Bond Graph Modelling : a good communication tool between University and Industry

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Abstract

The aim of this paper is the interest of the use of bond graphs as a modelling tool. The goal of this tool is to exchange knowledge between different communities such University and Industry. The paper will treat of how PSA had developed a data base to incorporate different models of parts of a car. These models are coming from their own research department and from partner university research laboratories. They allow a car maker to design quickly a new type of car.

1. Introduction

In teaching sciences for engineers, we must model physical phenomena and physical systems. The necessary steps are writing equations for each elementary physical system, sorting these equations and implement them in a solver. This approach requires attention when the system to model is complex and multidisciplinary (mechanical, hydraulic, thermal).

In the car industry, Mechatronics, a combination of Mechanics and Electronics had leaded to replace functions previously achieved by mechanical devices (Electronics injection had replaced mechanically driven spark emission) and to introduce "not previously thought of" functions such Anti Blocking System or traction control.

The highly competitive car market pushes the companies into a shortening of the product life cycle. Modelling, analysis and simulation are the necessary tools to reach this goal

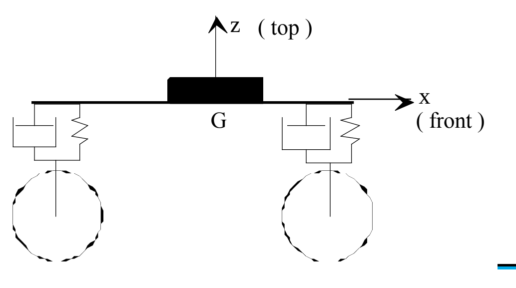
A common tool enabling a unified approach to the physical modelling of various disciplines is the Bond graph [1],[2],[3]. The hypothesis of localised physical elements enables a graphical representation supported by a complete coherent algebra.

The heavy use of mathematical modelling techniques in conjunction with user computer implementation will make fast iterations possible at the simulation level and the "Do it right at first" achievement. Mechatronics enhances these factors because its necessary multidisciplinary interfaces can

The French car maker PSA Peugeot Citroën had planed to develop the modelling of each part of a car using bond graphs [4],[6],[7]. In the frame of an European project OLMECO (an Open Library for models of Mechatronics Components), had engaged researches to create a library for mechatronics component models. So, engineers have the use of availability of validated reusable models. Bong graphs have been chosen as universal modelling language.

2. Modelling with Bond Graphs

The example concern an industrial problem : the design of a car brake system. In this paper, the model is chosen very simple (fig 1). The half car is moving on the plane. The body frame is attached at the centre of mass G. The main directions are : Gx oriented toward the front, Gz oriented toward the top. A classical suspension link the body to the wheels.



Figu re 1. Mechanical system

The torque applied on the wheels are obtained from the brake pedal using an hydraulic transmission (Fig 2).

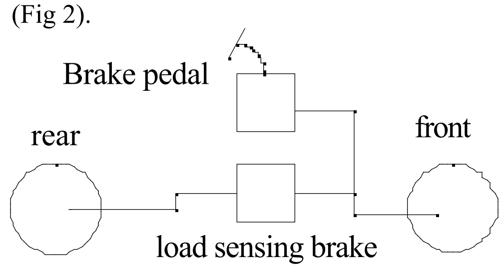


Figure 2. Hydraulic circuit

A 150 bars source pressure is provided by a pump and the brake pedal modulate this pressure which is sent to the front wheel. A load sensing brake attenuate this pressure versus the load to the rear wheel. The oil pressure reach a single piston sliding floating callipers through a flexible pipe for the front wheel and a spiral service brake line for the rear wheel.
Three dynamic must be taken into account

- the hydraulic dynamic very fast,
- the wheel dynamic, medium,
- the body dynamic, slow.

The figure 3 presents the bond graph of a braking process of automotive vehicle with mechanic (top) and hydraulic (bottom) part.
Many observations may be done about the hydraulic part.
The zero junctions are used to represent pressures and one junctions for flows. A rigid service brake line must be modelled with a resistive (R) and inertia (I) elements with : $R = \frac{128\rho L\nu}{\pi d^4}$ $I = \frac{\rho L}{S}$

ρ mass density,
ν cinematic viscosity,
L length of pipe,
S cross section,
d diameter.

A flexible pipe (front wheel) is modelled like a rigid one added by a special C element to take into account the compliance of the pipe. It means that the flexible pipe absorb a volume of oil depending the pressure. The special function "abslign1" shows this element. The special function "cetrierav" represents the mechanical compliance of the calliper under the force applied on the brake disc. These elements allow the simulation to take into account several phenomena close of the reality. The special element "frein1" provides the transformation between brake pressure applied on the piston and the braking torque applied on the wheel.
Concerning mechanical part of the bond graph, many observations may be done. The zero junctions are used to represent forces and one junctions for velocities. The mains velocities are :

vel_z vertical velocity of G,
vel_x horizontal velocity of G,
pitch_ang_vel angular velocity of G,
wheel_frangular velocity of the front wheel,
tang-vel_fr tangential velocity of the front wheel tyre.

Fx_fr is the horizontal force applied by the front tyre to the car.
The vehicle is decelerated through a friction force existing between wheel and road. The tyre-road interface is modelled with Pacejka model [9]. A braking torque provides a wheel slip expressed by :

$$Ws = \frac{vel\_x - tang\_vel}{vel\_x}$$

The slip determines the friction coefficient μ through a functional dependence shown in figure 4. The curve is

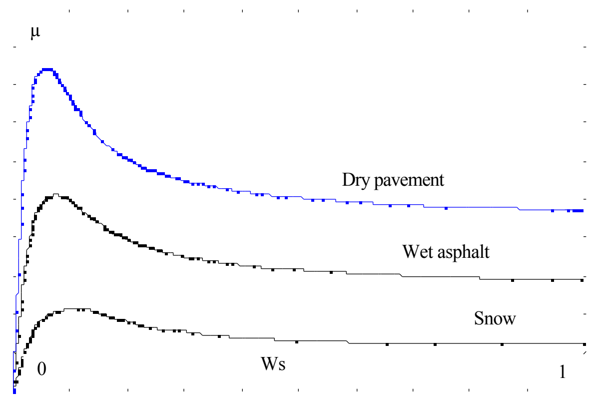


Figure 4

The force Fx_fr value is expressed by :
Fx_fr=μ.Fn Fn beeing the normal force applied on the tyre. It is interesting to note that the tyre-road interface is determined by a non physical law. It is computed in pacx5 (fig3).
The figures 5 and 6 show the results of a simulation using previous model. The car (a XM Citroën model) is launched with 20 m/s velocity and braked with a 120 bar pressure on the front wheel on a wet road. At the figure 5, the front wheel hydraulic phenomena are presented. The A curve is the pressure generated by the brake pedal. The B curve is the pressure applied to the calliper piston, one can see a delay due to the motion of the friction pad until it reaches the brake disc. The C curve is the oil flow toward the calliper piston, the oscillations are due to the flexible pipe dynamic.
The hydraulic variable behaviour has been verified by experiments.
On figure 6 are shown mechanical variables representing the car behaviour under braking operation. The time scale is zero to 5 seconds, the brake action begins at t= 0.5 s. The A and B curves are respectively the car and tyre velocities, one can see the wheel slip increasing and decreasing providing braking force. The C curve is the normal force applied on the front wheel. This force is increasing due to the braking torque effect improving the braking force ; There is an opposite effect on the rear wheel. The car is stopped in 3.4 seconds.

3. Integration into a library

This study may allow the design of a car braking system for a new model. In order to reach this goal, it is necessary to use a specific organisation : library of components, vehicle parameters for mechanical and hydraulic parts… This study must be reorganised to be added in a model data base to be easily reusable for an engineer.

In order to describe the model's data base it is necessary to define user needs. Basically the main objective is the creation of a library of mechatronics components in view of their reusing.
A model state evolves during its life :

- generic model,
- instantiated model,

- simulation model,
- validated model.

A generic model is a general representation of an actual mechatronics system. It describes physical phenomena taken into account to represent an organ. It owns local and external components. A generic model is associated to physical organ as electrical motor, battery… The figure 7 shows a technologic view of a generic model of an electric car, the figure 8 shows a mathematical representation of this generic model using a bond graph. The figures 9 shows the sub-models used by the generic model. The figure 10 shows the different kind of electrical motors available in the library.

An instantiated model is used to describe the behaviour of a particular organ already described by a generic model. For example, from an electrical machine generic model you may built a electrical to mechanical transformer (motor) or its invert (electrical generator) Two kinds of instantiated model are possible. An instantiated model needs a generic model, a causal analysis and a set of structural parameters.

A Simulation model allows dynamical analysis of an instantiated model. It needs a set of initial conditions, the definition of external entries and a numerical integration method with a computation step.

4. Conclusion

The study presented is a characteristic example of a university research work. It is important to note that bond graphs have been chosen as dynamic system powerful tool modelling using the same formalism for hydraulic and mechanical parts.

At the level of a car maker research department, it is important to develop fruitful collaboration with university research laboratories. Nevertheless, each study must be standardised to be used immediately, to be stored in a data-base and to be reused in other context.

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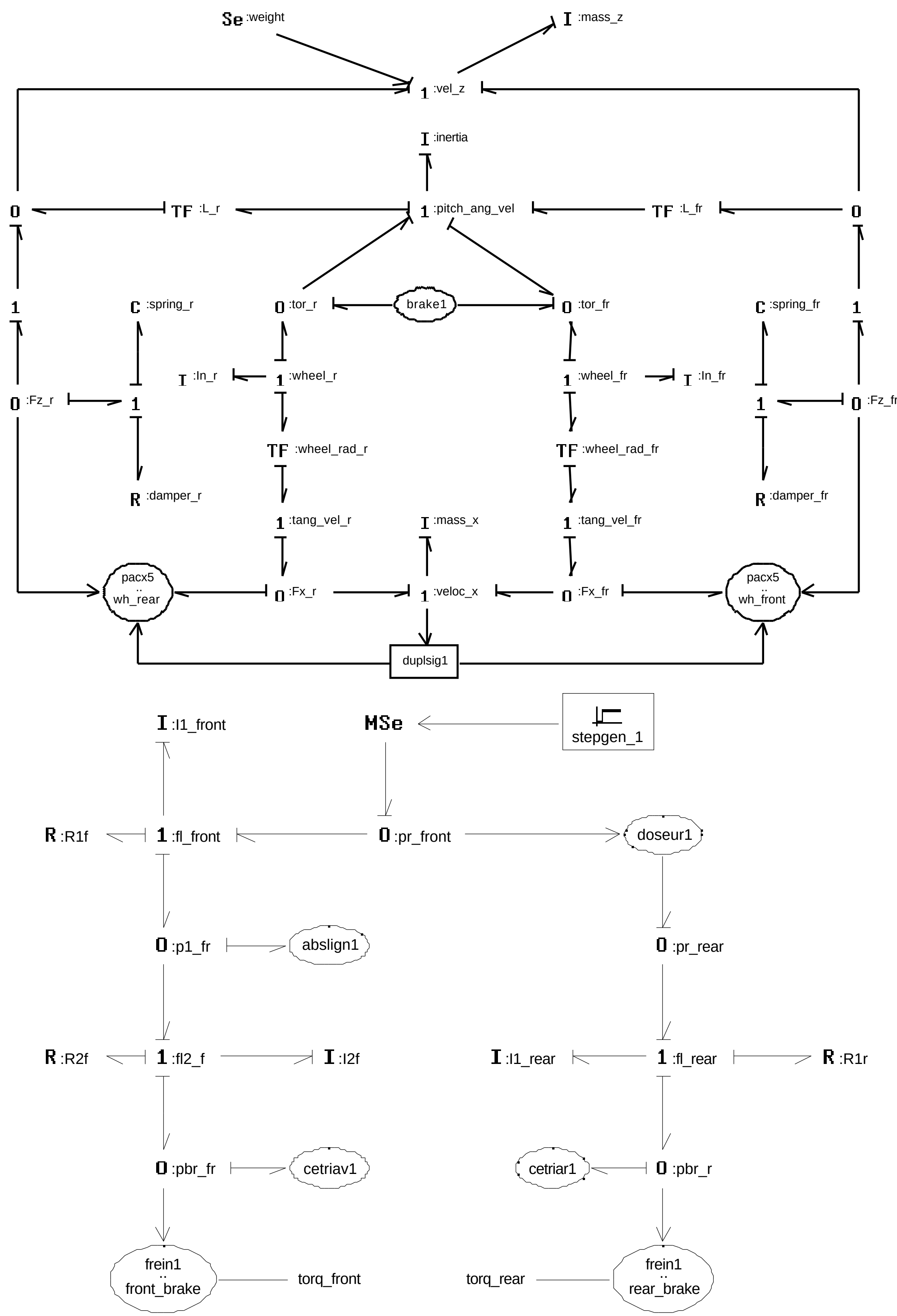

Figure 3. Bond graph of a car braking : mechanical part (top) and hydraulic part (bottom)

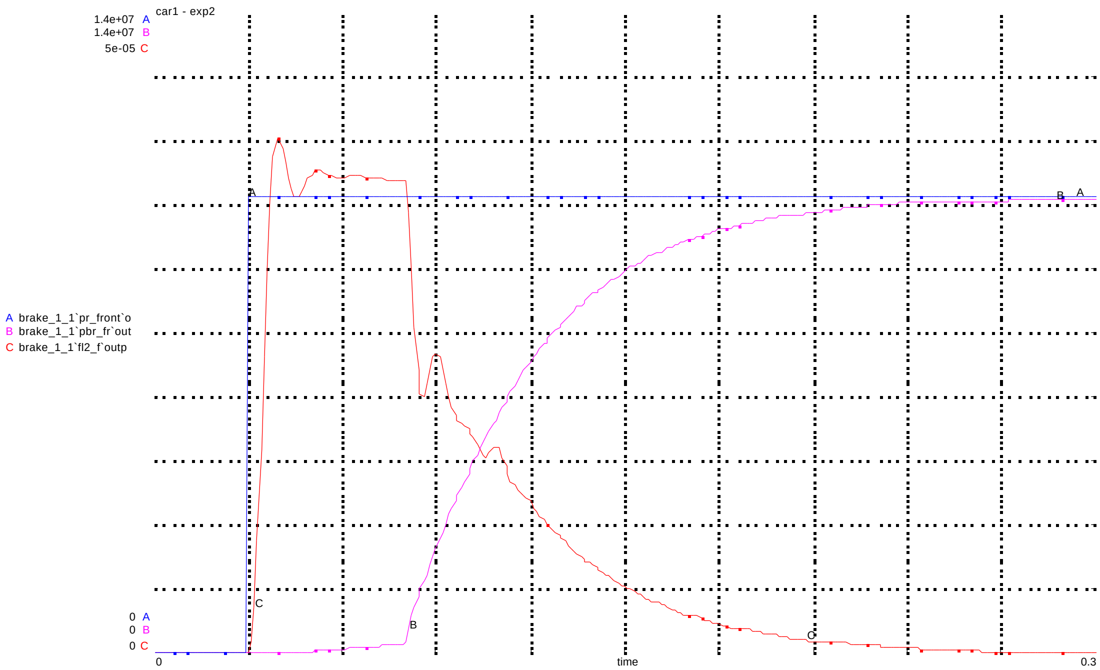

Figure 5. Hydraulic behaviour of front wheel

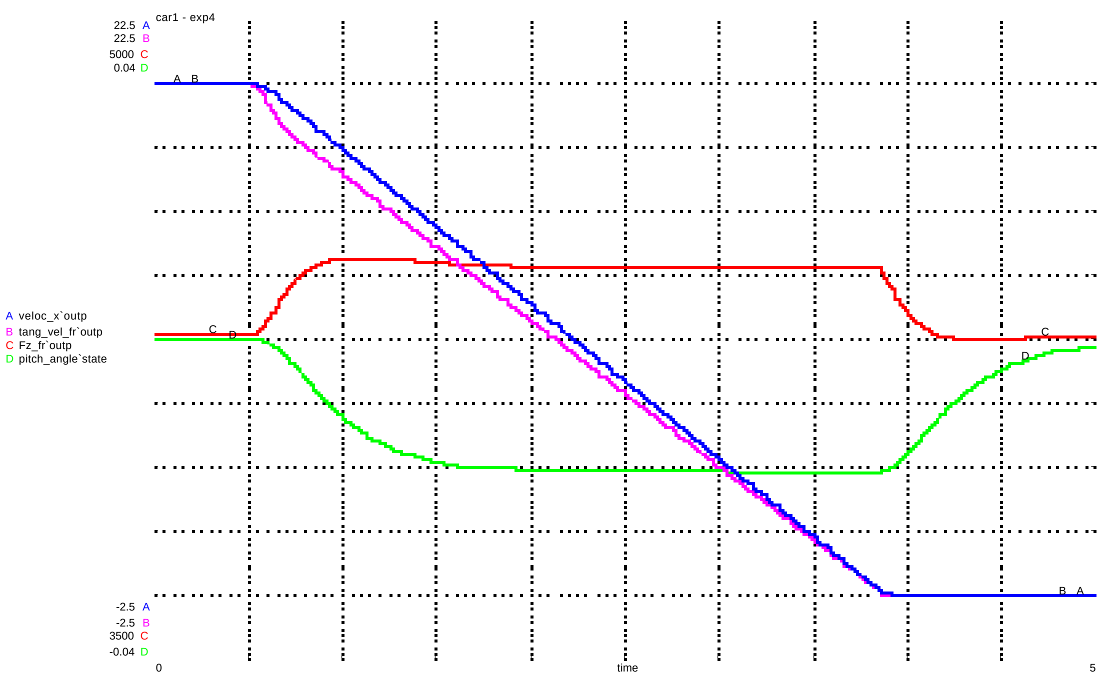

Figure 6. Mechanical behaviour of front wheel

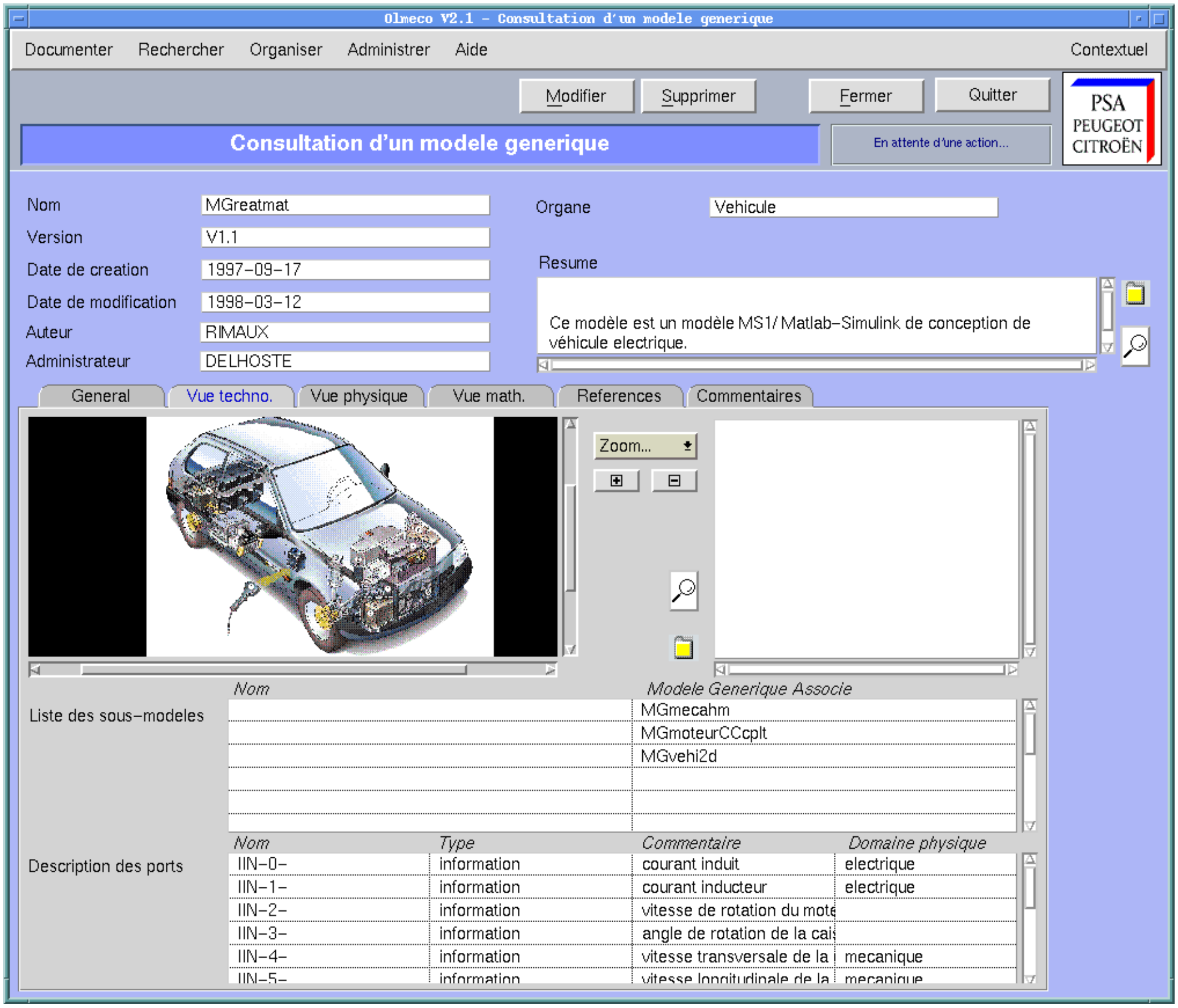

Figure 7. Technologic view of electrical car generic model.

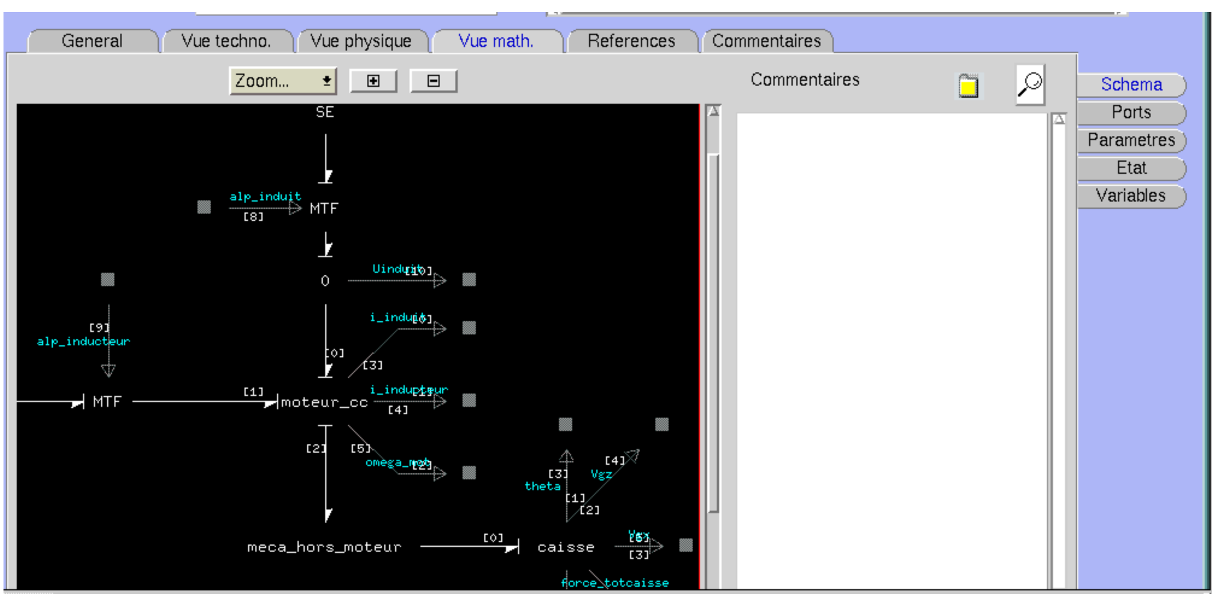

Figure 8. Mathematical view of electrical car generic model.

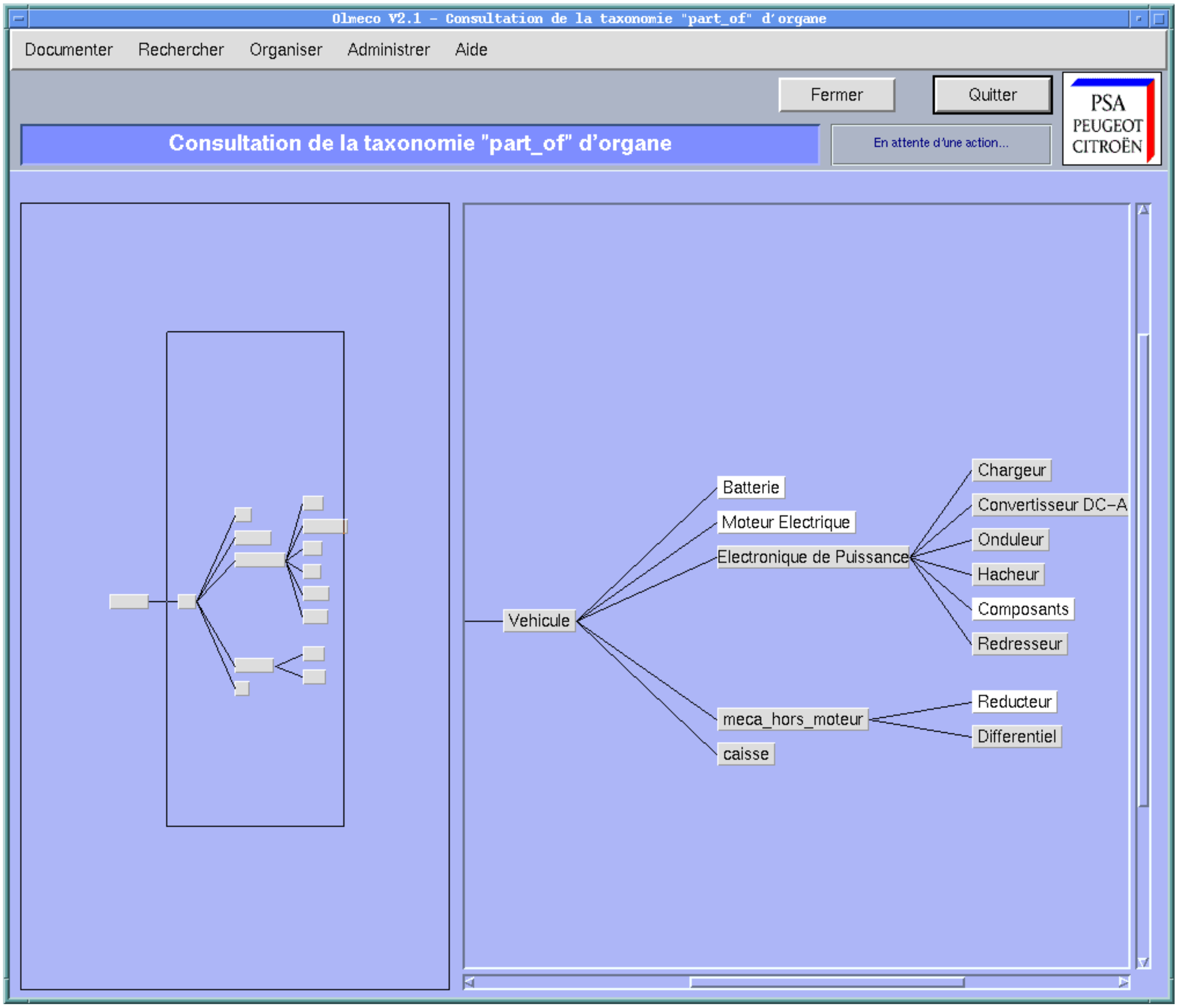

Figure 9. Library part of electrical car generic model.

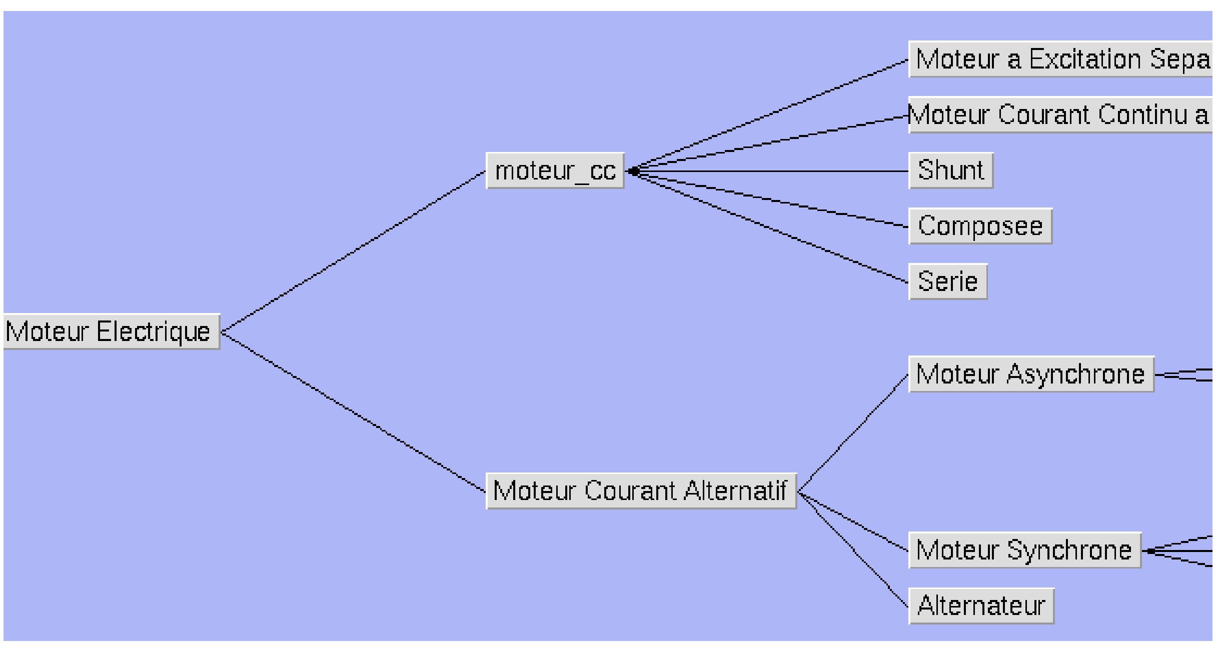

Figure 10. Library kind of electrical motor