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Research Paper

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Study of Current Variators Applied to Braking Energy's Recovery From a Vehicle

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Abstract—In electrical energy production systems, energy flows make use of various energy conversions which are, for the most part, essential. DC-DC conversion is one of them. Often, choppers, like step-down (Buck), step-up (Boost) or step-down-boost (Buck-Boost), ensure this conversion. In this work, the use of current variators, boost converter, is considered. These are power electronics converters, often used by various fields, including the field of transport. With the appearance of electric vehicles, they see themselves as being among the elements that will ensure the best energy exchange of the whole. And above all, its involvement in the regenerative braking of said vehicle is highlighted. Starting from the concept of recovery of braking energy, we will relay the type of converter used, often reversible in current. And without going into detail, the block diagram of the electric vehicle studied, equipped with the electronic differential is illustrated. The results obtained during the simulation using Matlab/Simulink clearly demonstrate the feasibility of recovering braking energy.

Keywords—Current variator, Boost, Regenerative braking, Energy management, Vehicle

I. INTRODUCTION

On the one hand, for several years, the price of oil has not ceased to fluctuate. Its scarcity and the harmful effects of gases harmful to the environment have triggered some of the recent studies on our transport system. A strict awareness has led to increasingly regulations on polluting emissions and vehicle consumption which become the two essential criteria for new vehicles design. Noise and greenhouse gas pollution, as well as constantly increasing fuel consumption, are increasingly involving this consumer item at the heart of energy debates [1], [2], [3]. In addition, the excessive use of vehicles is one of the factors of the proliferation of air pollution. The latter favors the increase in global warming.

To meet the challenge of further reducing fuel consumption and emissions, today's automotive industry has turned to electric and/or hybrid vehicles. In this communication, only electric vehicles are considered, since only one voltage source is used via an electric power system [4], [5]. The latter is connected to the assembly by a DC-DC conversion system ensuring the constant maintenance of the DC bus voltage and above all the good management of the vehicle's energy flows [6], [7].

On the other hand, the presence of one or more electric motors, with their energy conversion systems, in these types of vehicles makes it possible to recover energy during their braking [8], [9].

Changing one form of energy changing into another is a part of an energy conversion. Specialized in this field, manage that system help us to review some existent electrical or mechanical recovering part. This is why we are going to make a review study of current variators, Boost converters, applied to the recovery of braking energy from a vehicle.

Going through a brief presentation of the different types of braking (mechanical and electrical), it is necessary to know the type of energy that can be recovered. To do this, the mechanism ensuring the recovery of braking energy offers a better description of the current reversibility of the Boost converter studied. The results and discussions on the simulations will be presented in order to quantify the braking energy restored.

II. METHODOLOGY

With the year of experimentation (field and laboratory), relevant details, with appropriate statistical methods, should be given including experimental design and the technique. Whatever the braking system and its use, a brake absorbs external mechanical energy which may be either potential energy due to gravity (in the case of lifting devices), or kinetic energy (in the case of vehicles), or both. at the same time (case, for example, of a launched vehicle approaching a descent).

The mechanical energy absorbed is returned by the brake in another form which depends on the braking system considered.

2.1 Vehicle braking system

By definition, braking equipment is a set of braking devices fitted to a vehicle and whose function is to reduce or cancel its speed or to keep it immobile if it is already stationary [1]. To brake is to absorb energy from the mechanical system. Depending on the use made of this absorbed energy, there are several types of braking: mechanical braking and electrical braking.

2.1.1 Mechanical braking

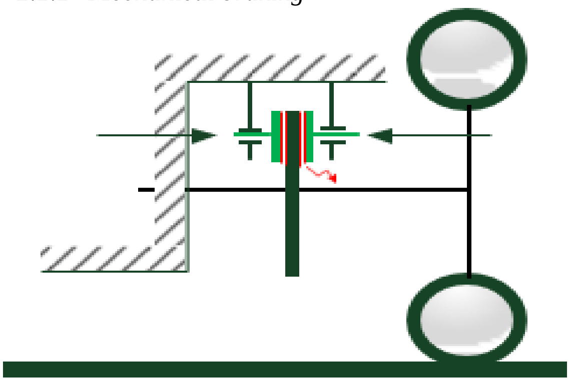

Figure 1: Mechanical braking principle

Its operation is based on the dissipation of the kinetic energy of the vehicle into thermal energy.
The friction of moving parts (rotors) on fixed parts (stators) is generally used. The brake is therefore a heat absorption system. Its effectiveness is linked to the ability of its constituents to absorb and resist heat, and to the coefficient of friction between them.

2.1.2 Electric braking

During electrical braking, the kinetic energy of the moving part is converted into electrical energy which can be dissipated into heat in a resistor or alternatively, reinjected into their source (regeneration). Note that electric braking cannot immobilize the motor (of the system), for this you need a mechanical brake. However, the main advantages of using electric braking are to reduce the wear of the mechanical brake and thus to be able to recover the kinetic energy [4].

A method for braking an electric motor is to reverse the direction of the excitation current (for the DC motor with separate excitation), to invert two three-phase wires (for the three-phase motor) or to invert the supply voltage (for permanent magnet DC motor).

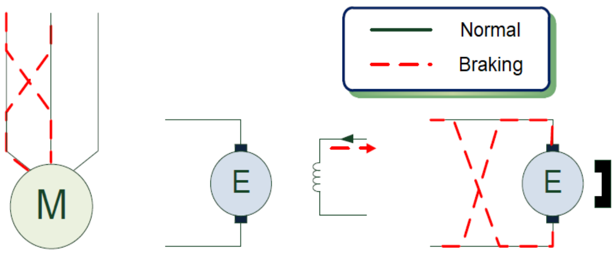

Figure 2: Electric motor braking principle

The brakes are an important safety device:

- on vehicles, they make it possible to regulate the speed, and to stop, therefore in particular to avoid a collision (emergency braking)
- on machines with moving parts, motion management is an important part of the machine's work.

2.2 Braking energy recovery

2.2.1 Braking energy

Kinetic (braking) energy is the energy possessed by a body due to its movement relative to a given reference frame. For a material point, the kinetic energy is equal to the work of the applied forces necessary to move the said body from rest to motion [2], [3], [5].

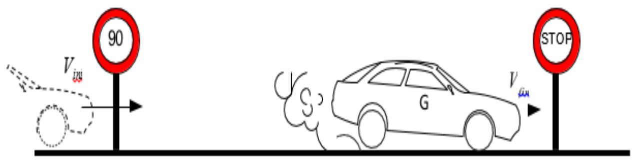

Figure 3: Braking's illustration

This energy has the expression:

$$E_c = \frac{1}{2} m V_x^2 \qquad (1)$$

The recoverable kinetic energy is the difference between the initial energy, ie the energy at the deceleration bridge, and the final energy.

$$E_{CR} = \Delta E_C = E_{Cfin} - E_{Cini} = \frac{1}{2} m \left(V_{xfin}^2 - V_{xini}^2 \right) \qquad (2)$$

2.2.2 Principle of the recovery of this energy

When you release the accelerator pedal, the engine no longer supplies energy to the vehicle.

It's the kinetic energy that keeps it going. To brake, it is necessary to convert this kinetic energy into another form of energy, here into electrical energy.

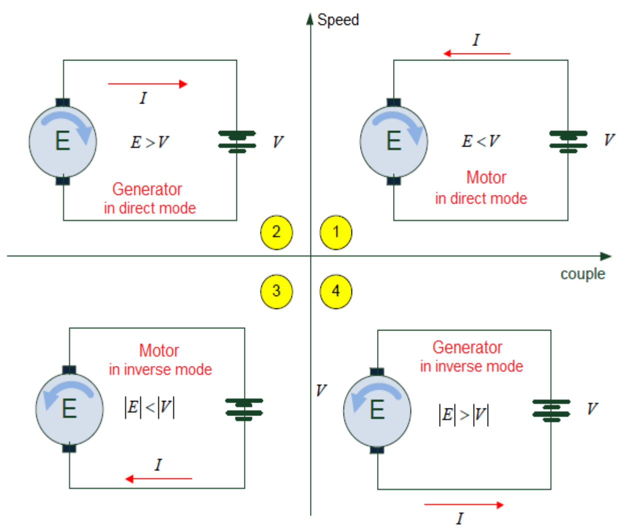

Figure 4: Four-quadrant operation of a motor

For this, the reversibility of the electrical energy chain is exploited by operating the motors in generator mode (2nd quadrant, figure 4).

During a descent, the speed of the vehicle increases, in order to keep this speed constant, it is in our interest to also recover the energy which caused it. This is potential energy.
This is where the Boost type current variator comes in, of course, reversible in current.

2.3 Modeling and control of a current converter, Boost type

2.3.1 Boost chopper

Also called "parallel chopper or step-up chopper or booster chopper", its electrical circuit is given by figure 5. Inductance in series with a voltage source are the part of the input source direct current type. Capacitor in parallel with the resistive load are the output load direct voltage type [6], [9].

The transistor T is closed during the fraction αT of the switching period T. The energy is stored in the inductance L, the load is disconnected from the assembly (diode D blocked).
When the transistor turns off, the energy stored in the inductor is discharged into the capacitor and the load resistor.
In continuous conduction mode, we have the current and voltage waveforms of figure 6. We deduce from this figure the output voltage in average value:

$$V_s = \frac{1}{1-\alpha} V_e \tag{3}$$

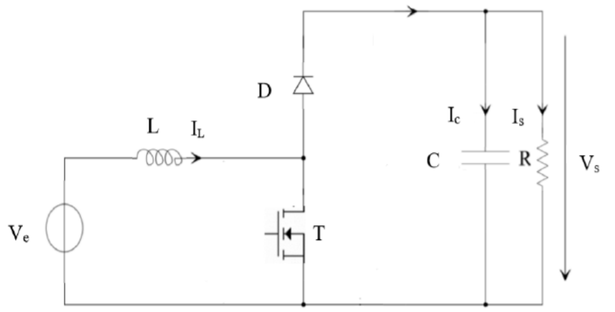

Figure 5: Current converter, Boost type

The duty cycle α being between 0 and 1, the average output voltage can vary by Ve and more.

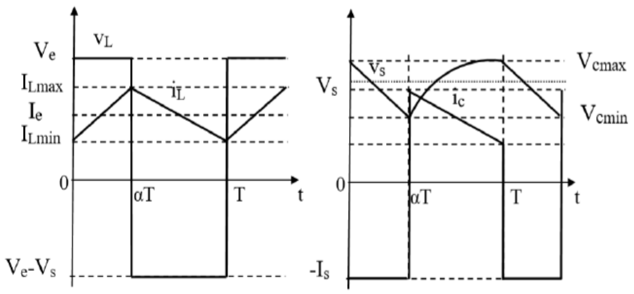

Figure 6: Boost chopper waveforms

2.3.2 Current reversibility of this chopper

In such a system, the change in the direction of the energy flow is linked to the change in sign of the current while the voltage remains constant, see figure 7.

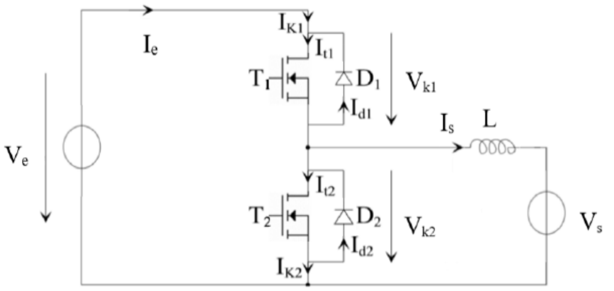

Figure 7: Current reversibility of the converter

The current I_s at the output can change sign during a switching period, which requires the sequential conduction of each of the four switches.

2.1 General structure of the vehicle model considered

The simulation of all the components that electrically make up the vehicle and a system generating the resistive torque (sensor) is complicated.

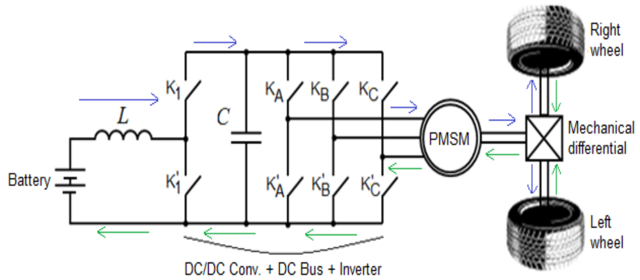

Figure 8: First structure of the considered vehicle

The speed and steering angle setpoint block gives the general reference of the vehicle, that is to say the desired speed and the turning of the steering wheel. The electronic differential unit integrates the calculation of the speed setpoints of the two motors and synchronization.

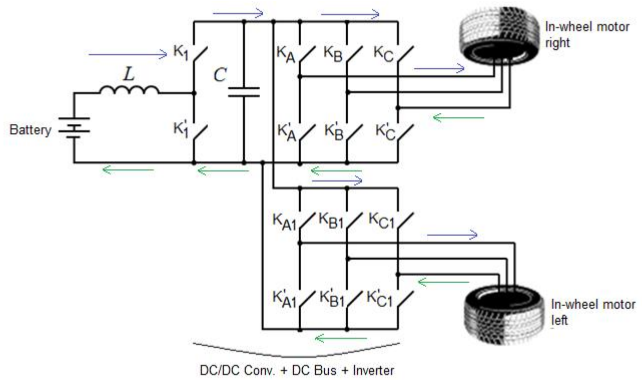

Figure 9: Second structure of the considered vehicle

Each system block is composed by controller, inverter and motor. And the sensor, from the rotational speed

measurement of each engine, the traction power and the longitudinal speed of the vehicle are estimated.
By knowing these values, we can also estimate the resistant couples.

III. Results and Discussion

Under Matlab/Simulink, the model in figure 10 below has been taken into account.

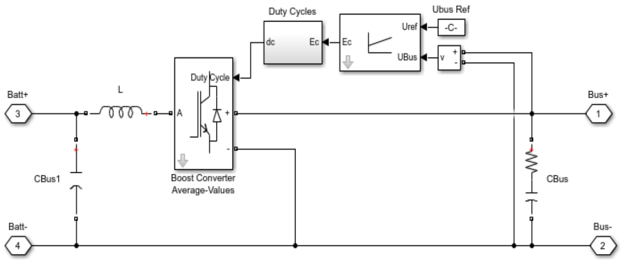

Figure 10: Simulink model of Boost converter adjustment and control elements

Figure 11 represents a simplified block diagram of the system to be studied [7], [8].

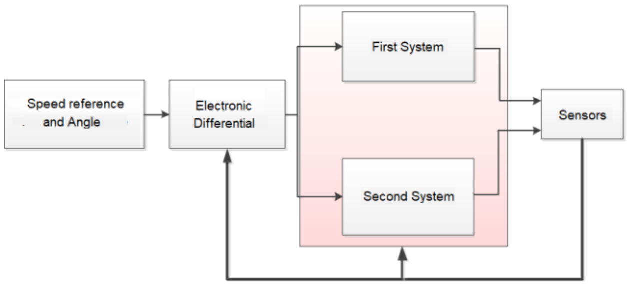

Figure 11: Simplified configuration of the considered two-in wheel system

3.1 Case of a simple electric vehicle

After modeling the system in Matlab/Simulink in Figure 2, for a personalized mission profile, we obtained the following results:

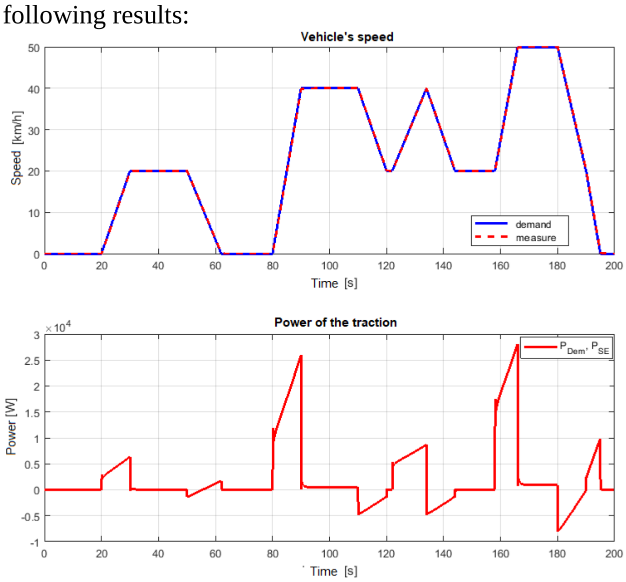

Figure 11: Simulation results of the simple EV: (a) The speed of movement of the vehicle, (b) The powers

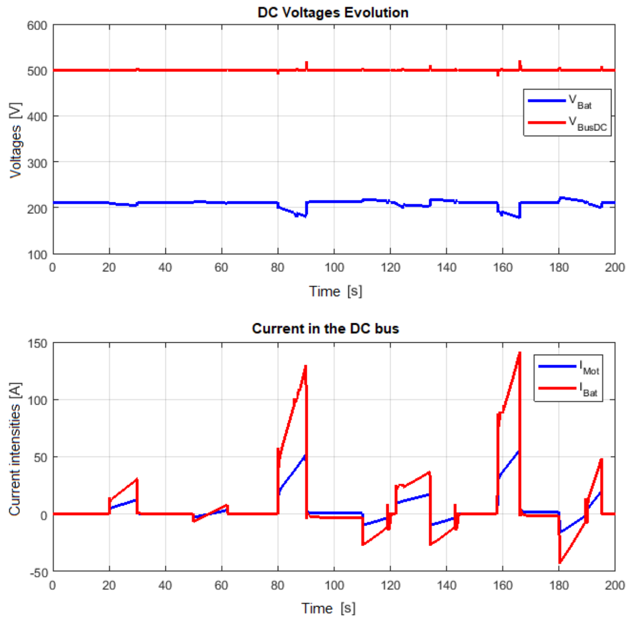

Figure 12: EV simulation results: (a) DC bus and battery voltages, (b) Electric motorization and battery current intensities

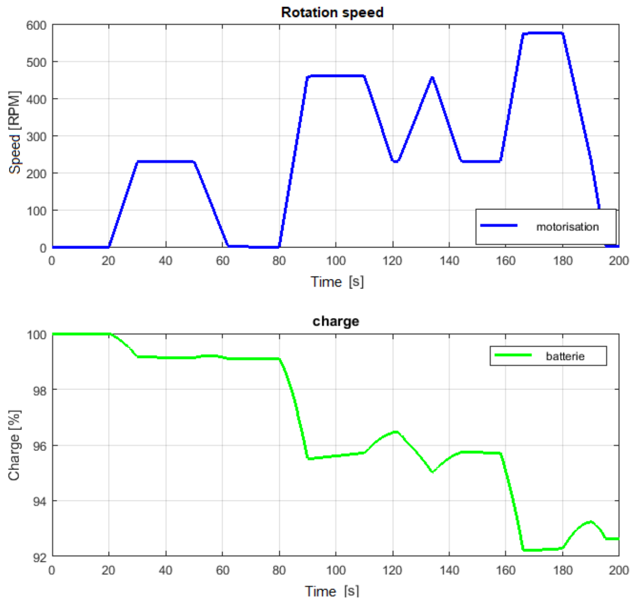

Figure 13: Simple EV simulation: (a) Brushless motor rotational speed, (b) Battery's state of charge evolution

By analyzing these curves, we notice that, all the time, the reference speed (the demand) were followed by the displacement speed (the measurement). Throughout the trip, following various changes in demand, the crucial element of our system always tries to satisfy the electric motorization demand.

The vehicle changes gear at t=20s. The battery compensates the motorization power demand. All the journey, this compensation is always noticed.

In figure 13(a), we see good stability of the voltage, V_{BusDC} = 500V. DC bus and battery voltages are illustrated. It show some drop according to the importance of the load's power to be compensated.

At the level of the battery, the voltage remains constant. Every power's demand increase the current intensities at its output, as illustrated in figure 13(b). This increase has an effect on its state of charge.

Firstly, maintained at 100%, the battery charge decrease as soon as the compensation comes into play (figure 14(b)) when the system operates in braking or deceleration mode. The vehicle resumes acceleration at t=80s. Satisfying the demand is important for the battery. At this step, power's demand were increased and it was noticed in the battery's state of charge. A 95.5% of decreases were shown.

All the time, the battery always recover as much energy as possible as opportunities arise. At t=50s, t=110s, t=134s and t=180s, the vehicle goes into recovery mode until the electric motor speed stabilizes. All this can be visualized in figure 14.

3.2 Case of a two-wheel drive electric vehicle

3.2.1. Rotational speed of the motors and longitudinal speed of the assembly

For the simulation of the assembly, at the start, the speed setpoint is at 50% of the accelerator and this speed is increased linearly up to 100% with $t_{acc} = 0.8s$. From this instant, the speed is maintained until $t_2 = 1.4s$; to go through a bend, downshift to 80%; at this speed we steer at an angle $\delta = 5.15$ to the left is a radius turn $R = 20.57m$, figure 8, up to and we return to $t_3 = 1.8s$, a straight course. During steering, you can see the effect of the differential.

In figure 16, it can be seen that the speed reference of the first motor decreases and symmetrically the other increases with respect to the general speed setpoint.

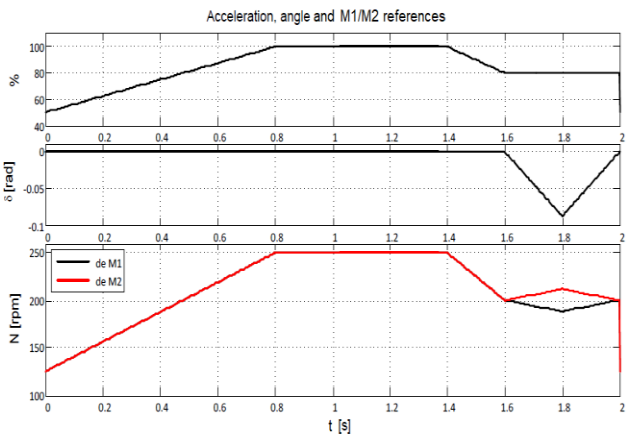

Figure 14: Instructions and references

The difference in speed is $\Delta\omega = 5.24 rad/s$ (the equivalent of 50 rpm). The speeds of rotation, illustrated in figure 11, of each machine follow the references which have been imposed. At the moment of deceleration (or braking), there is a little delay (negligible) and then the speeds of the motors decrease until this next reference.

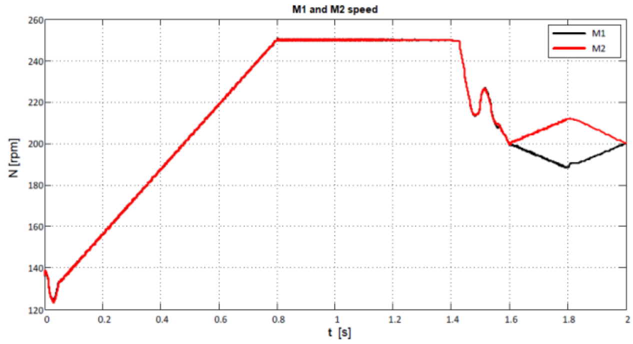

Figure 15: Patterns of motor rotation speeds

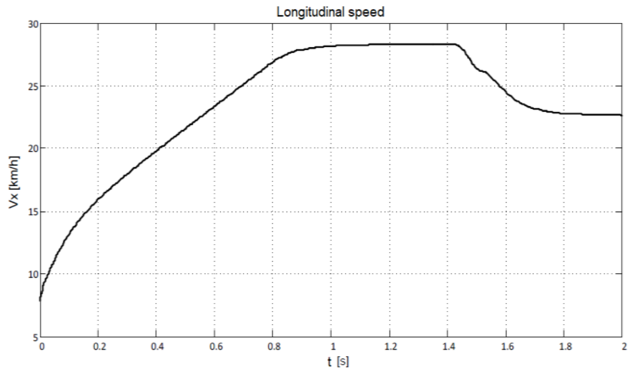

Figure 16: Longitudinal speed of the assembly

A remarkable unexpected gear response appeared at the maximum steering point, a sharp jump in gear.
The total acceleration of the vehicle made it possible to travel at a speed $V_x = 28.27 km/h$. For a spoke wheel $R_r = 0.3m$. The difference between the speeds of two wheels has no influence on the longitudinal speed of the vehicle.

3.2.2. Pulling power

The tractive power is calculated from the longitudinal speed, apart from the simulation

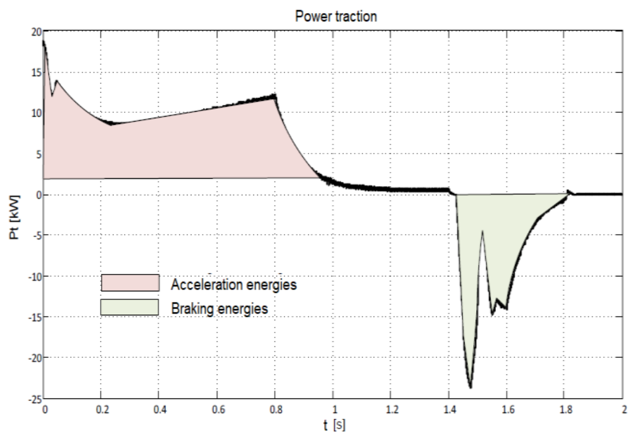

Figure 17: Vehicle traction power

of the complete system, we've try to do another simulation to have knowledge of the characteristic of the acceleration or deceleration. The resulting (or measured) tractive power seems impossible for the traction of the vehicle, because it reaches a maximum value $P_{\max} = 18kW$ at system startup.

And during the acceleration phase it is around $P_{\max} = 10kW$. These values are not impossible but just, in fact, the presence of the inertial force of the system which is very important during an acceleration phase, speed variation which is of short duration. At stabilized speed, the requested power returns to its normal value

During a sudden deceleration, in short time, the recoverable power peak also reaches a very high value $P_{r\max} = 24kW$ and the recoverable energy during this time is estimated at $E_r \approx 3.2398\ 10^3 J$, this energy must be limited so as not to damage the systems.

So we must have another evacuator system to not deteriorate the systems to evacuate this energy as soon as the batteries are charged, or use a mechanical brake in the event of sudden braking. Emergency and parking braking cannot be guaranteed by the regenerative braking system.

IV. CONCLUSION

The objective of this communication is to situate the place of reversible converters implemented for regenerative braking. The reversibility of the chopper used under the studied current variators is ensured by pulse width modulation control.

The use of a PI (Proportional -Integral) regulator has been taken into account to maintain the stability of the voltage at the DC bus level of the electric vehicle.

The future scope of this work is focused on the use of a bidirectional buck-boost converters under an energy recovering system.

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