Final Report

Central School of Lille

Two Liters per Hundred Kilometers

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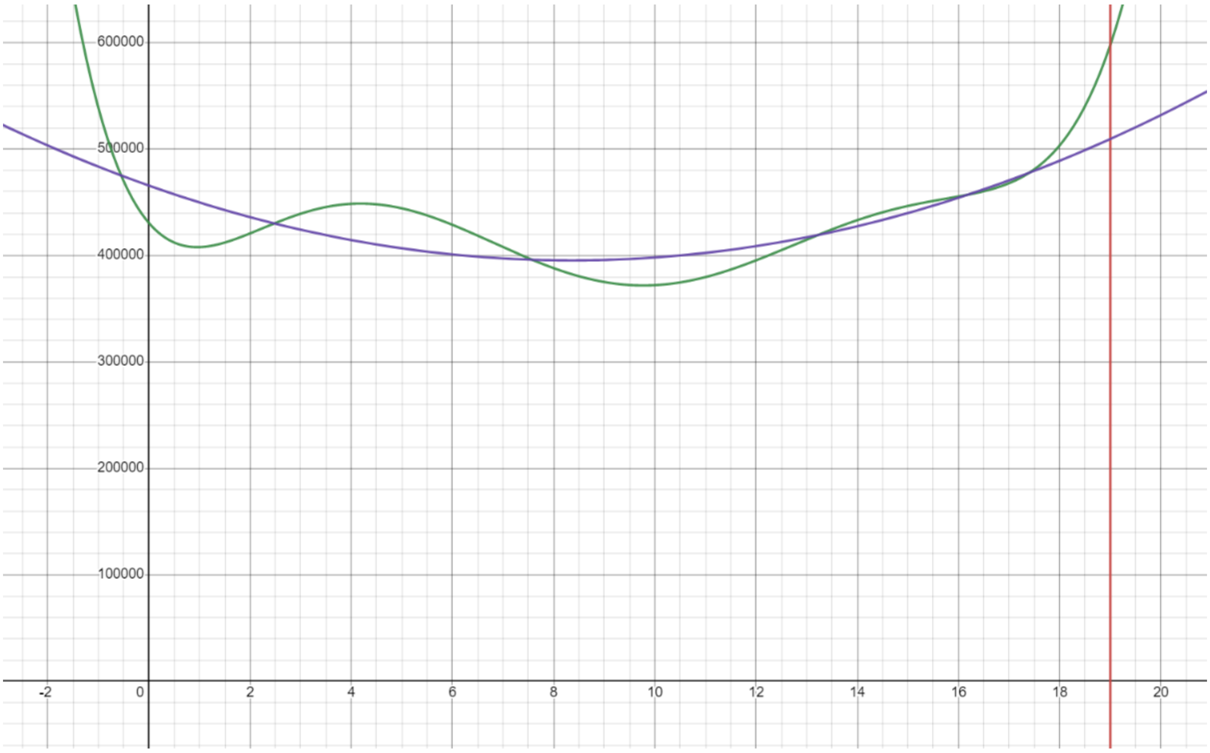
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Context

As part of the integration elective Two Liters to One Hundred Kilometers, 8 students from the Ecole Centrale de Lille aim to size and propose a market launch of a vehicle consuming less than Two liters s of fuel - or equivalent in other primary energy - to travel a distance of one hundred kilometers.

To do this, they were able to count on the experience of the teacher-researchers of the Ecole Centrale de Lille and on the many digital and bibliographic resources available. The student team therefore focused on the technical and marketing parts to carry out the project.

To meet this problem of 2L/100km, the choice fell on a light commercial vehicle based on the Stellantis model. This hydrogen fuel cell hybrid car has a 100 kw AC engine. The car has a chassis similar to a Mercedes-Benz Sprinter. It also has innovative technologies to refuel in 3 minutes, a range of more than 400 km and a capacity similar to a minivan.

The placing on the market of such a vehicle, innovative and technologically innovative, must adapt to a demanding environment and to a market that is constantly changing because of political, economic and economic constraints. environmental. For this, and in order to best meet the needs of consumers, it seems necessary and mandatory to carry out a marketing study so that the new vehicle can gradually enter the automotive market.

Thus, specifications were established to define the profile of the car. Then, a PESTEL analysis allowed us to study the various economic, political, etc. issues to draw a conclusion. Potential buyers have therefore been targeted to meet their demand and predict a potential market over the coming years.

Reminder of the technical project

Criterion	Demand
Fuel cell system	Power from 40 to 60 kW 40-60% efficiency
Battery	Capacity from 10 to 15 kWh Power from 25 - 40 kW
Power Management System	Efficiently manage the distribution of energy between the fuel cell system and the battery Ensure maximum efficiency and performance
Chassis	Robust and durable Capable of supporting the weight of fuel cell and battery systems
Powertrain	Reliable and efficient Power from 60 to 150 kW
Brakes and suspension	Reliable and efficient is essential to ensure safe and smooth operation of the delivery vehicle in an urban environment
Driver assistance systems	Lane departure warning Adaptive cruise control Automatic emergency braking
Autonomy	Greater than 400 km
Speed	Max speed of 130 km/h
Capacity	Load equivalent to half the weight of the car
Reloading	3 minutes in a hydrogen station
Cold start	Avoid waiting for the battery to heat up thanks to the battery
Price	Accessible for multinationals

PESTEL

	FACT	CONCLUSION
Politics	State-funded carbon reduction policy. Crit'Air certificate.	Interesting for a company because it reduces costs
Ecological	The transport sector accounts for 31% of greenhouse gas emissions. Non-polluting solutions exist, but have advantages as disadvantages.	The transport sector = one of the most polluting (therefore carry out actions). The hydrogen vehicle would drastically reduce these emissions.
Social	The car is the most used means of transport for deliveries and switching to environmentally friendly vehicles improves the brand image.	Real desire for companies delivering investir in a hydrogen car fleet.
Technological	Electric is more accessible, hybridization is exploding and the hydrogen fuel cell is developing.	We can seize the opportunity of a growing market.
Economical	The standard of living is higher in cities. The price of gasoline and diesel rises Today , the price of hydrogen and diesel are equivalent.	Usage a other fuel → hydrogen
Legal	Euro 7 standard: NOx emission < 0.4g/kWh Regulation 224-15-11 low emissions < 50 gCO2/ km	Find alternatives to meet these standards

Profile and needs/constraints of potential buyers

Context

The vehicle sized by our team is a transport or delivery vehicle.

It is able to transport up to objects the size of furniture, in terms of order of magnitude.

It is therefore a vehicle of choice for companies providing transport or delivery services in the city in particular. The Coronavirus epidemic has made this delivery service even more important in the eyes of individual customers who can therefore stay at home. Our potential customers are therefore transport and delivery companies. Examples include companies such as Amazon, La Poste and Auchan. Indeed, these companies will have to continue to deliver goods even when, in 2035, thermal cars will no longer be allowed.

In order to continue their activity, they will have to finance innovative and more environmentally friendly vehicles: this is where our vehicle comes into play and provides a solution to these companies.

Figure 1: Proposed Transportation Vehicle

amazon Auchan LA POSTE

Figure 2: Examples of Enterprise Clients

Benefits

Innovative technologies to

- Refuel in 3 minutes
- >400 km range
- Same capacity as a minivan.
- Cold start.

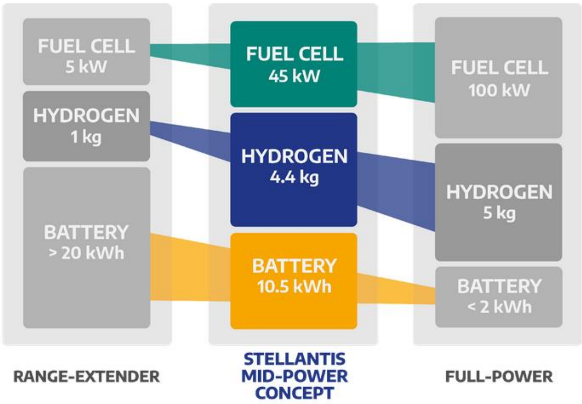


Figure 3: Innovative concept

The mid-power concept adapted to our conditions of use strongly distinguishes this vehicle from electric vehicles.
Indeed, it makes it possible to obtain a range comparable to diesel vehicles while offering a much faster charging system.

Usage

The number of hours a delivery vehicle travels in a year can vary significantly depending on several factors, such as the type of delivery service performed, the location of the vehicle, the size of the fleet and the efficiency of the delivery routes.

For example, a delivery vehicle for a parcel delivery service may run several hours a day, 5 to 6 days a week, and take a few days off to maintenance, while a delivery vehicle for a major work delivery service can only run for a few hours and this 2 to 3 days a week.

In general, the total number of hours travelled by a delivery vehicle in a year can range from 2000 to 10 000 hours, depending on the specifics of the delivery service and the efficiency of the Delivery routes.
It is important to *be aware of this in order to estimate the maintenance price.*

Customer Demand

Amazon has 100,000 trucks, including 10,000 electric in 2023. Knowing that combustion engines will be banned by 2035, their demand will therefore increase and our vehicle profile fits perfectly with customer demand . A short-distance driver drives about 350 km/day compared to 1050 km/day for long distances. In Paris, more than 200,000 parcels are delivered every day, which is thousands of km driven every day and CO2 emissions. Our vehicles with a hybrid hydrogen fuel cell engine are therefore feasible for ecological reasons. La Poste owns 27,000 vehicles in 2023, including 7,000 electric cars. The company plans to buy 15,000 by 2025 alone while the forecast market is growing. Other potential customers in the same operating dynamic are logistics and delivery companies. In addition,

pharmaceutical companies like CERP have a fleet of 750 gasoline-powered vehicles in 2023 and are therefore targetable for our hydrogen fuel cell hybrid vehicles.
More specifically, we target the 59% share of the 5.8 million light commercial vehicles on the road reserved for professional use. Indeed, the diagram below taken from Vehicules-Utilitaires.fr [9] shows that the majority of these commercial vehicles are used by companies at 90%.

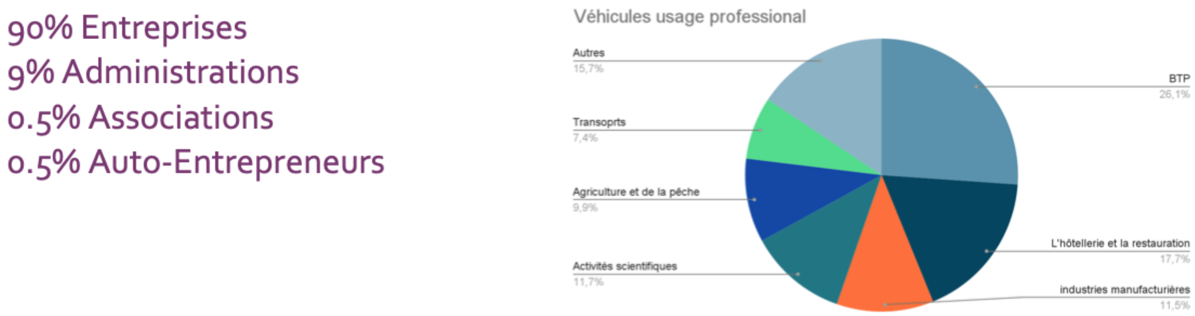


Figure 4: Client Demand

Manufacturers

Manufacturers for current hydrogen vehicles.

In this part, we will discuss the relationships between car manufacturers. There are many groups of different countries that invest in various technologies. The vehicles produced are the mark of increasing competition in this sector. Innovation is the hallmark of companies that manage to stay in the competition for vehicle manufacturing and the comparison with conventional hybrid vehicles therefore comes from support here a potential manufacture of our vehicles by car manufacturers. This is a trend, but the marketing and manufacture of our vehicles may take place differently depending on the resources available for our particular vehicle.

Above all, the manufacture of hybrid vehicles must be placed in a more global context. To understand why some companies are investing in hybrid technologies, you need to know the major car manufacturers.

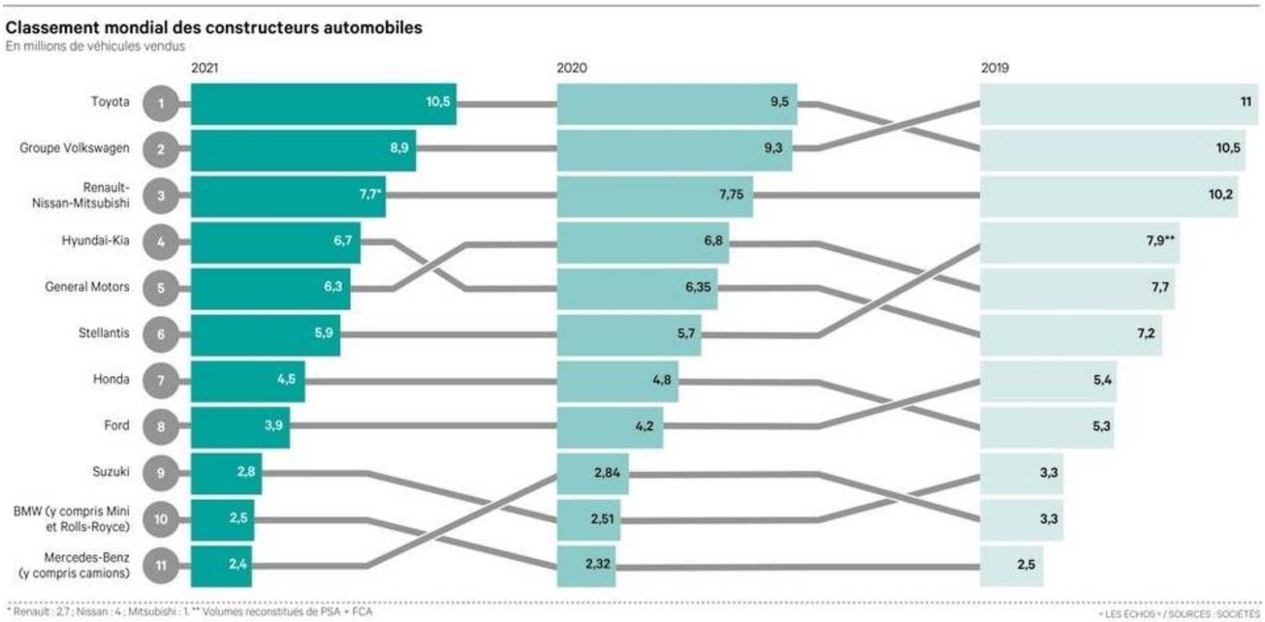


Figure 5: Global ranking of car manufacturers from 2019 to 2021 (in number of vehicles sold)

In the figure above, it can be seen that some companies remain at the top of the ranking for several consecutive years. These include Toyota, Honda, BMW, Ford...

Let us now take a closer look at who are the main car manufacturers in the hybrid range.

The hybrid vehicle market mainly consists of manufacturers belonging to the ranking of the most popular manufacturers. These include Toyota, Nissan, Honda, BYD, Mitsubishi, BMW and Ford that largely dominate the hybrid field.

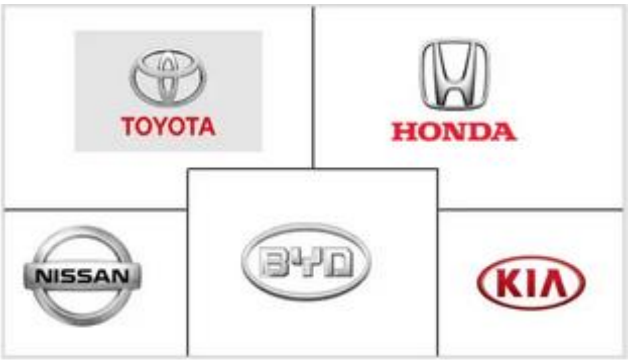


Figure 6: Dominant Manufacturers in the Hybrid Sector

On the other hand, it is interesting to note that some companies use this dominance as a business argument. Indeed, Toyota defines itself as the leader of the hybrid.

To understand how Toyota was able to obtain this leading position, understanding their strategy note, and in particular the analysis of their SWOT matrix, are interesting tools.

First of all, according to Toyota, all cars are created equal. In other words, the market is hypercompetitive, it will be very difficult to stand out with a classic car today, at least in the eyes of private customers. It is therefore necessary to focus rather little on the visual and practical aspect of the vehicle because these are no longer elements that make the difference.

In addition, it is a market where there are few entrants. Very few new manufacturers are entering the market. So according to Toyota, the competition would come on everything from manufacturers already existing on the market. Methods chosen by competitors and technology investments, such as hybrid vehicles, can help take market share from the competition. Manufacturers' experience is a key factor.

In addition, manufacturers must take into account the needs of customers, those who will buy their vehicles. Manufacturers have understood that a vehicle that pleases the customer is a vehicle sold . In its strategy note , Toyota explains that manufacturers' dependence on customers is growing. You have to know how to listen to the needs and desires of consumers. Current customer requirements are often linked to the need for cleaner vehicles. Thus, it seems completely logical that Toyota has been developing its hybrid model for several years now. Unfortunately, for some manufacturers, the cost of hybrid vehicles is still a little higher than on some combustion cars.

Finally, two other factors influence the fashion of hybrid vehicles and may encourage the development of this range of vehicles for manufacturers. On the one hand, innovative technologies such as hybrid are making it possible to cope with x government pressures seeking to reduce the manufacture of internal combustion vehicles for environmental considerations. On the other hand, investing in hybrids makes it possible to circumvent the fluctuations of fossil fuels, such as oil.

Fuel cell

For our fuel cell, we turned to a French brand : Symbio. We opt for the cheapest range adapted to the needs of the user.

By driving profile analyses, a 40 kW battery is sufficient.

There are several manufacturers:

1. Symbio
2. Plug Power
3. Ballard Power Systems
4. Hydrogenics
5. FuelCell Energy

The choice of this battery compared to other manufacturers is made on several criteria :

- Local production : Symbio is a French brand, which is an economic and environmental advantage.

- Compact design: The compact design of the StackPack 40 makes it easy to integrate into a delivery vehicle and saves space.
- High power output : With a power output of 40 watts, StackPack 40 might be able to meet the power needs of a delivery vehicle.
- Durability : Fuel cell systems in general are known for their reliability and durability, and the StackPack 40 can offer these benefits as well.

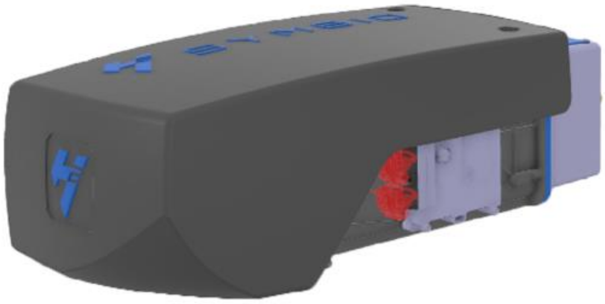


Figure 7: Hydrogen Cell

Price: About 40 000 euros with a durability of 7000 hours. An optimized system is then needed that activates the fuel cell during the appropriate phases (peripheral) and solicits the battery during city trips.

For a solicitation such as delivery of colis, the life of the battery is estimated to be between 1 year and a half and 2 years maximum.

It is difficult to predict the extent to which fuel cell prices might decline over time, as this will depend on a variety of factors, including the adoption of fuel cell technology, growth of hydrogen infrastructure and advances in manufacturing processes.

However, in recent years, the price of fuel cells has declined due to technological advances and increased production, which has led to economies of scale and lower costs. . Some experts predict that the cost of fuel cells will continue to fall in the coming years as demand for fuel cell vehicles and other applications continues to grow.
They estimate a 50% reduction in costs by 2030.

Hydrogen tank

Hydrogen tanks vary greatly in their use. The tank that is put on our vehicle must be safe and resistant to leaks, shocks and fires to avoid any danger to passengers and users to comply with the standards and laws in force. It must also be light enough not to overload the vehicle but must be large enough to store a quantity of hydrogen for adequate autonomy . The choice of tank design is then a compromise between these different factors and the cost of production.

According to a 2019 study by the Association of European Automobile Manufacturers, the production costs of hydrogen tanks for vehicles were estimated at between €50 and €100 per kilo of hydrogen stored.

Hydrogen is mainly stored at 700 bar, at this pressure it has a density of 42 kg/m3 against 0.09 kg/m3 at atmospheric pressure. Thus we can store in a tank of 125 L, 5 kg of hydrogen which corresponds to about 500 km.

The main manufacturers of hydrogen tanks are:

1. Hexagon Purus
2. Toyota for its main vehicles
3. Linden
4. ITM Power
5. Air Liquide
6. Plastic Omnium

We chose to turn to Air Liquide, which has experience in the field of hydrogen and other gases, whether in storage or production. It is also present all over the world and more particularly in Europe.
They are also developing innovative hydrogen storage solutions such as solid hydrogen or more promising liquid hydrogen with their partnership with Faurecia.

This tank will store hydrogen at a temperature of -252.87 °C and a pressure of 1,013 bar which will allow the 5 kg of hydrogen to be stored in a tank of only 75 L. These tanks are currently in the prototype phase, they will be developed in 2025 and deployed for market launch in 2027.

Battery

Our delivery vehicle has a 40 kW fuel cell with a range of 400 km and circulates in the city. A large capacity lithium-ion battery would probably be a suitable choice. Lithium-ion batteries are commonly used in fuel cell vehicles because of their high energy density, which provides a good balance between weight, size and capacity.

When choosing a battery for a fuel cell delivery vehicle that meets these requirements, it is also important to consider other factors such as safety. , durability and ease of integration with the fuel cell and other vehicle systems. In addition , the specific requirements of city driving, such as stops and starts and the need for rapid acceleration, may affect the choice of battery.

We opt for a 90 kW battery, with a capacity of 10.5 kWh, durable and safe.

The different manufacturers are then :

1. Panasonic
2. LG Chem
3. Tesla

4. CATL
5. WORLD

The manufacturer selected is a lesser-known producer: Automotive Cells Company, already operational in Bruges (Bordeaux), and Nersac, France (Nouvelle Aquitaine). Their first Gigafactory is being built in Billy-Berclau Douvrin, Hauts-de-France.

- Their research and development center ensures that they have batteries at the forefront of current technology.
- Production is environmentally desirable rather than importing products from another continent.
- Their powerful partners allow them to keep prices affordable.
- They specialize only in the field of vehicle batteries. Price: About 8000 euros.

Figure 8 : logo ACC

Three-phase motor

The vehicle has a three-phase motor of 136 Hp (100 kW) with a maximum torque of 300 Nm at 3674 rpm and an operating voltage of 400V.
This engine allows the car to generate 0 carbon emissions at the time of operation.
The three-phase motor is used in various engines and in industry for the transformation of electrical energy into mechanical energy. And its principle of operation is the same as that of another electric motor.
The engine allows a maximum speed of 130 km/h for a 3.5-tonne car.

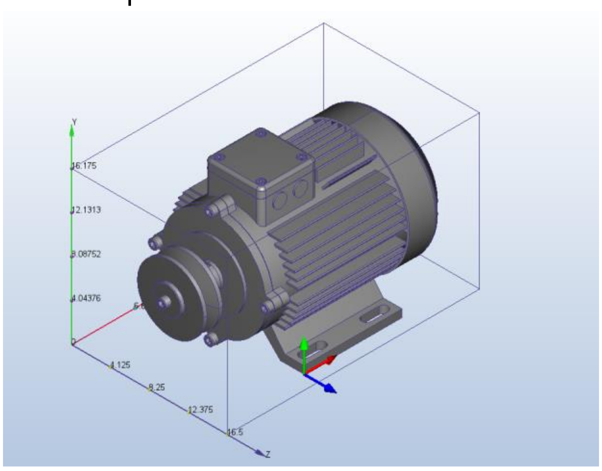


Figure 9: AC Motor 100 kW

The engine is used for the stellantis group, is that of a Citroën Ë-BERLINGO.

Also the 100 kW three-phase motor is used in electric cars from Toyota, Dacia, Renault, Fiat, MG, Peugeot, Nissan, Mazda, Kia, Cupra, Opel, and others.

There are different producers of three-phase motors, however the most important producers in France are:

- 3X MOTION TECHNOLOGIES CO.,LTD.
- AB SHOT TECNICS
- ABB Motors Drives and Power Electronics
- ABM Greiffenberger Antriebstechnik GmbH

The average price of a 100 kW three-phase motor is 5000 euros

Resellers

The main resellers of fuel cell delivery vehicles are:

1. Toyota with FedEx
2. Hyundai with DHL
3. Nicholas
4. Isuzu (Honda Fuel Cell)
5. Daimler
6. Stellantis

Knowing that we are moving towards companies, there are two possible alternatives. They can either directly buy vehicles for their fleet, which is used by the largest delivery companies to benefit from advantageous rates by buying in mass or make a lease that is to say a rental contract for 3 or 5 years. We then realize that the dealership is only targeted for individuals and is therefore not interesting for us at first. It may be used in a second time to ensure that vehicles that have already been leased under contract several times their end of life.
It would therefore be necessary to deal directly with companies to conclude contracts or to partner with already existing resellers to benefit from a greater commercial force.
Our preferred reseller would then be stellantis because it still has several advantages: Stellantis, which is already a grouping of several brands, with its vast reach and experience in the automotive industry, may be able to supply a wide range of vehicles. and support services , including fuel cell delivery vehicles.
We could therefore expand its service offer while benefiting from its network. Knowing that combustion cells have an estimated lifespan of 2 years, we can then imagine setting up rental contracts over this period and thus be able to change The PAC enters two rentals to ensure perfect performance of the vehicle.

Availability of hydrogen as a fuel

The number of hydrogen refuelling stations is gradually increasing as the demand for fuel cell vehicles increases, and additional efforts are being made to develop hydrogen infrastructure in the country. . These efforts will have to be significant in order to eventually catch up with gasoline because there are now more than 11,000 petrol stations in France, which makes it by far the most important fuel. accessible.

The French government has set a target of having 100 hydrogen refuelling stations by 2023, which should stimulate the development of hydrogen refuelling infrastructure. in the country. In addition, private sector investment, including automakers, energy companies and hydrogen suppliers , also plays an important role in the growth of hydrogen stations in France. That is why the development of light commercial delivery vehicles is particularly interesting. Indeed, if a major delivery player such as Amazon launches into hydrogen, they will have the means to build their own charging stations, whether in their warehouses or stations accessible to all. This will have the effect of improving the distribution of hydrogen on the territory and therefore we can imagine an acceleration of the development of this resource including for individuals, as a cascading effect. However, the speed of growth will depend on several factors, including technological advances, cost reductions and the availability of financing.

Indeed, today the storage and transport of hydrogen remains an obstacle because it is costly in energy because of the high pressure required. However, it would be interesting to develop technologies in favor of hydrogen given its very strong energy potential: it has an energy density Mass 3 times higher than diesel for example (1 kg of hydrogen allows a range of 100km).

Hydrogen is currently an important industrial gas: 75 million tonnes are supplied annually to the chemical industry, nearly 45% for oil refining (desulphurisation), almost as much for the production of ammonia and nitrogen fertilizers, about 10% for the food, electronics and metallurgical industries and finally about 1% for the Space propulsion of rockets by combustion of liquid hydrogen and oxygen.

The France produces nearly one million tons of H2 per year, or 1.5% of world production (compared to about 10 Mt per year for the United States or China)

The production prices of hydrogen are closely linked with those of electricity and today the price per kilo is between 10 and 12 € with the techniques currently used . It remains to take into account the price of transport to storage.

For short and medium distances, the preferred solutions are truck and pipeline transportation. For transport by trailer, the price is between €0.5 and €1.5 per kilo of hydrogen over distances of less than 400 km. For longer distances, pipelines are preferred, which reduce this cost to €0.2 per kilo.

Figure *10: Hydrogen transport*

Several storage techniques exist but the one that interests us most for charging stations is that in high-pressure tanks. These tanks go up to 700 bar and are filled with hydrogen gas transported in trailer trucks.

Figure 11: Hydrogen Storage

Carbon cost of production

In terms of production, currently most hydrogen is produced by steaming, this is an inexpensive technique but releases a significant amount of hydrogen dioxide. carbon in the atmosphere. In order to make this production more proper, there are 3 alternatives: alkaline electrolysis of water, electrolysis P.E.M. and electrolysis at high temperature. Alkaline electrolysis of water has the disadvantage of being expensive but it is carried out at moderate temperatures and pressure (80 to 160 ° and 3 to 30 bar). It also has a very good yield (between 80 and 92%). Electrolysis P.E.M. is even more expensive, but it has a better yield. As for the last form of electrolysis, it was the subject of much research in the 2010s because it could represent a good solution for production of hydrogen by reducing carbon emissions thanks to an even higher efficiency (closer to 90%) because the conditions are optimized during production.

Both of these methods have their advantages and disadvantages, and the choice of method will depend on factors such as resource availability, cost , and environmental impact. For example, the cost of hydrogen produced by reforming is around 1.5 € / kg against 6 € / kg for hydrogen produced by electrolysis, so it is clear why today The most preferred method is that by reforming. However, this method has a terrible carbon cost since at each stage of production a large amount of CO_2 is released: conversion of CO from the reformer, combustion of fuel for steam production and for energy input into the reformer. In the end, it is estimated that for every tonne of hydrogen produced, about 12 tonnes of CO_2 are released into the atmosphere.

The French government and industry are actively investing in the research and development of clean hydrogen production methods to reduce the carbon footprint of hydrogen production and ensure the long-term sustainability of the hydrogen industry.

Resource requirements

Battery

There is currently enough lithium to produce batteries for vehicles, but the availability of lithium could become a concern as demand for electric vehicles and energy storage increases. Efforts to ensure the sustainability of the lithium industry, including the development of responsible production practices and the recycling and reuse of batteries, are in course.

Thus, we opted for a solution requiring hybrid vehicle-type batteries that have a much lower environmental impact than electric vehicles. In addition, the utilitarian aspect is not negligible. Indeed, these goods are not intended for individuals but for a reduced market, which will limit the impact on the stock of raw materials available. Finally, juggling betweenfuel cell and battery in their comfort zone will drastically increase the life of both elements.

Fuel cell

Raw materials are generally abundant and readily available. The main components of a fuel cell include membrane electrode assembly (MEA), bipolar plates, and flow fields.

MEA consists of a proton exchange membrane (PEM), catalysts and a gas diffusion layer . PEM is generally made of a polymer of perfluorosulfonic acid, and catalysts are generally made of platinum or other precious metals . These materials are widely available, but their high cost is one of the main challenges in commercialising fuel cell technology.

Bipolar plates are usually made of stainless steel, carbon composites or other metal alloys and are widely available . Flow fields are usually made of plastic or other lightweight materials, and are also widely available.

In summary, raw materials for fuel cell stacks are generally abundant and readily available, but the high cost of some materials, such as catalysts, is a challenge for the commercialization of fuel cell technology. Efforts to reduce the cost of fuel cells and increase their competitiveness vis-à-vis other power generation technologies are ongoing.

Hydrogen as a raw material

It is the most abundant element in the universe, accounting for about 75% of its elemental matter by weight. Hydrogen is also abundant on Earth and can be found in water, hydrocarbons and other organic compounds.

However, hydrogen does not exist naturally in its elemental form on Earth and must be produced by various processes such as steam reforming of natural gas, electrolysis of water or biological processes as we have seen.

Hydrogen is widely available on Earth, but its production can have a significant impact on the environment and global energy systems, and responsible production practices are needed. to ensure its long-term sustainability.

On the other hand, unlike oil, it is not considered a fossil resource, which makes it a sustainable investment.

Sales : calculation methods

There are different methods for calculating sales in the next period, and they are based on the sales history of recent years.
As the market it targets is a market that is under development, the sales history of light commercial cars in France is used, as well as a comparison of cars to hydrogen in Europe. With these two pieces of information, we can interpret and approach the closest trend to reality if our market is the period 2023. Also it's important to consider the political and legal factors of France transportation, so it can have a positive impact on our product.

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Annee	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Ventes	407500	419000	439200	461000	458900	372500	412300	425600	384100	367300	371600	378800	410100	438700	459100	478000	430200	516240

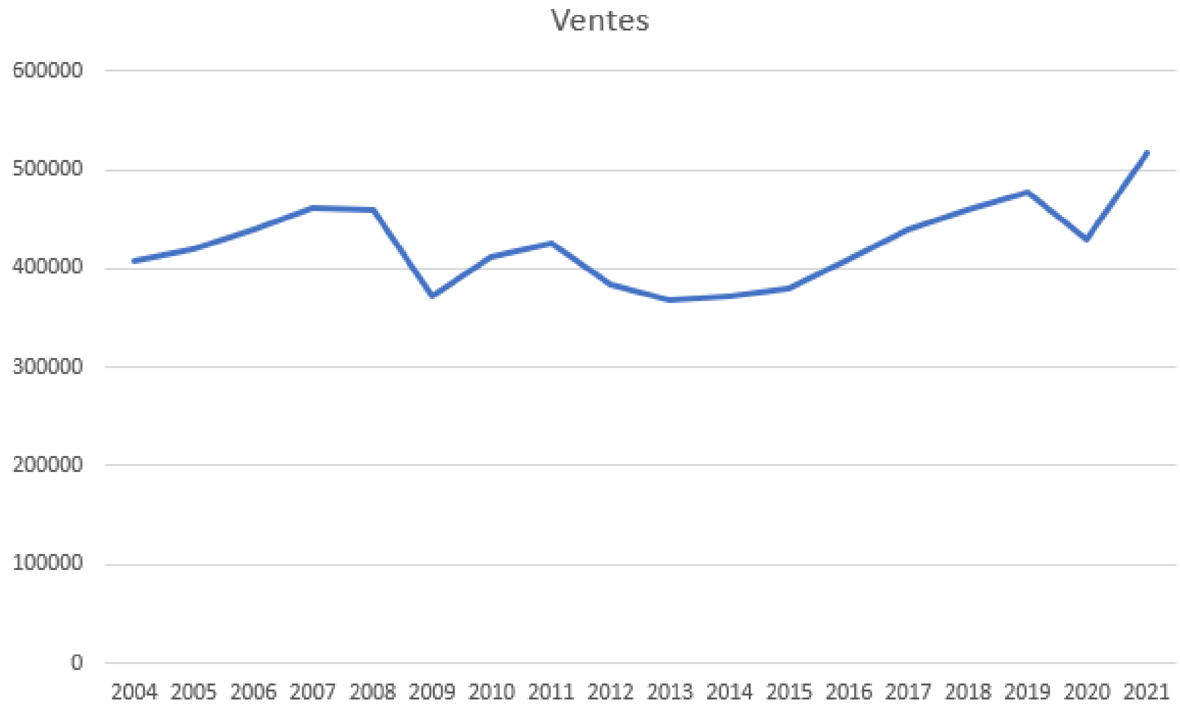


Figure 12: Graph of commercial car sales in France.

The extreme point method

It consists in connecting by a straight line the two most extreme points. It can be useful to visualize the evolution of turnover or sales volume, but also to define one of the two indicators, or both.

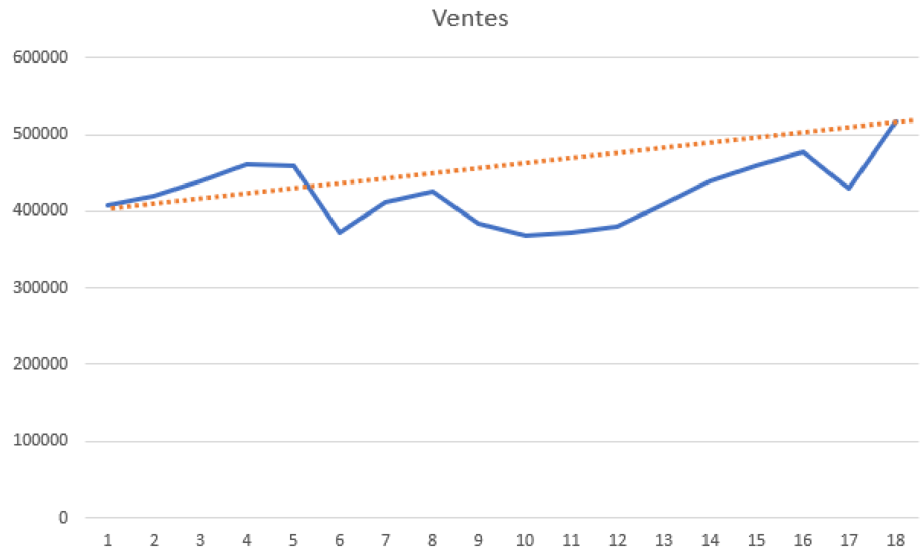


Figure 13: Data Graph with Extreme Points Method

The equation of the rect is : $Y = 6396.47X + 401103.5294$

The average points method

Mayer's method consists of dividing the data series into two subseries, which allows all points in the series to be taken into account.

The average point of each subseries is then calculated before determining the equation of the adjustment line that passes through these two average points.

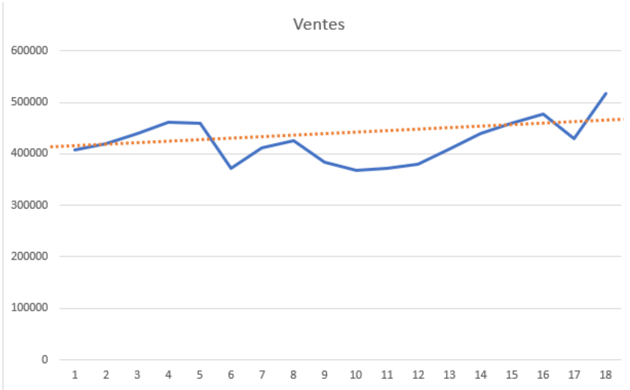


Figure 14: Data graph with average point method

The equation of the rect is: Y = 863.456X + 415693.8272

The method of least squares

Y is the sales volume; X is the year sought for the forecasts, minus the average of the years; a is the sum of x x y, which is divided by the sum of x^2; b is determined by subtracting from the average volume (or turnover) the value of a multiplied by the average of the years.

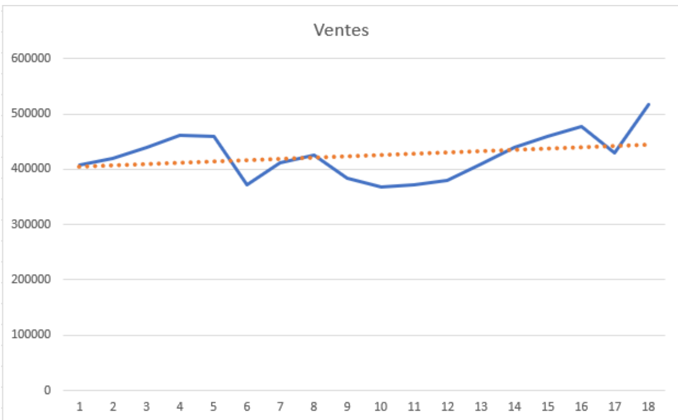


Figure 15: Smallest squares data graph

The equation of the rect is : y = 2306.7x + 401983

This method will take into account a corrective R number, to best approximate the equation by considering the error.

The exponential smoothing method

Exponential smoothing is not the most widely used method of calculating sales forecasting. Exponential smoothing gives greater weight to the most recent data, thanks to the calculation of a weighting coefficient.

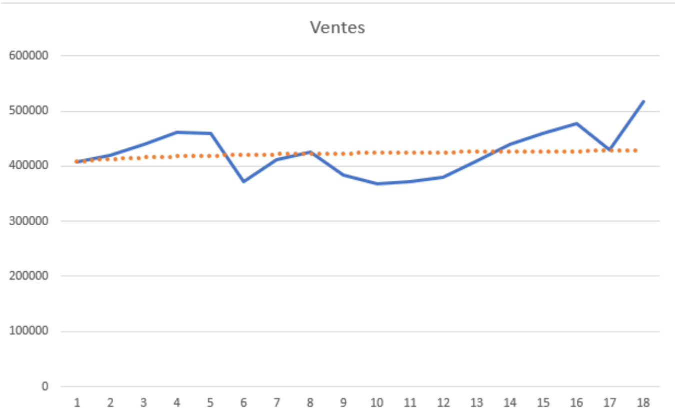


Figure *16: graph of data with the exponential smoothing method*

$$y = 408183x^{0.0165}$$

The regression and correlation method

Multiple regression makes it possible to analyse the relationship between a dependent variable (turnover or sales volume) and several other independent variables. Given the accuracy of the calculation, this is one of the most common methods used by companies wishing to forecast sales of one or more products. .

To better assess the level of quality of the forecast by the regression method , it is necessary to measure the correlation coefficient. The correlation expresses the intensity of the binding between the variables studied. The correlation coefficient formula, which is rather complex at first sight, relates the variables studied to their respective means . The coefficient is between 1 and –1: when it is close to one of the two ends, the sales forecast is all the more accurate and reliable.

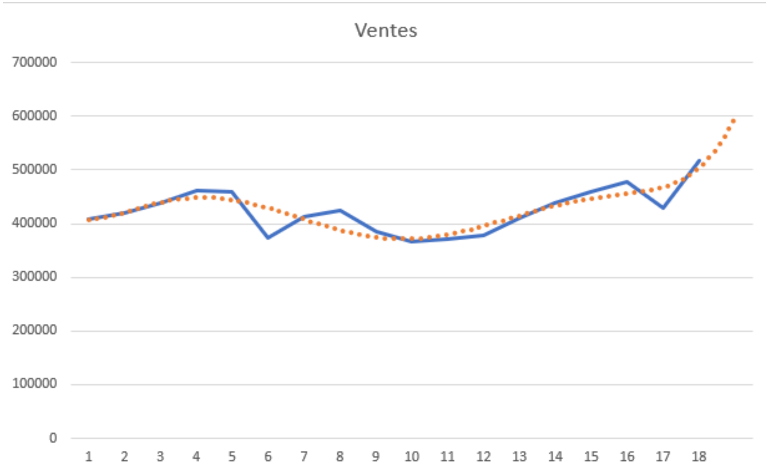


Figure 17: Data graph with regression method

The polynomial equation of the function is $y = 0{,}9163x^6 - 51{,}588x^5 + 1084{,}3x^4 - 10285x^3 + 41779x^2 - 55178x + 430592$

This method makes it possible to link all the data by a curve, however, it can be optimized with the correlation of variables.

Comparison of methods

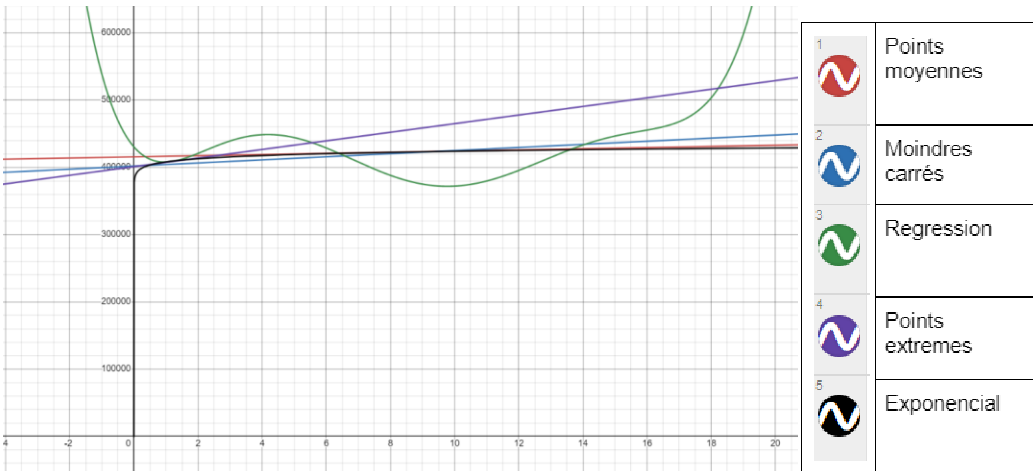


Figure 18: Graph of the different methods of analysis

If we analyze the different points obtained in period 19, the most likely is the regression method as well as the extreme points has a result granted to possible sales.
Because the regression method is the closest to reality, if we consider a comparison with the increase in sales of hydrogen cars in recent years, we decided to evaluate with a square polynomy.

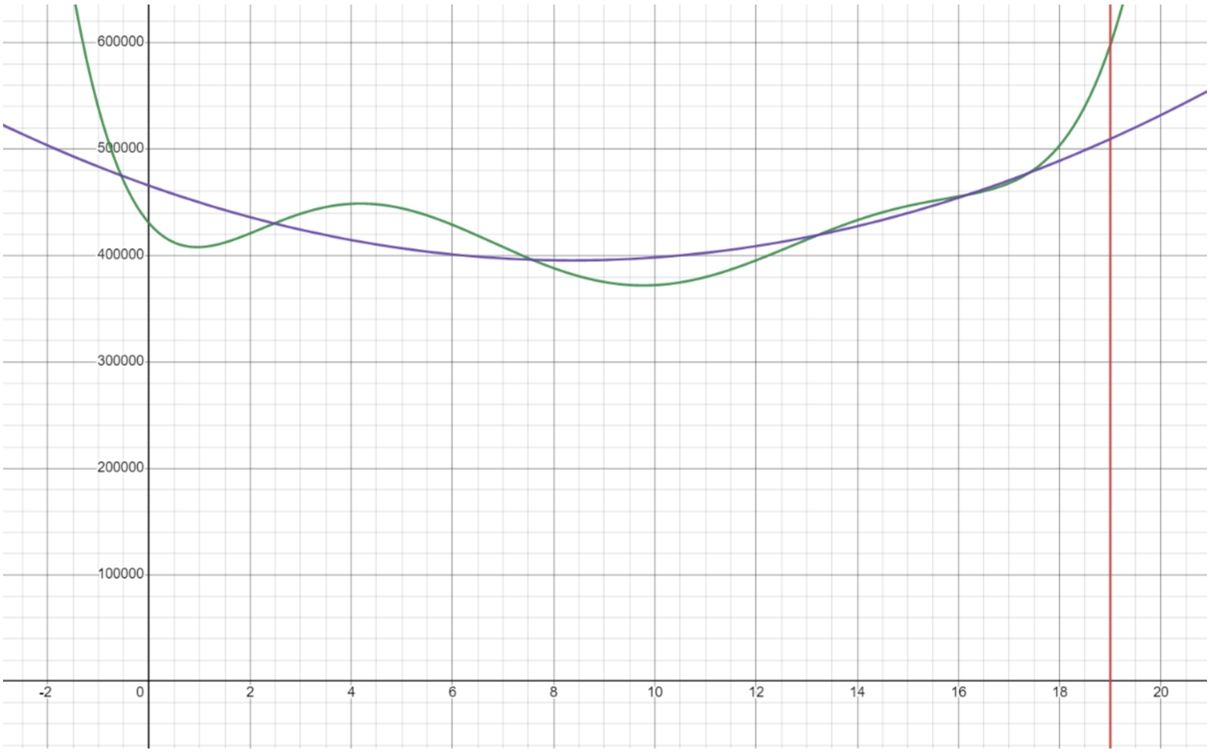


Figure 19: Graph of Linear Regression Analysis Models

It is important to consider that forecasts are not guaranteed, however with an estimate in period 19 (2022) with the linear regression method we expect sales of 509,353 vans in the year, with a possible increment aimed at increasing sales of hydrogen cars.
So the sales model follows the following curve: $y = 1006.5x^2 - 16818x + 465731$

Costs and market prices

Fuel cell demo:

Currently, there are no real studies that are able to quantify the impact of the democratization of fuel cells on the price of fuel cells. However, over the last ten years the price has fallen drastically by about 70 to 80%, which allows us to hope without too much fear that this curve still follows a trend. descending over the next few decades.

Current price :

Component	Fuel cell	Battery	Engine
Price	40 000	8000	5000

Maintenance price:

Change every 2 years of the CP: 40,000 euros.
Change every 3 years of the battery : 8000 euros.

Cost in consumption Hydrogen

With the current advancement of technologies, a hydrogen vehicle is capable of driving 100 km on 1 kilo of hydrogen . The capacity of a diesel light commercial vehicle tank is around 90 L, with an average consumption of 8.5L per 100km for urban use like our delivery truck (Peugeot Boxer data). This gives it a theoretical autonomy of just over 1000 km. The same range is theoretically achievable with 10 kg of hydrogen, which is higher than the tanks currently used in this type of vehicle. Tanks of 5 to 7kg are used for reasons of space so as not to reduce the useful space. This still allows a sufficient autonomy between 500 and 700 km which covers the daily needs of a medium-distance delivery person.

In terms of price, for a full tank of diesel today, a 90L tank costs 180 € and for 10 kg of hydrogen, we can count 120 € . As the price of hydrogen is certainly set to fall in the coming years, we can estimate that this resource will become really economically advantageous.

Cost in tax

For company vehicles, there is a specific tax : the company car tax, which consists of two subparts. One subpart concerns CO_2 emissions and the other concerns other air pollutants. Vehicles using hydrogen have the advantage of being fully exempt from this tax, unlike conventional combustion vehicles.

In addition, newly registered vehicles usually have to pay registration tax. However, since 2020, this tax no longer applies to vehicles using hydrogen: they are exempt from this tax and therefore enjoy an advantage over thermal vehicles.

Everyone's contribution to marketing

Membre de l'équipe	PESTEL	Ventes	Valeurs (couts)	Demande (clients)	Fabricants	Demande	Fournisseurs	Prix de vente (marche)	Revendeurs
Alice Dupont-Franklin		1		1			1	1	
Antony Davi	1	1	1		1				
François Tamba	1			1			1	1	
Ignacio Perez			1		1	1		1	1
Mateo Auza	1		1			1	1		1
Mathis Leroy		1	1				1	1	
Maxime Retureau		1		1	1	1			1
Timothée Chailley	1			1	1	1			1

Technical part

Contribution of each in part technical

Link to the trello: https://trello. com/b/o72EWcHA/project

Mechanical analysis

Equations of motion

To obtain the equations giving us the strength that the engine must provide several factors will come into play:

- The propulsion force of the rear and nose axle of the vehicle that is provided by the engine
- The rolling force of the rear and front axle
- The gravitational force acting on the vehicle
- The aerodynamic resistance force that applies when the vehicle is in motion
- The strength of resistance of the soil

We will therefore apply the first law of dynamics to the vehicle and we will project it on the axis of the road (called x) in which the vehicle circulates, we will also neglect the scope. This gives us:

$$m_v \frac{dv}{dx} = F_{tav} + F_{tar} - (F_{rtav} + F_{rtar} + F_g + F_{aéro})$$

with :

- m_v the mass of the vehicle
- $\frac{dv}{dx}$ vehicle acceleration
- F_{tav} and F_{tar} being respectively the tractive force of the front axle and propulsion of the rear axle
- F_{rtav} and F_{rtar} being respectively the rolling force of the front axle and the rear axle
- F_g The gravitational force on the vehicle equals with the $m_v * g * sin(\alpha)$ angle α with the horizontal (if we have a slope for example).
- $F_{aéro}$ The aerodynamic strength of the car

We will also assume that the vehicle is a traction which brings together the two tensile forces in a single force. Similarly, we will assume a uniformally loaded vehicle to simplify the calculations (knowing that in reality the rear tires will have more weight and so will be more loaded).

So we have $F_r = c * m_v * g$ where $c = 0.005 + \frac{1}{\text{Pression des pneus}} * (0.01 + 0.0095 * (\frac{v}{100})^2)$

For the aerodynamic force we have: $F_{aéro} = \frac{1}{2} * (C_d A * \rho * v^2)$ with Cd: the drag coefficient of our vehicle A, A the frontal angle of our vehicle, rho the density of the air and v the speed of our vehicle .

We can therefore deduce the power required for our vehicle which is:

$$\text{Puissance nécessaire} = F_{tr} * v_{pneus} = (m_v * \frac{dv}{dx} + F_r + F_{aéro} + F_g) * v_{pneus}$$

For an acceleration of 1,736 m/s-2 (0 to 100 in 16 seconds) and a speed of 50 km/h, a mass of 3 tons (loaded) on a flat road we have:

- $m_v * \frac{dv}{dx} = 5208 \text{ N}$
- $F_r = 232.39N$
- $F_{aéro} = 199.76N$

We already notice here that it is the acceleration phase that requires the most power. If we consider that we have a return of 80%, we then have :

$$\text{Puissance nécessaire} = 98 \text{ kW}$$

I. Study of each element

1. Fuel cell (FC)

1.1 Theoretical operation of the fuel cell for our vehicle

The operation of our vehicle is based on the joint use of a fuel cell and a battery. These two elements are very important in the architecture of the system as they are the ones that power the engine of our car.

Now let's study the theoretical operation of a fuel cell.

The purpose of the fuel cell is to transform chemical energy into useful electrical energy to either power the vehicle's electric motor or recharge the vehicle's battery.

A fuel cell is made up of hundreds of similar cells that are the sites of chemical reactions. Each cell can be seen as a subunit of the fuel cell. A cell consists of an anode, a cathode and an electrolyte (liquid separating the two electrodes).

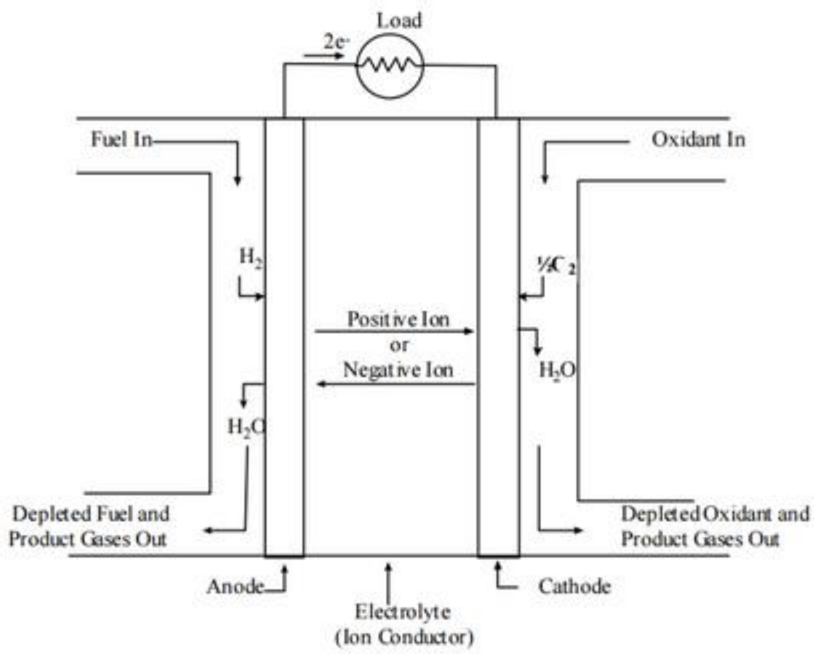


Figure 20: Cell of a fuel cell.

Fuel (usually hydrogen) is introduced into the anodic compartment of the fuel cell, while air or oxygen is introduced into the cathode side of the cell.

The reactants are therefore hydrogen and oxygen. The products of the reaction are therefore water molecules and thermal energy.

Oxidation reaction *at the anode:*

$$H_2 = 2 e^- + 2 H^+$$

Reduction reaction at the cathode:

$$The_2 + 4 H^+ + 4 e^- = 2 H_2O$$

Overall response *to the functioning of the CAP:*

$$2 H_2 + O_2 = 2 H_2O$$

It should be emphasized that, unlike internal combustion engines, in which fuel is mixed with air and combusted, in a fuel cell there is separation of fuel and oxidizer, without fuel combustion.

In addition, in cases other than that of our vehicle, fuel cells may exist with a fuel other than hydrogen.

In addition, two modes of operation should be distinguished for the fuel cell. Depending on traffic conditions and parameters of speed, acceleration etc., it would be wiser to use the fuel cell or battery. The fuel cell is interesting to power the electric motor only when it manages to deliver a voltage constante output. When this is not the case, it is used to recharge the battery. The battery is used to power the electric motor. Thus, the fuel cell is systematically in use when the vehicle is in motion. Either it powers the engine directly, or it recharges the battery.

The advantages of such a fuel cell are the emissions it produces. Indeed, water and heat are low pollutants. However, this remains to be put into perspective because its use requires the joint use of a battery which can be polluting and not reclaimed at the end of its life. In addition, it is necessary to look at the origin of the hydrogen. Depending on the production methods of this hydrogen, its use is more or less environmentally viable.

The conditions of use of a fuel cell in the vehicle sector are quite variable. In particular, the operating temperatures of the heat pumps vary between 50 and 200 ° C.

The output power varies between 0.1 and 500 kW. The output voltage for a cell is about 0.7 V to 0.8 V. So for 400 cells, we get an output voltage around 320 V.

The efficiency of a fuel cell is about 50 to 70% (between the chemical energy provided by hydrogen and the electrical energy output) but if we take into account the production of hydrogen, this yield decreases. Electrical energy must be used to achieve hydrolysis and produce hydrogen. The total return is therefore 30 to 50%.

1.2 Fuel Cell Modeling in Matlab/Simulink

a) Matlab operating diagram

Below is the operating diagram of the fuel cell under Matlab/Simulink.

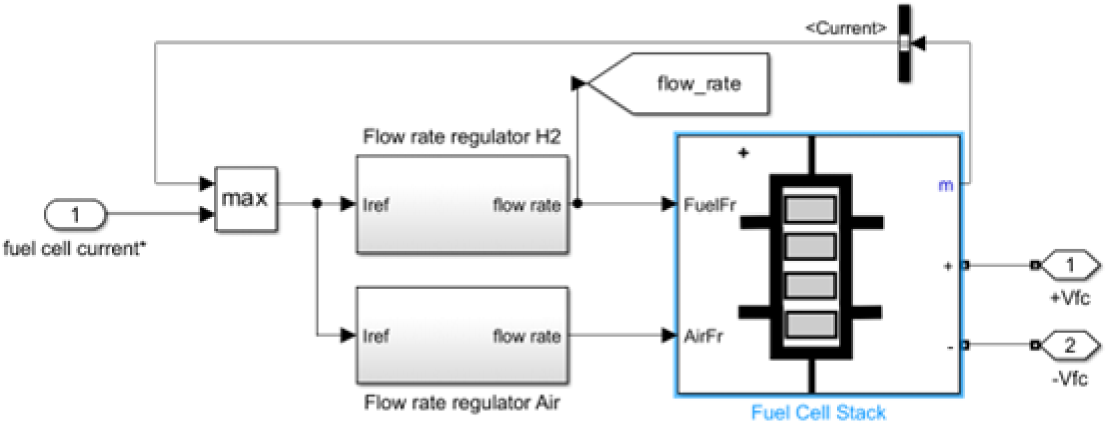


Figure 21: Fuel cell under Simulink.

b) Simulations Matlab :

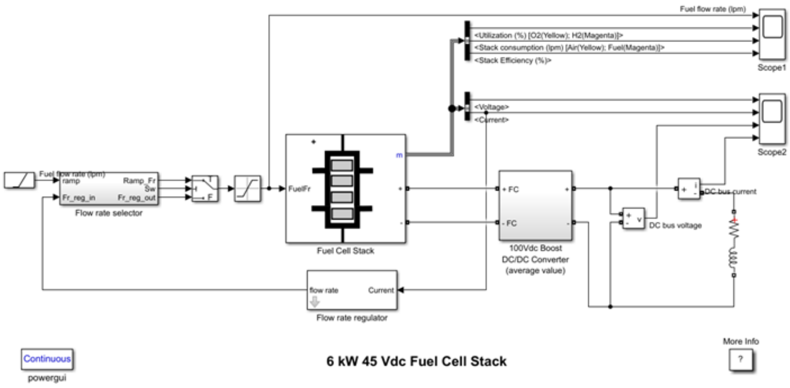


Figure 22: Diagram of the CAP *to exploit* the *output results of the CAP.*

At the entrance, a ramp is chosen, the slope of which may vary according to the simulations.

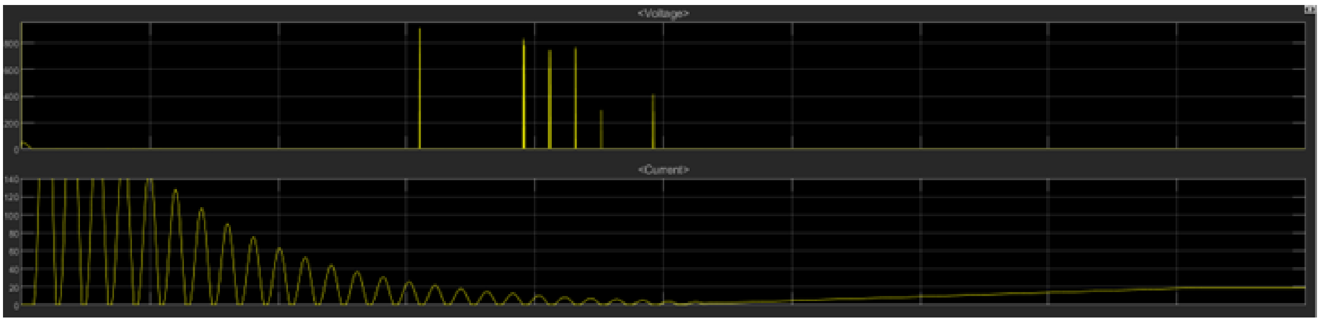


Figure 23: *Evolution* of the *voltage and current at* the *output* of *the AP: observation of* a *dynamic* regime *then a static regime.*

The graph above shows the simulation of an output current and the output voltage for a PEMFC (Proton Exchange Membrane Fuel Cell) at 50 kW and 625 Vdc. The dynamic regime corresponds to the start-up of the heat pump and the static corresponds to the operation after a start-up time, it is the regular operation.

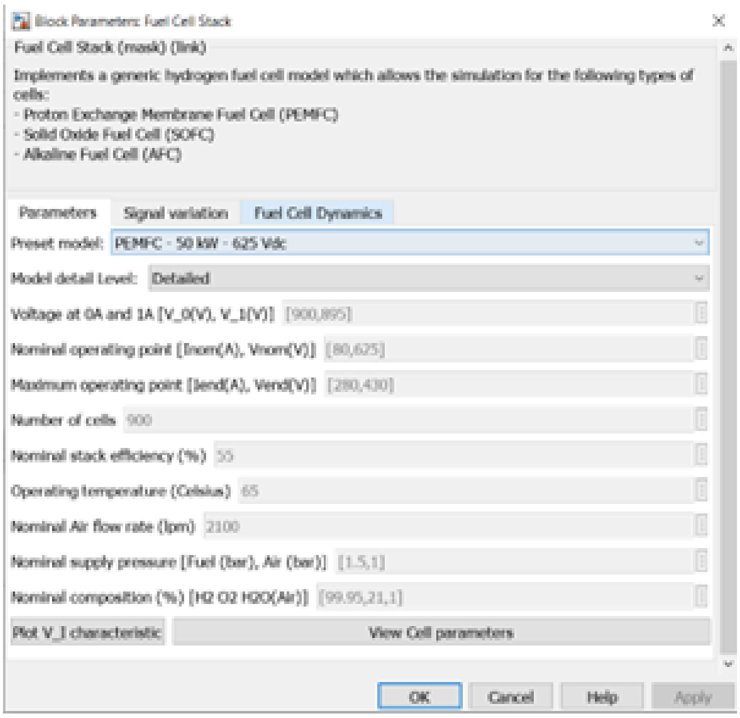


Figure 24: Parameters chosen for simulating the *operation of the CAP. We take the case of 900 cells.*

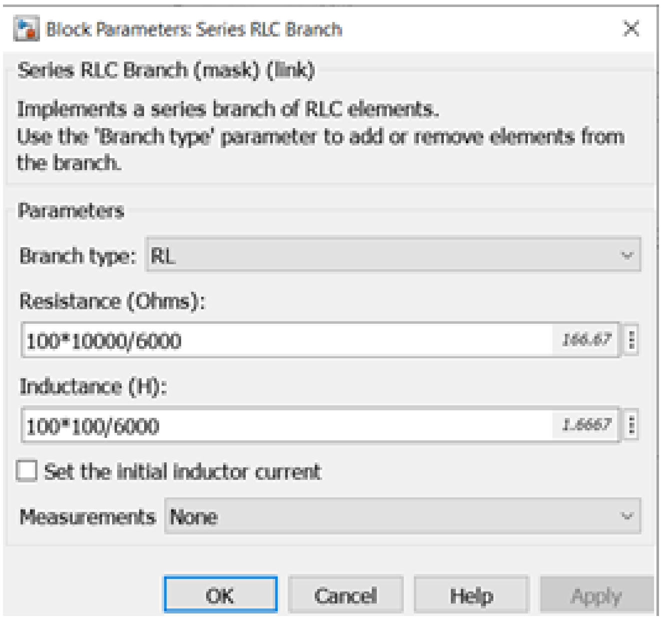


Figure 25: Output load values.

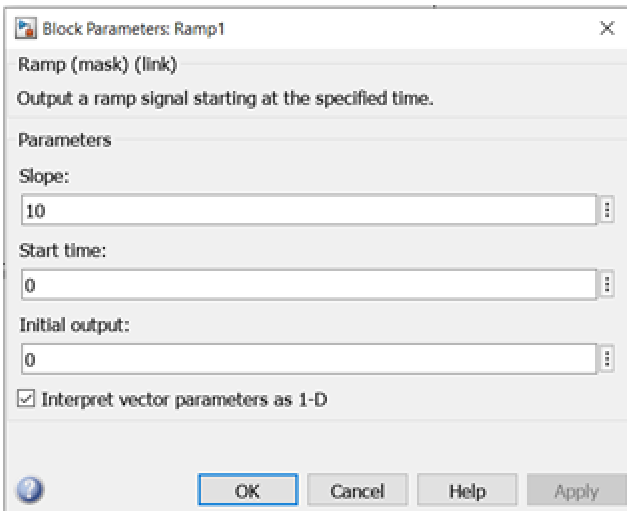


Figure 26: Values of the *slope of the ramp at the entrance.*

Now let's look at the results obtained for the parameters of the figures above:

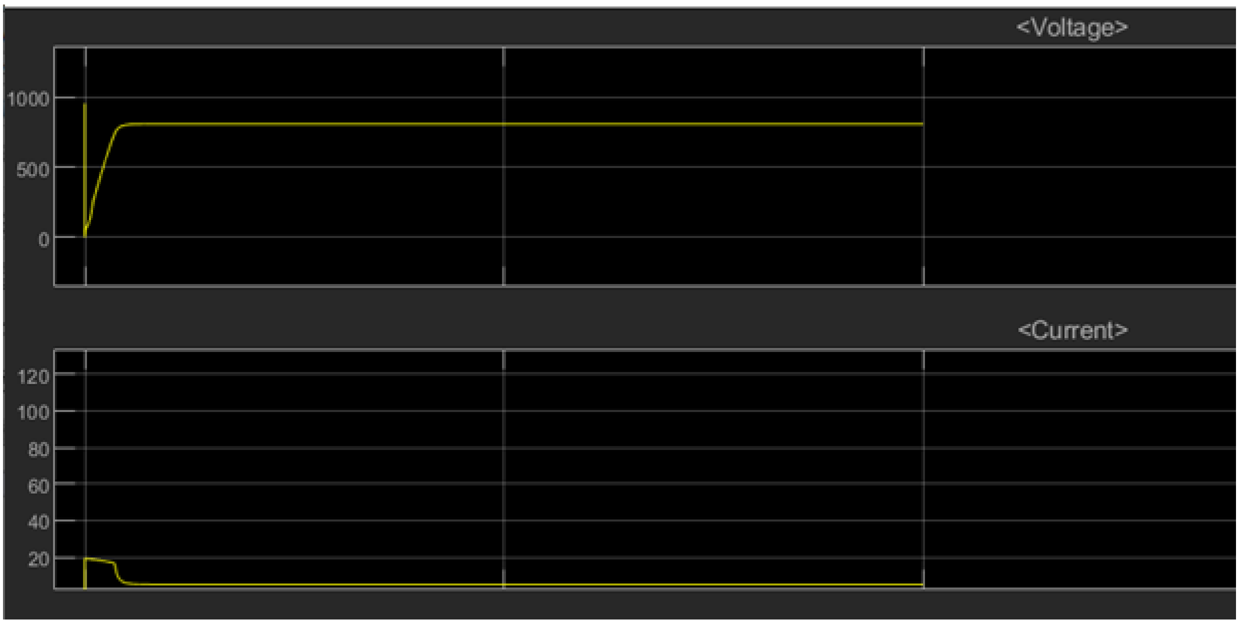


Figure *27: Output voltage and current.*

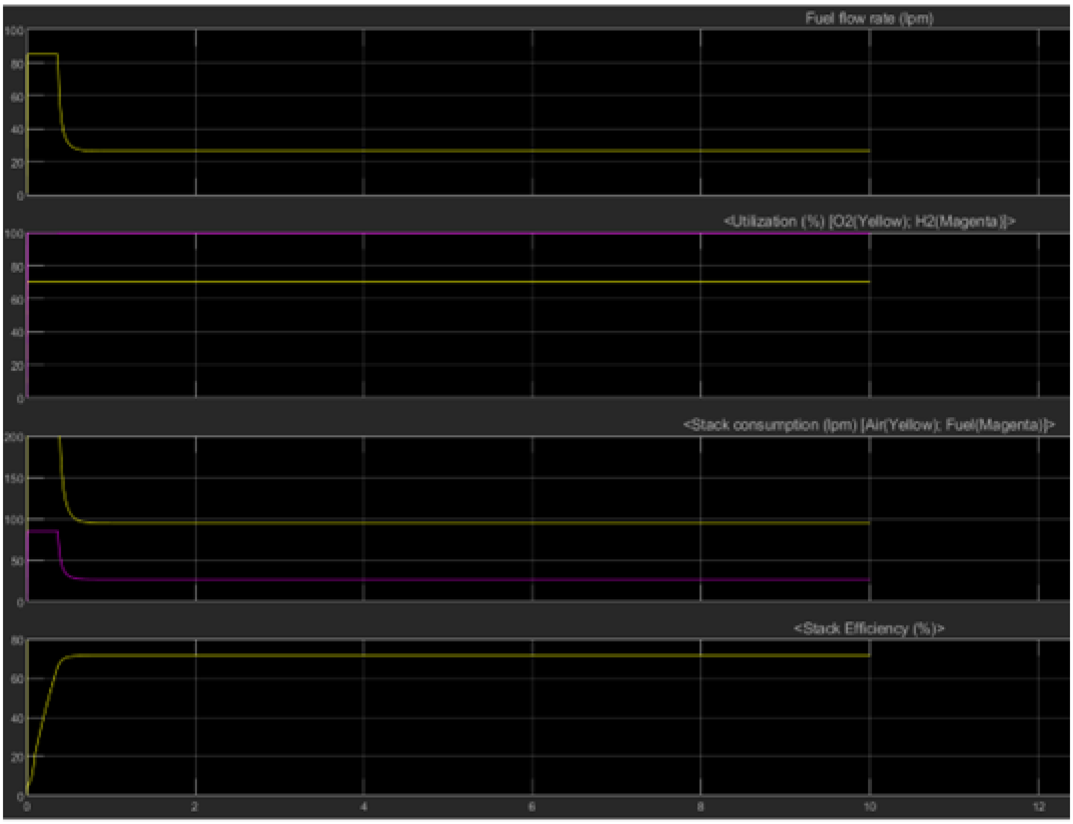


Figure 28 : Fuel flow rate et stack efficiency.

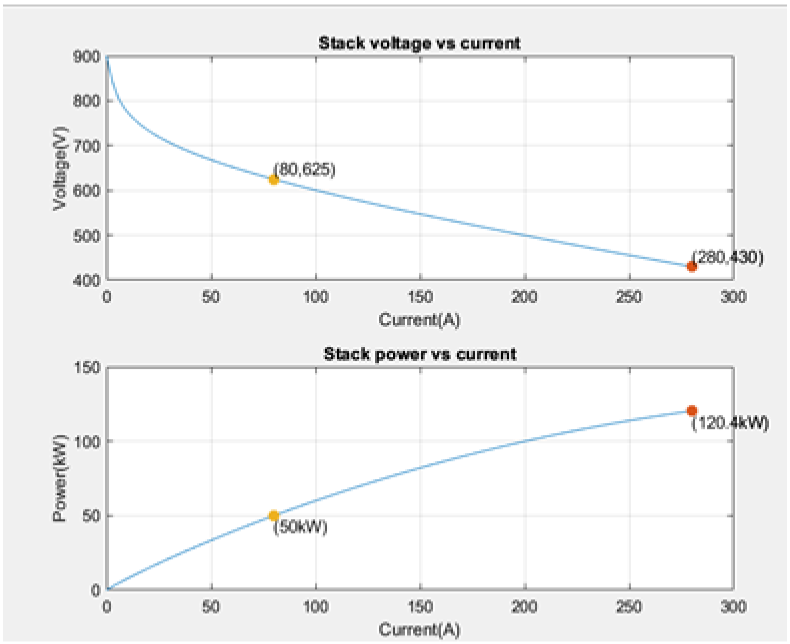


Figure 29: Characteristics as a function of current.

From these simulations and graphical analyses, we can observe that:

- The output voltage is constant and equal to 800V.

- The output current is constant and has a value close to the zero constant.
- The efficiency of the system is constant at around 70%.
- The flow rate is constant.

In addition, we obtained the voltage/current and stackpower/current characteristics for the selected parameter values.

(c) Influence of the load on the output current and voltage according to the values of the load (resistance)

- R = 0.01667 Ω :

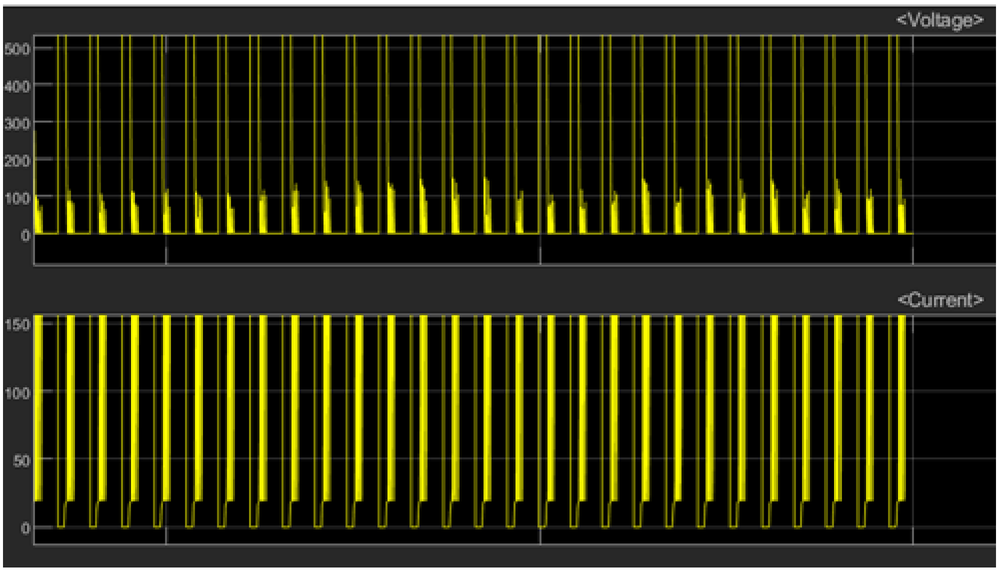


Figure 30: Voltage and current for R = 0.01667 Ω.

- R = 1.667 Ω :

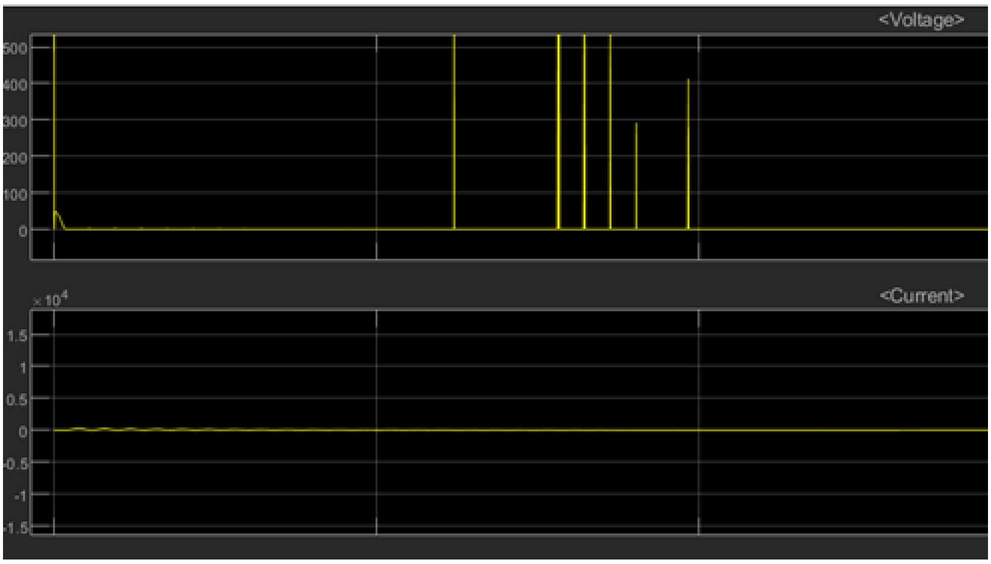


Figure 31: Voltage and current for R = 1.667 Ω.

- R = 166.667 Ω :

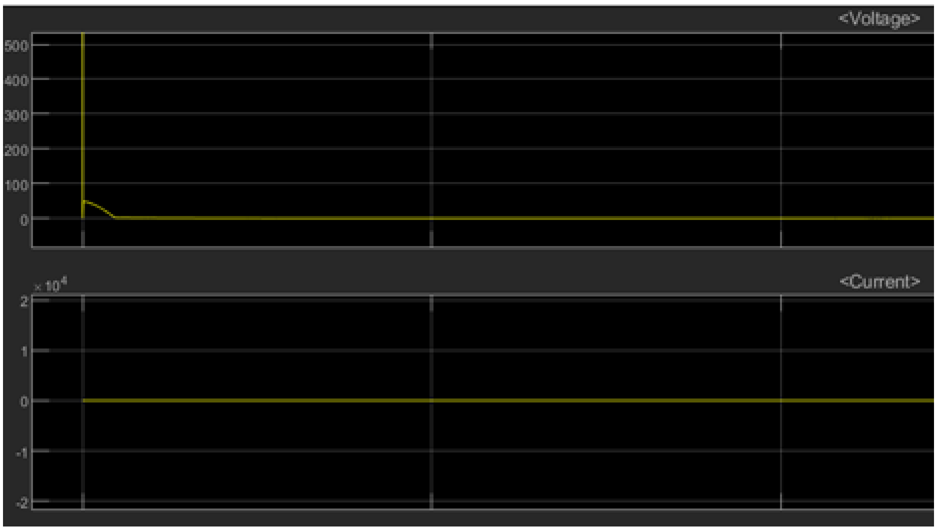


Figure 32: Voltage and current for R = 166.667 Ω.

- R = 16 666,667 Ω :

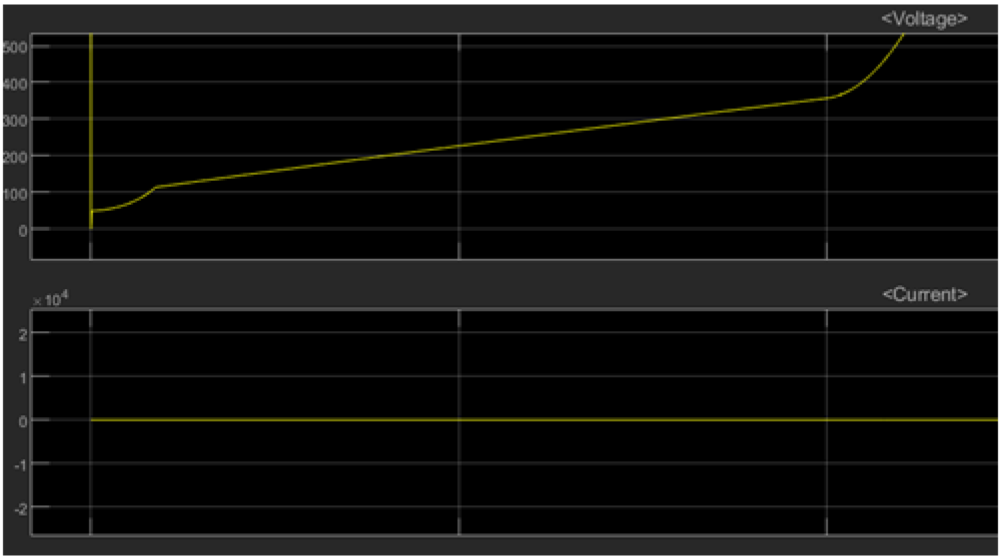


Figure 33: Voltage and current for R = 16,666,667 Ω.

After testing for different resistance values (load value), it can be seen that there is a significant influence on the output parameters.

Indeed, for voltage, we go from a sinusoidal, or at least periodic, system to a signal with a few peaks at a constant signal zero to a signal that diverges as and as the value of resistance increases.

For the current, we quickly pass from a periodic signal to a very attenuated signal, there are some oscillations of low intensity on the first seconds of the simulation and then the signal is constant with the value zero as the resistance increases.

(d) Influence of slope on the effectiveness of the CAP

- Slope = 1 :

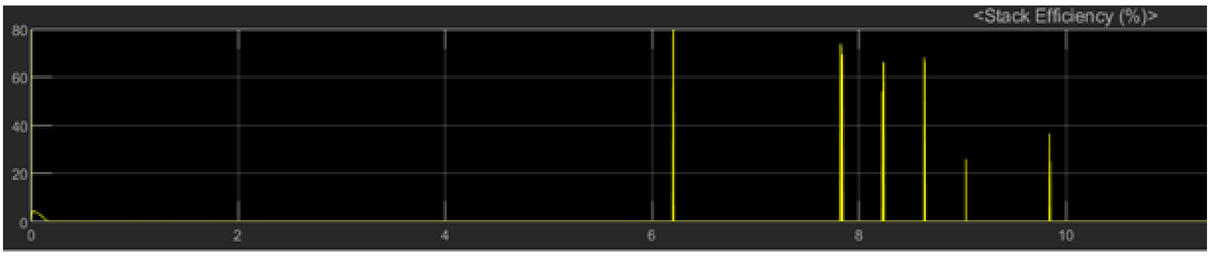


Figure 34: Efficiency for slope of 1.

- Slope = 5 :

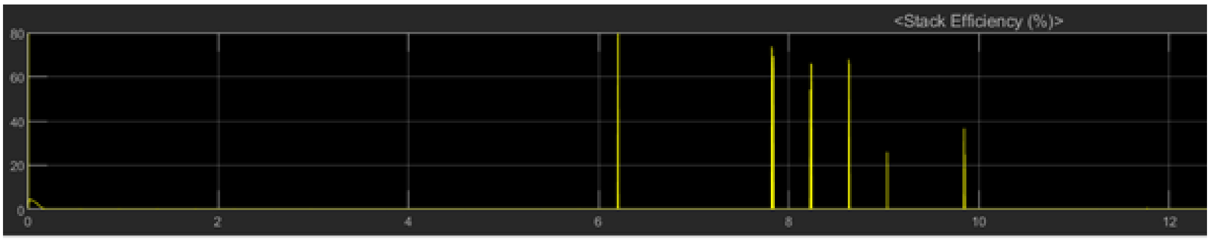


Figure 35: Efficiency for slope of 5.

- Slope = 10 :

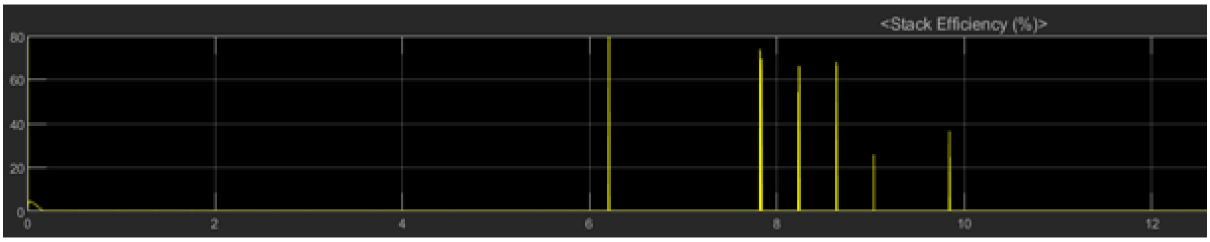


Figure 36: Efficiency for slope of 10.

- Slope = 100 :

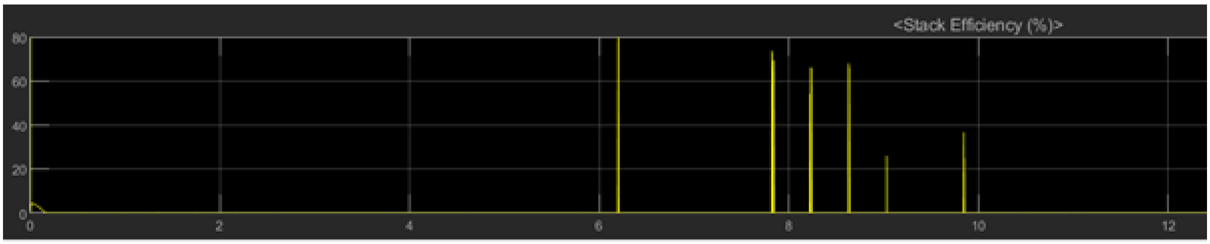


Figure 37: Efficiency for slope of 100.

After several simulations by varying the value of the slope of the inlet ramp, it would seem that this parameter has little or no influence on the efficiency of the CAP. Indeed, the curves obtained all have similar peaks.

1.3 Fuel Cell Bond Graph

The Bond Graph diagram of the fuel cell below from a thesis. There is a hydrogen supply at the anode. In the case of a simulation of the overall car, we could reproduce this Bond Graph scheme under 20-Sim.

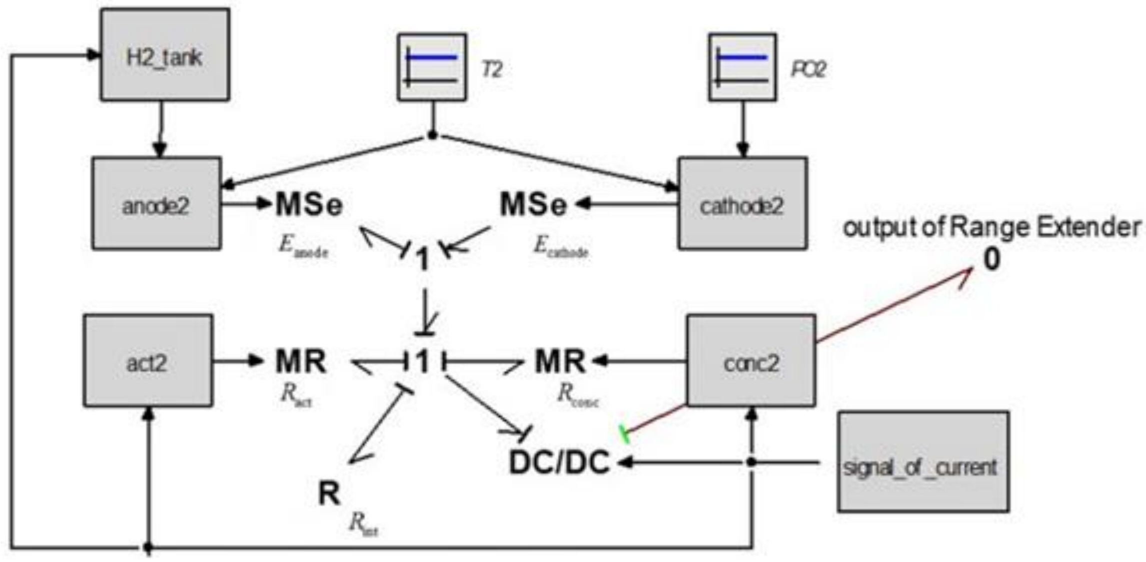


Figure 38: Bond Graph diagram of a fuel cell

2. Battery

2.1 Theoretical operation of the battery for our vehicle

The circuit parameters can be modified to represent a specific battery type and its discharge characteristics. A typical discharge curve consists of three sections.

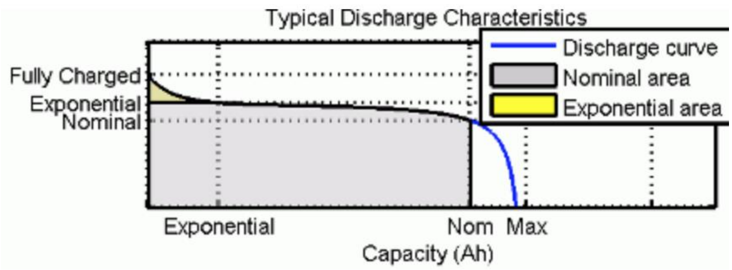


Figure 39: Typical discharge curve

The first section represents the exponential voltage drop when the battery is charged. The width of the drop depends on the type of battery. The second section represents the charge that can be extracted from the battery until the voltage falls below the nominal voltage of the battery. Finally, the third section represents the total discharge of the battery, when the voltage drops rapidly.

When the battery current is negative, the battery is recharged according to a charging characteristic.

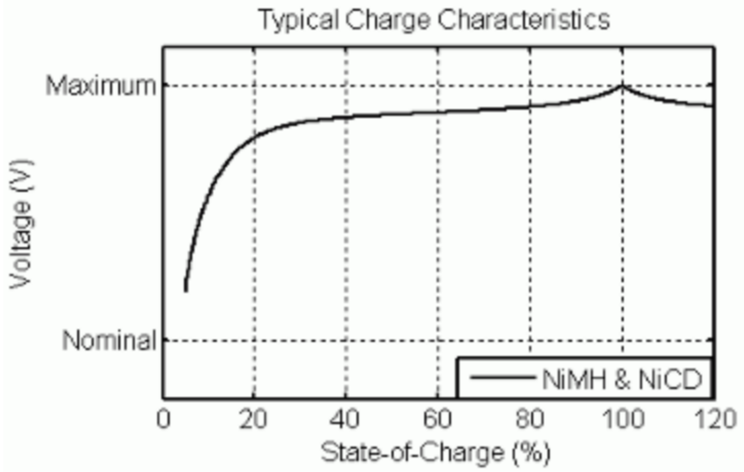


Figure 40: Voltage / SOC curve - NiMH

A battery's state of charge (SOC) is a measure of the battery's charge, expressed as a percentage of the full charge. The depth of discharge (DOD) is the digital complement of the SOC, such that DOD = 100% - SOC.

For example, if the SOC is :

-100% - The battery is fully charged and the DOD is 0%.

-75% - The battery is 3/4 charged and the DOD is 25%.

-50% - The battery is half charged and the DOD is 50%.

-0% - The battery is not charged and the DOD is 100%.

For nickel-cadmium and nickel-metal-hydride battery types, the model uses these equations.

- Discharge Model (i* > 0)

$$f_1(it, i*, i, Exp) = E_0 - K \cdot \frac{Q}{Q - it} \cdot i* - K \cdot \frac{Q}{Q - it} \cdot it + \text{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot 0\right)$$

- Charge Model (i* < 0)

$$f_2(it, i*, i, Exp) = E_0 - K \cdot \frac{Q}{|it| + 0.1 \cdot Q} \cdot i* - K \cdot \frac{Q}{Q - it} \cdot it + \text{Laplace}^{-1}\left(\frac{Exp(s)}{Sel(s)} \cdot \frac{1}{s}\right).$$

With the following parameters :

- EBatt is the nonlinear voltage, in V
- E0 is the constant voltage, in V
- Exp(s) is the dynamics of the exponential zone, in V
- K is the   polarization constant in V/Ah or the polarization resistance in Ohms
- i* is the dynamics of the current at low frequency, in A
- i is the ant heart of the battery, in A
- Q is the maximum battery capacity, in Ah
- A is the exponential voltage, in V
- B is the exponential capacity, in Ah-1
- Sel(s) represents battery mode

  Salt(s) = 0 during battery discharge

  Salt(s) = 1 while charging the battery

2.2 Operating diagram in Matlab/Simulink

The Battery Pack implements a generic dynamic model that represents the most common types of rechargeable batteries.

This figure shows the equivalent circuit that the block models.

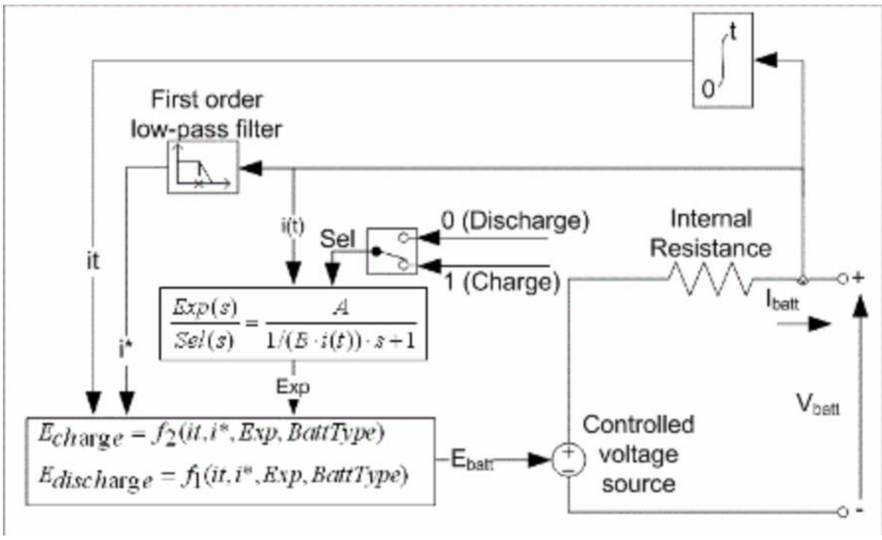


Figure 41: Battery - equivalent model - in Simulink.

2.3 Simulation in Matlab/Simulink

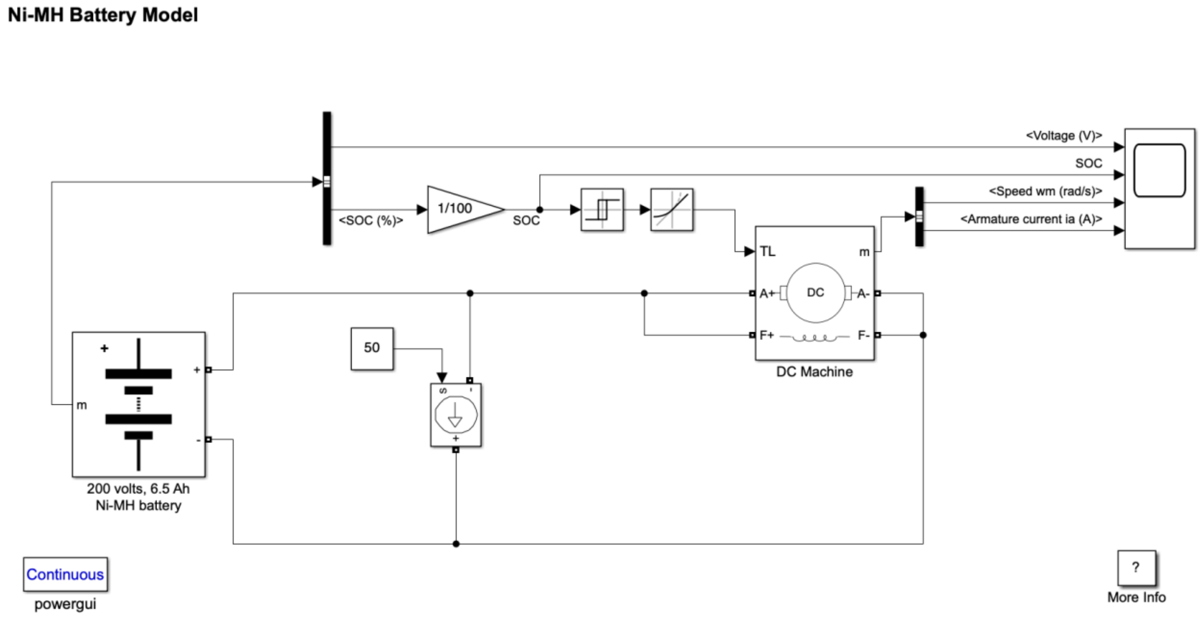


Figure *42: Diagram of* the *battery to exploit the output results.*

At t = 0 s , the DC machine is started with the battery power. The speed increases to 120 rad/s. The battery is also discharged by the constant DC charge of 50 amps. A t = 280 s, the SOC falls below 40%. A mechanical torque of -200 Nm is applied to the machine so that it acts as a generator and provides a current of 100 A. Therefore, 50 A go to the load and 50 A are used to recharge the batterie. At t = 500 s, the SOC exceeds 80%. The mechanical torque is removed and the machine works freely. And the cycle starts again.

The battery is connected to a constant charge of 50 A. The DC machine is connected in parallel with the charand operates with no-load torque. When the state of charge of the battery is less than 0.4 (40%), a negative torque of 200 Nm is applied to the machine which then acts as a generator to recharge the battery. When the SOC exceeds e 80%, the charging torque is removed and only the battery powers the 50 A charge.

Battery voltage, SOC, motor speed and motor current signals are available at the block output.

Below are the parameters of the battery and the DC machine.

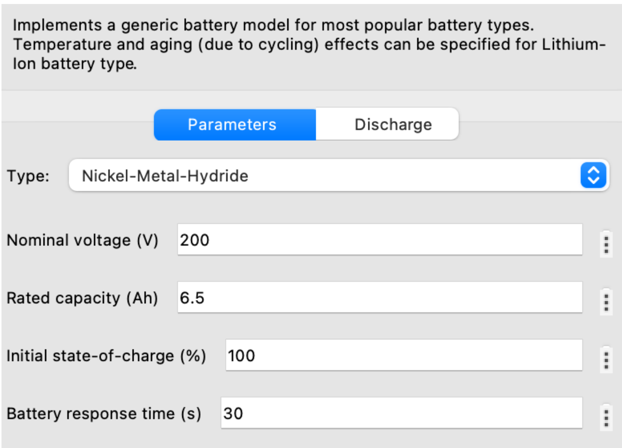


Figure 43: Battery Settings

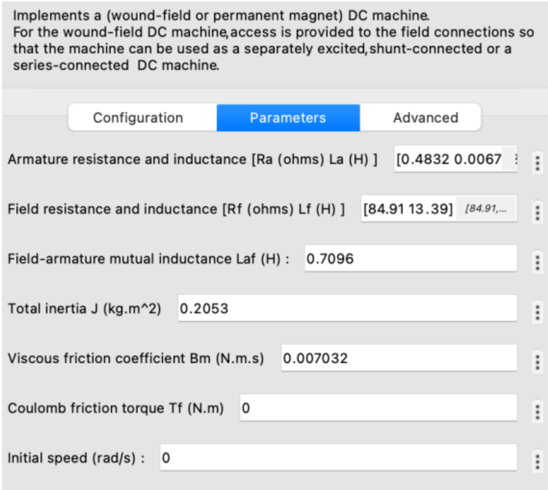


Figure 44: DC Machine Settings

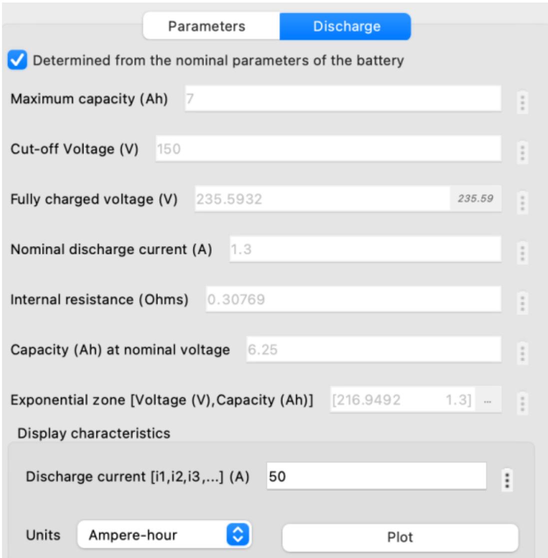


Figure 45: Battery discharge parameters

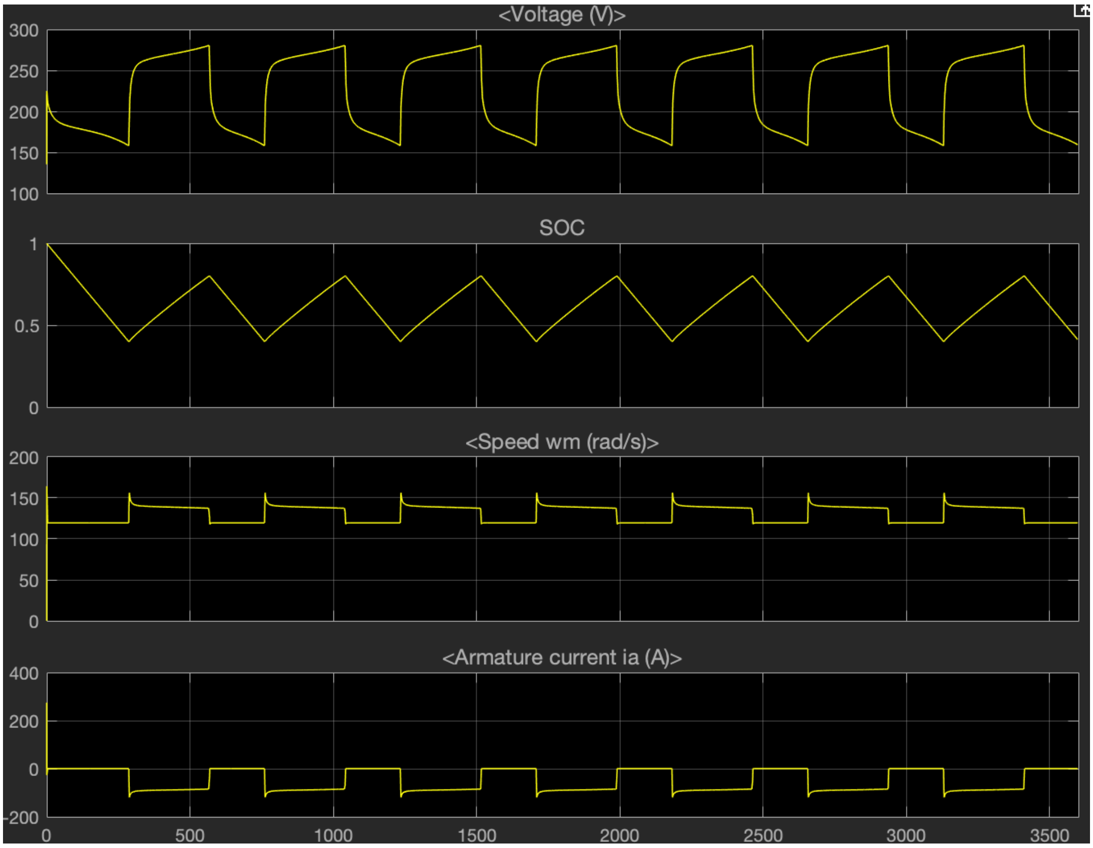


Figure 46: Voltage curves, SOC, Rotational speed, Current

2.4 Parameter analysis

2.4.1 Change in nominal voltage

We will vary the nominal voltage to see its influence on the output parameters.

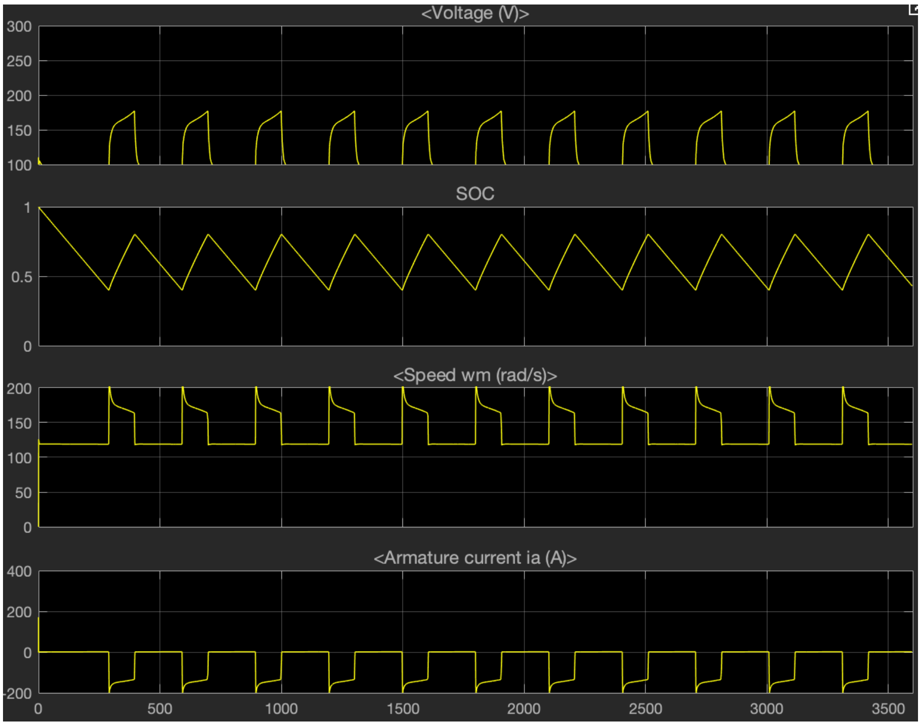


Figure 47: Voltage curves, *SOC, Rotational speed*, *Current*
Nominal voltage *of 100V*

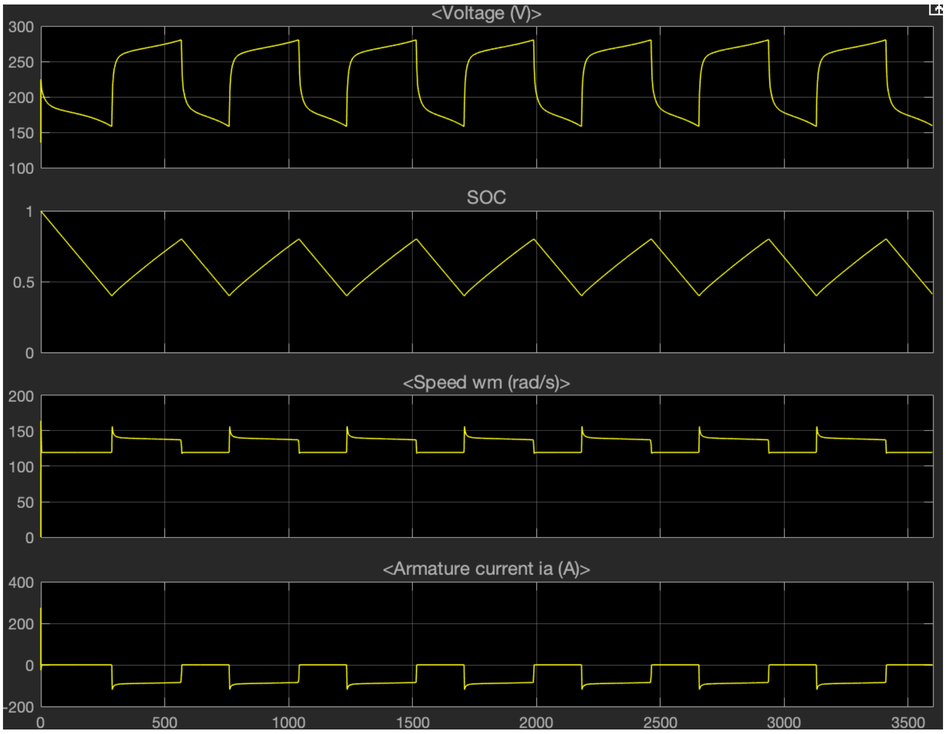


Figure 48: Voltage curves, *SOC, Rotational speed*, *Current*
Nominal voltage *of 200V*

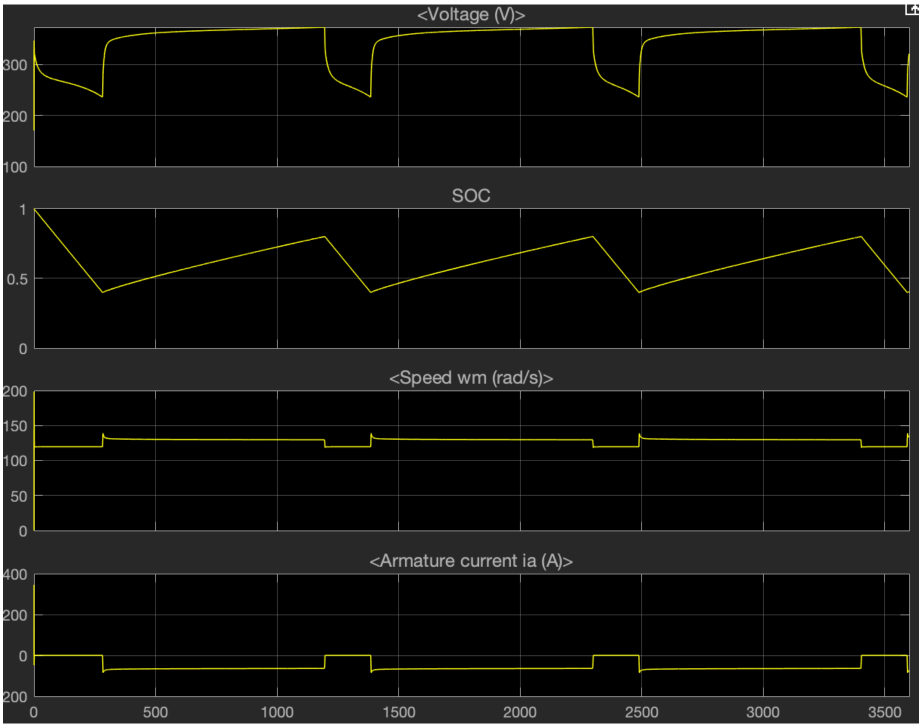


Figure 49: Voltage Curves, *SOC, Rotational Speed, Current*
Nominal voltage *of 300V*

The cycles are of a longer duration as the nominal voltage is greater. The parameter values are similar.

2.4.1 Variation in SOC

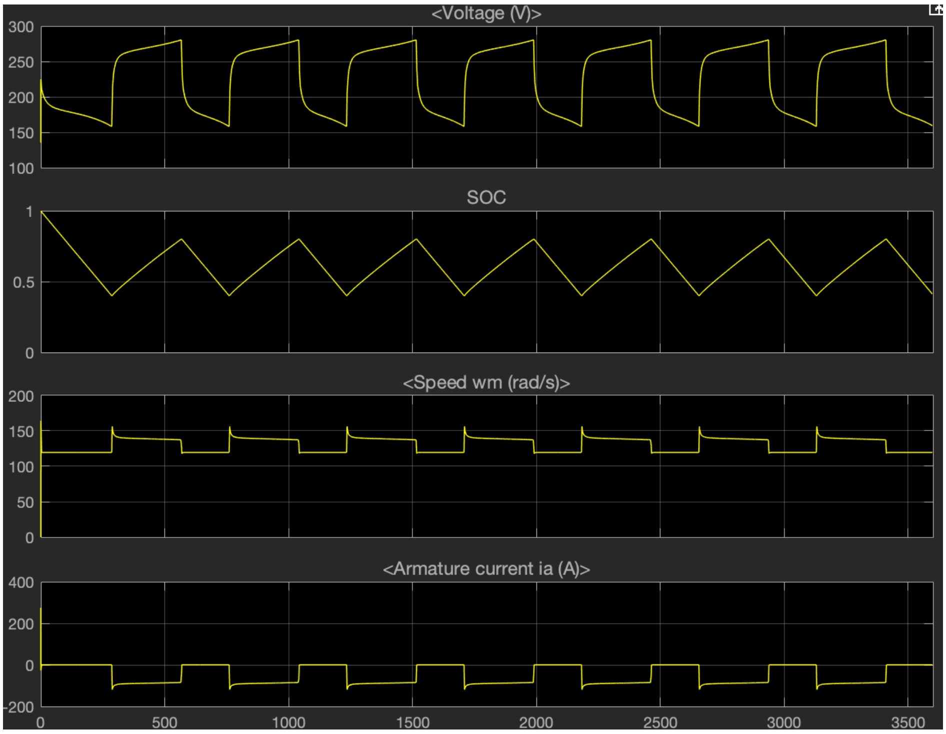


Figure 50: Voltage curves, *SOC, Rotational speed, Current*

100% SOC

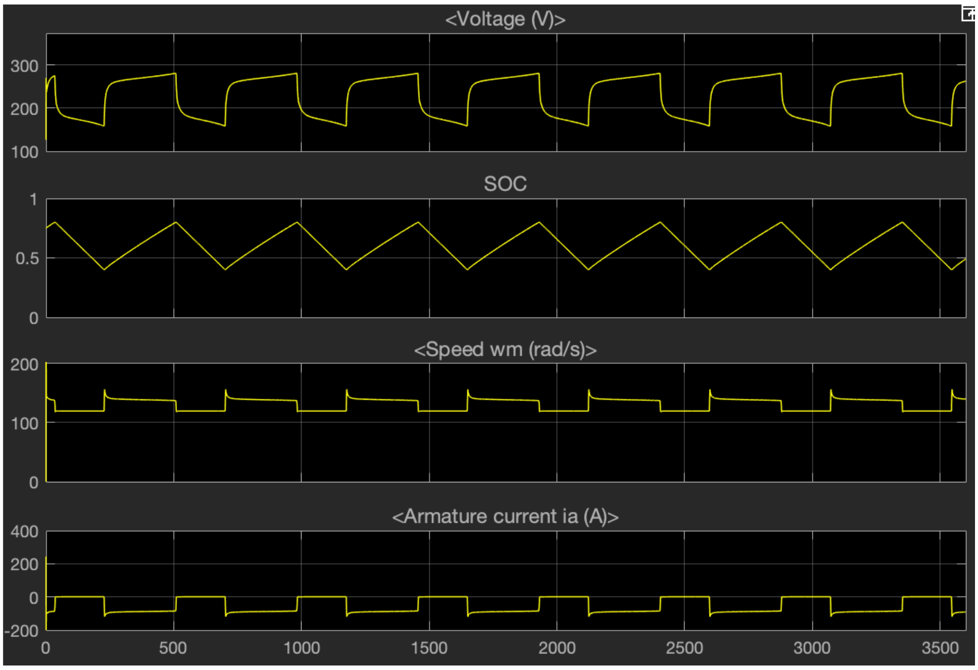


Figure 51: Voltage curves, SOC, Rotational speed, Current

SOC of 75%

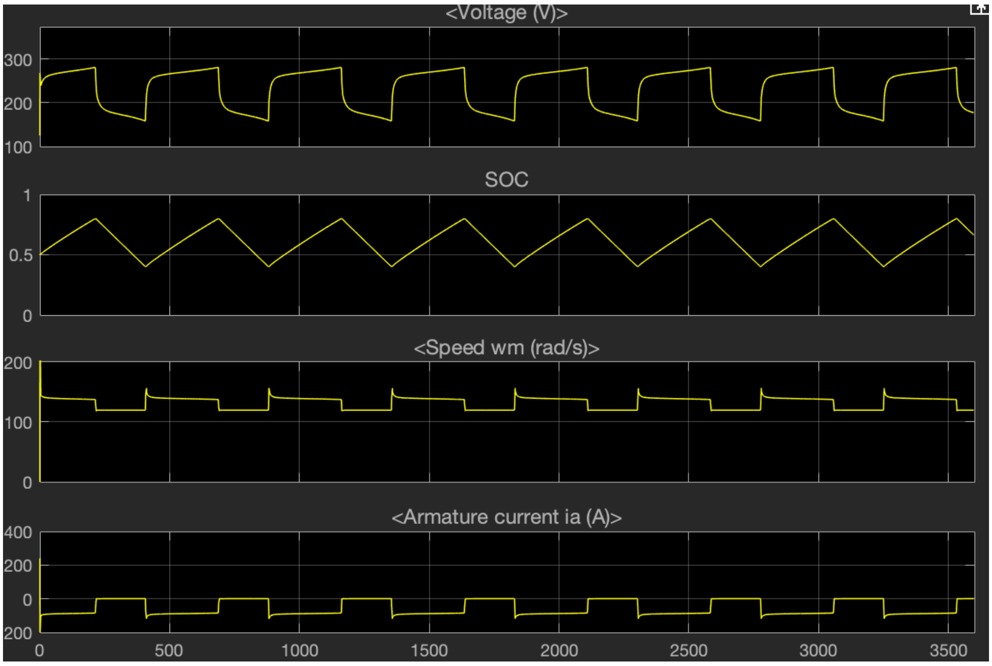


Figure 52: Voltage curves, SOC, Rotational speed, Current

50% SOC

When the SOC is not fully charged, it is found that the maximum voltage during cycles is lower.

3.Moteur

The vehicle has a three-phase motor of 136 Hp (100 kW) with a maximum torque of 300 Nm at 3674 rpm and an operating power of 400V.
This engine allows the car to generate 0 carbon emissions at the time of operation.
The three-phase motor is used in various cars and industry for the transformation of electrical energy into mechanical energy. And its principle of operation is the same as that of another electric motor.
The engine allows a maximum speed of 130 km/h for a 3.5-ton car

There are several ways to optimize a three-phase AC motor:

- Voltage and frequency control: by adjusting the voltage and supply frequency, it is possible to optimize the performance of the motor in terms of torque and power.
- Temperature control : by monitoring the engine temperature, we can avoid overheating and improve the durability of the engine.
- Rotor balancing: By balancing the rotor , vibration and engine noise can be reduced, which also improves durability.
- Preventive maintenance: By performing regular maintenance, you can extend engine life by detecting and correcting potential problems at an early stage.
- Proper choice of materials : by choosing the right materials for engine components, you can improve corrosion and degradation resistance, which also improves sustainability.

3.1 Voltage and frequency control

To control the voltage and frequency of the motor, several factors are used. First, variable frequency drives are used. Variable frequency drives (VFDs) are electronic devices that can adjust the motor feed frequency in real time. This makes it possible to control the speed and power of the engine. So, reduce losses in certain situations and better distribute power. This one is useful especially with the changes of the slopes en route.
Then the transformers are used. Transformers can be used to adjust the supply voltage of the motor. Transformers allow us to link the different devices in the electrical chain; or the path from the hydrogen fuel cell to charging for braking. However, this method will not affect the frequency of feeding. However, for this we use voltage regulators.
Voltage regulators can be used to keep the supply voltage constant, regardless of variations in the general supply voltage.

3.2 Temperature Control and Rotor Balancing

For temperature control, it is important to keep a reduced temperature to avoid losses in electrical conduction, however allow the proper mechanical operation of the engine.

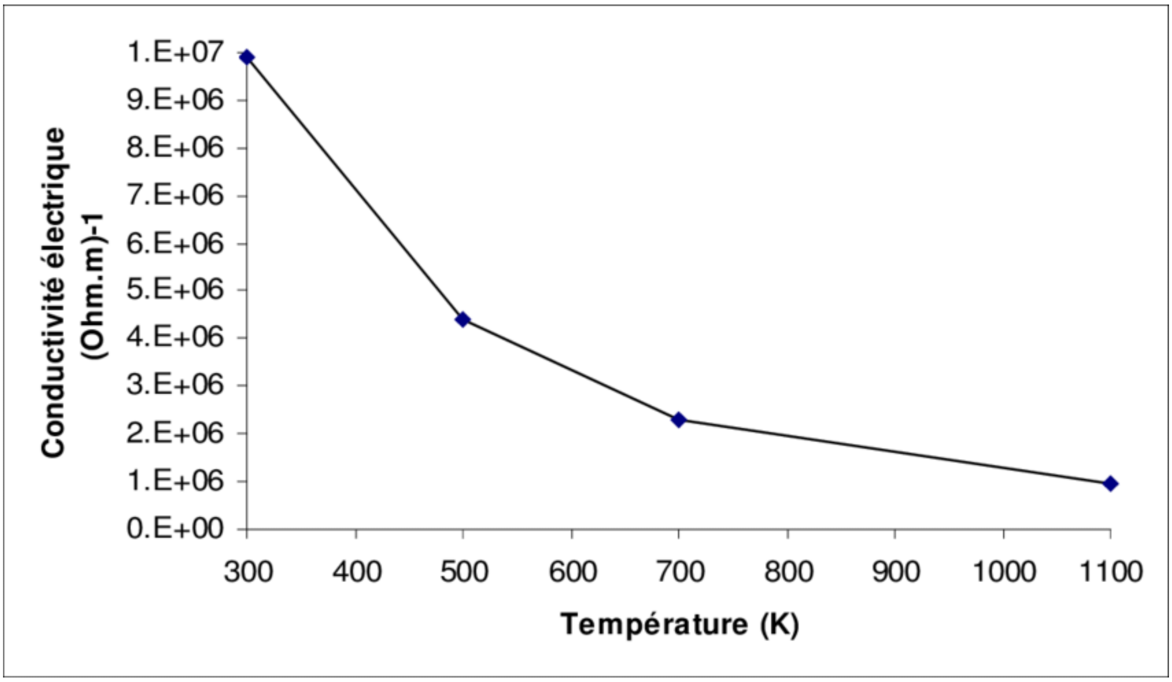


Figure 53: Thermal conductivity curve *temperature of a strongly coupled AC motor*

As can be seen in the figure, the electrical conduction of the motor fuel system is reduced as a function of temperature change. This curve was plotted by experiments using a low- and high-coupling AC motor. So we observe that to reduce losses it is important to avoid temperature increase.

Engine operation was simulated to observe where the temperature increased the most. Here are the results:

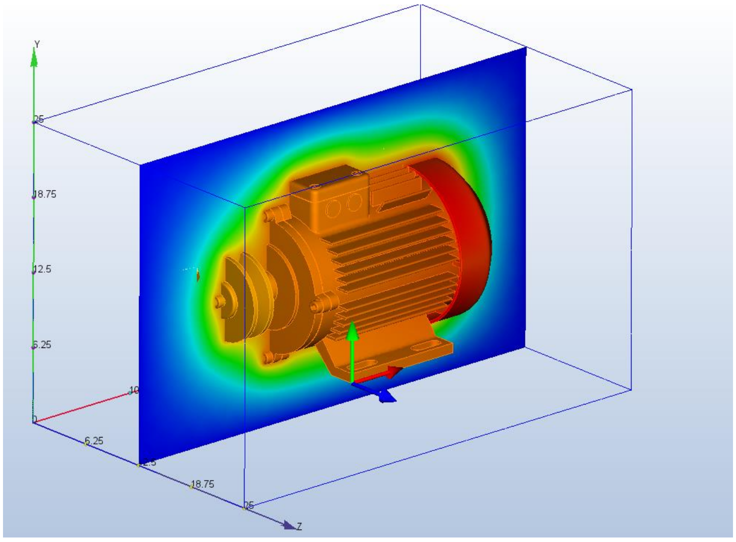


Figure *54: Temperature increase* of *an* AC *motor in operation*

We can notice that the heating zone is the part where we have the induction and the current, so it would be interesting to position it on the air intake to reduce the temperature at the time of operation.

3.3 Choice of materials

For the choice of materials, it is possible to analyze different parameters. As part of this project, we were left with an engine manufactured by a supplier. However, with the Granta software and the following properties , it is possible to create a graph of the materials for the different parts and to improve the properties by considering other factors such as the price and specifications of the car.

- **Electrical** conductivity : Conductive materials such as aluminum and copper have commonly been used for motor stator and rotor windings.
- **Heat resistance** : Materials that can withstand high temperatures, such as aluminum alloys, are typically used for engine components that generate heat.
- **Corrosion resistance** : Corrosion-resistant materials, such as stainless steel alloys, can be used for parts exposed to corrosive environments.
- **Lightweight**: Lightweight materials such as aluminum and magnesium can be used to reduce the overall weight of the engine, which improves the fuel efficiency of the car.
- **Durability** : Durable materials such as high-strength steel alloys can be used for parts of the engine subject to heavy mechanical loads, such as pulleys and gears.

3.4 Matlab Optimization

Finally, we used the Matlab code provided by Mr. Gillon to simulate the three configurations analyzed on the current TP, with the objective of selecting the one that was closest to our needs.

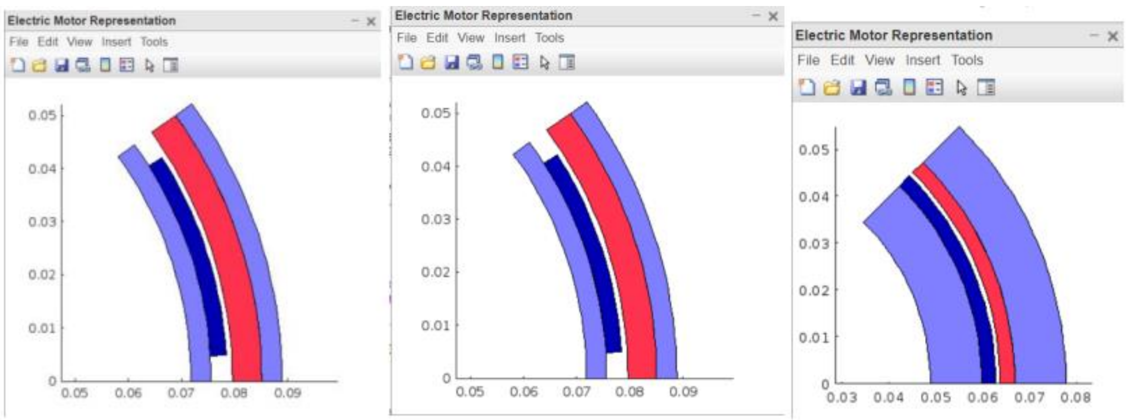


Figure 55: Different possible configurations of an optimal engine

For our car, the third option represents a possible optimization. The one because in the third profit format, we have a minimization of losses by joule effect. Even though engine costs and costs are increasing, our main goal is to reduce losses.

4.Convertisseur DC/DC

The converter will for our vehicle have as main interest the control of the DC voltage of the battery, increasing or decreasing it depending on the system and the power necessary.

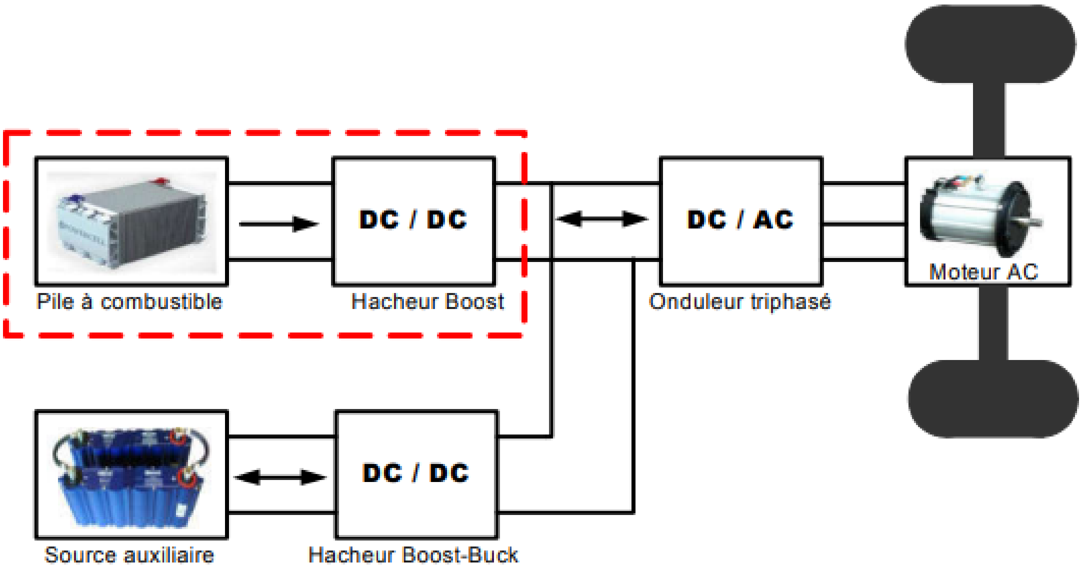


Figure 56: Energy Structure of a Fuel Cell Electric Vehicle

In a powertrain of a hybrid vehicle, the use of an adaptation system between the supply loads and the load which may be an AC motor or a Direct current is required. This system is a power electronics converter that must condition and manage energy via a continuous bus. Thus, the latter can be fixed or variable depending on the specifications and the mode of operation of the system.

A) **Theoretical** aspect

There are two types of DC /DC converter:

- Isolated DC/DC converters
- Non-isolated DC/DC converters

1) **Isolated** DC/**DC** converter

In most applications, it is desirable to use a transformer to achieve isolation between the input and output of the converter.

Here are 2 examples of basic circuit configurations for isolated DC /DC converters:

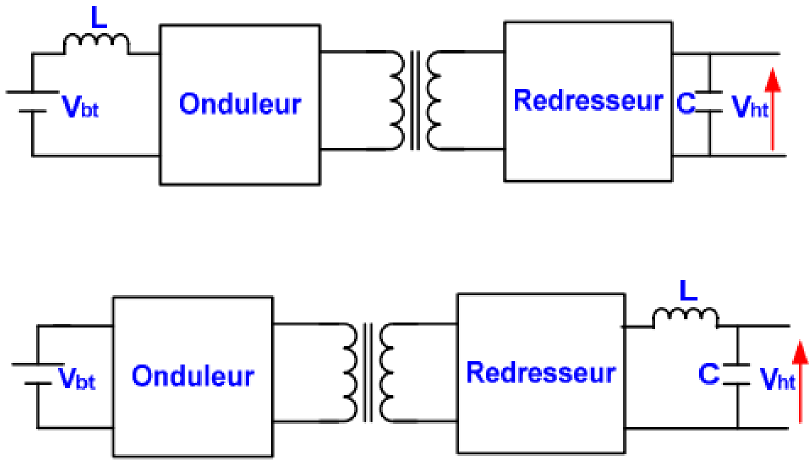


Figure 57: Basic Configurations of the Isolated DC-DC Converter

The inductor that serves as a current source can be placed on the low or high voltage sides. Placing the inductor on the low voltage side requires a large current carrying component. Placing the inductor on the high-voltage side requires a high-voltage semiconductor device. It is also possible to integrate this inductance into the leakage inductor of the transformer.

The pu sh-pull converter shown in the figure below is one of the topologies suitable for fuel cell applications. This converter is suitable for low voltage applications with low consumption. Its main disadvantage is that it handles the input timetwice. For this purpose, a high-voltage device (MOSFET or IGBT) is required. In this case , there will be high conduction losses due to a high conduction voltage drop and, consequently, low efficiency.

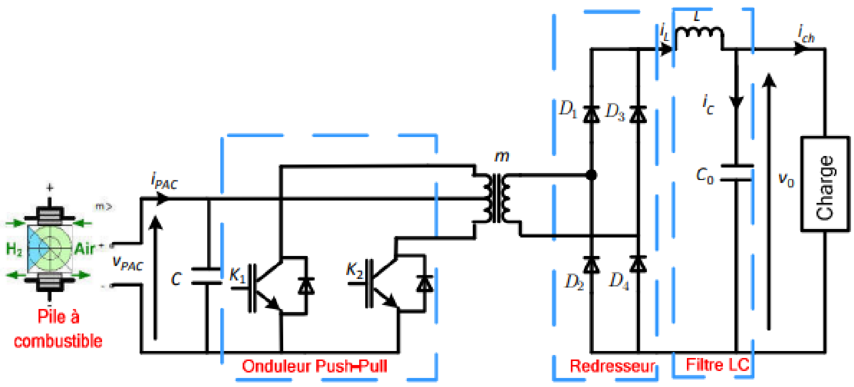


Figure 58: Isolated push-pull DC-DC converter

2) Non-isolated DC/DC converters

Non-isolated converters are used in applications to increase voltage. Several DC /DC Boost topologies are available to improve efficiency, voltage gain, and power handling capability.

The topology that turns out to be the most suitable today is the topology called floating converter-dualBoost (FDB), which is found below.

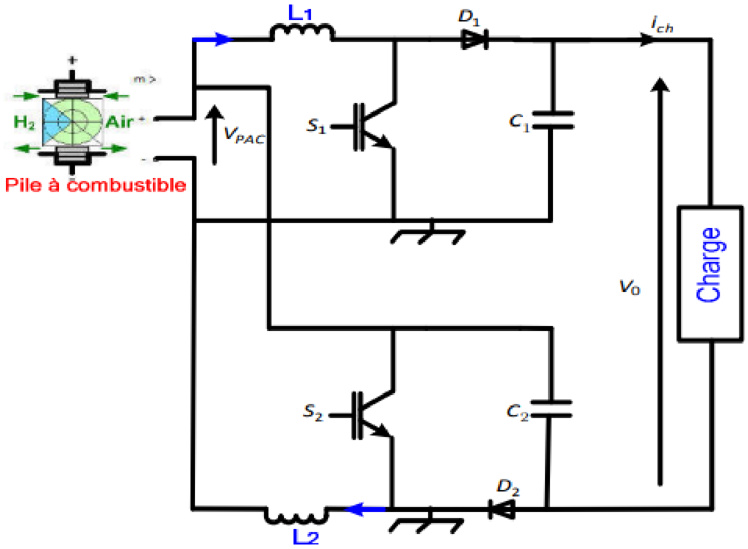


Figure 59: Floating Double Boost Converter *(FDB)*

In fact many different topologies can be derived from the FDB convertisseur, the two main ones being firstly the floating double boost interleaved converter (FDIDB) and secondly the boost-double stage double floating amplification (FDBDSB).

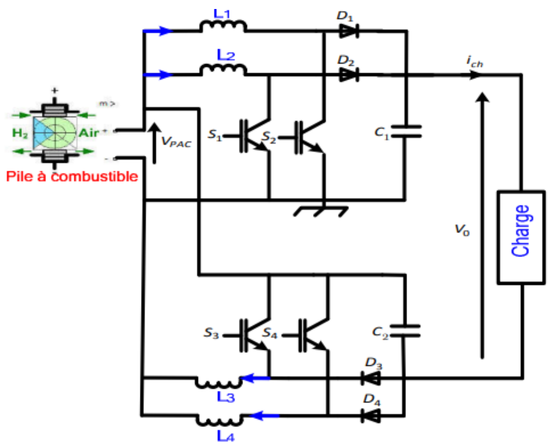


Figure 60: Dual Boost *Dual Boost* Floating *Between Left (FDIDB)*

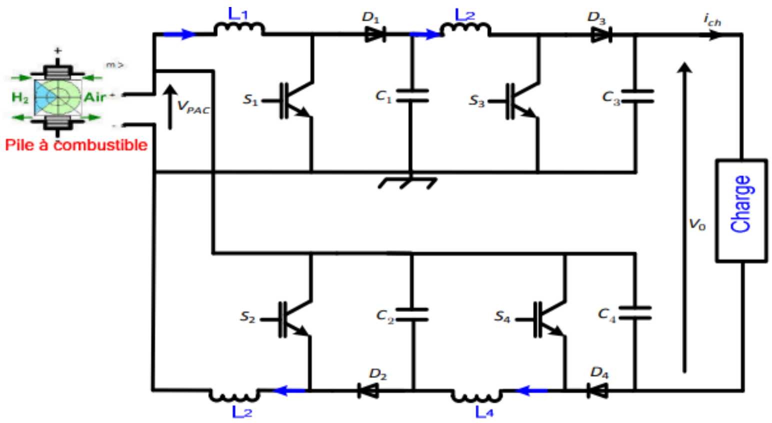


Figure 61: Floating Double Stage Dual Amplification Boost-to-Stage Converter (FDBDSB)

The voltage gain of the FDIDB topology is: $\frac{V_0}{V_{PAC}} = \frac{1+d}{1-d}$

And as for the FDBDSB topology, the voltage gain is: $\frac{V_0}{V_{PAC}} = \frac{2}{(1-d_1)(1-d_2)} - 1$

5. Cooling

There are several elements in our vehicle that will require cooling :

- The battery that must be kept around 20 °C +/- 5 °C
- The fuel cell that must be kept around 65 °C +/- 20 °C
- The motor that must be kept around 100 °C +/- 30 °C

All these elements will generate heat by Joule effect due to the current that passes through them as well as their internal resistance. The power dissipated by Joule effect is equal to RI^2.

The battery has an internal resistance of 0.207 Ohm tandis that the fuel cell has an internal resistance of 0.66404 Ohm knowing that the current in both is maximum 280 Amps and is on average 100 A. We therefore have a maximum power release of 52 kW for the heat pump and 16 kW for the battery, and the nominal power is then 4 kW for the heat pump and 1.3 kW for the battery.

Knowing that the heat exhaust is not the same at all times with acceleration, we decided to couple the two conventional cooling systems , cooling air and fluid cooling. Thus air cooling will be able to cool the components at any time and during the phases (acceleration) where the temperature will increase, a coolant circuit The first system will be used. We will also have a system to warm up the components when starting the vehicle if there is a need.

Knowing that the 3 components do not have the same operating temperature, the cooling systems of chacun will be different.

We will come to simulate the evolution of the temperature around the battery which is the most sensitive part to validate our model.

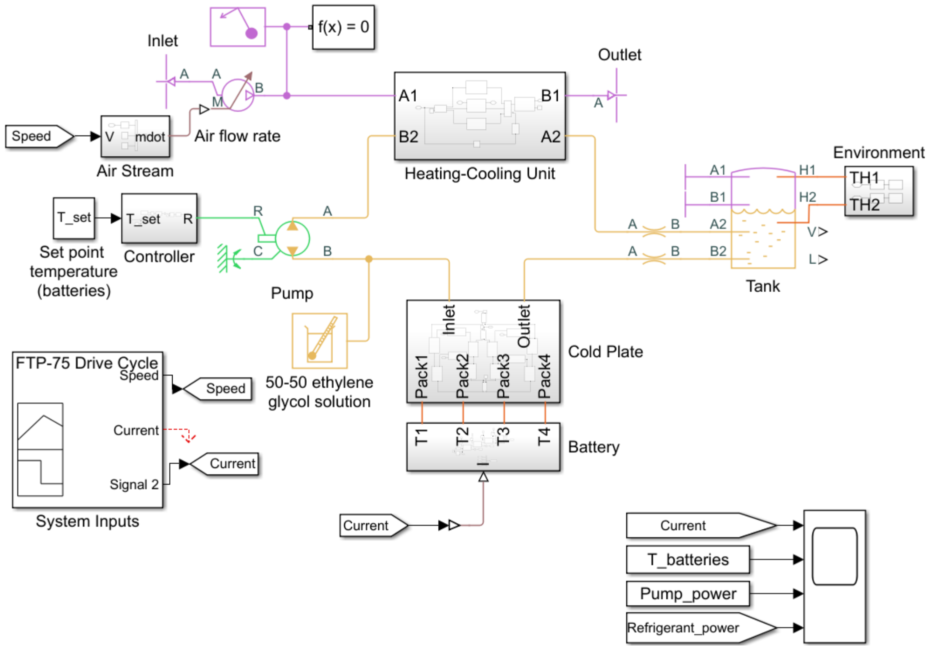


Figure *62: General diagram of a cooling unit*

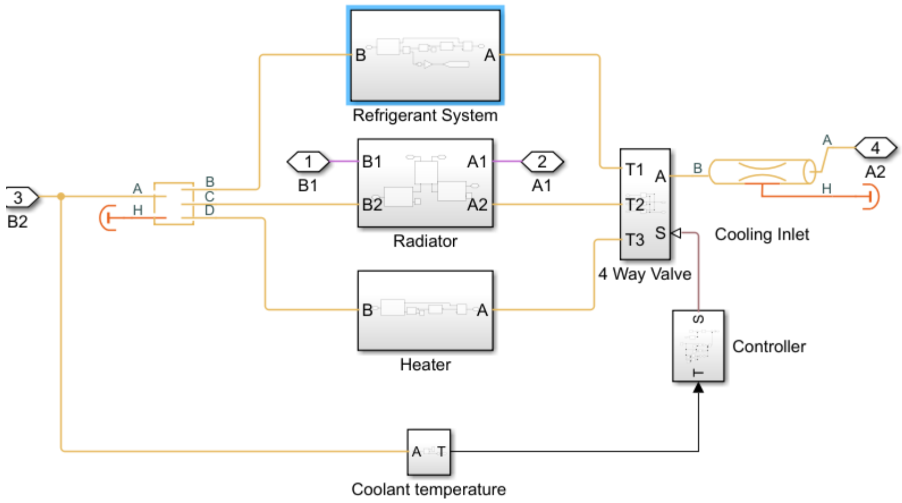


Figure 63: Diagram of the 3 coupled systems

We see that if we put an initial temperature of 80 ° C on the batteries, the coolant pump starts immediately until the batteries return to an ideal temperature.

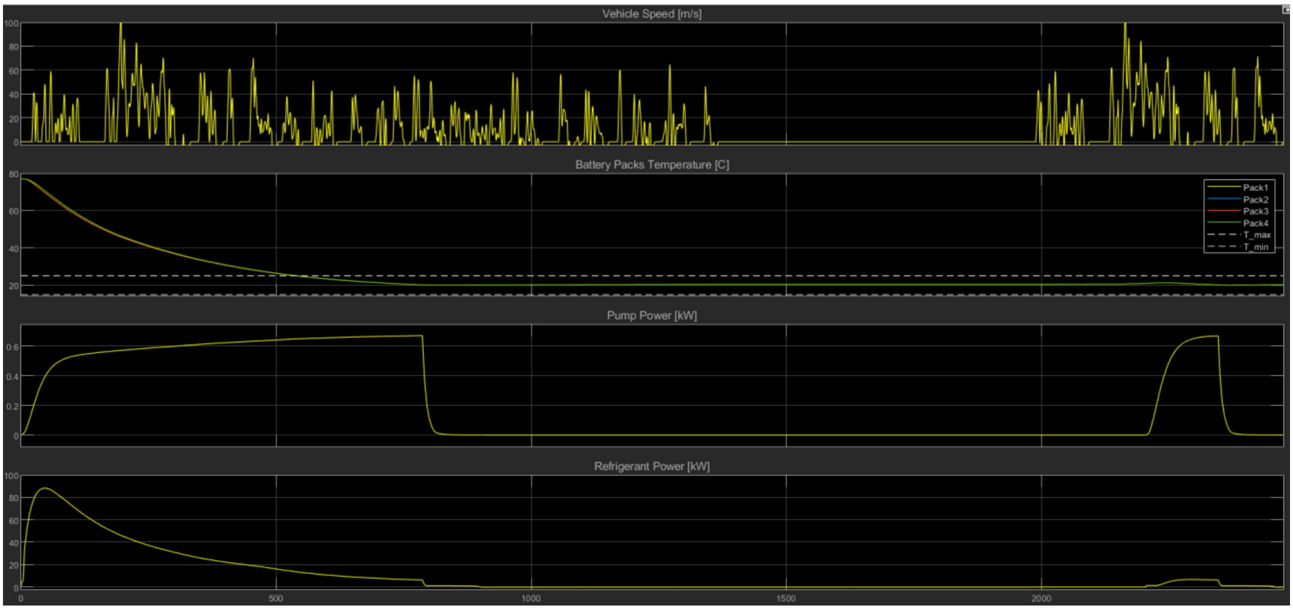


Figure *64 : Evolution of battery temperature*

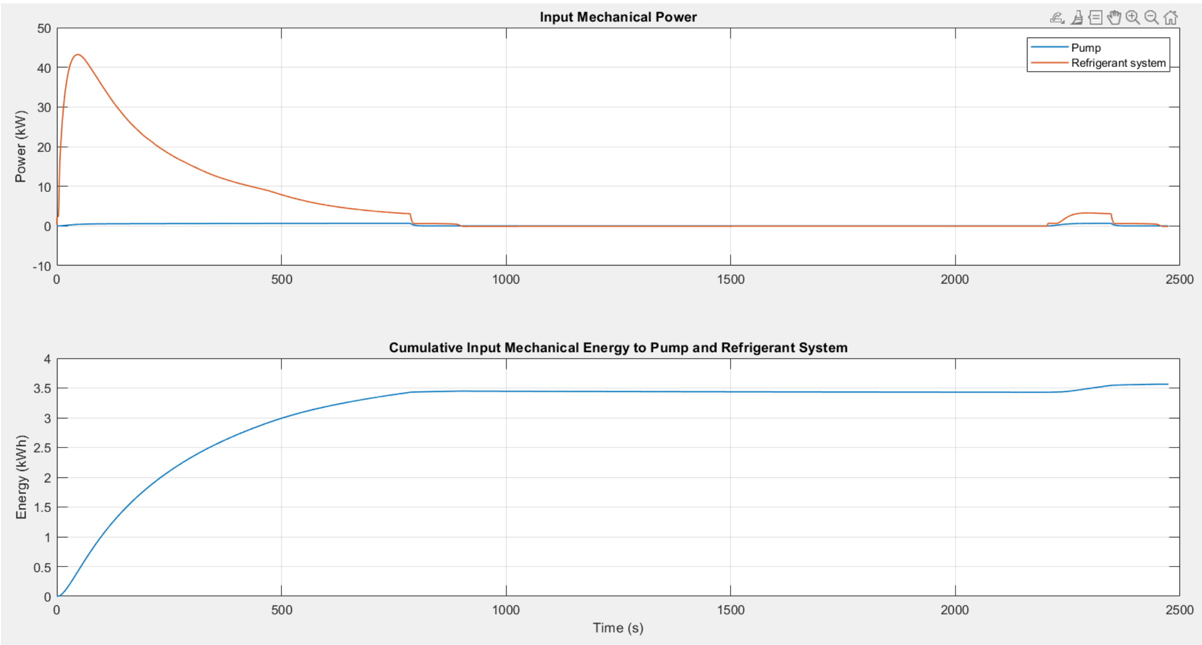


Figure 65: Power consumed by refrigeration systems

It can be seen that the power that is consumed by cooling systems should not be neglected even if in steady state it remains low.

This time, let's take the worst case if the current running through the battery is still 100 A, which corresponds to a phase of constant acceleration.

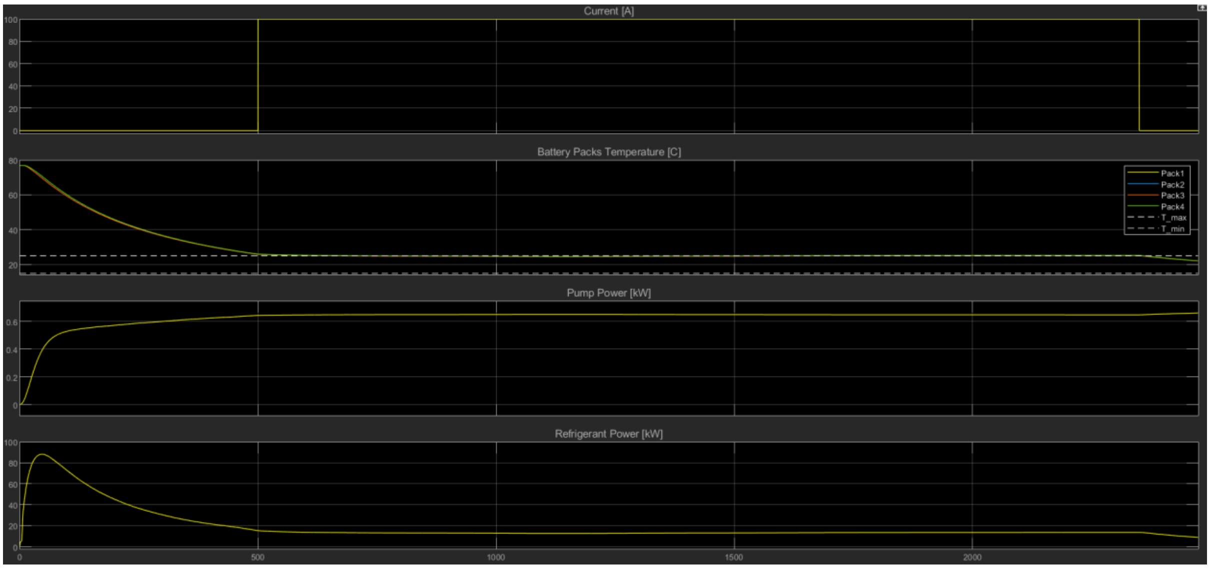


Figure 66: Evolution of battery temperature in the worst case

Here we see that the temperature stabilizes around the agreed value as maximum with the power of the pump and the refrigerant which remains almost constant after having decreased the temperaturein The acceptable domain which shows that this system can support this energy input.

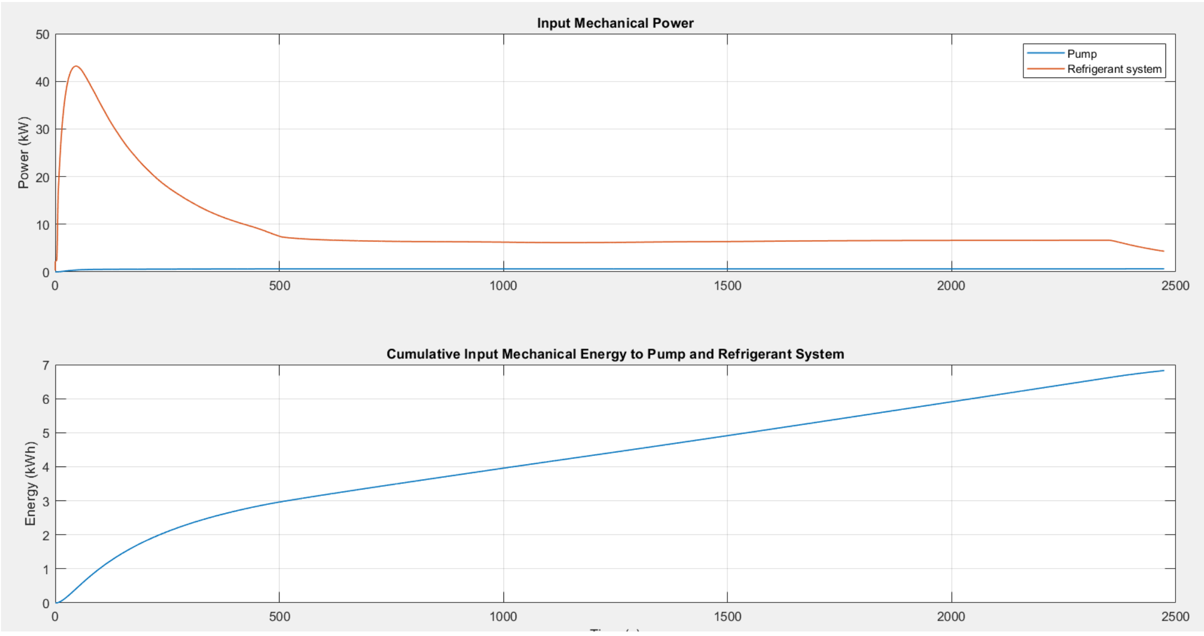


Figure 67: Worst-case power consumed by refrigeration systems

We see here that the power consumed is much greater than in the previous case but it remains reasonable.

The same goes for the heat pump and the engine which will have a power consumed in the same order of magnitude because even if it generates more heat, the power dissipated with the Radiator is larger knowing that their operating temperature is higher so the temperature differential with the ambient air will be greater.

Knowing that we can also recover the heat produced by the batteries to heat the cabin if necessary given the similarity of temperatures to save energy.

6.Transmission

The transmission part was agreed to be carried out by Ignacio. Also accepted by Ignacio. However, there is no information available. [Monday, February 6 2:15 am]

II. Study of the vehicle as a whole

1. Global Architecture

Based on two sources [1] and [2] matlab as well as the different courses:
The vehicle contains the following architecture :

- A power management system to be distributed:

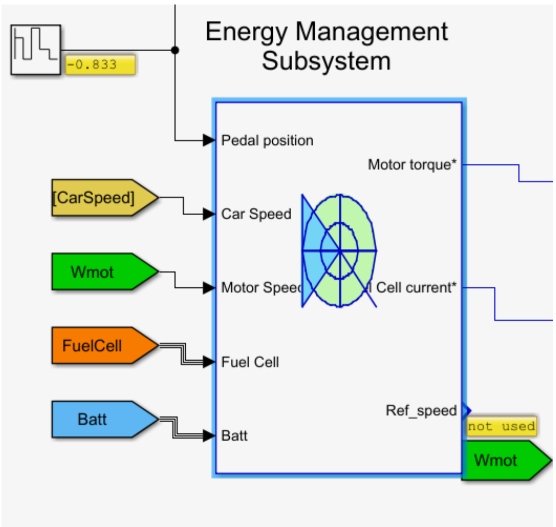


Figure 68: Power Management System

It makes it possible to manage the distribution of the power to be supplied between fuel cell and battery.

In it we then find :

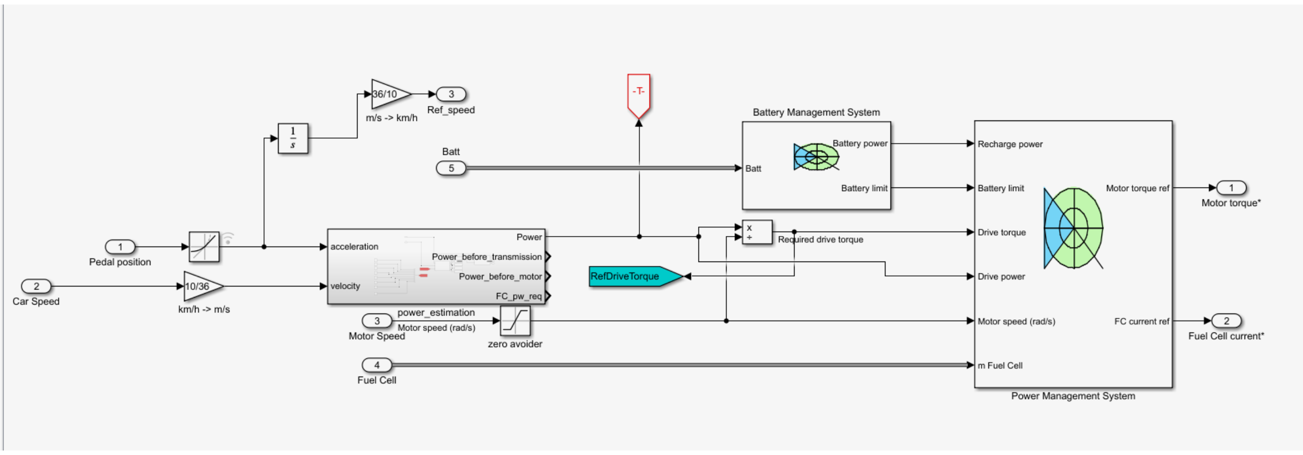


Figure 69: Power Management System

From acceleration and speed, we determine the power to be provided and then obtain the ideal torque.

At the level of the calculation of the power, we take as a parameter what is specified in the theoretical part:

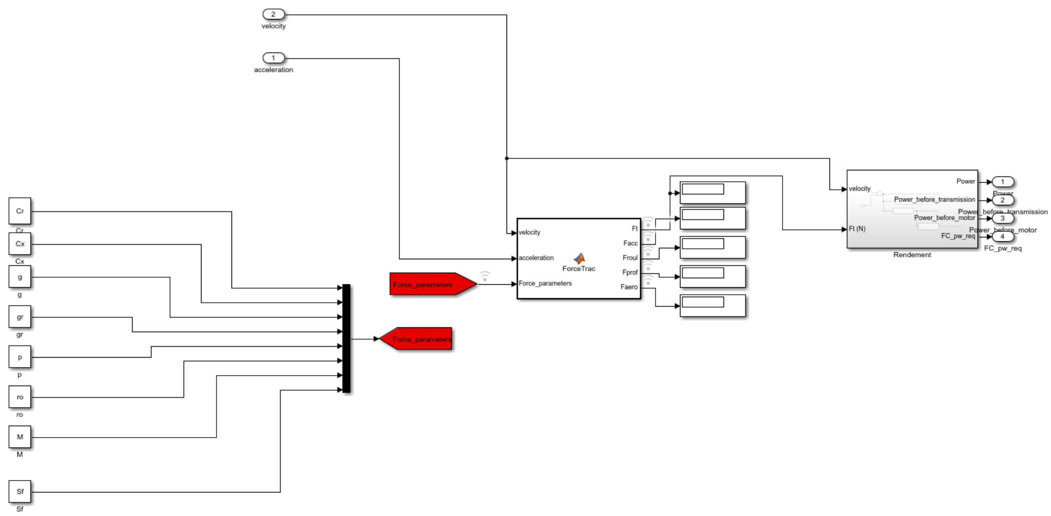


Figure 70: Power calculation system , Mr. Gillon's method

We then evaluate the output power, sum of Facc, Faero, Froul and Fprof.

Regarding the battery management system, the principle is quite simple, depending on the state of charge and the power supplied to the battery , we calculate the power that the battery can provide:

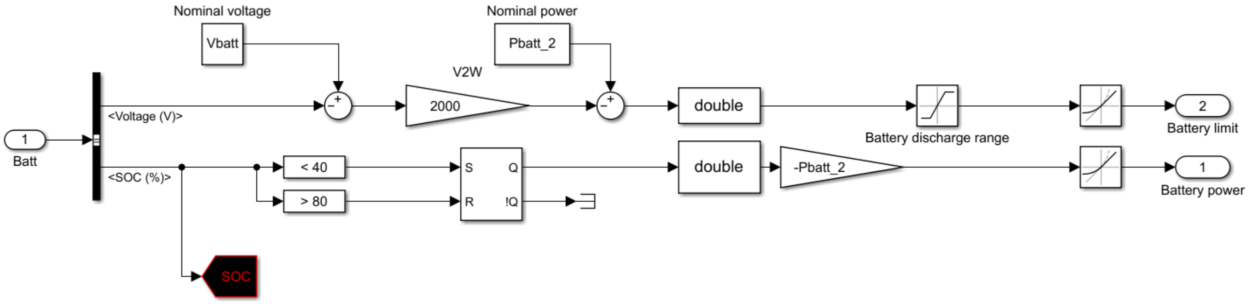


Figure 71: Battery Management System

This depends on the nominal voltage of the battery as well as the rated power it can provide. In the simulation, we take a power battery of 2.5 kw with a voltage of 288 V.

- If the SOC is less than 40%, we start on the optical that if the HR can, it recharges the battery up to 80%, in any case the battery will not help the HR .

- If the SOC is greater than 40%, then the battery helps the HR to below 40%.

Regarding obtaining the current to be supplied to our fuel cell (FC), as well as the reference torque that the motor must provide, this is known in the next block.

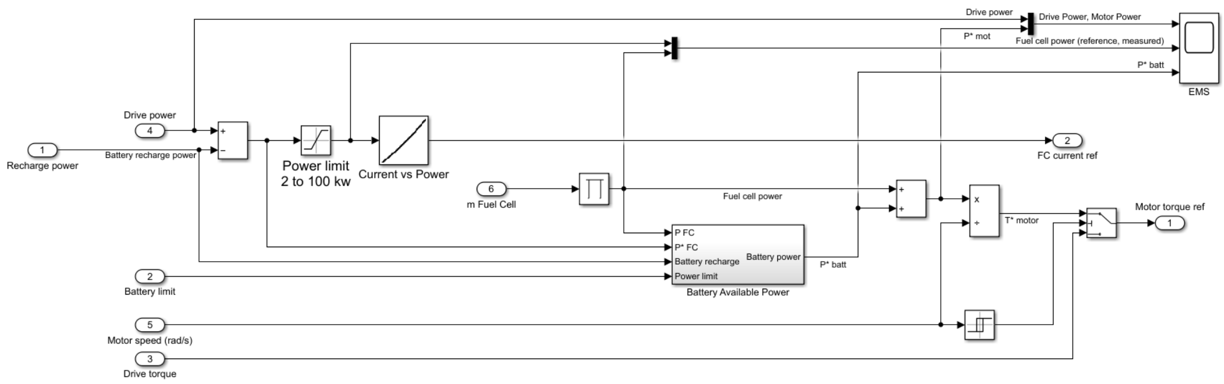


Figure *72: Obtaining* the reference *torque and the reference intensity*

Thus, we know the power to the wheel, power that must provide the motor in the ideal case, it is drive power. It is compared to that available by the battery and then the power that must be provided by the fuel cell is recovered . Using a table, one obtains from the power the necessary current of the heat pump and on the other hand one divides the sum of P_FC and P_batt* (reference power of the battery) by the rotational speed of the motor to obtain its reference torque.

Knowing then the ideal current of the fuel cell as well as the adequate torque, we can train our propulsion system knowing the speed of rotation engine:

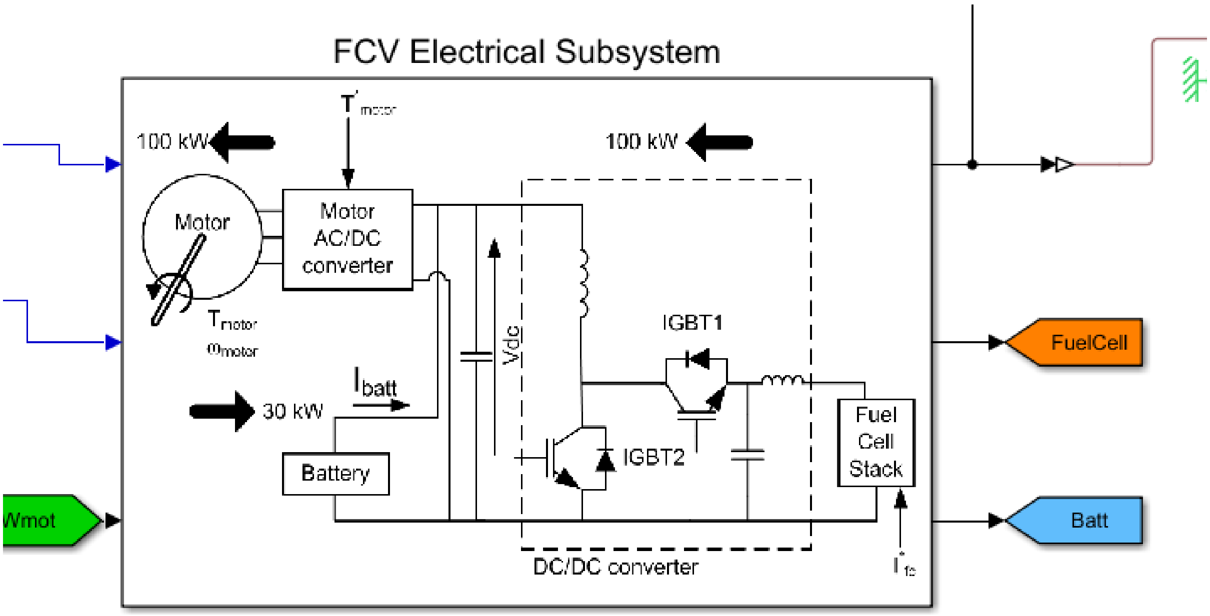


Figure 73: Power Transmission System

Here is the inside of the system:

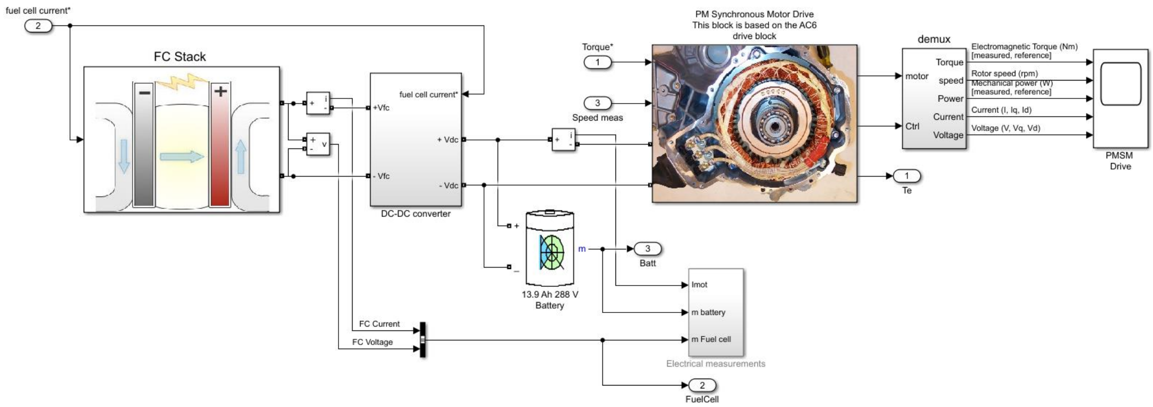


Figure 74: Power Transmission System

The motor is based on a nominal voltage between 250 and 300 V, the DC-DC transformer then converts the voltage supplied by the FC stack of 400 cells with a nominal voltage between 400 and 300 V.

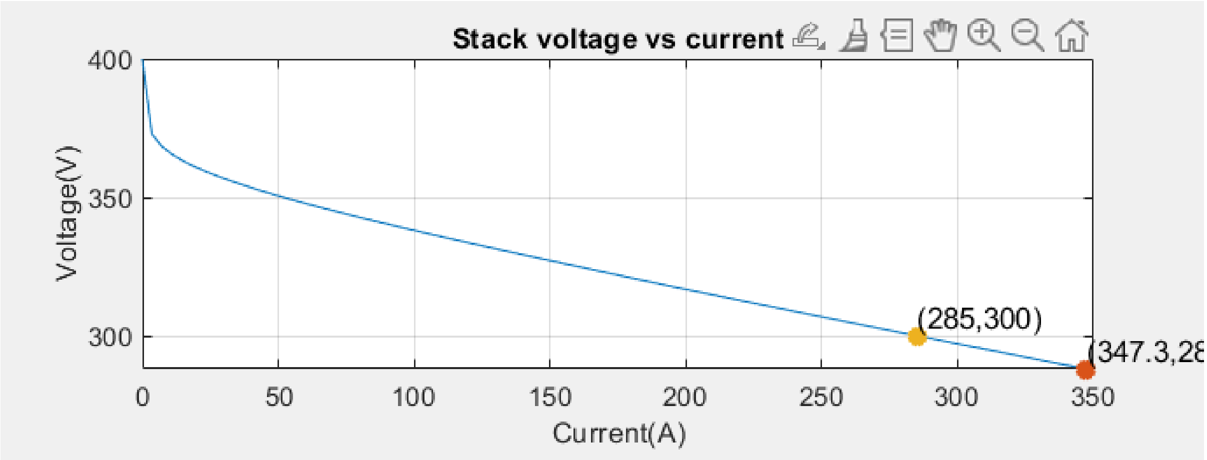


Figure 75: voltage vs current in the heat pump

The battery complements voltage and intensity drops to provide the engine with the necessary torque during acceleration phases.
We obtain in output the real torque as well as the real powers.

The output torque is then transmitted to the transmission system where the engine rotation speed is recovered as well as the current speed of the car which is subsequently injected into the energy management system and so on:

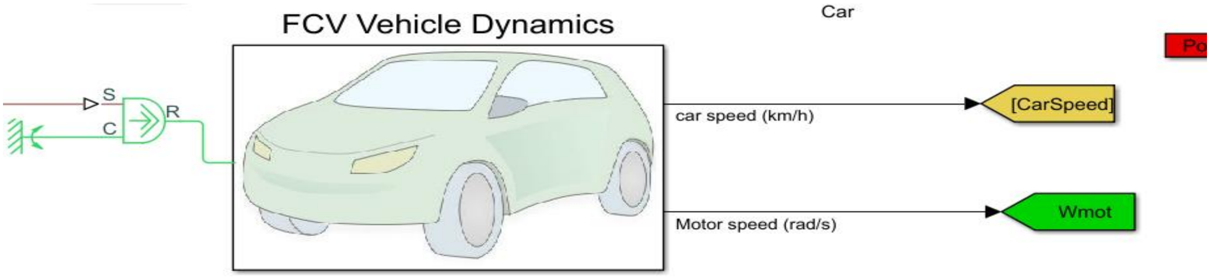


Figure *76: Eentered dynamic information of the system*

Here is our transmission system:

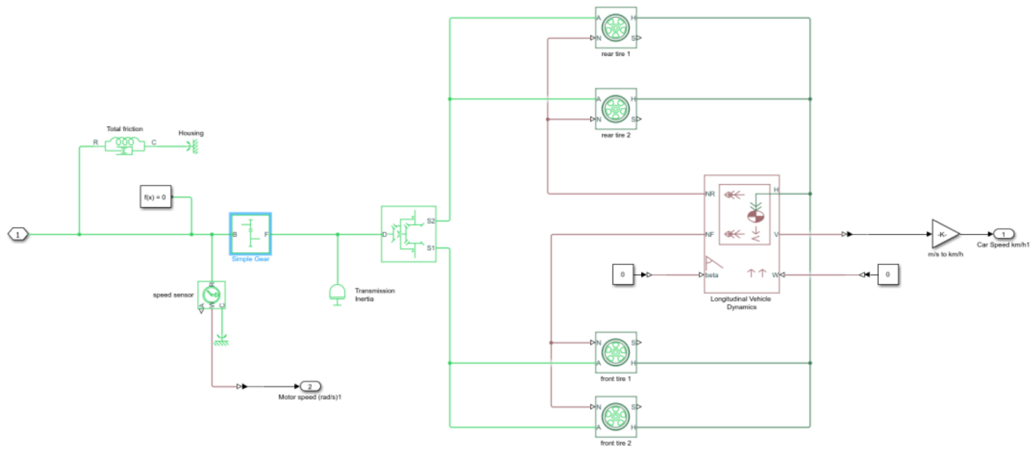


Figure 77: Transmission System

It consists of a speed, a differential, and a neglected energy loss .

We then recover the data via another block:

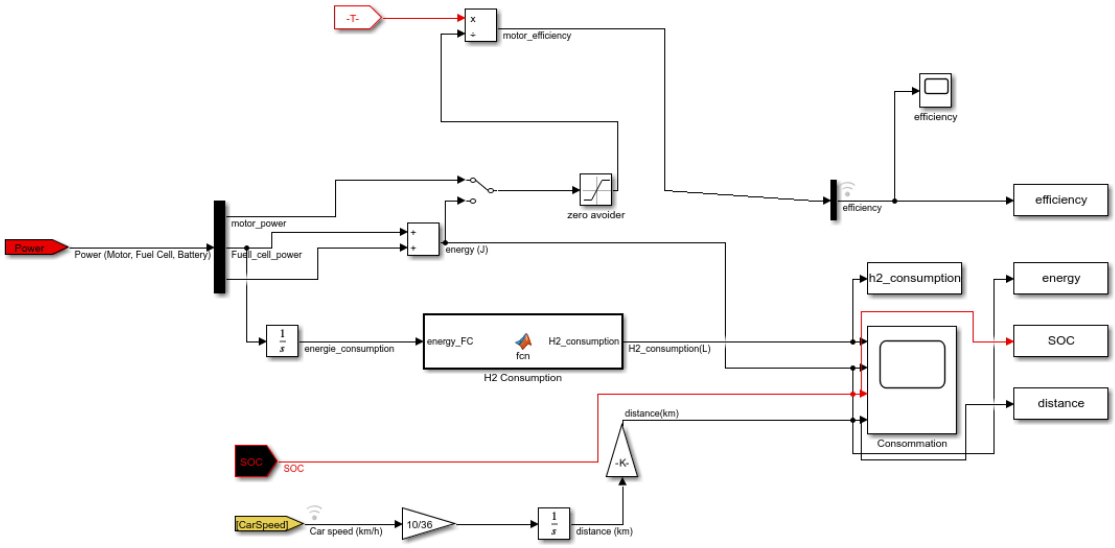


Figure 78: Data Recovery System

It evaluates the state of charge of the battery, hydrogen consumption , energy expended and more.

- The objective of such a modeling is above all to evaluate the performance of the vehicle without enslaving in speed and then find the defects in particular battery power and engine which would not be there .
- Also, to have a realistic visual of the efficiency of a hybrid battery/fuel cell system with an elaborate transmission system.

Bibliography :

Partie gestion de l’énergie [1] : Thèse de master , Université de Californie , Joseph Kenneth Smithson Bell : Design and Control of a Hydrogen Fuel Cell Vehicle (escholarship.org)
Core of the electronic and mechanical system: Pierre Mercier (2023). Fuel Cell Vehicle (FCV) [2] :
https://fr.mathworks.com/matlabcentral/fileexchange/33309-fuel-cell-vehicle-fcv-power-train

2. Distribution of forces

2.1 Vehicle model

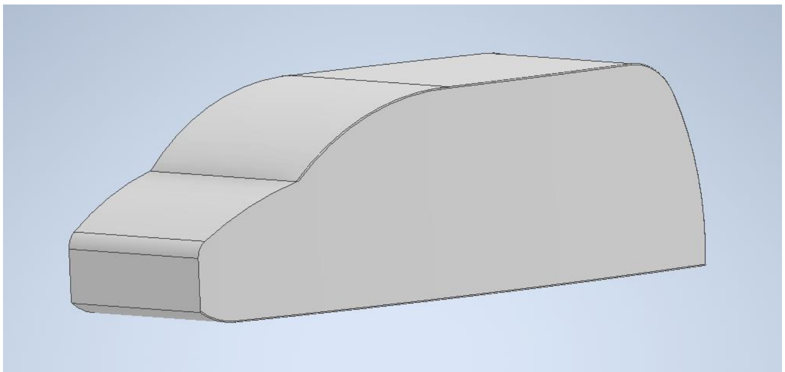


Figure 79: Final model of the car

With the Autodesk Inventor software, we have developed a model of LCV (Light Commercial Vehicle) which has been constantly improved to achieve the best ratio between size, capacity of load and drag force reduction.

The final car has the dimensions marked in the figure above. The distance between doors is 1.904m^2, and the load capacity is 8.m^3 The weight without load is 20,000kg empty, with a maximum load of 1 ton. So the maximum weight of the car is 3.5 tons.

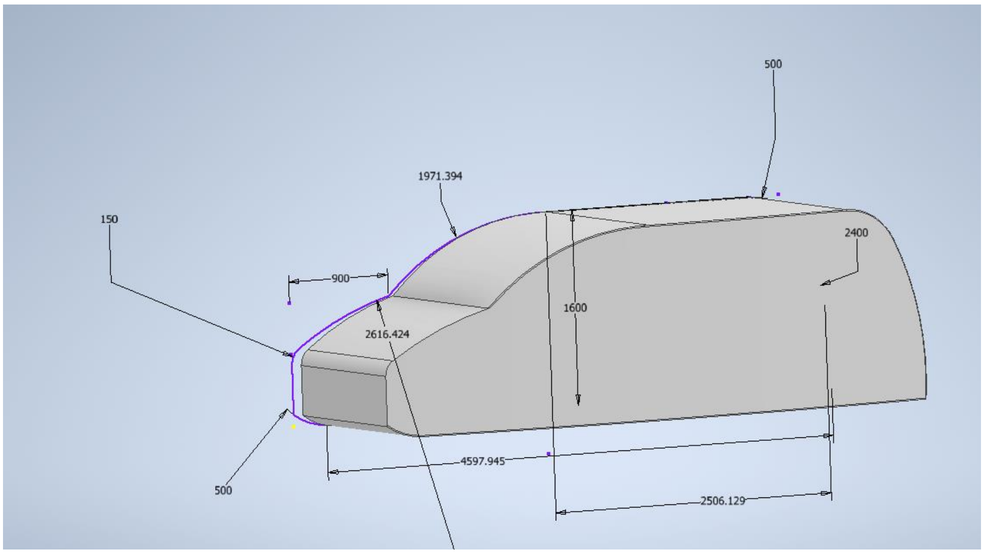


Figure 80: Car dimensions

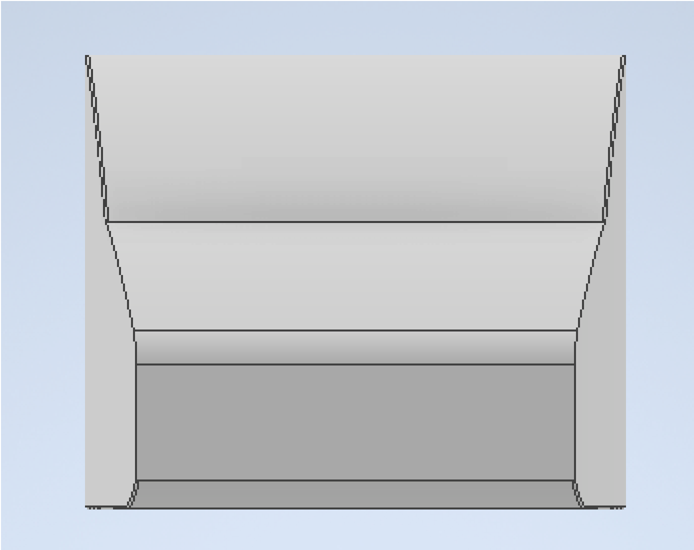


Figure 81: Front view of the car

2.2 Aerodynamic forces

We did an aerodynamic study of the car. After several iterations, we managed to minimize drag forces with modifications on the initial model. First, we reduced the size of the car, as well as the addition of curved surfaces instead of frontal planes that increase drag force. Here are some figures of the results of the last iteration

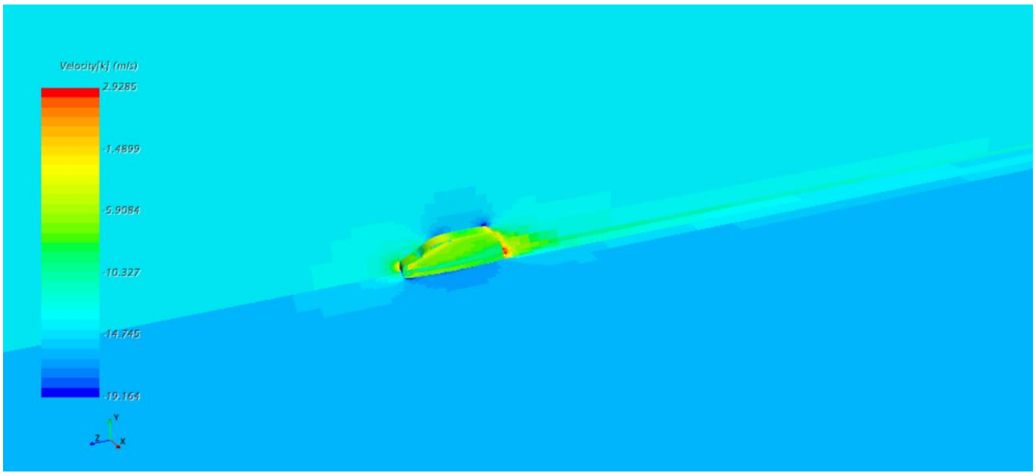


Figure 82: Iteration of the final model on Star CCM+

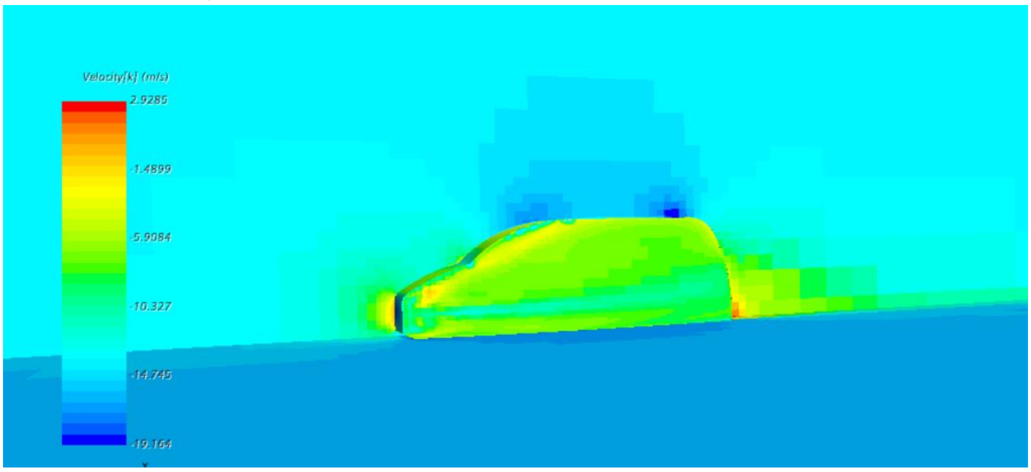


Figure 83: Velocity on the K-axis

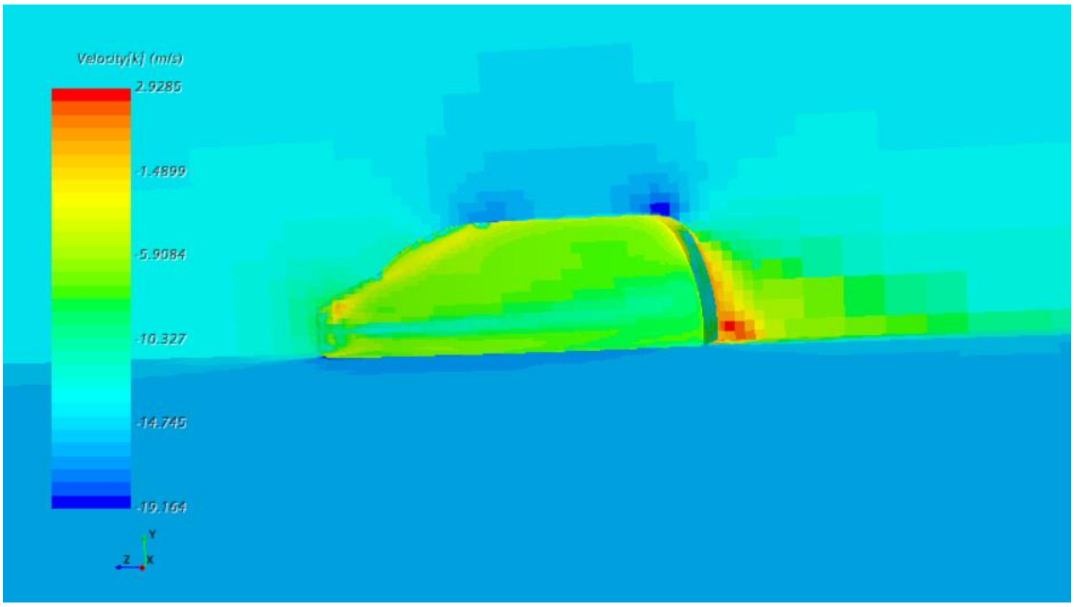


Figure 84: K-axis velocity , flow

Summary					

Total area, 339614, cm^2					
TOTAL FX, 0.490324, Newton					
TOTAL FY, -1.29719, Newton					
TOTAL FZ, -200.986, Newton					
Center of Force about X-Axis (Y-Z), 103.866, -422.699, cm					
Center of Force about Y-Axis (X-Z), 67.6608, 27332.9, cm					
Center of Force about Z-Axis (X-Y), 94.2985, 58.4645, cm					

Figure 85: Force Results Table.

With the values found in the simulation, the drag coefficient can be calculated.

$$C_x * A = \frac{2 * 200.986\ N}{1.205 * 13.888^2} = 1.720851\ m^2$$

If we compare the drag coefficients with the literature, we can notice that the coefficient has been reduced from 0.60 to 0.56, and that the contact area is less than that of the competition. . The forces of the contrails will be minor.

2.4 Impact of forces as a function of speed

For modeling , we used the following constants :

Gr	0.2656
g	9.81
M	2000 Kg (unloaded)
p	0 (zero slope)
ro	1.23
Cx	0.56 (See above)
Cr	0.013 (Standard pressure)
r	0.25

Figure 86: Table of constants.

With such a weight and at low speed, the acceleration force that takes the ascendancy during the NEDC cycle, the one that is most relevant in the study of our vehicle:

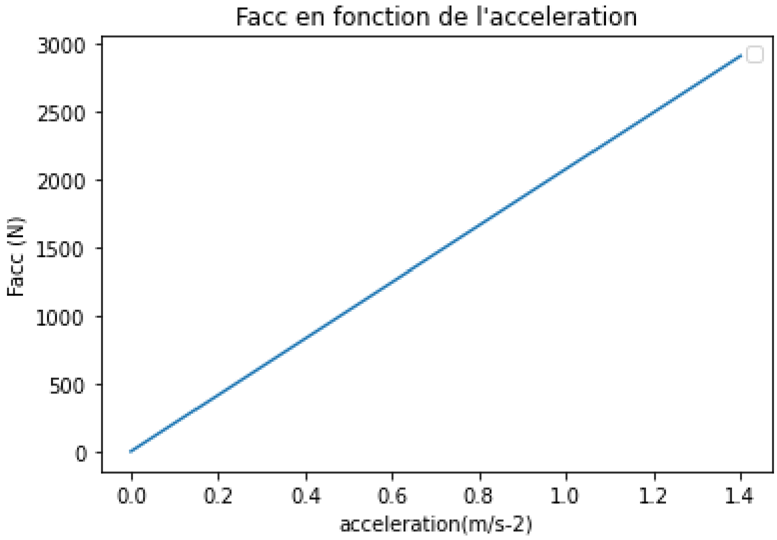


Figure 87 :Acceleration force

The aerodynamic force gives:

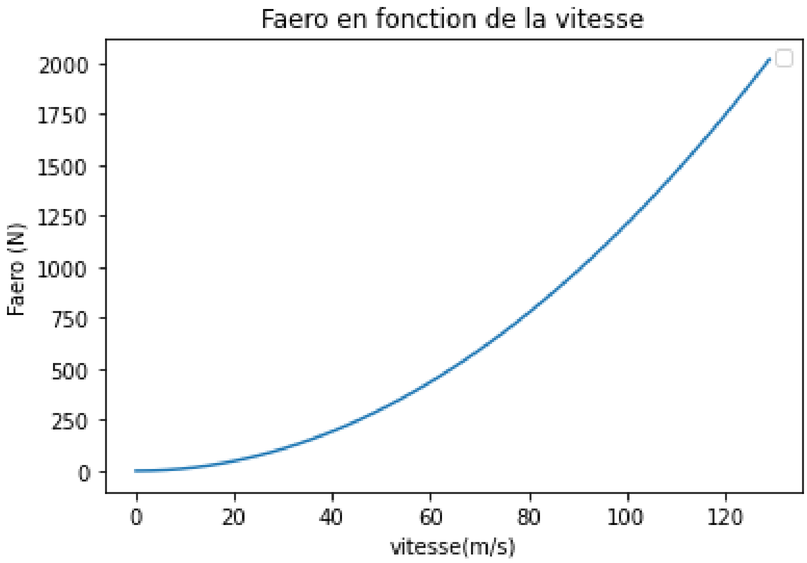


Figure 88: Aerodynamic force

Thus, it competes with the acceleration force from 70 km / h, which is why the optimization of the drag coefficient remains interesting especially during trips on peripheral.

The slope force, on the other hand, is not to be taken lightly , and circulation in steep environments can be compromised:

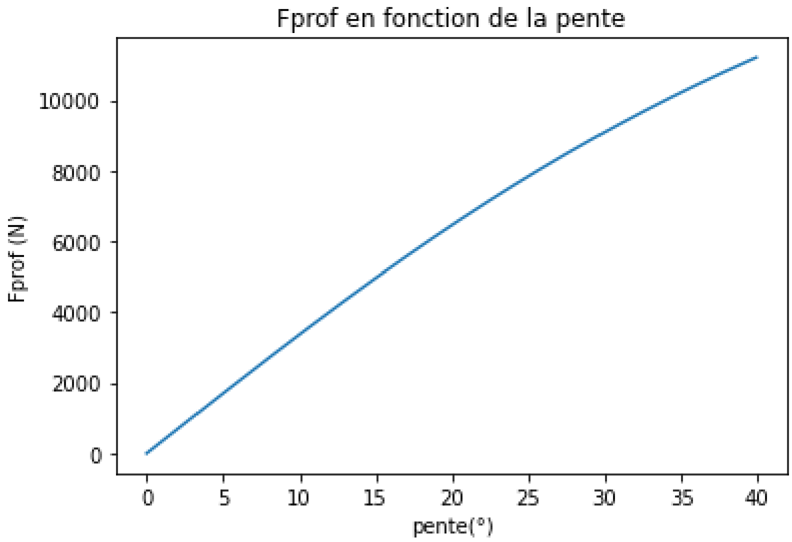


Figure 89: Force as a function of slope

On the other hand, the rolling force is negligible after the first km/h, only 7 N.

2.3 Boundary Study

Engine power hasquite low, battery power also.

We have carried out several tests to evaluate the relevance of our choices, our PAC + battery set is blocked at 125 kw of power then, for maximum acceleration we get the   S-curves:

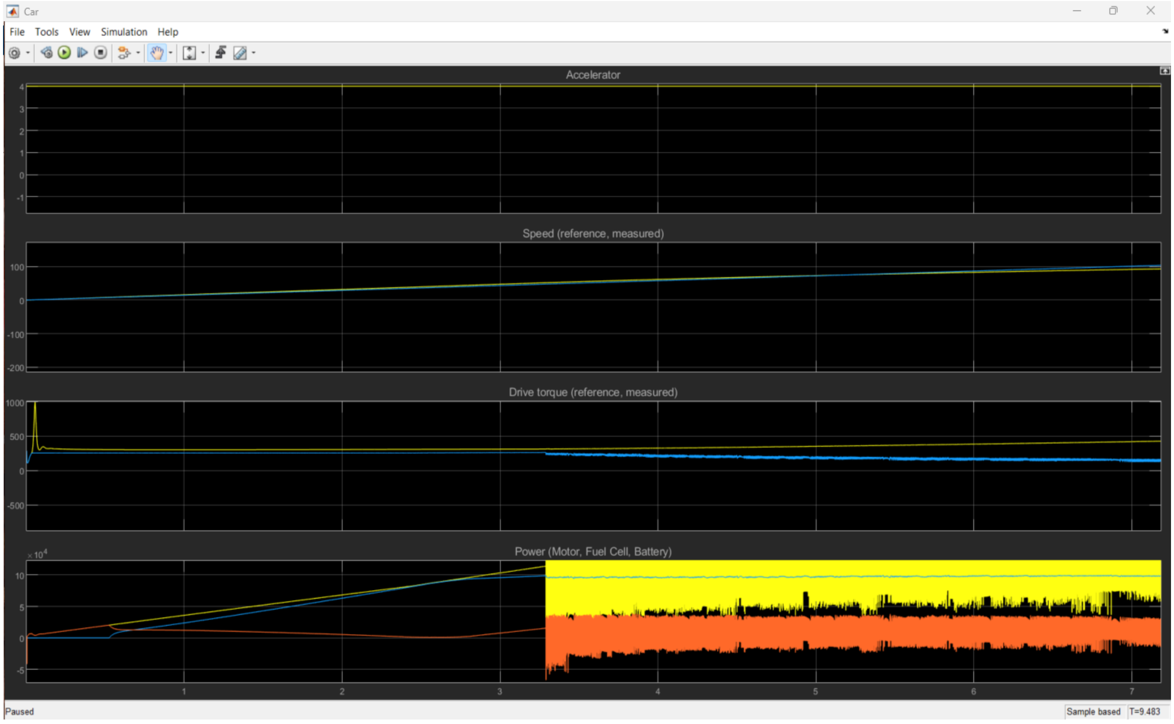


Figure 90: Acceleration, velocity, torque and power

Note that when the required power exceeds 125 kw, the power no longer follows and the vehicle can no longer exceed the speed in question. On the other hand, the heat pump shows its preuves before this fateful bar by using the battery to compensate: real and reference engine torque merge.

Thus, the sizing is correct for acceleration at 4 m/s-2 maximum up to a speed of 90 km/h reached in only 6 seconds.
In the following figure we can see the effect that this power overrun has on the engine power:

Figure 91: Motor, Cell and Battery Power

We can clearly see the power of the battery that supports the power of the heat pump to suit the engine demand and which then reaches a threshold . With this in mind, we then decided to increase the power provided by the battery to 40 kW rather than 25 kW to reach the desired 130 km/h with acceleration. Reasonable:

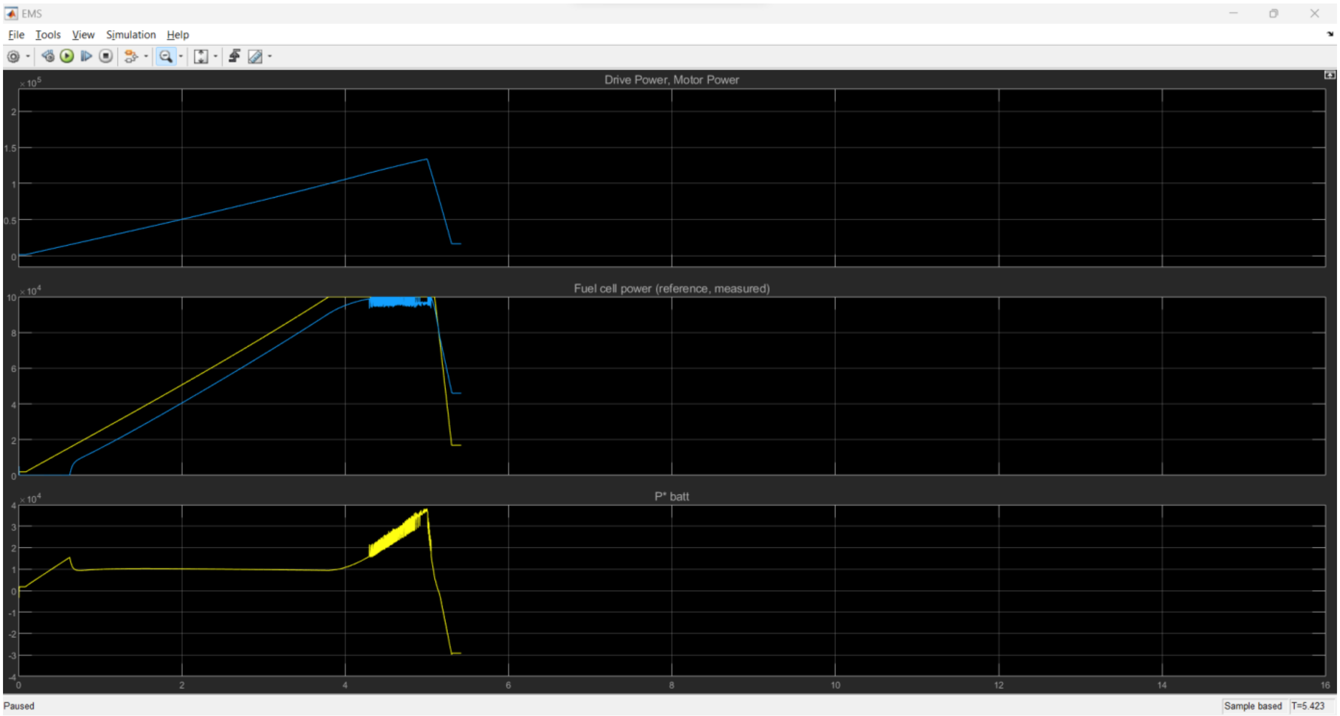


Figure 92: Accelerating Engine and *Battery Power*

In this case, it is the engine that no longer follows and this then requires a more powerful motor that i is not limited to 130 kw and a motor torque of 250 Nm.

Increasing the engine power amounts to increasing the price of the system as well as its consumption, this choice is not necessarily wise and it was preferred to limit the acceleration thereafter to avoid reaching this saturation zone.

Need for a battery

The CAP must heat on the one hand certainly, but on the other hand shows poor performance when it comes to drastic change in power to provide:
If you start without battery aid, the desired speed during the acceleration phase will be reached with a certain delay:

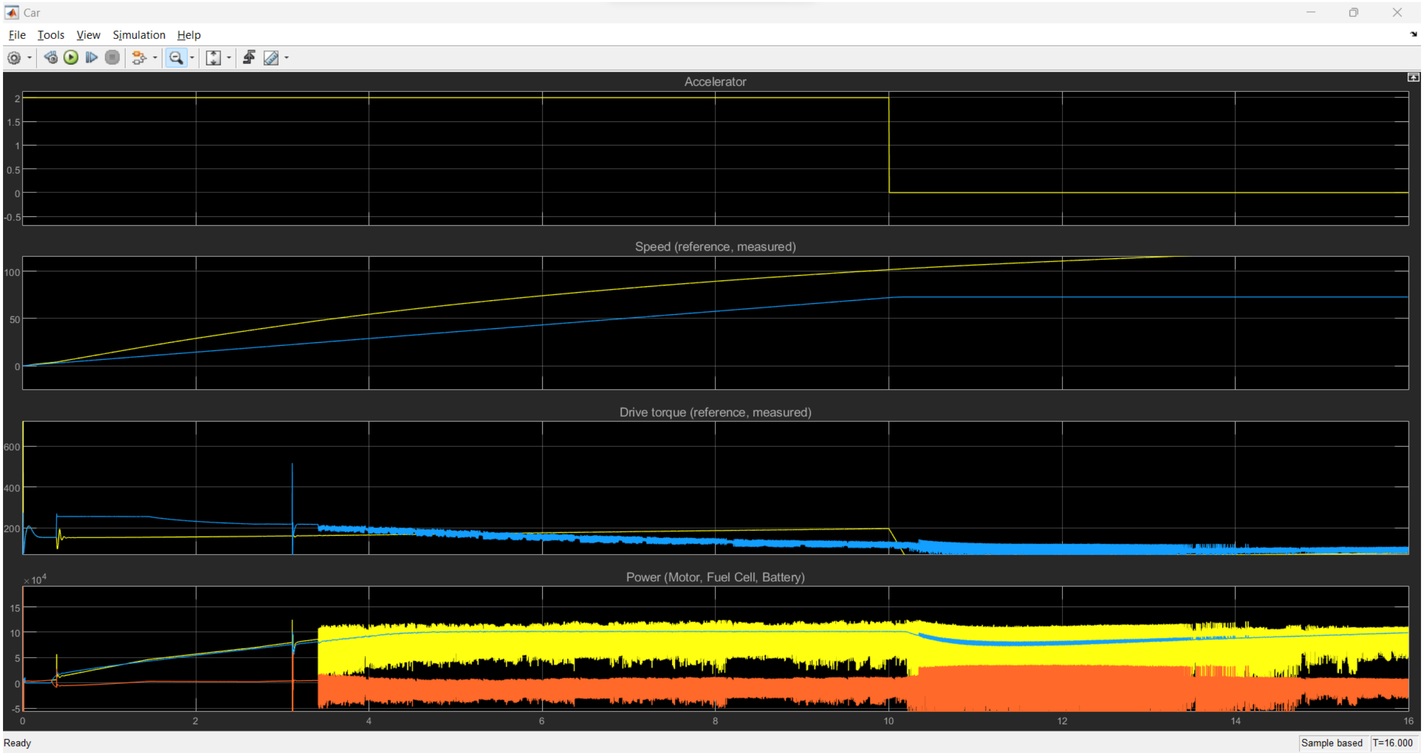
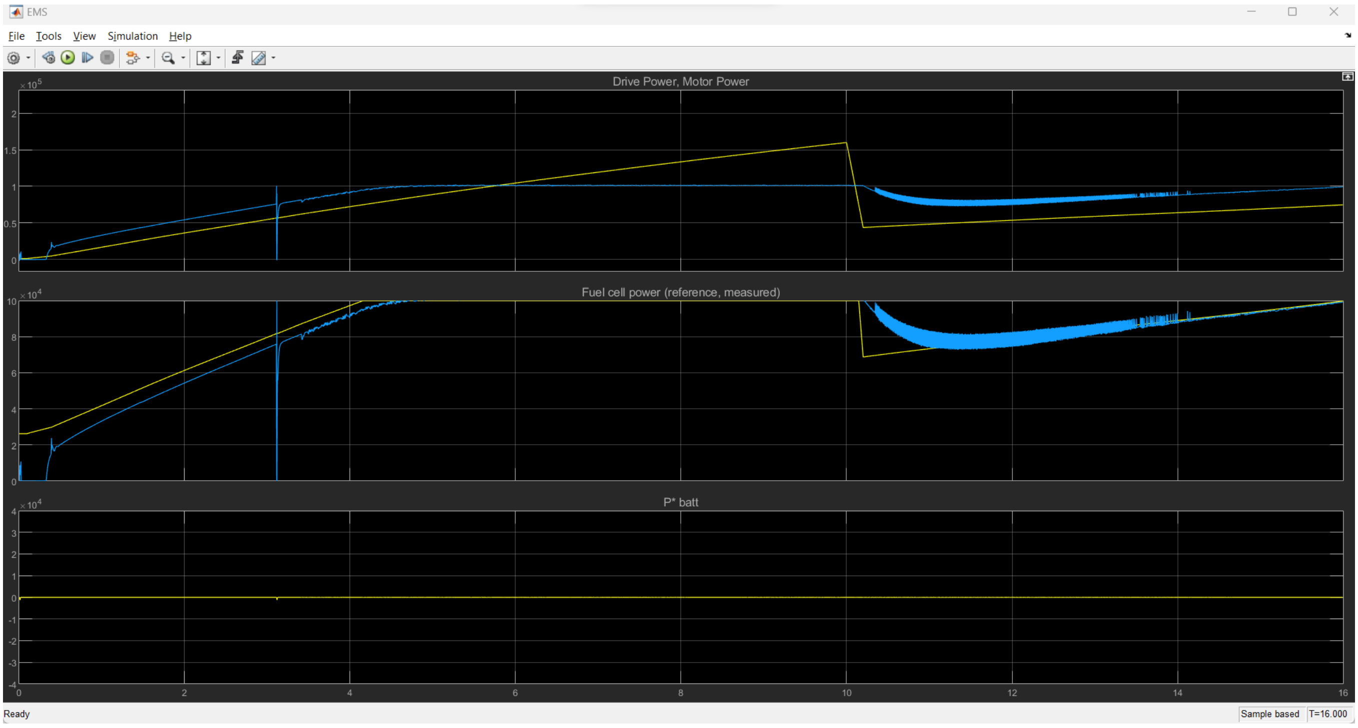


Figure 93: Acceleration, velocity, torque and power with battery only in operation

The power of the battery is zero (orange curve), the engine torque provided during the first kilometers (blue curve) is then very low compared to what is asked (yellow curve).
Here is the profile of the powers provided more closely :

Figure 94 : Power of the cell, *cell and battery when* the *hydrogen fuel cell is only in operation*



- It is clear that the start-up and the saturation phase (100 kW) of the heat pump are areas where the battery is needed because the engine does not have sufficient resources to reach the power requested.
- We then understand the challenge of a battery and the need to size it well in order to be optimal during the acceleration phases but also to have sufficient capacity to withstand the phases of Implementation.

Effectiveness :

We chose to quantify the efficiency of the system in order to know the adapted operating ranges of the vehicle and to adapt accordingly the power input of the battery to get the best return.

Regarding engine efficiency , this is consistent with the theory :

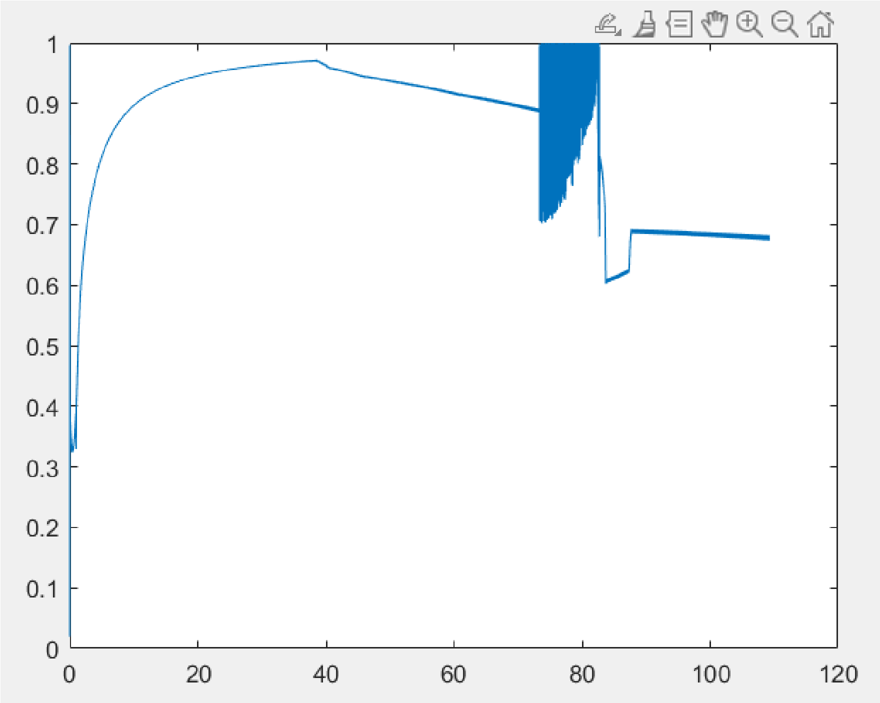


Figure *95: Engine Efficiency*

Here is the engine efficiency as a function of speed, its optimal efficiency being in the 50 km / h, this engine is then suitable for city traffic, which is most often the case.
Finally, although not very powerful, it turns out to be correctly sized as part of its use , up to 70 km / h. Its yield drops drastically past this speed.

Regarding the PAC + Battery efficiency, here is the profile:

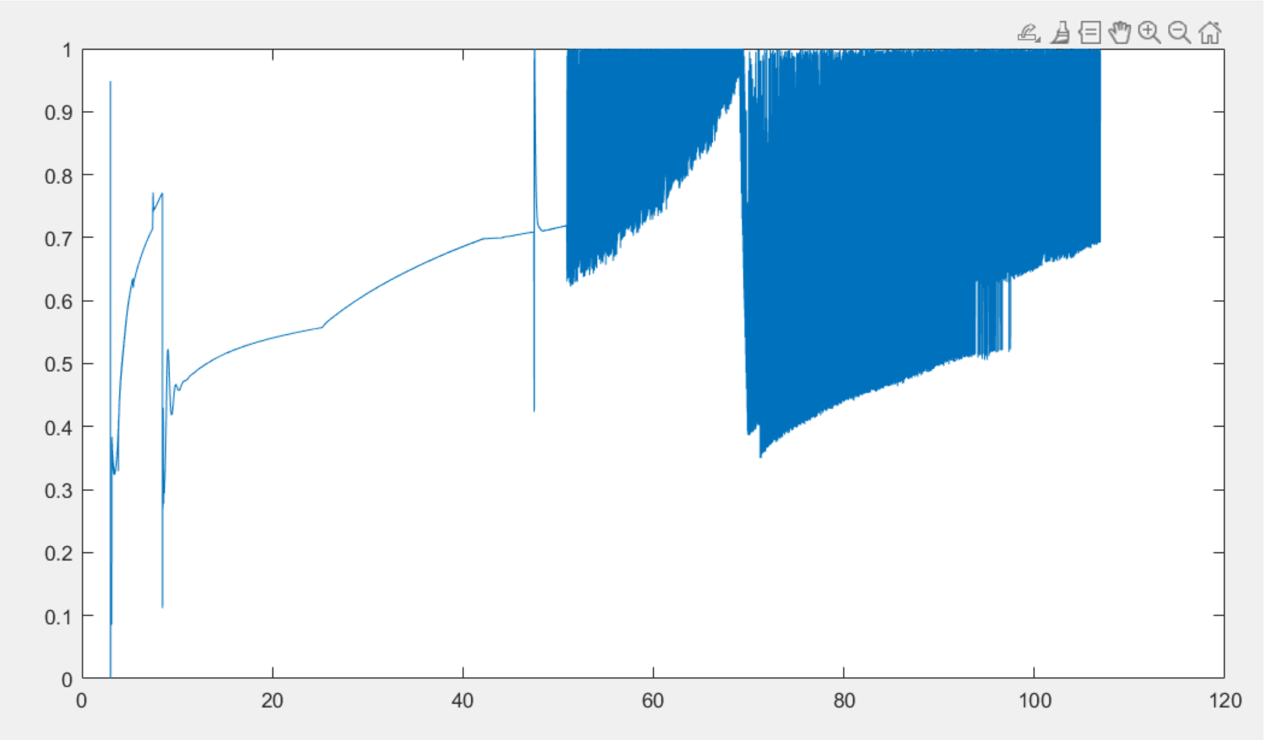


Figure 96: PAC + Battery Efficiency

Thus, the efficiency is optimal for a speed range between 20 and 60 km / h which is consistent with the chosen engine having optimal efficiencies in these same ranges.
After 70 km / h, the efficiency decreases drastically, and is not adapted to this situation.

Finally, the choice of our elements suits the envisaged speed profile , in the city around 20 to 60 km / h.

3. Study on the NEDC cycle

NEDC cycle, speed servo:

In order to evaluate the performance of our car, we will apply a speed cycle to it. For this, we will enslave its speed so that it follows the desired profile unlike previously.

Here is the change in the energy manager:

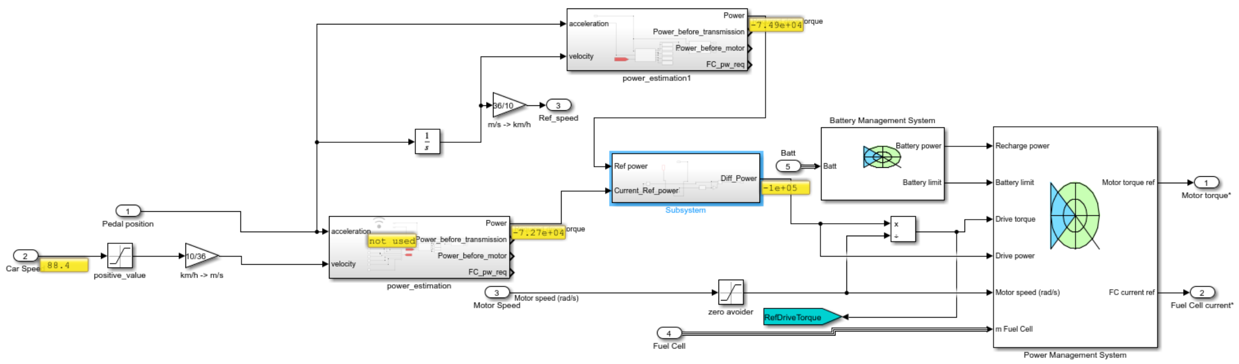


Figure 97: Modified Energy Manager

Thus, we compare reference power with the power needed to reach the desired speed, the code is accessible on the associated github: https://github.com/k0raty/2LC

In the comparison block of thepossibilities (current speed vs desired speed) we find:

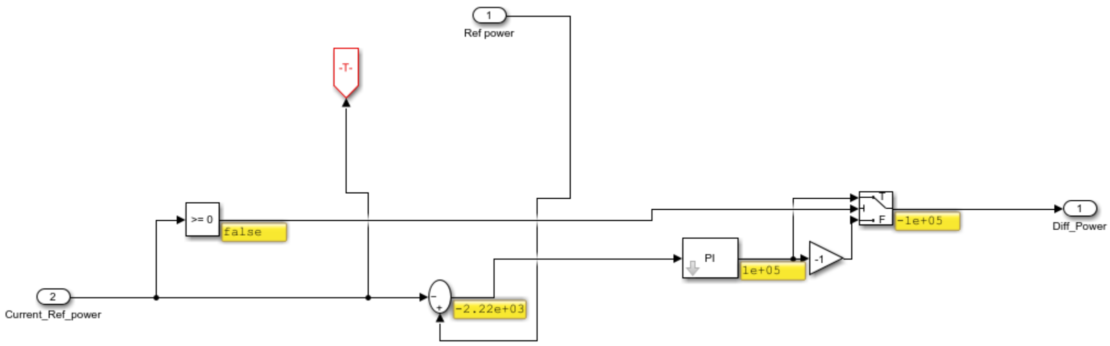


Figure 98: Power Control Block

Thus, if there is acceleration, the power difference is necessarily positive at the output, and negative otherwise.

The model incorporates a PI corrector that must be well sized at the risk of having unwanted saturations.
Here is an example of the speed response if the corrector has output terminals too wide (150 kW):

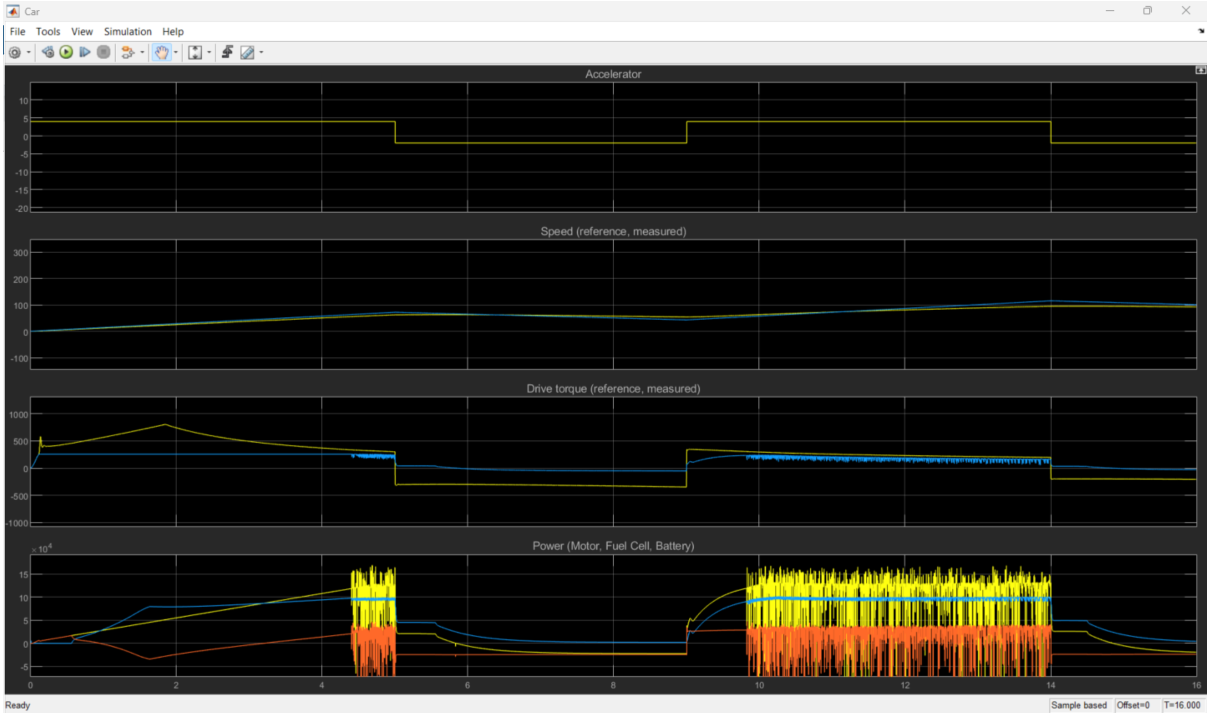


Figure 99: Acceleration, *velocity, torque and power for 150 kW*

On the contrary, here is the answer for 100 kW terminals, there is then no more saturation:

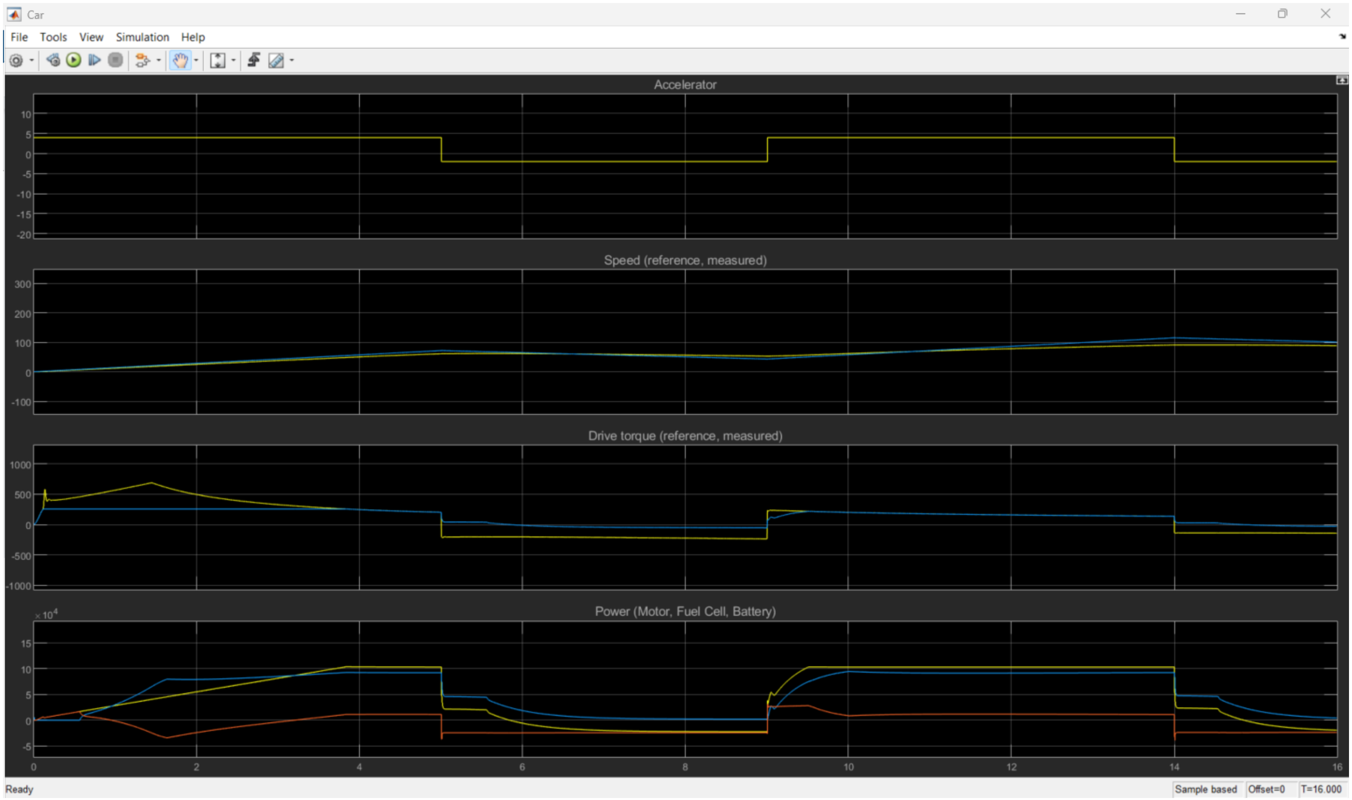
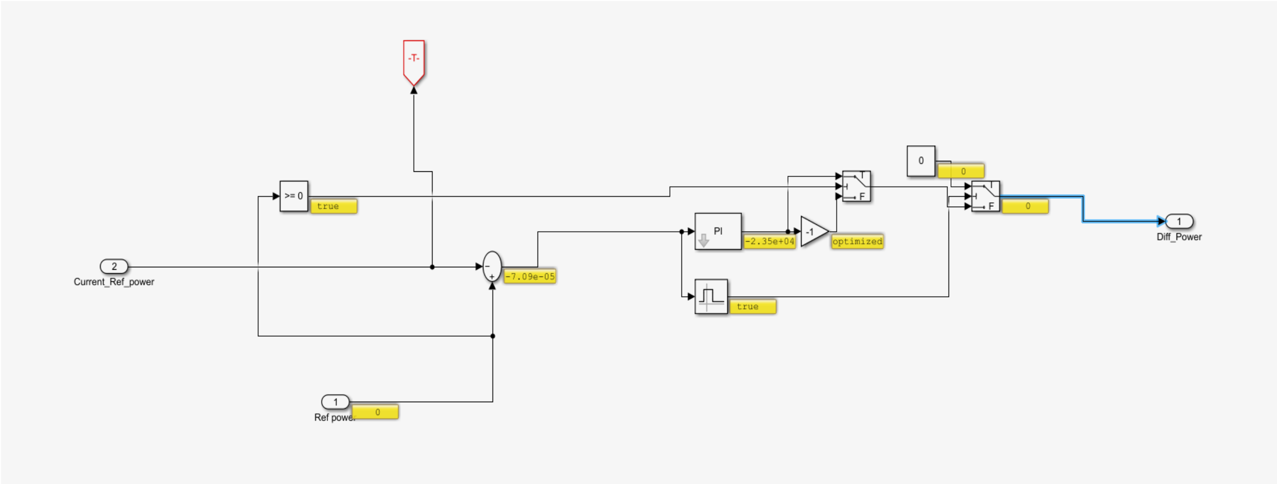


Figure 100: Acceleration, *velocity, torque and power per 100 kW*

After multiple tests, the servo block in puissance has been slightly modified to treat special cases (zero speed, detection ...) and finally becomes:



We now apply the *NEDC cycle* to *our vehicle and analyze the results obtained.*

1.1. Profile of the cycle studied.

First of all here is the profile of the cycle studied:
This cycle is established on 1175 seconds, the speed profile being in km/h:

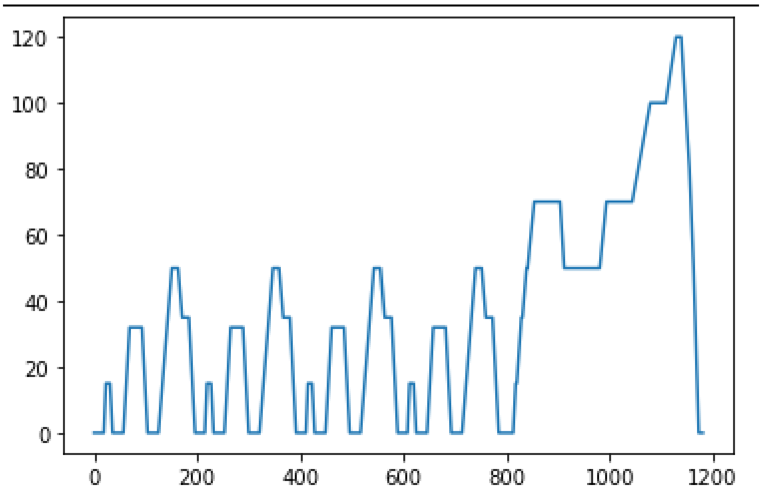


Figure 101: Cycle profile (speed in km/h)

The acceleration is then quite weak over time:

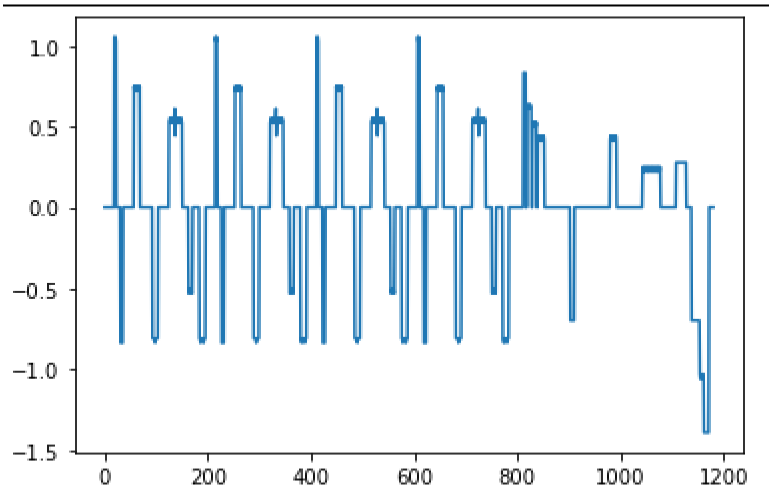
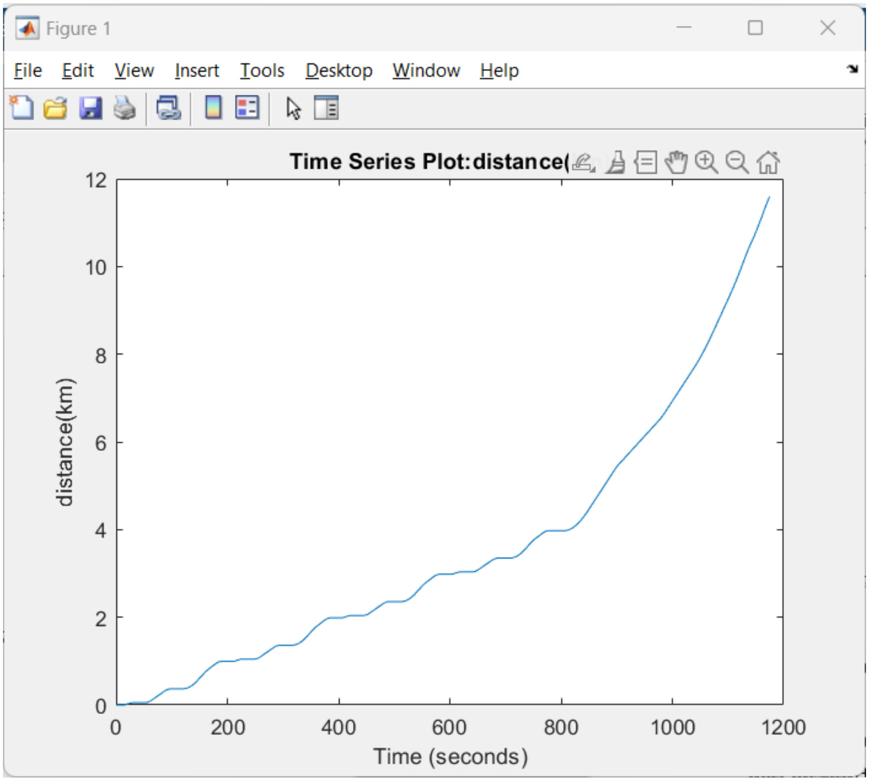


Figure 102: Cycle acceleration profile

The total distance is: 11.6 Km (in our case, see after why)



Thus, it is a cycle at low speed and suitable for city driving with an acceleration phase at the end.

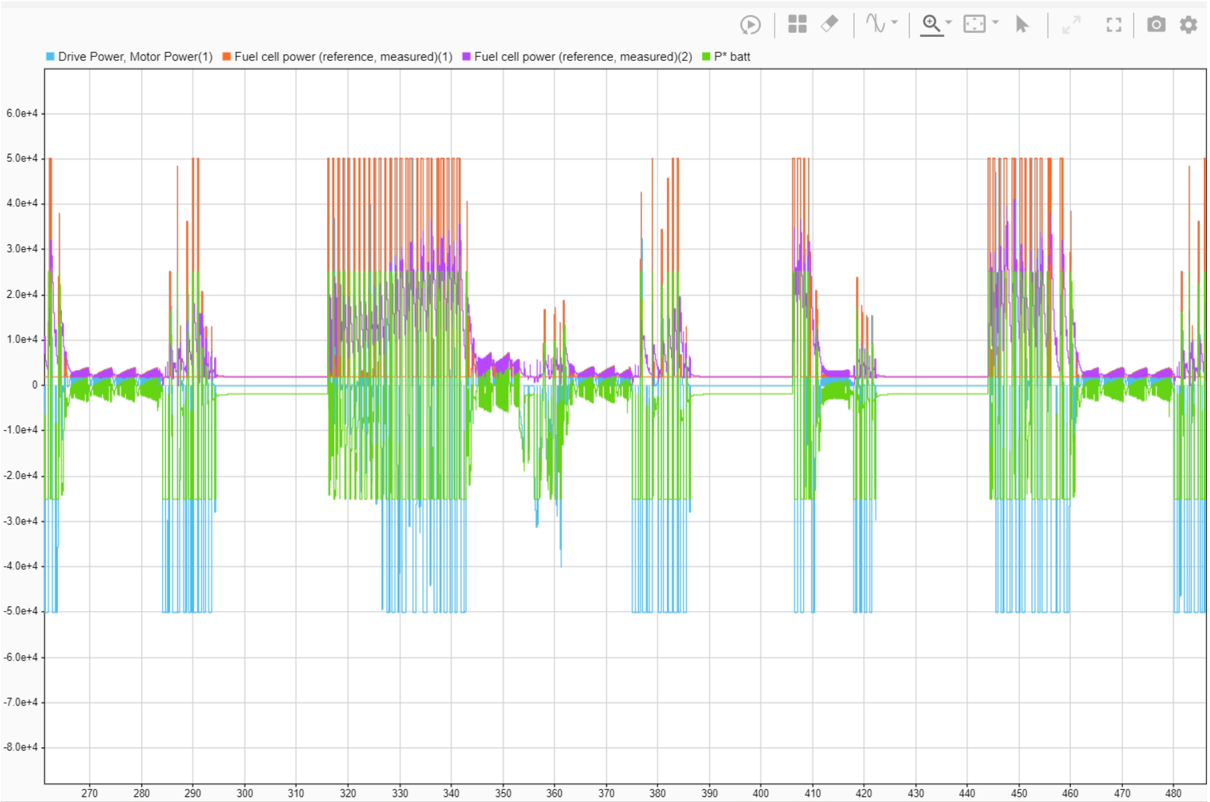
1.2. Result of enslavement in speed.

We then obtain the enslavement in speed with the respective following powers of each element.

Here are the reference and real powers of the heat pump and that of the battery during the cycle

Thus, the battery helps during consumption peaks and recharges during constant phases.

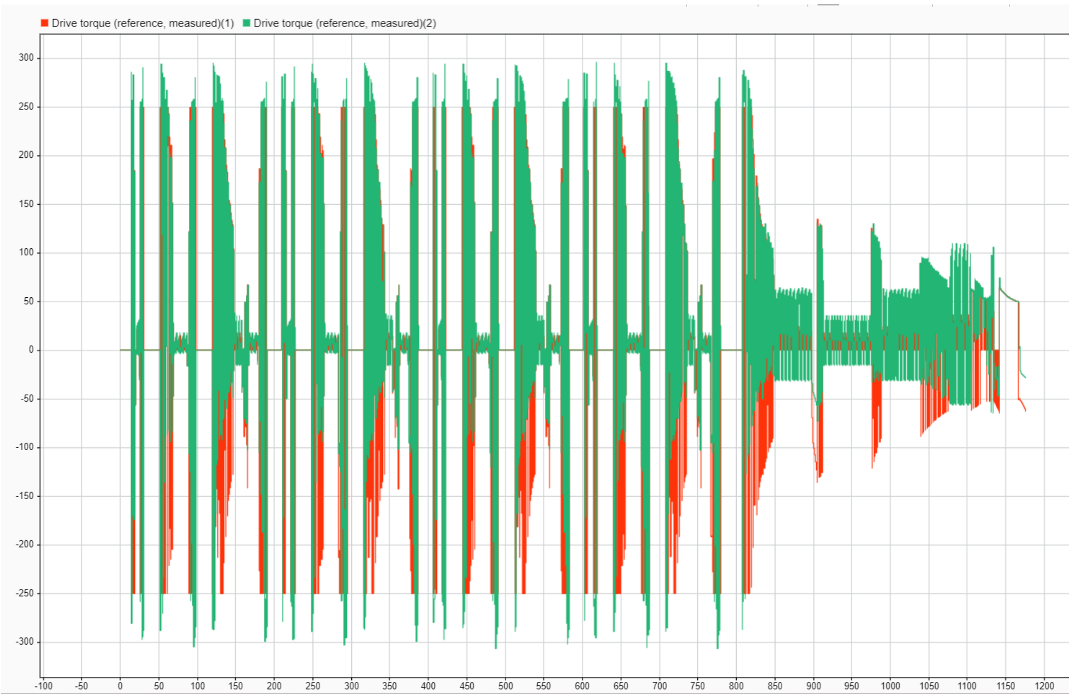
By zooming in on an interval and adding the engine power, we can clearly see the heat pump that powers the engine and the battery to recharge it :



Here is the comparison between reference power andactual engine power during a cycle (zoomed, extract of 60 seconds) in the city:

Thus, the servo is correct during acceleration phases but less good when the torque is negative, which shows a difficulty of the system to control during decelerations .

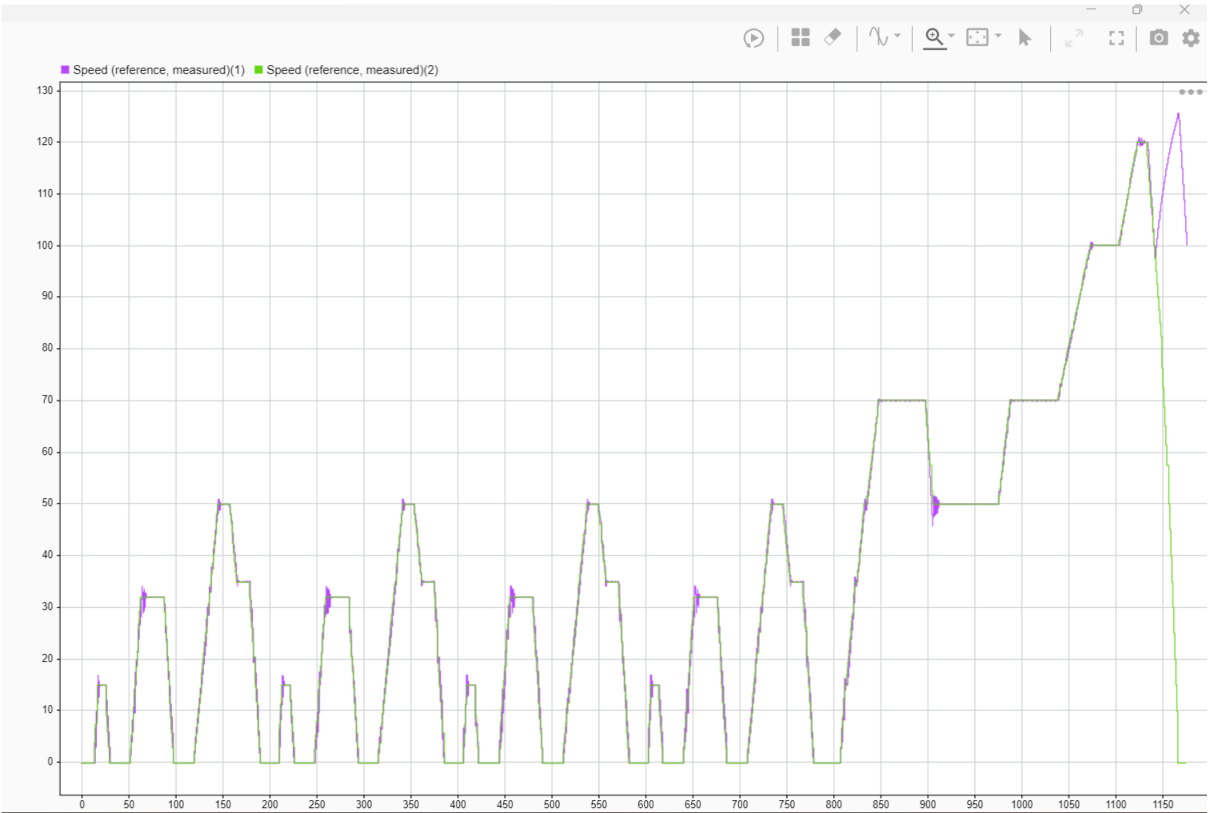
The superposition of the two pairs (reference / real) throughout the cycle gives:



This is consistent with what is expected. Finally, let's look at the engine power during the cycle in its entirety:

Again, the actual power is consistent with what is expected.

Here is the speed servo associated with the end of the simulation:



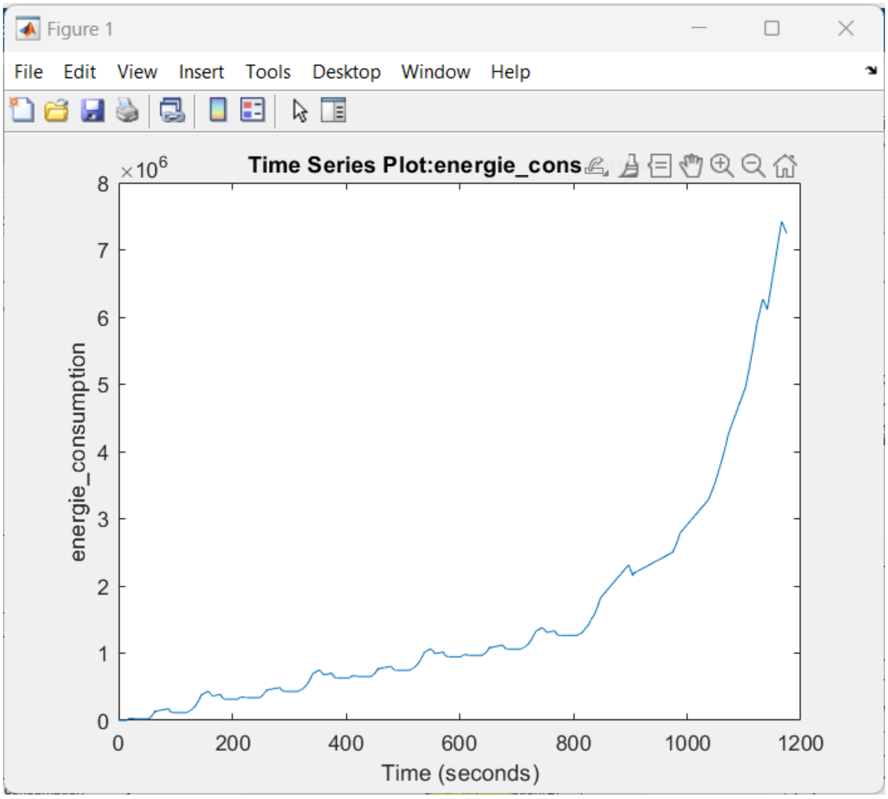
Overall, the servo is successful and the results subsequently valid (green: ideal, purple: real), small problem at the end during deceleration which slightly increases the Consumption and distance over the cycle *(more curves are available on GitHub).*

1.3. Result of hydrogen and energy consumption.

Knowing the energy consumed by the fuelcell, it is easy to determine in kg and then in liters (for 700 bar) the consumption during the cycle.

```
%calculate the hydrogen consumption in grams, knowing that that the energy density of
%hydrogen is 142MJ/kg which is equal to 142,000J/g
H2_consumption = energy_FC./142000;
H2_consumption = H2_consumption /1000; % to Kg
H2_consumption = H2_consumption*(1000/42); %to L at 700 bar
```

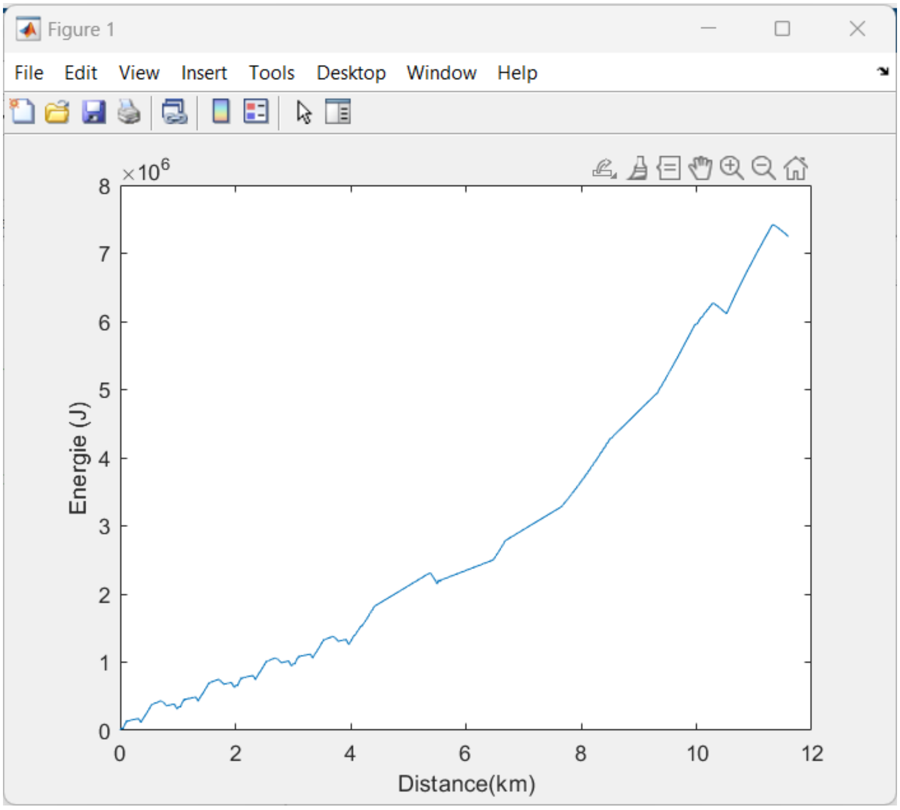
The energy production (battery + fuel cell) as a function of time is given below:



We obtain a final consumption of about 3.56 liters of hydrogen and an equivalent of 21.23 MJ at the end of the cycle, or for 11.6 km.
We obtain per 100 km, a consumption of 30.68 liters per 100 and an equivalent of 183 MJ per 100 km or an equivalent of 5. 44 L/100 petrol . This is a relatively low consumption for a vehicle of this weight, for comparison, the average light commercial vehicle is 9 L/100km.

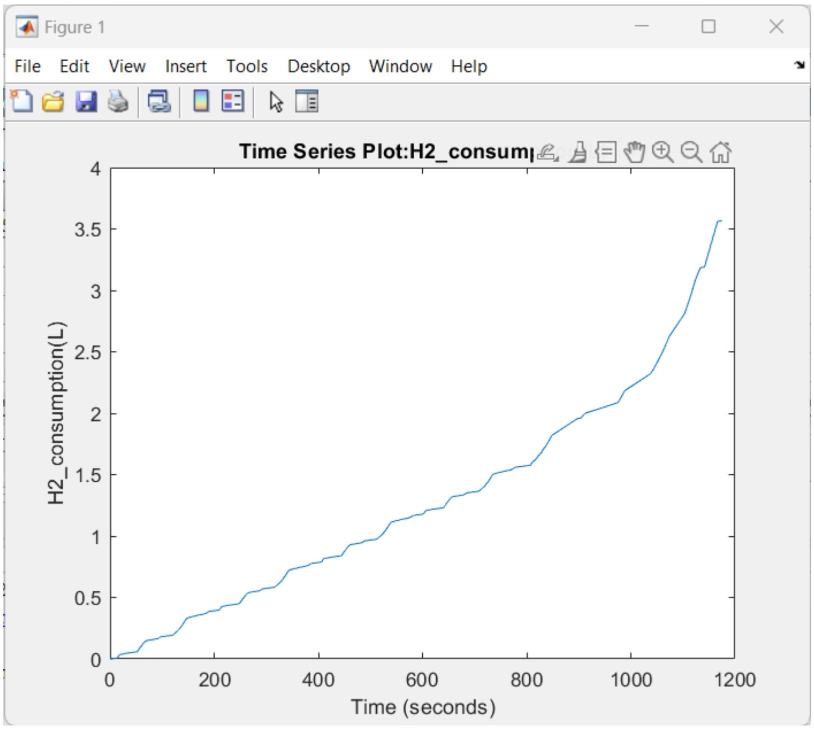
However, it is clear that it is the last phase of acceleration that exponentially reduces consumption, since we are leaving the appropriate speed range. However, the vehicle adapts and finally consumes less than in the city where the battery also recharges the battery!
Thus, before the acceleration phase, so in the city (time 800 seconds), the energy consumed is 1.75 L of H² for 4 Km or 43.85 L per 100 hence 261 MJ for 100 km a petrol equivalent of 7.78 L/100 which is still below average.

This is confirmed by the energy profile produced according to the mileage:

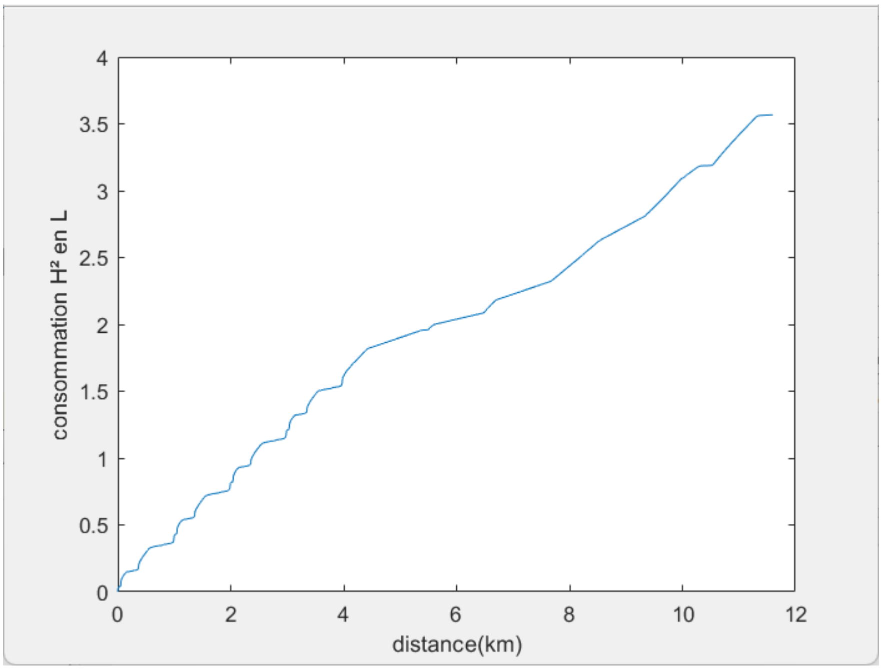


The car certainly produces a lot of energy, but looking at the hydrogen consumption, it varies little.

The associated hydrogen consumption profile during the cycle is then over time:



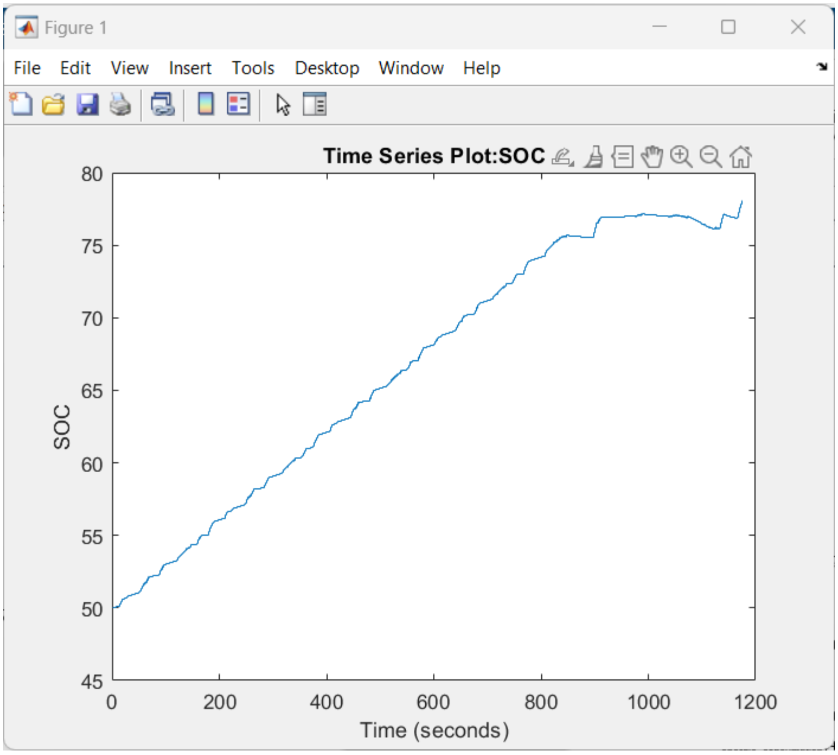
Which depending on the mileage gives :



It is clear that consumption remains relatively constant, it is the whole objective of the battery which aspires either to help the CAP, or to be restored, but in any case to avoid too great a variation of hydrogen flow to achieve maximum efficiency and also too high speed (>110 km / h).

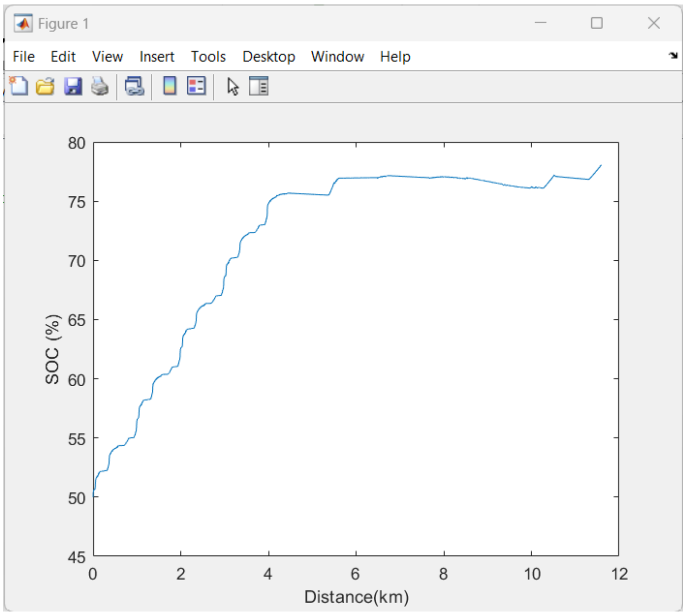
2. Evolution of the state of charge of the battery as a function of the distance in km.

The evolution of the state of charge of the battery over time is:



It is clear that the battery helps during acceleration phases but is constantly charged overall. Thus, the vehicle will never run out of battery during a NEDC cycle and will be able to start cold without worries.

Which depending on the kilométrage gives:



The battery then helps by acceleration phase during a city circuit but is continuously recharged, it constantly helps during the high-speed phase.

In conclusion, thanks to an optimization of hydrogen consumption supported by a lithium-ion battery we are able to minimize the energy consumed, especially in the city. However, the performance is very limited during peak speeds (> 80 km/h).

3. Safety and related items of the vehicle

3.1. Driver assistance systems

Our vehicle will be equipped with a 12V auxiliary battery like most current vehicles to power the electronic systems. We have chosen to add driver assistance systems to make our van as safe as possible and to improve user safety. Among all the options available today, we focused on 3 systems:

- **Lane departure** warning : thanks to a camera placed near the interior rear-view mirror that detects markings on the ground, the driver is warned when changing lanes without flashing. This system makes driving safer by avoiding collisions due to driver carelessness. The installation of this system on a compatible vehicle that does not have it as standard costs on average a few hundred euros in a garage or dealership.

- **Adaptive cruise control**: this system not only maintains a constant cruising speed but also calculates and maintains a safe distance with the previous vehicle. This system is based on radar or laser placed at the front of the vehicle. It can be used from 30 km/h, which makes it relevant for our city delivery vehicle. This system also makes it possible to brake the vehicle but is not entirely sufficient to achieve possible emergency braking. That's why we chose to add an automatic emergency braking system. This very technologically advanced system is quite expensive, it takes between 1200 and 2000 euros to integrate it on a vehicle.

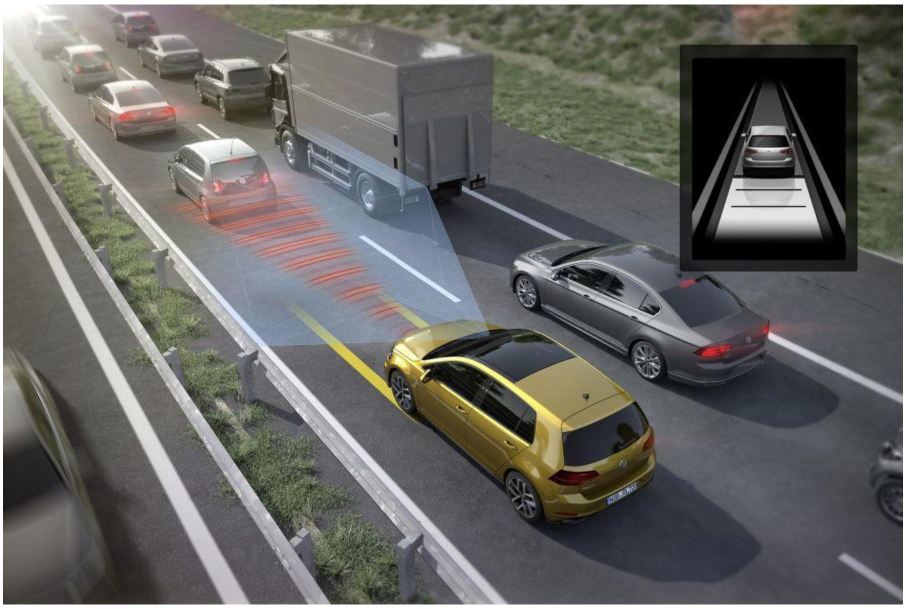


Figure : Representation of the dynamic speed control system

- **The autonomous emergency braking system**: it is based on the same radar as cruise control, but it is at the level of the computer that everything is played. The new technologies that we have chosen to integrate into our vehicle allow dynamic brake control, which increases safety and avoids collisions due to too hard braking . We have also chosen to further improve this system with the camera already present for the lane warning system. Indeed, it will also be used to detect pedestrians who represent a significant danger during urban travel that our vehicle will have to carry out. (These are not detectable by radar which only captures the vehicle in front or large obstacles). This will significantly reduce accidents because according to the American road safety organization, NHTSA, 2/3 of collisions in the city are caused by late braking. .

Thus, according to the UNECE regulation of July 2020, this system allows in the case of car-car braking an impact with a speed of 35 km/h for an initial speed of 60 km/h and braking is Triggers between 10 and 60 km/h and in the case of car-pedestrian braking an impact with a speed of 45 km/h for an initial speed of 60 km/h and braking is triggered between 20 and 60 km /h.

3.2. Hydrogen tanks

Hydrogen vehicles are often considered dangerous, at risk of explosion because the hydrogen is tocké at very high pressures in the tanks (700 bar). It is therefore necessary to pay particular attention to this point so that consumers are not reluctant to buy.

The first safety element present on hydrogen tanks is a pressure sensor that will detect any anomaly in the tank to warn the driver and/or solve the problem. In addition, the selected tanks are tested under extreme conditions to ensure maximum safety. They have several thicknesses of reinforced materials.

Figure : Pressure sensors

Since the ignition and detonation ranges are particularly wide with hydrogen, maximum means are taken to prevent leakage, including in the event of a vehicle accident. This is the number 1 objective of manufacturers when it comes to the safety of vehicles running this product. However, they must consider an accidental or voluntary release (in case of fire of the vehicle) of the gaz which must be able to escape from the machine without creating damage. additional. That's why the tanks are equipped with safety valves, multiple valves and a ventilation system that directs the gas outside the vehicle in the event of an accident. .

Conclusions

Vehicles consume a large amount of energy, which can lead to an increase in air pollution and the greenhouse effect. Reducing energy consumption can help reduce greenhouse gas emissions and other types of pollution, which is beneficial for the environment .
Vehicles also consume a large amount of gasoline or electric power, which can result in significant costs for vehicle owners. Reducing energy consumption can help reduce vehicle operating costs, which is beneficial for vehicle owners.
In addition, vehicles consume a large amount of energy produced by fossil fuel sources such as oil. Reducing energy consumption can help reduce dependence on these energy sources, which is beneficial for energy security and economic stability.
Finally, the amount of energy consumed by a car can lead to accelerated wear and tear on engine and other vehicle components. Reducing energy consumption can help extend the life of the vehicle, which is beneficial for vehicle owners.
Hydrogen-powered vehicles have several advantages that justify their importance for the future:

- Zero emissions: Hydrogen vehicles emit only water, making them free of any air pollution. This can help reduce greenhouse gas emissions and other types of pollution that can have a negative impact on the environment and health.
- Energy independence : Hydrogen can be produced from different renewable energy sources such as solar, wind and geothermal, which can help reduce dependence on fossil fuel sources such as oil.
- Range: Hydrogen-powered vehicles can travel long distances without charging, making them more convenient for drivers than electric vehicles that require frequent charging. .
- Cost reduction : The costs associated with hydrogen production are falling, which can make hydrogen vehicles more affordable for consumers.

However, the development and implementation of hydrogen distribution infrastructure remains a major challenge for the development of hydrogen vehicles. In addition, hydrogen production can still be expensive and may involve greenhouse gas emissions if produced from non-renewable energy sources.
In conclusion, hydrogen vehicles have advantages in terms of zero emissions, energy independence, range and cost reduction , making them a promising future for the automotive sector. However, the development of reliable and environmentally friendly infrastructure for hydrogen production and distribution remains a major challenge, but it is an area of innovation at the moment such as the alliance of Stellantis with Engie to supply hydrogen to these customers or the first hydrogen train that is in experimentation.

- Regarding our model, we have opted for a modest sizing that will not allow the vehicle to travel long distances at high speed.
- With a 130 kw engine, a 25 kw battery and a 100 kw heat pump at the maximum of performance, the vehicle can still reach 130 km/h and works optimally in the speed ranges between 20 and 100 km/h.
- The advantage of electrically powered vehicles is also a respectable acceleration from 0 to 90 km/h in 6 seconds.

- Its consumption is optimized by a battery which then helps the heat pump when it cannot change its power production in the time interval imposed on it (phase acceleration) but also serves to avoid overconsumption at low speeds (< 20 km/h).
- We have seen that, on the other hand, the consumption in H² being kept constant , driving in the city consumes more than driving at higher constant speeds.

- Finally, such a choice is also explained for the price, choosing a more powerful motor and a more powerful battery can be expensive. As the price of a CAP is currently excessive, costs should be kept to limit in other respects.

It would have been desirable to carry out a hillside study and a fully loaded study, but the time of a simulation being relatively long, this will be kept for the final presentation .

The simulation is admissible as has been shown.

Not loaded , off slope we obtain according to the cyclee NEDC :

A consumption in H² of 30.68 liters per 100 and an equivalent of 5.44 L/100 petrol.

In town :

7.78 L/100 km petrol or 43.85 L/100 km of hydrogen under 700 bar.

Knowing our 125 L tank, we then obtain as part of the NEDC cycle, a range of 407 km, which is in accordance with the specifications.

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