PLATHEE
A Platform for Energy Efficiency and Environmentally Friendly Hybrid Trains

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Abstract

Although railway is known to be a sustainable transport with few carbon emissions thanks to the electrical traction which is the most widely used, SNCF still wants to improve its energy and environmental asset in order to prepare the 'zero oil era' for diesel rolling stocks. To achieve these goals, PLATHEE research programme (Platform for Energy- Efficient and Environmentally Friendly Hybrid Trains) is studying and testing solutions for future railway systems by using hybridization.

The idea is to separate the generating block from the consuming block of the locomotive energy chain with the addition of a buffer block. In that way, an energy management is necessary. The management system embedded on board of PLATHEE is an innovative one.

Introduction

In response to economic concerns over train manufacturing, the environment and growing energy costs, operators and rail industrials are exploring new concepts for propulsion and energy management. The objectives for rolling stock, in mainly urban areas, are:

- to improve energy efficiency,
- to reduce consumption,
- to diversify energy sources,
- to respect the environment by limiting gas and particle emissions, plus noise pollution,
- to recycle and upgrade equipment at the end of its lifespan.

To achieve these goals, SNCF's PLATHEE research programme (Platform for Energy- Efficient and Environmentally Friendly Hybrid Trains) is studying a hybrid diesel locomotive built from a shunting locomotive BB63000.

The hybridization consists in separating the generating block from the consuming block with the addition of a buffer block. The generating block has to provide the average power supply consumed by the system, whereas the buffer block has two different functions: energy recycling and power supply smoothing. One of the project objectives is to identify and study these technological blocks to optimise their sizing and their use to guarantee, for example, their lifetime for low cost. It is important to notice that breaking the unique and usual link between power producing block and the consuming block is an innovative principle on rolling stocks. In that way, the energy management system embedded on board of PLATHEE is an innovative one.

Integration of these blocks is studied and will be tested on a demonstration platform which is going to be built from a shunting locomotive BB63000. Moreover, this platform will be modular. Indeed, the connections are designed to allow easy changes of the energy production and storage systems in order to evaluate different configurations.
The first version of the hybrid locomotive is composed of a generator and a fuel cell as generating block with batteries and ultra capacitors as energy storage systems. In addition, power electronic is necessary to manage this energy on board.

Finally, results obtained will be used not only for retrofit but also to deliver specifications for future equipment and rolling stocks. Nowadays, it is still difficult to assess economical and environmental benefit for the whole traffic of the company, because SNCF ensures many kinds of exploitation. However, according to the first simulations carried out by SNCF on a hybridized shunting locomotive, ensuring missions with many stops, profits could reach 20 to 60 % concerning consumption and, for pollutant emissions, the reduction of CO and HC emissions could reach 80 %.

Locomotive BB63000 can achieve several types of mission:

- Switching mission : to form freight trains, to push trains in the hump yard;
- Urban service mission: to operate branch lines located in urban zone for example or distanced of 20 – 40 km of a freight station;
- Mission in station: to form passenger trains;
- Track side mission: to ensure night-works trains in urban zone or tunnel
- Assistance mission in tunnel: to ensure the assistance of a train in tunnel for example during the absence of the catenary voltage.

In a first step, PLATHEE is going to be carried out for the two first missions: switching and urban service.

In this paper, the sizing of PLATHEE will be explained.. Then main characteristics of the components chosen will be given. Finally preliminary tests and integration will be presented.

Laying out the hybrid locomotive

The dimensioning of the energy chain of the hybrid locomotive will be done on the basis of the characteristics of these missions and thanks to the frequency method analysis. Then, several configurations could be tested on the platform. Thus, first energy storage systems chosen could contain batteries but also ultra capacitors. Their buffer functions are the same but time constants of these components are different. That is why ultra capacitors will be used for peaks of power. Concerning energy production, besides the downsizing of the diesel engine, a 50 kW HELION Fuel cell is going to be tested by using the modularity of the platform.

In order to cover all the technical competences which are necessary to carry out this project, co-financed by the French Environment and Energy Management Agency, a consortium of industrial

and academic partners are working together: SNCF, 2HENERGY, ERCTEEL, INRETS, LAPLACE, ALSTOM, SOCOFER, SOPRANO and MAFELEC.

Architecture of PLATHEE traction chain

The electricity-generating group supplies the four traction groups and auxiliary converters with 540V direct voltage. Each traction group supplies a traction engine. They run independently.

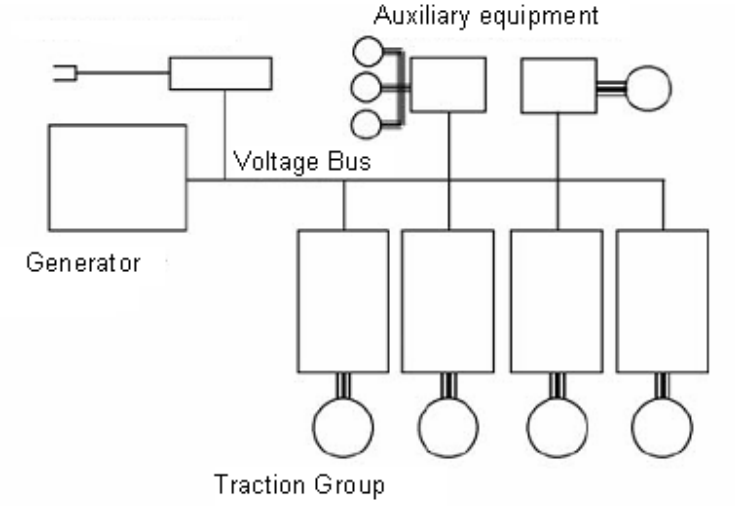

Figure 1: traction chain scheme

Traction chain sizing

This hybrid locomotive is original not only because associated components characteristics are complementary but also because the method used for the components sizing is the same than the component management. A PhD thesis driven by LAPLACE and SNCF has defined a strategy for the sizing and the energy management.

The sizing of the energy traction chain consists in sharing out the necessary power for the mission to the components in function of their intrinsic characteristics:

- The generator and/or the fuel cell provides the average power;
- Battery modules provide the energy demand (low power during a long period);
- Ultra capacitors provide the peak power demand.

The power allocation depends on the mission, that why a spectral analysis of the power supply for different kinf of mission has been done, The following graphs shows the spectral analysis of shunting mission in blue and urban mission in red.

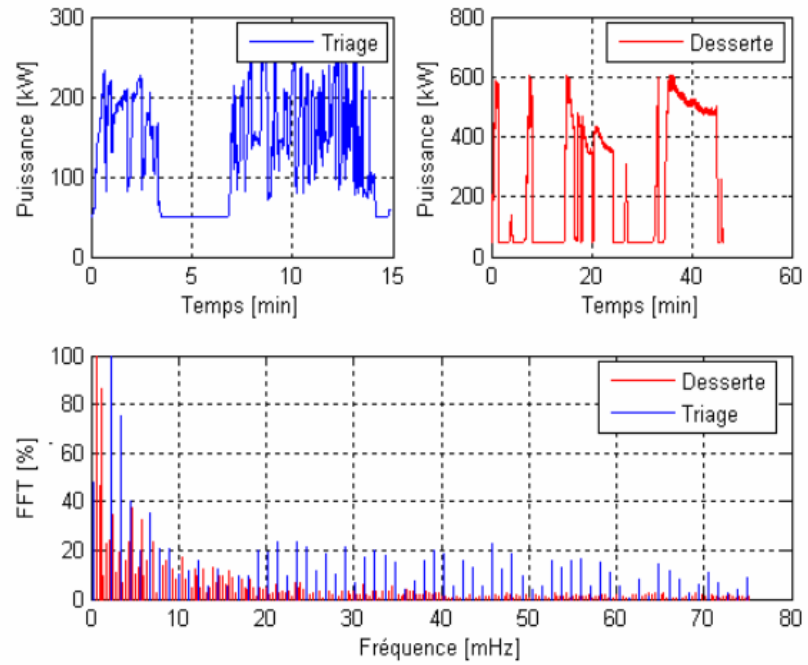

Figure 2: spectral analysis of shunting mission and urban service mission

After using frequency filters we can obtain the following allocation of power for an urban mission:

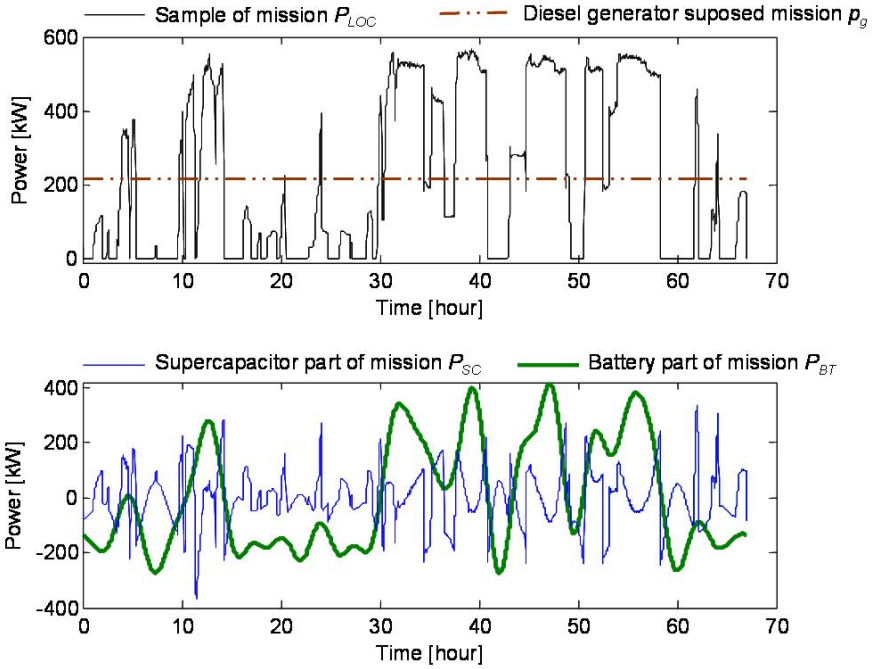

Figure 3: allocation of mission power

Traction groups

These are modular sets made up of the following elements:

- A battery module,
- An ultra capacitor module,
- Static converters (CVS) for traction and loading stocking elements. These converters are reversible and include power modules that are tightly integrated into the IGBT. Layout of the traction group enables a 100kW power supply to the wheel rim.

Battery module

The storage battery must have the following characteristics:

- capacity: 138 Ah
- efficiency: 75%
- length of life: >1000 cycles
- discharge current: 5C
- Charge current: C/3

For each axle, the module is composed by almost 300 serial elements

We first wanted to use a new technology battery, the Nickel Zinc technology, because with this new type of elements, the performances are close to the traditional battery and the advantage is that no toxic components are used (recycling rate of 90% is possible with these battery modules). Nevertheless, procurement of the required capacity was not possible at this phase of the project. That's why for the first development phase, Nickel Cadmium batteries are going to be used. This technology is specially adapted for railway application and we have also chosen a model with low maintenance.

Ultra capacitor module

The ultra capacitor that has been chosen has the following technical characteristics:

- Capacity: 5000 F
- Nominal tension: 2.5V
- Length of life: 500 000 cycles

ERCTEEL is in charge of the elements assembling. Due to the required main bus voltage and power supply, many ultra-capacitors are associated in series. Moreover, ultra- capacitors are known to be very sensitive to voltage and temperature. To avoid a differential ageing of the elements, an active balancing system has been developed to impose the same voltage to each cell. It results in a more efficient use of the stored energy.

Converters

All the converters combine a unique module with an industrial scale, commutable 1200V 450A IGBT: this is the "building block". This module can operate as a step-down chopper for traction battery or ultra capacitor charges. It also acts as a step-up chopper for recycling energy on board the machine, i.e. delivering output from batteries and ultra capacitor to the voltage bus. These modules are also used for auxiliary equipment. This power electronics is defined and tested by INRETS.

Generator

Concerning the generator, the diesel engine (2H ENERGY) and its alternator are associated with a semi-conductor rectifier in order to produce a 540V voltage in a bus bar. In the original locomotive, the nominal power of the generator was 600 kW, because of the important demand during the moving off. . Now that the generator is sized to provide only the average power supply, its nominal power is reduced nearly to 235 kW. This sizing has been made using power measurements for shunting missions and urban service missions, which are usually ensured by the BB63000.
Contrary to usual engines, which have a single operating area (the operating speed), the PLATHEE's one uses variable speed. Therefore, several operating areas are defined. For example, when the locomotive will be waiting at the platform of a station, the lowest rating will be used. The generator will be able to adapt to the real need of the system, so we can reduce gas emissions and noise pollution.
Moreover the diesel engine is able to operate with biofuel.

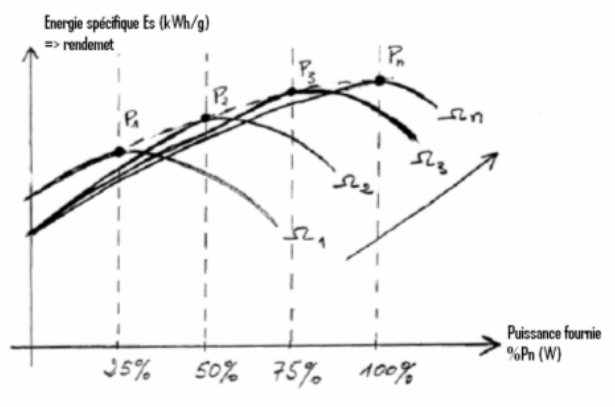

Figure 4

In addition to the generator, SNCF decided to test a new energy production system: the fuel cell. This fuel cell is developed in the SPACT80 project (80 kW fuel cell system for transport application in partnership with HELION, CEA, INRETS, FCLab, CNRS,DGA and SNCF). Like the engine, the fuel cell is connected to the 540V bus bar. During the first development phase, the fuel cell is going to be installed in the hybrid platform. Its power will cover one part of the power consumption; the generator will cover the second part.

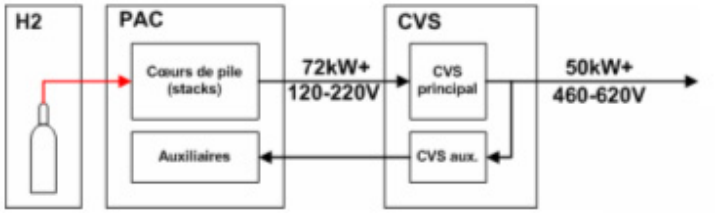

Figure 5: fuel cell system scheme

The fuel cell system that has been chosen has the technical characteristics following:

- PEM Technology, Hydrogen + O_2 from the Air
- Gross Power: 72 kW
- Net Power > 50 kWe

- FC system provide by HELION: FC (2 stacks) + Auxiliaries + Converter
- 24 000 hours of tests

Strategy for energy management

With the similar spectral analysis method of the power supply proposed by LAPLACE, the system will allow one or other storage elements to provide energy to the system or to reload, here is the strategy for energy management.

The energy management consists in filtering high and low frequencies. High frequency mission is provided by ultra capacitors low frequency mission is provided by generators and batteries. Diesel generator and fuel cell run in their optimal power (for consumption, for pollution, for life time, …) and batteries provide the rest of the low frequency mission.

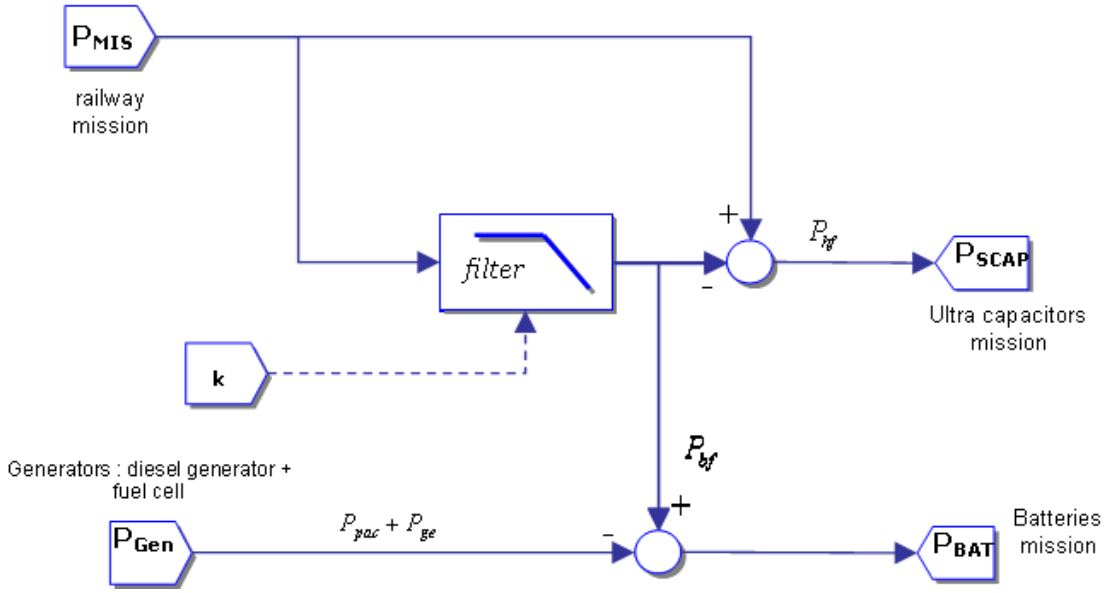

Figure 6: energy management strategy principle

Energy management carrying out

In order to take account this energy management on board a supervisor is necessary to be integrated in the locomotive. This supervisor is developed by SOPRANO. It is composed by a programmable logic controller and an on-board computer

Preliminary tests

PLATHEE is currently being developed. The technology blocks are undergoing laboratory tests to define their lifespan and reliability. Each of these elements will be integrated in two phases – validation of the equivalent of an axle on a mini bench in a SNCF Workshop in LE MANS and then validation on the platform in fall 2008.
The static bench is representative of the traction chain on ¼ scale.

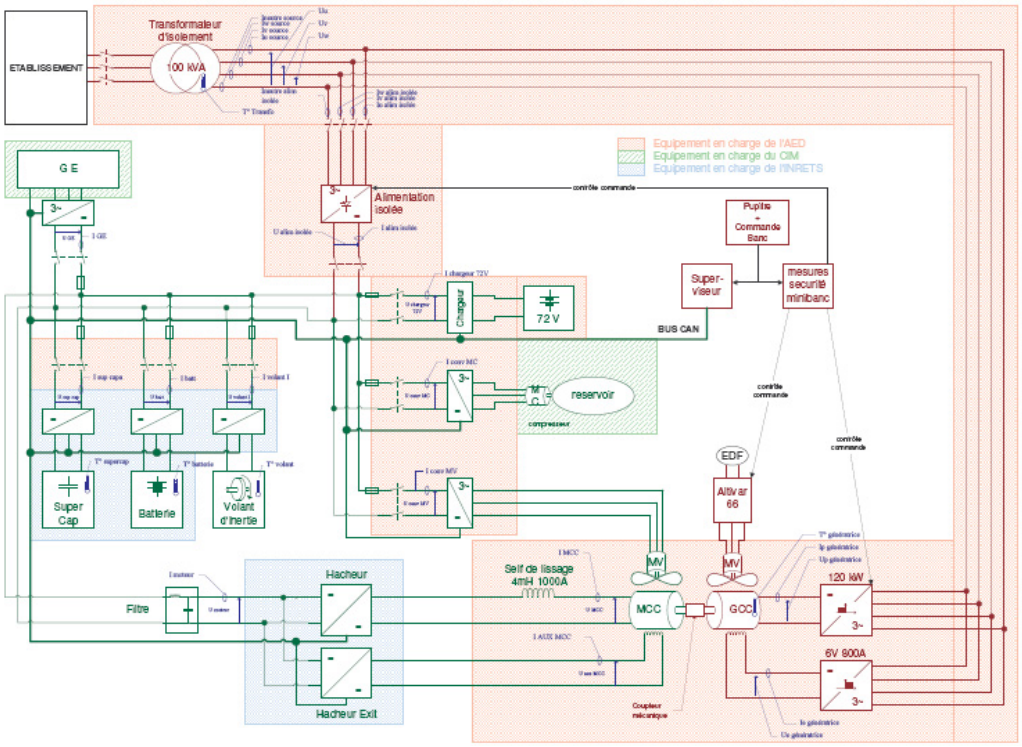

Figure 7: static bench configuration

The first brick arrived in SNCF workshop in November 2007, firsts tests are realised.


Figure 8: Fuel cell in Le Mans SNCF Workshop

Integration

The hybrid locomotive has been designed by SOCOFER in order to simplify the maintenance and interchangeability. The generator is placed on the conductor cabin side because of the position of the exhausts. Then, the fuel cell is implanted, ultra capacitor modules and power electronics will be at the front of the locomotive, batteries will be under the car body.

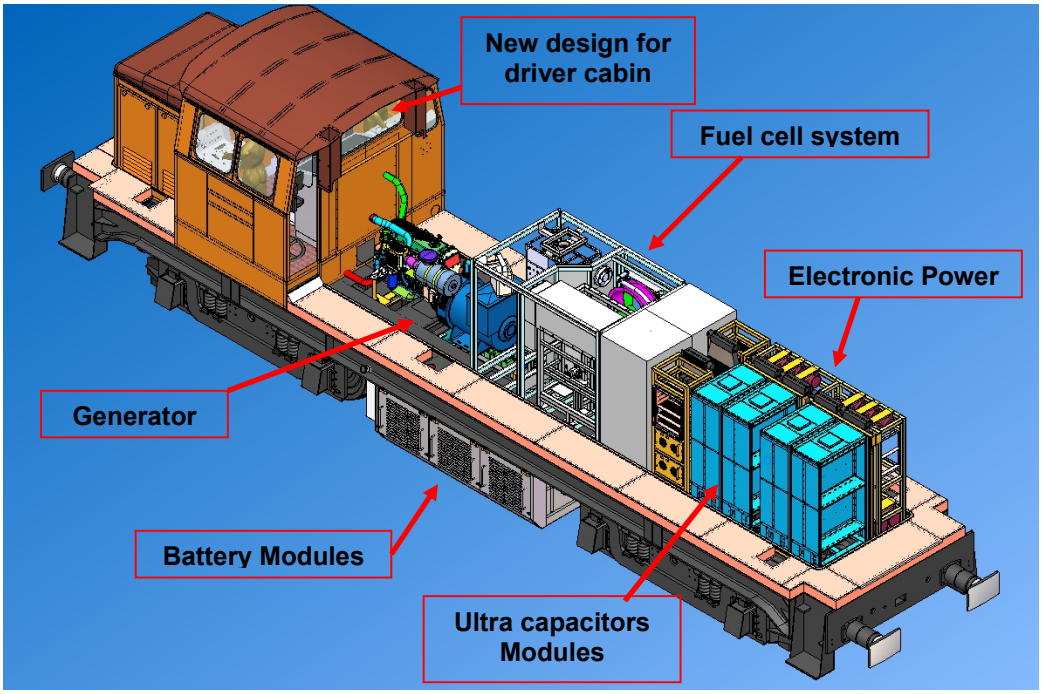

Figure 9: PLATHEE integration principle

Conclusion

The hybrid concept was also tested in North America (Canadian Pacific Railway with "Green Goat" hybrid locomotives), in Japan (JR East with NE Train). PLATHEE will be the first hybrid demonstrator in Europe with this innovative energy management. This modular demonstrator is an opportunity for SNCF to test new components, technologies, energy management on board in order to improve energy effectiveness by reducing the consumption of rolling stocks.

The results could be used for rolling stocks retrofit but the main objective is notably to deliver good specifications for future rolling stocks traction chains. However these results could be also used for others applications in the railway system. For instance, ultra capacitors could be used for Diesel engine starting up; fuel cell could be used for embedded auxiliaries feeding but also for railway stationary equipments.

Acknowledgment

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