products
- Electricity
- Water
- Heat



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Introducción | History

1801
Humphry Davy demonstrates the principle of what became fuel cells.

1839
William Grove invents the 'gas battery', the first fuel cell.

1889
Charles Langer and Ludwig Mond develop Grove's invention and name the fuel cell.

1950s
General Electric invents the proton exchange membrane fuel cell.

1959
Francis Bacon demonstrates a 5 kW alkaline fuel cell.

1960s
NASA first uses fuel cells in space missions.

1970s
The oil crisis prompts the development of alternative energy technologies including PAFC.

1980s
US Navy uses fuel cells in submarines.

1990s
Large stationary fuel cells are developed for commercial and industrial locations.

2007
Fuel cells begin to be sold commercially as APU and for stationary backup power.

2008
Honda begins leasing the FCX Clarity fuel cell electric vehicle.

2009
Residential fuel cell micro-CHP units become commercially available in Japan. Also thousands of portable fuel cell battery chargers are sold.

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Introduction | Production Cars

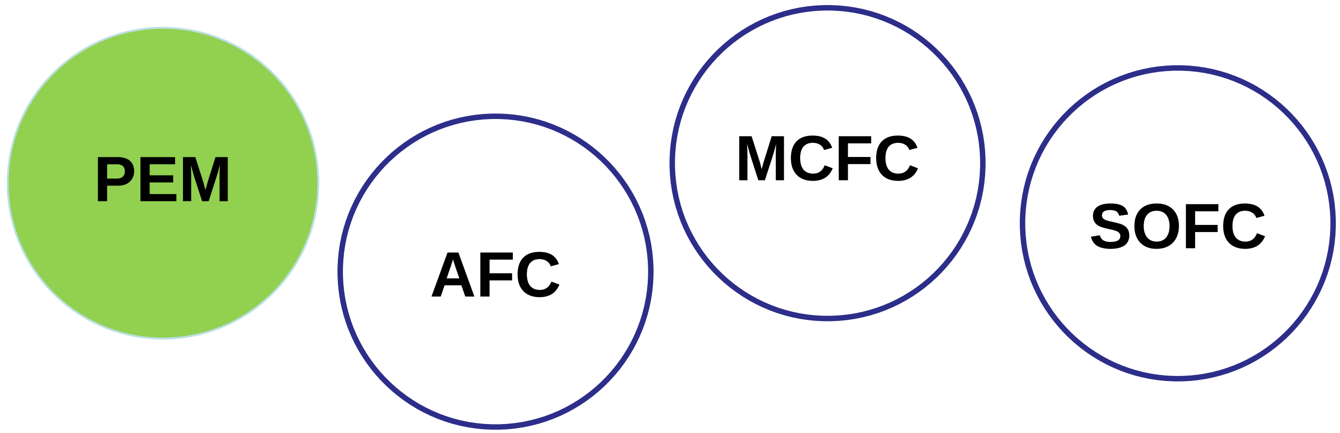
Introducción | Hydrogen

Hydrogen can be produced using a variety of resources including biomass, hydro, wind, solar, geothermal, nuclear, coal with carbon sequestration, and natural gas. This diversity of sources makes hydrogen a promising energy carrier and enables hydrogen production almost anywhere in the world.

- 95 % of hydrogen is produced from fossil fuel.
  - Natural Gas and Oil.
- To obtain hydrogen it is necessary to separate CH_4 (methane)

- Obtain Hydrogen from fossil fuels
- The reaction is in 2 parts:
  - Steam methane
    - $CH_4 + H_2O$ (+ heat) $\rightarrow CO + 3H_2$
  - Water –gas shift reaction
    - $CO + H_2O \rightarrow CO_2 + H_2$ (+ small amount of heat)

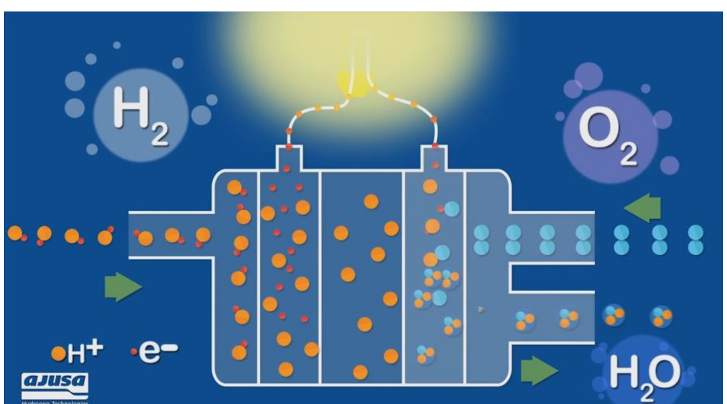
Introducción | Fuel Cell types



PEM -> Protonic Exchange Membrane
AFC -> Alkaline Fuel Cell
MCFC -> Molten Carbonate Fuel Cell
SOFC -> Solid Oxide Fuel Cell

Basic Concepts

- **Advantages:**
  - **Use in mobile applications.**
  - **High electricity power in a small size and weight.**
  - **Low heating.**

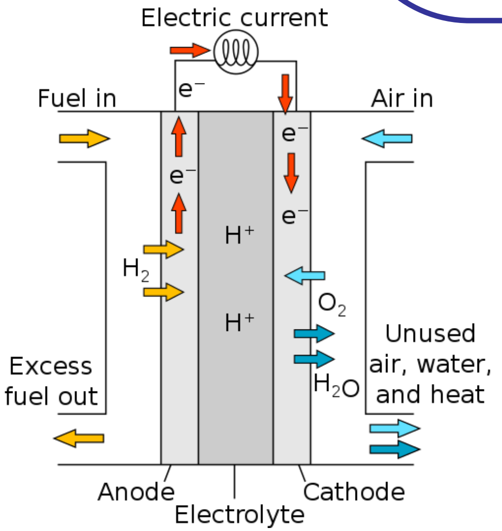


- **Disadvantages:**
  - **The membrane is really complicate to make and to control**

1. Operator
2. FC-42/HLC fuel cell stack
3. Stack holder
4. Controller
5. Power Supply Unit

Basic Concepts

- **Characteristics:**
  - **Working temperature: 50-80ºC**
  - **2 electrodes**
    - **Negative and Positive**
  - **Electrolyte**
    - **Polymer Membrane**
    - **Divide the Anode and Cathode**
    - **Humidity constant value**



1. Air inlet
2. Coolant outlet
3. Hydrogen inlet
4. Hydrogen outlet
5. Coolant inlet
6. Air outlet

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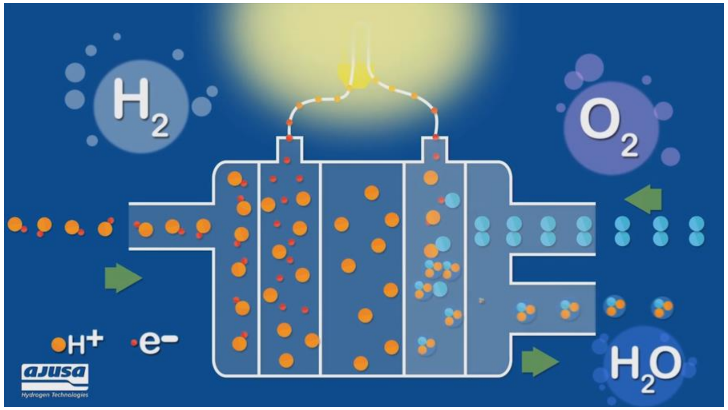
Basic Concepts

- **Characteristics:**
  - **High protonic conductivity, water transport, gas permeability, mechanical resistance and dimensional stability.**
  - **Maintain chemical stability.**
  - **Made of copolymer of tetrafluoroethylene and several sulfonated perfluoro monomers**



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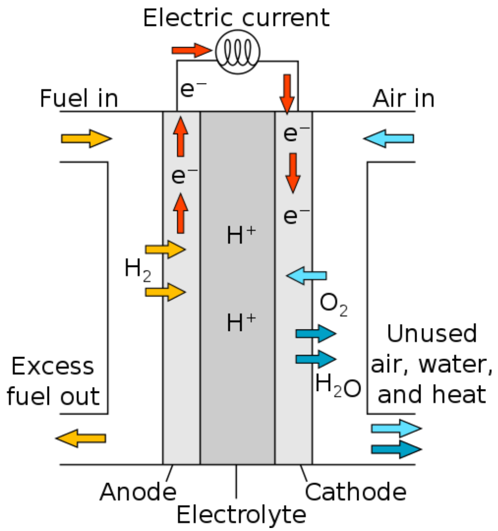
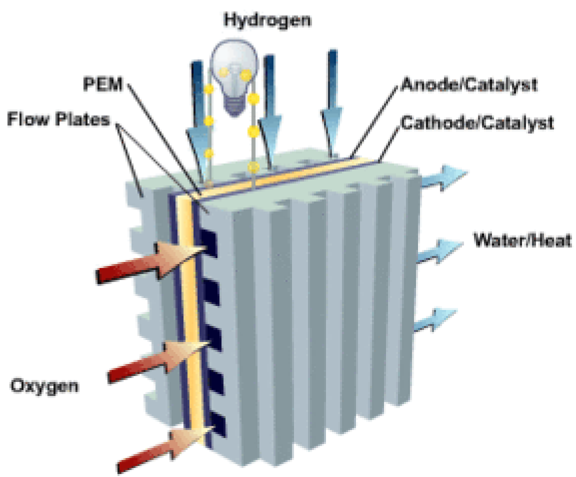
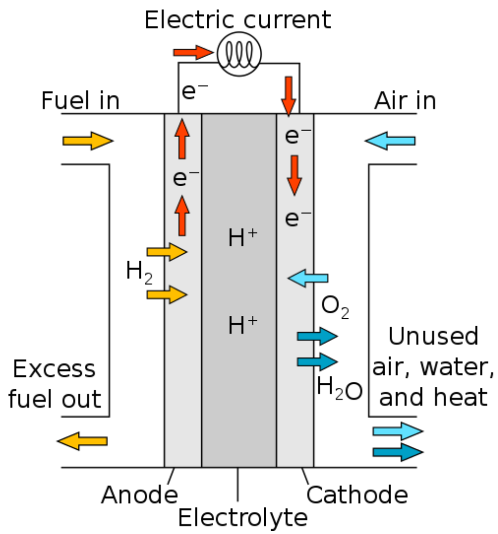
- **Electrodes are catalytic layers, locate between the membrane.**
- **The electrochemical reaction take place here.**
  - **The gases gives the electrodes and protons, which react in electrodes surfaces**
- **Use Platinum catalyst to make reaction**



Basic Concepts

- **Chemical Reactions**
  - **Anode** $H_2 \rightarrow 2H^+ + 2e^-$
  - **Cathode** $\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O$





Basic Concepts

- Oxygen:
  - Supplied by compressor.
    - It takes form the ambient and compress specifically for the PEM
- Hydrogen:
  - PEM use high-purity hydrogen supply.
    - 99.99 % (No traces of CO)
  - It storage in a proper pressure for PEM.

- Water:
  - Necessary to control ionic conductivity on the membrane.
  - So need a pipe to remove the exceeded water.
- Heat:
  - Using coolant to extract.

Basic Concepts | Summary

- **Fuel Cell system generate electricity making chemical reaction.**
- **It is a clean reaction, which no produce contaminants.**
- **The reactants are Hydrogen and Oxygen.**
- **The products are electricity, water and heat.**
- **PEM Fell Cell it is build by specific membrane.**
- **Those membranes have to be in a constant humidity.**

1. Operator
2. FC-42/HLC fuel cell stack
3. Stack holder
4. Controller
5. Power Supply Unit

1. Air inlet
2. Coolant outlet
3. Hydrogen inlet
4. Hydrogen outlet
5. Coolant inlet
6. Air outlet

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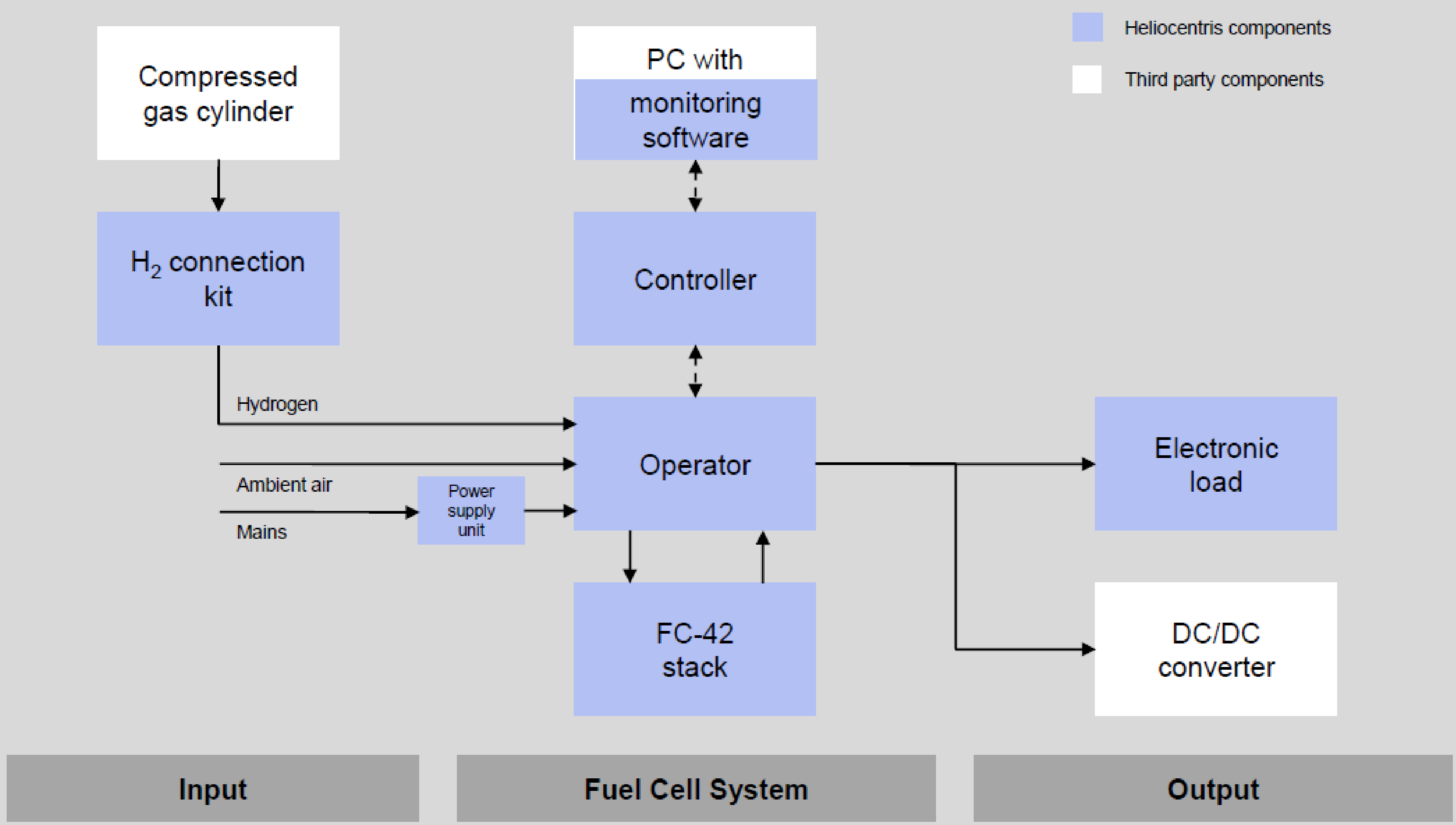
Basic Concepts | Summary



PEM Fuel Cell

CONTROL SYSTEM

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Achieve and objectives

PEM

- Control the Fuel cell to follow 2 references
  - Max Power and Max efficiency.

Problem

- We need a device to connect in the PEM, which change the resistance.

Solution

- We are going to use DC-DC
- This DC-DC is going to be control.

Control our System

- The electricity that we obtain is in DC mode.
- Depend on the resistance that we connect fuel cell Works different.
  - High Resistance -> High Consumption.
- We cannot manipulate PEM basic control.
  - It could be dangerous if we modify the membrane humidity control.
- It is necessary another device to control Fuel Cell reference.
  - We use DC/DC converter.

Control our System

- **Different types:**
  - **DC/DC boost**
  - **DC/DC buck**
  - **DC/DC buck-boost**

- **Boost**
  - **Output voltage higher than Input voltage**

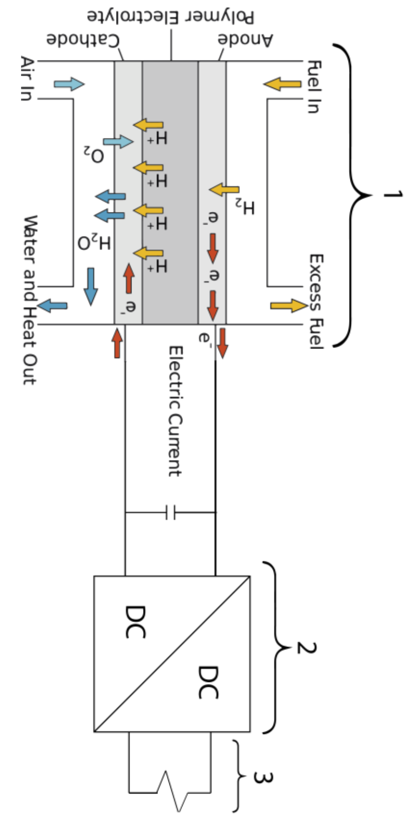
- **Buck**
  - **Output voltage lower than Input voltage**

- **Buck-boost**
  - **Output Voltage can be higher or lower, it depends on duty cycle**

Control our System | DC/DC converter boost

- **Characteristic:**
  - **Power control systems**
  - **Depends on their components to control de Power**
  - **It is locate between the resistance and the PEM**

- **How it Works:**
  - **We manipulate the transistor switching cycles**
  - **For that we use PWM signal**



1 - Pila de combustible PEM
2 - Convertidor DC-DC boost
3 - Carga resistiva

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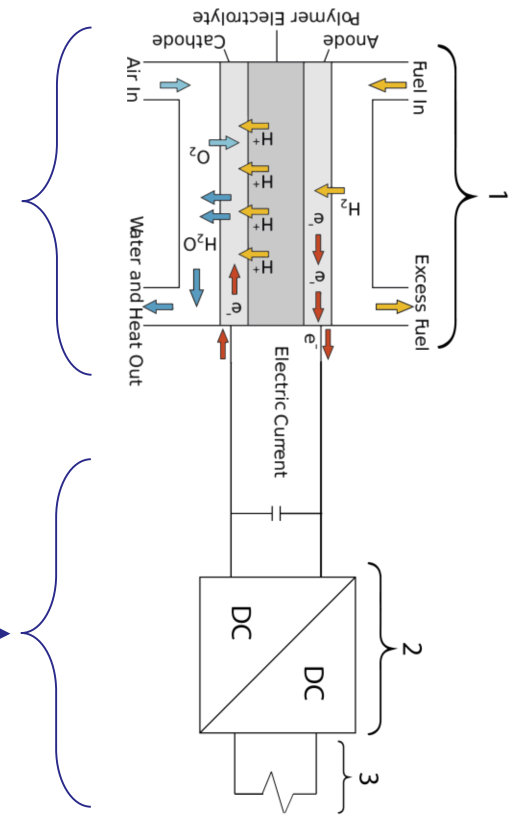
Control our System | DC/DC converter boost

- **Black box**

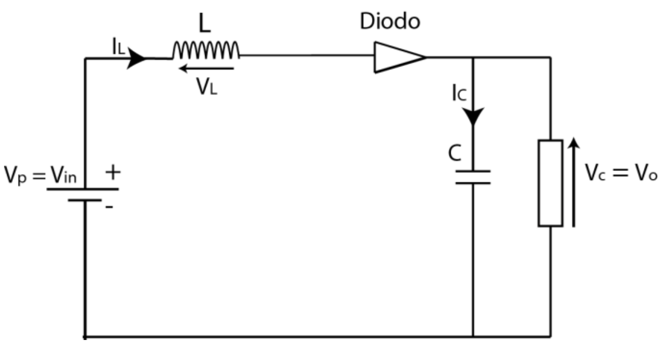
- **Control unit**

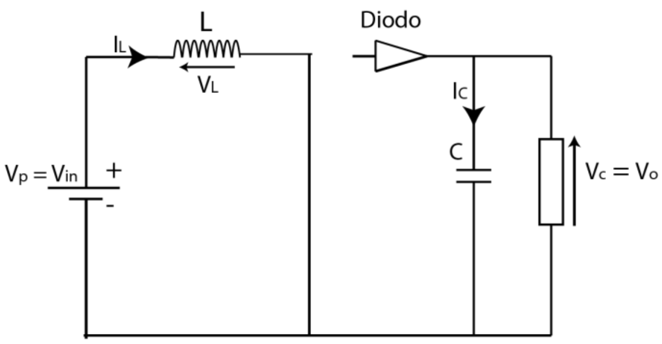


1 - Pila de combustible PEM
2 - Convertidor DC-DC boost
3 - Carga resistiva

Control our System

- **Electric model for the control**
- **U takes 0 or 1 value.**
  - **Depends on the switch state**

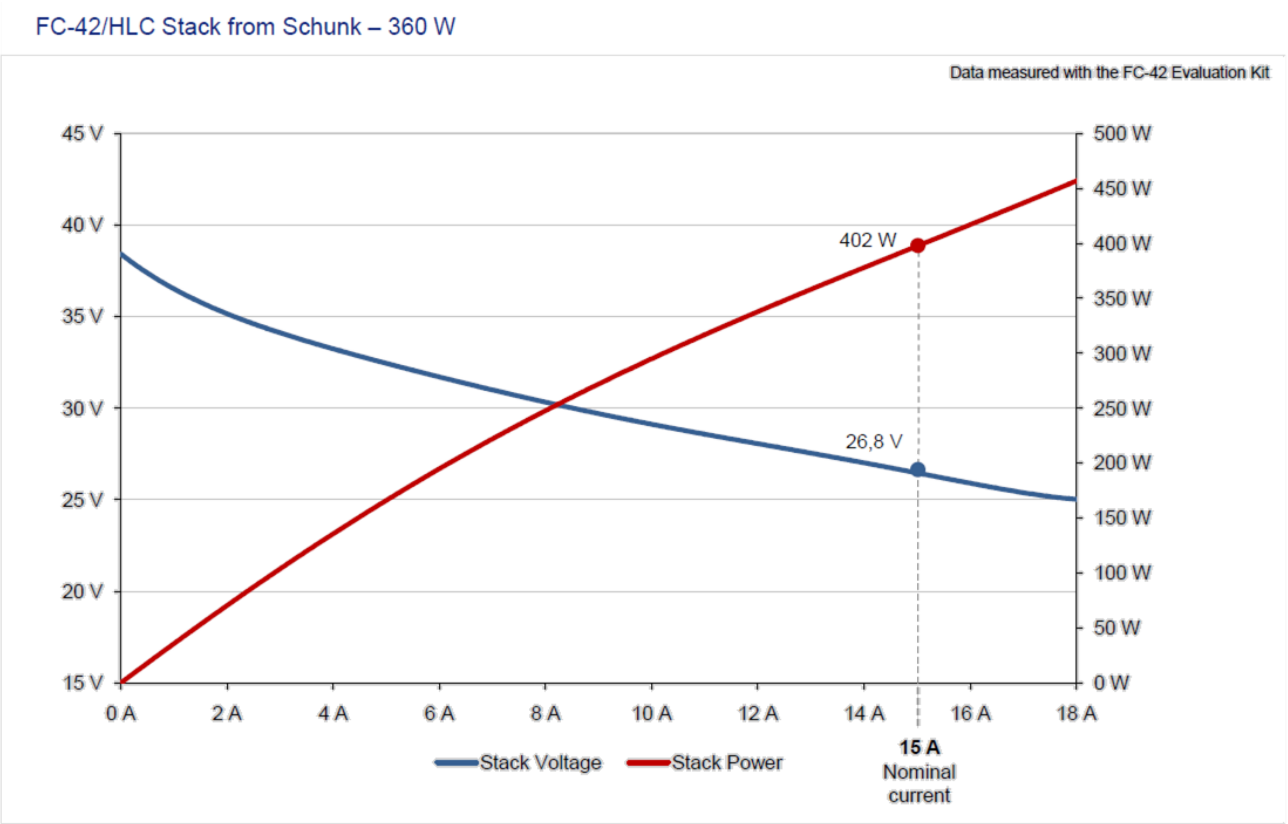




$$\begin{bmatrix} \frac{di_p}{dt} \\ \frac{dv_c}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & -\frac{1}{RC} \end{bmatrix} \begin{bmatrix} I_p \\ V_c \end{bmatrix} + \begin{bmatrix} -\frac{V_c}{L} \\ \frac{I_p}{C} \end{bmatrix} u + \begin{bmatrix} -\frac{V_p}{L} \\ 0 \end{bmatrix}$$

Control our System

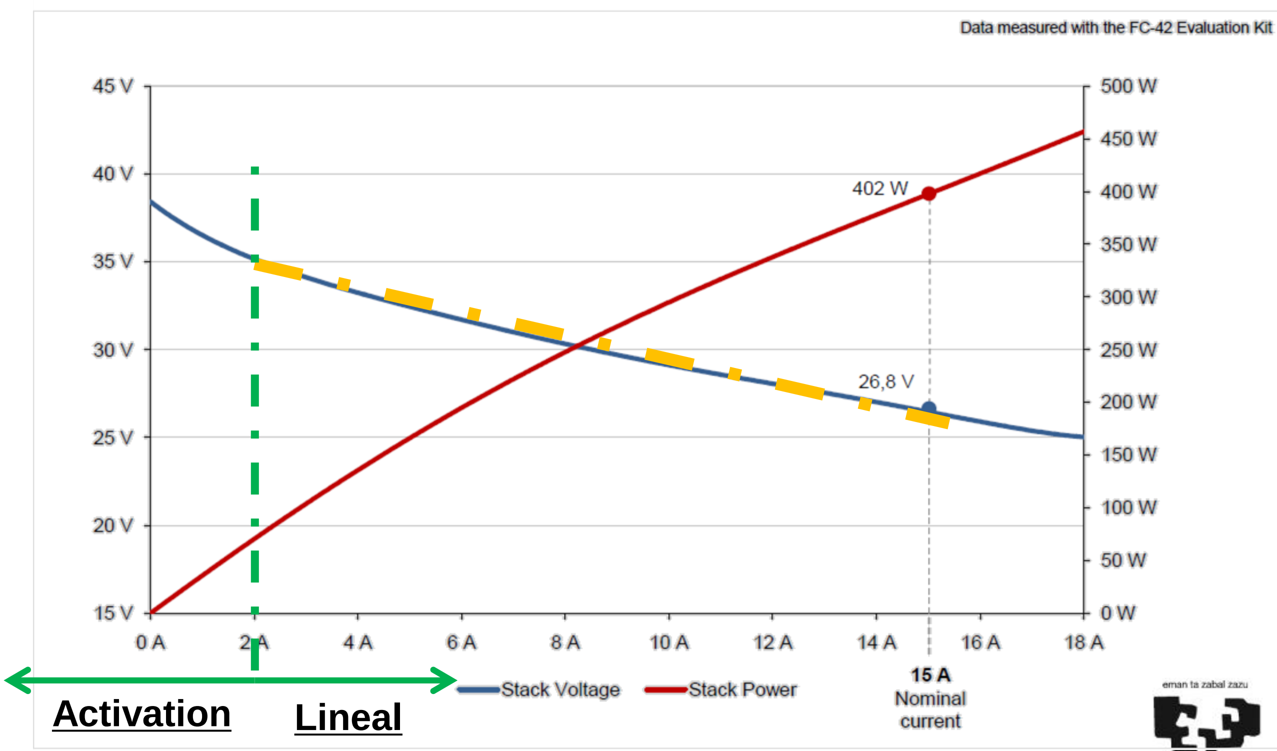
- Two references to obtain.
- We have to check PEM characteristics
  - The max power -> Nominal current
  - No information about max efficiency.



Control our System

- To identify the max efficiency point, it is necessary to locate 2 zones in the graphics.
  - Activation and Lineal zone

FC-42/HLC Stack from Schunk – 360 W



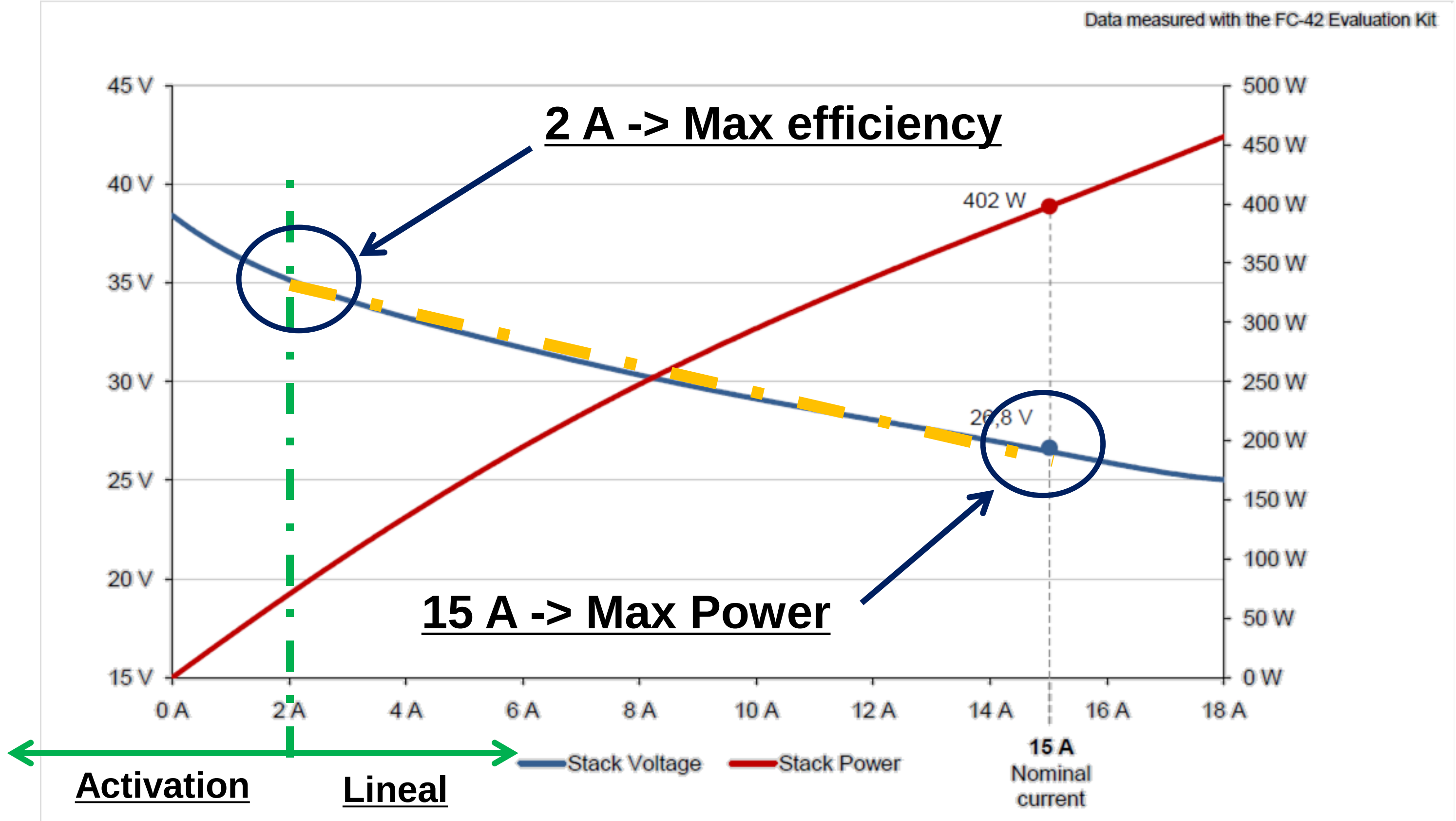
Control our System

- Activation Zone:
  - The consumption is high. The system need more fuel to start to operate
  - There is a voltage lose.
- Lineal Zone
  - The best zone to operate.
  - First point is max efficiency
  - Last point is max power

- Those references are theoretical.
- Not enough sensors to identify exactly those points.
  - It is not possible to make an algorithm, which secure the references.

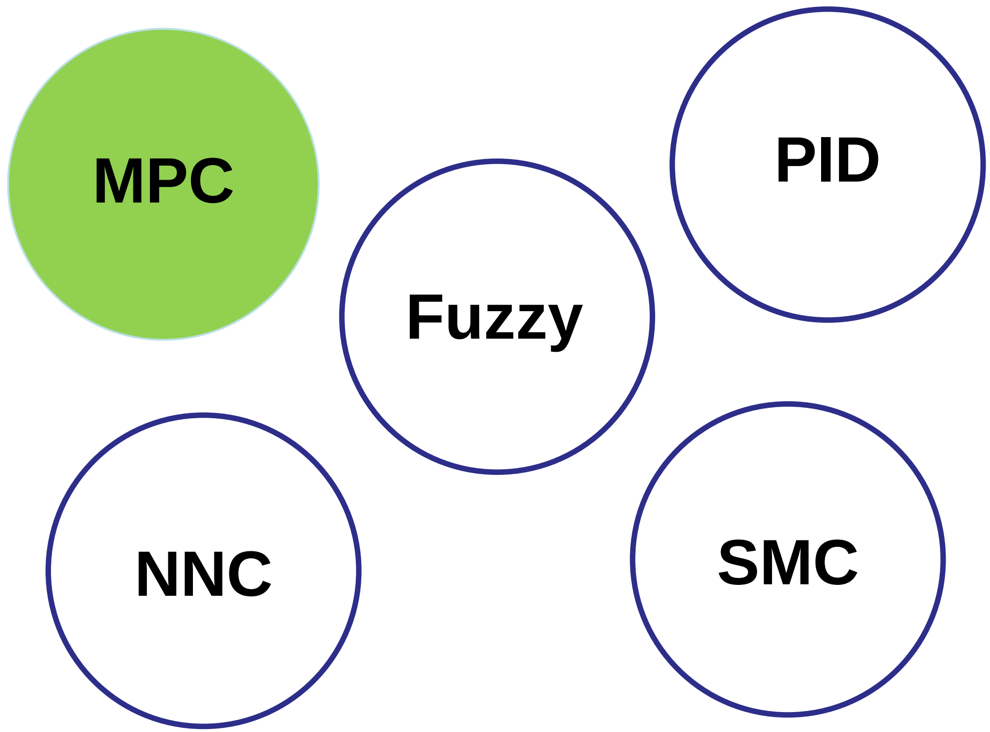
Control our System

FC-42/HLC Stack from Schunk – 360 W



Controller

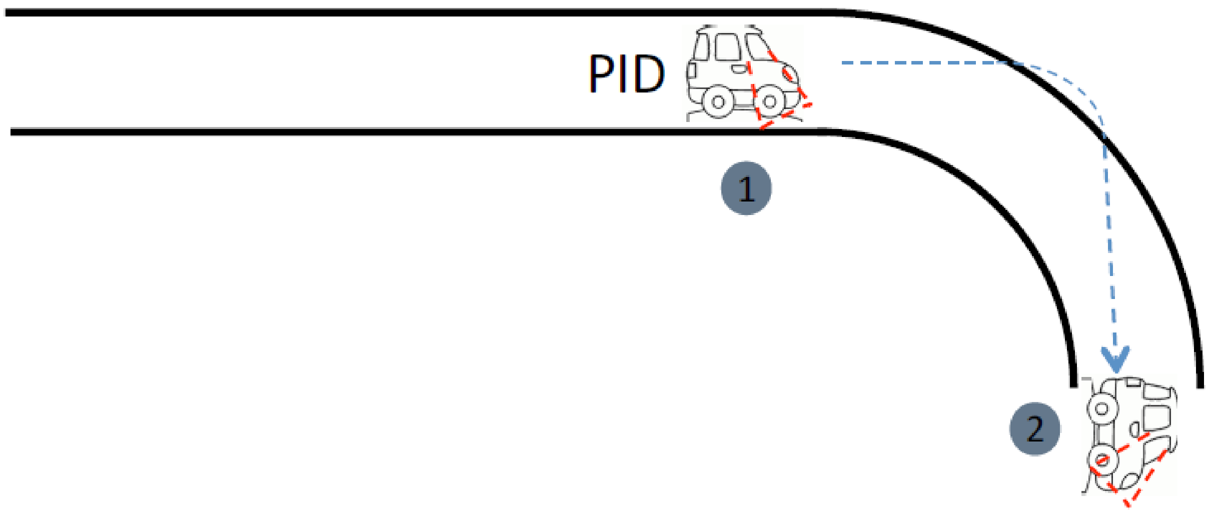
Time to choose a controller



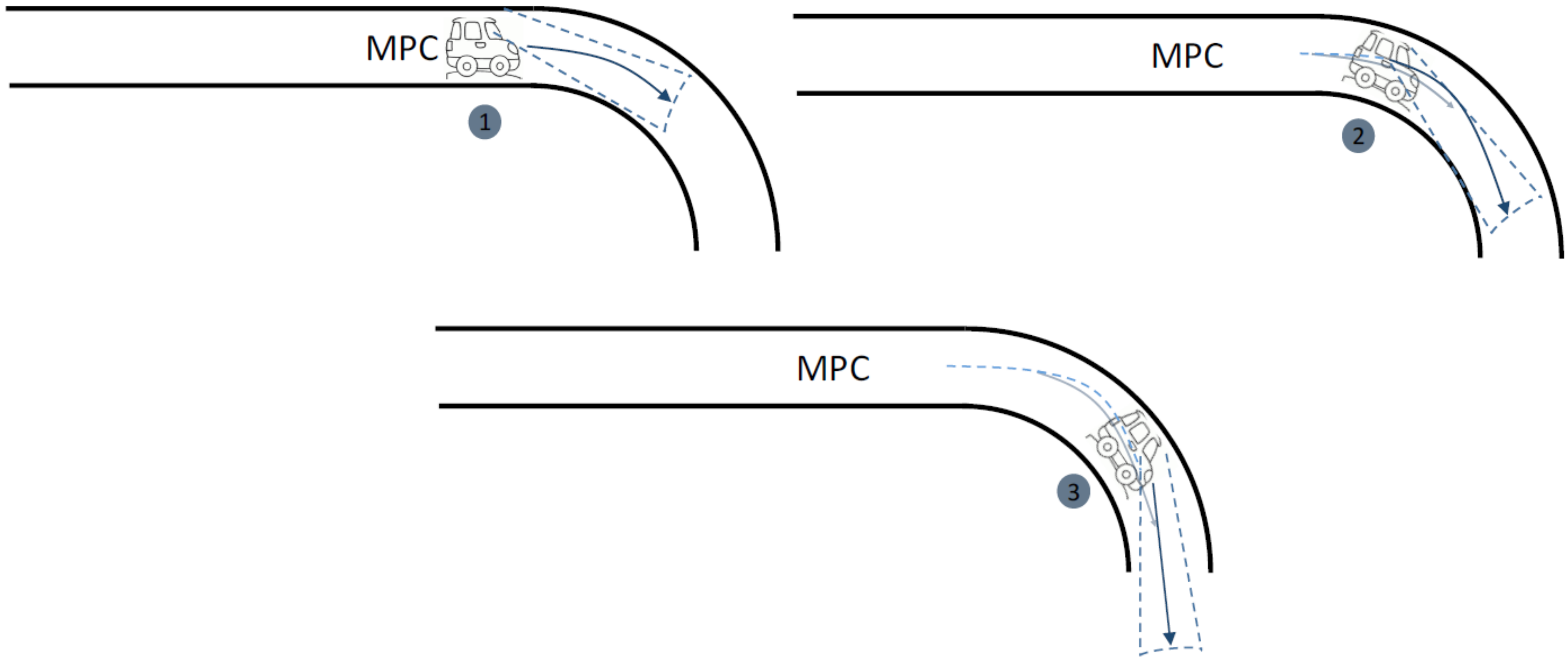
- MPC -> Model Predictive Control
- It use a Mathematical Model to predict the best control action.
- You can only apply on Discrete Time
- It is need to define the horizon.

- **Compare with PID**

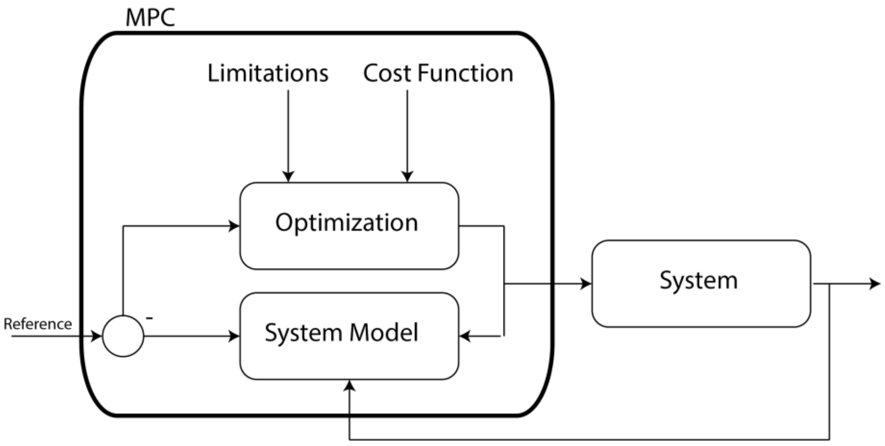
$$u = K_p \left(1 + \int \frac{1}{T_i} e(t)\, dt + T_d \frac{de(t)}{dt}\right)$$



- **Compare with PID**



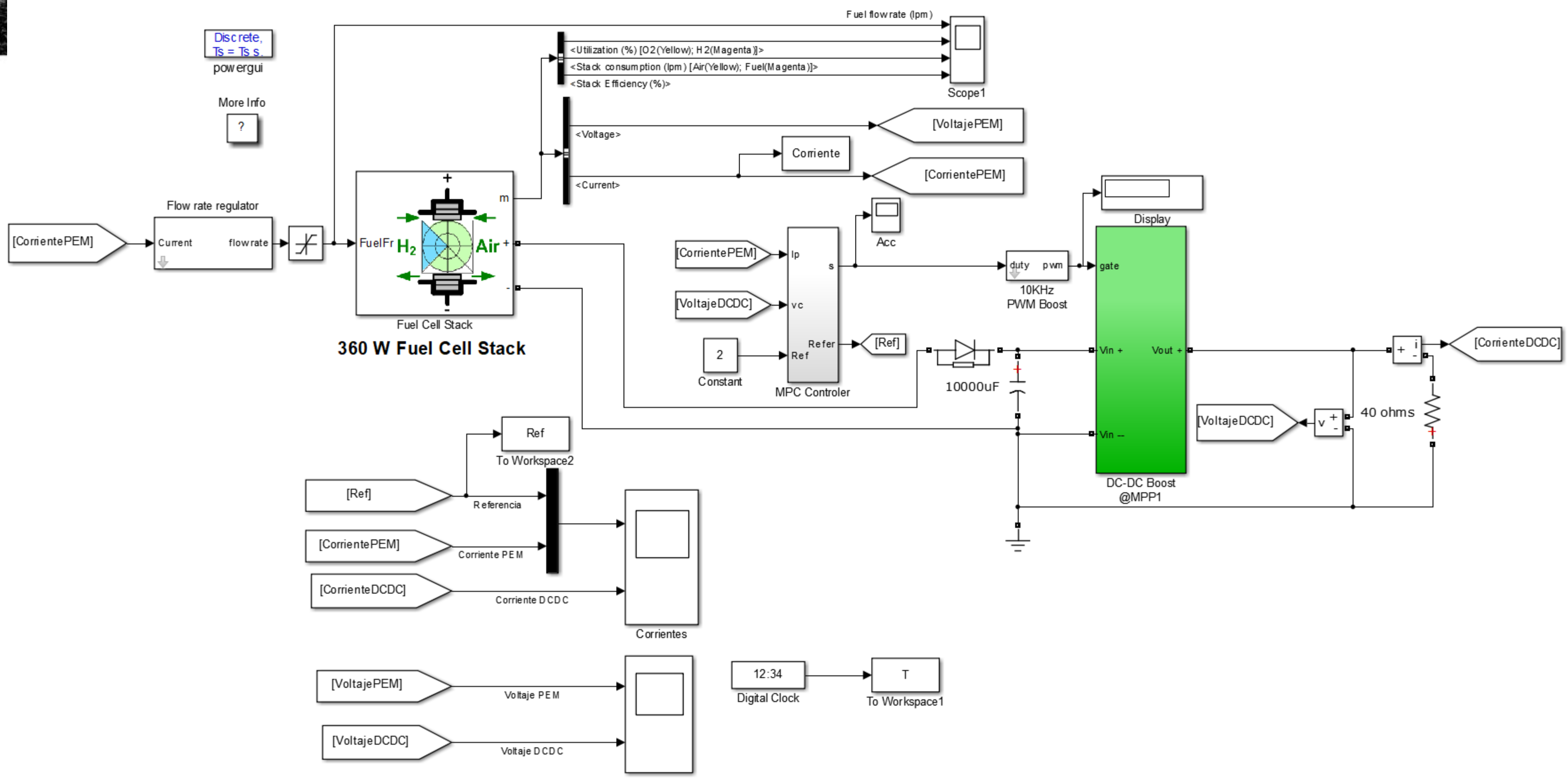
- It analyze what is going to happen in the future to select best action.
- It use a Cost function.
    - It minimize the error between the reference and response



- **Advantages:**
  - **It can optimize the cost and quality**
  - **You can control a Multi variable system**
  - **You can consider de limitation of the actuators**

- **Disadvantages:**
  - **Using cost function, the computational cost is to high.**
  - **You need the mathematical model**

Controller Test | MatLab Simulink



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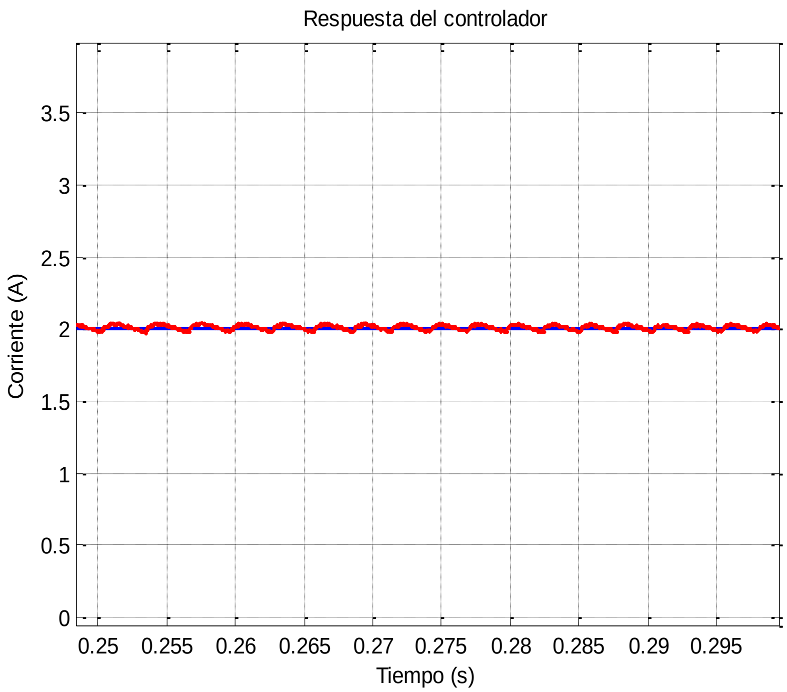
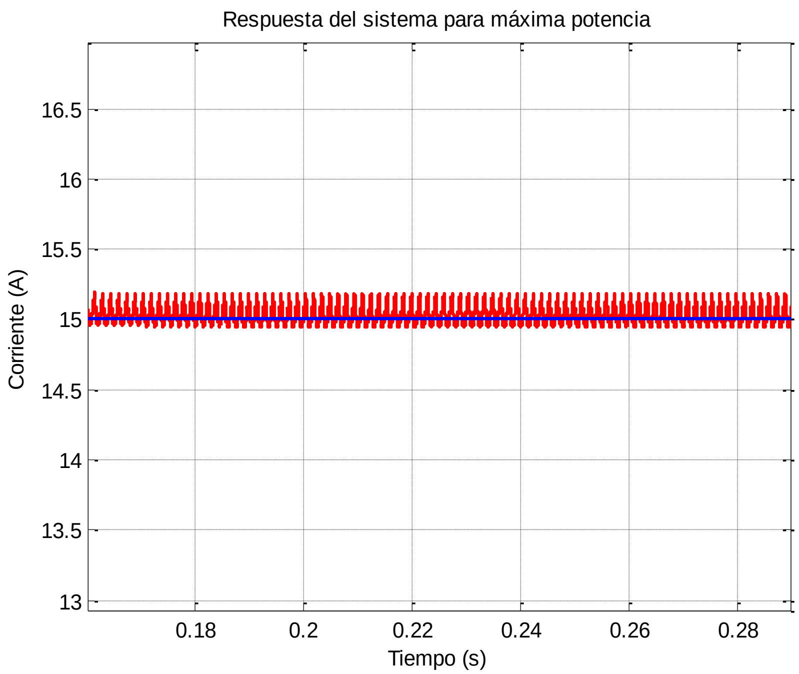
Controller Test | MatLab Simulink

- **Our system slide around the reference**





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Implement our Controller

First Step	• Understand how it works dSPACE platform.
Second Step	• Test Fuel Cell system.
Third Step	• Test the controller.

Implement our Controller

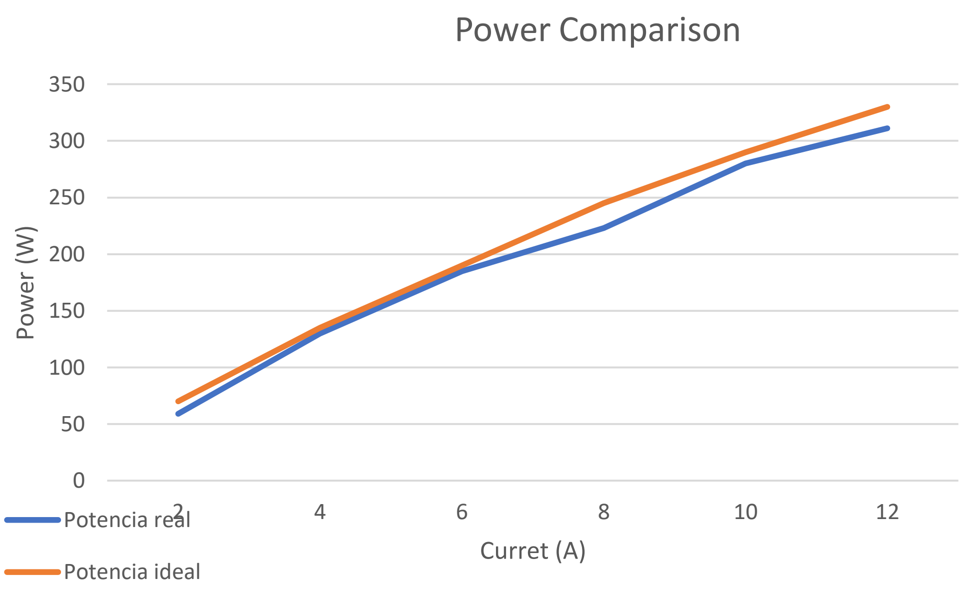
- It is necessary to use a device for make the communication and control.
- These device is going to control the system in Real Time.
- MicroLabBox

Implement our Controller

- For this case, it is necessary to control input current and output voltage from the DC/DC.
- We send a PWM signal from MicroLabBox

Fuel Cell Test

- The aim idea is compare the power which give the real Fuel Cell system and the theoretical power.
- Our Fuel Cell system give less power.



Control System

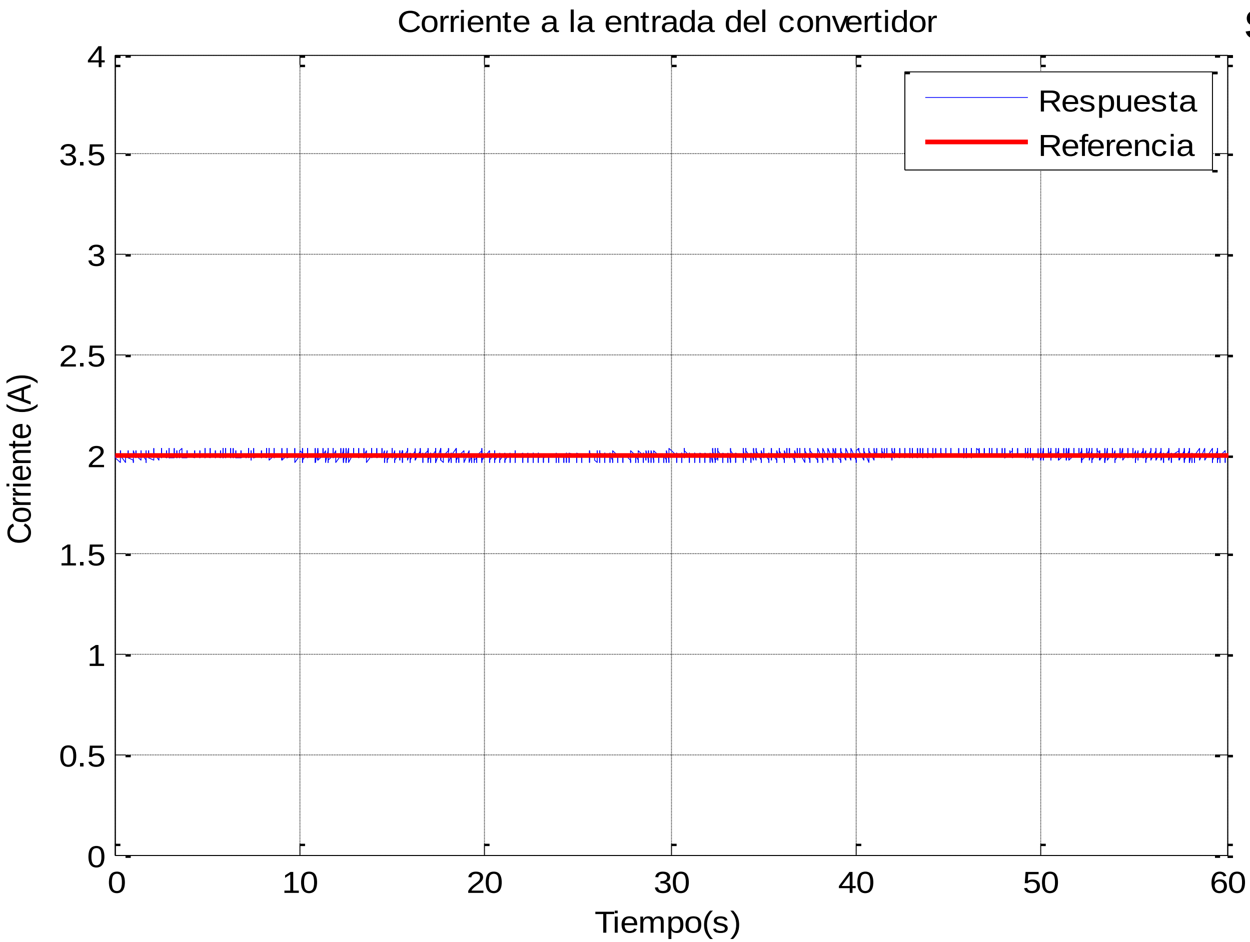
- The controller is implement in DC/DC boost converter
  - It change the resistance from PEM output to move the system to that reference.
- 2 References to follow
  - Max Power and Max efficiency. Both are theoretical.
- MPC Controller
  - It need a Plant model to operate
  - It works in discrete time to predict the future
  - It calculate the best action control.
- The controller is implement on MicroLabBox
- The power of our PEM is lower than theoretical Power

PEM Fuel Cell

TEST THE CONTROLLER

Test and results | Max efficiency

- **Results**
  - System follow the reference.
  - The median from that signal is 1.994 A (2 A).



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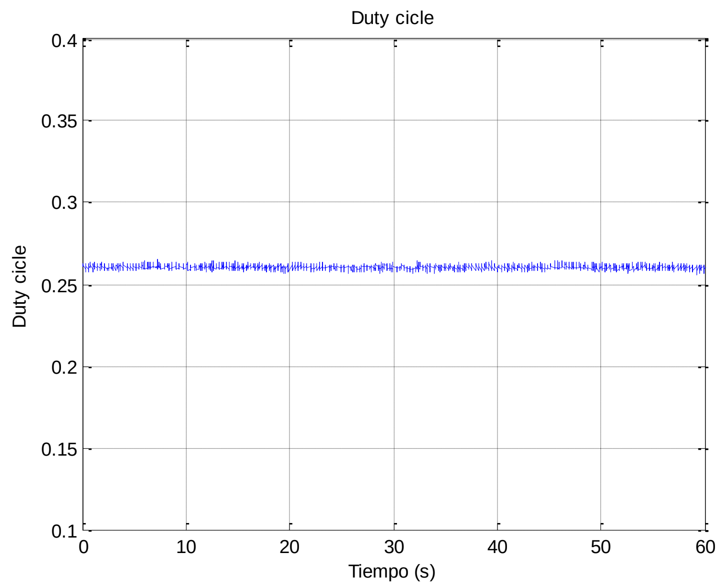
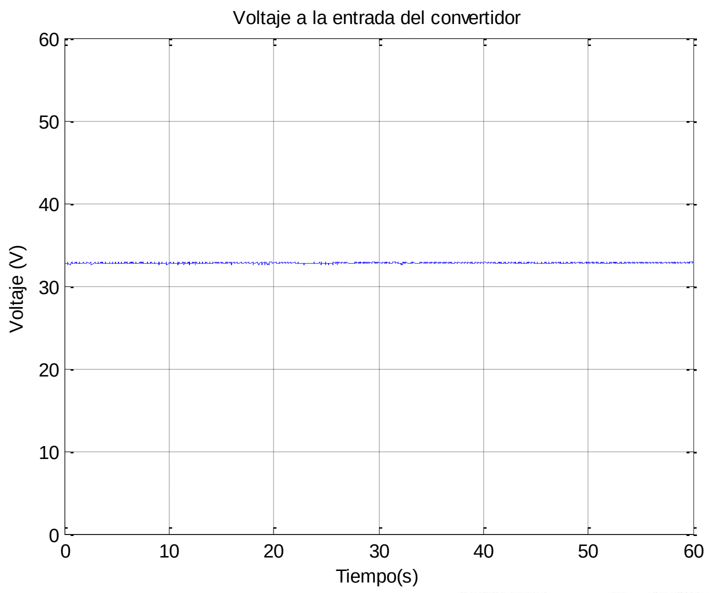
Test and results | Max efficiency

- **Results**
  - **Duty cycle median is 0.2604 (0.26).**
  - **Input Voltage median is 32.78 V (32.8 V).**





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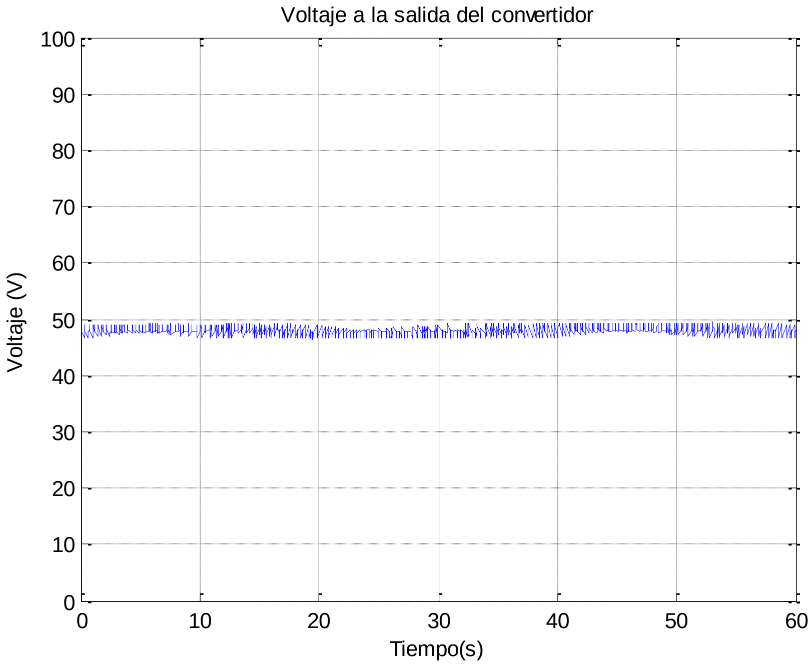
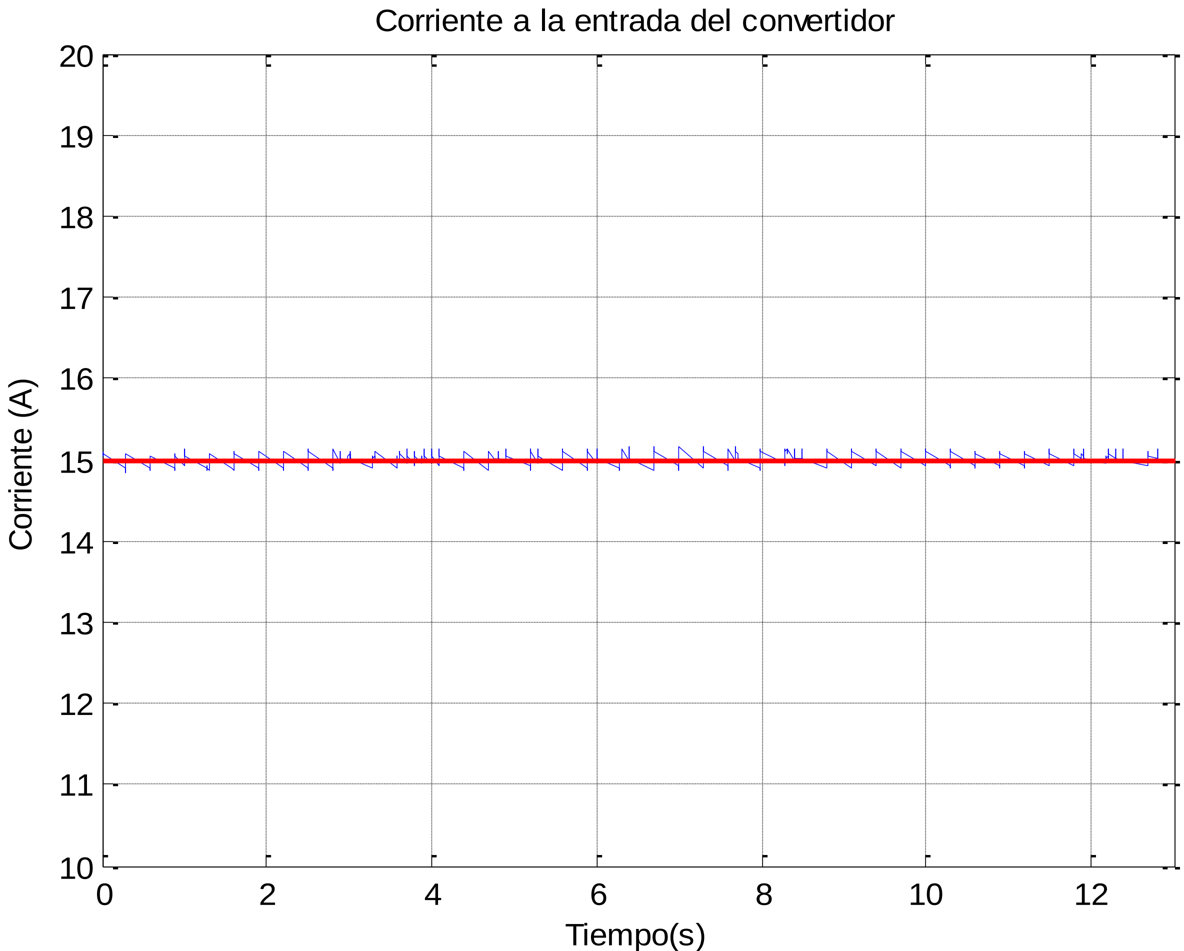
- **Results**
  - DC/DC output voltage is lower than reference ones.
  - The median value is 47.91 V (48.1 V).

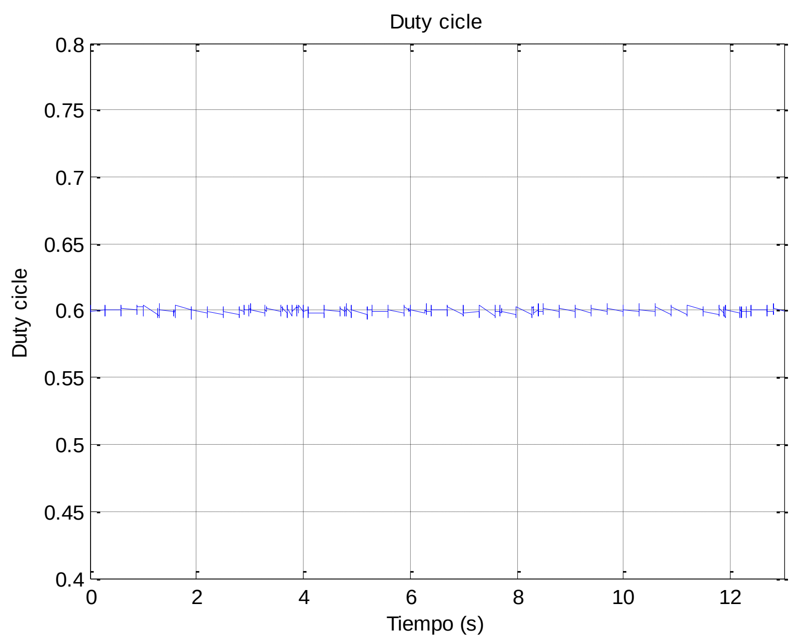


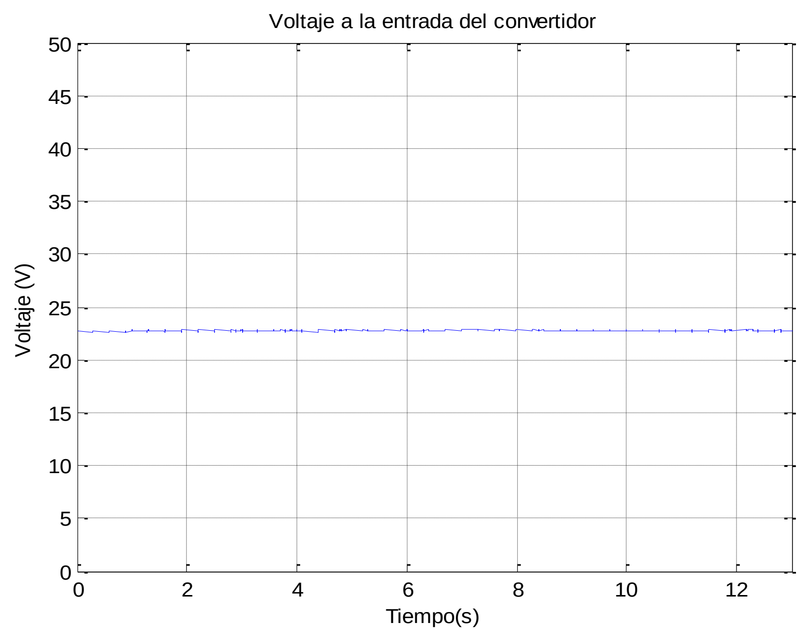
Test and results | Max Power

- **Results**
  - **System follow the reference.**
  - **The median from that signal is 15.01 A (15 A).**



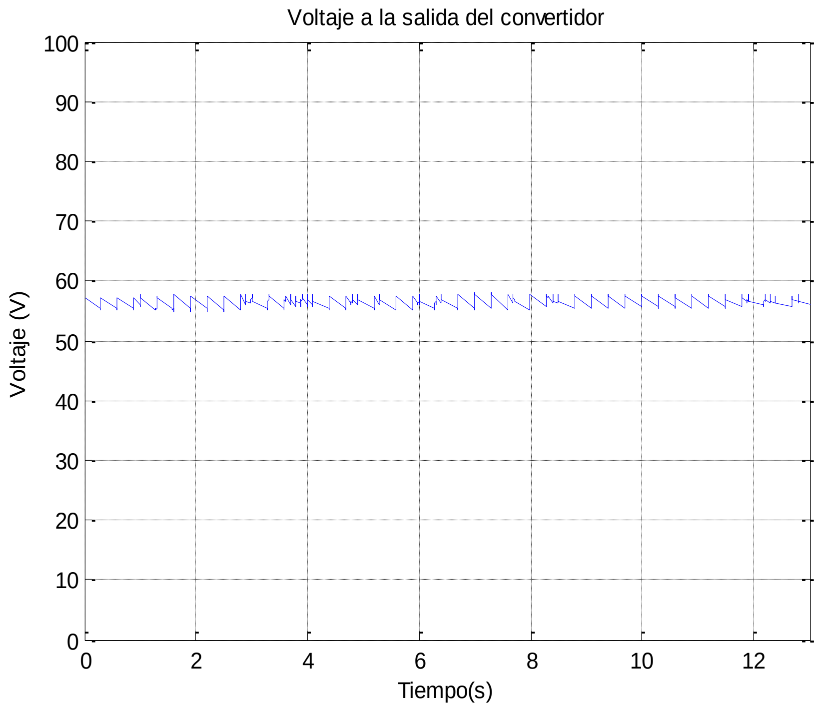
- **Results**
  - **Duty cycle median is 0.6 (0.596).**
  - **Input Voltage median is 22.795 V (22.8 V).**





Test and results | Max Power

- **Results**
  - **The median value is 56.5 V (56.5 V).**



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