Electronic Accelerator Control in VEIL

Frederico Santos, João Pedro Trovão and António Luís Marques

Departamento de Engenharia Electrotécnica
Instituto Superior de Engenharia de Coimbra
Rua Pedro Nunes - Quinta da Nora
P-3030-199 Coimbra - Portugal
Tel.: +351 239 790 320, Fax: +351 239 790 321;
e-mail: {fred, jtrovao, lmarques}@mail.isec.pt

Abstract: Pollution problems in medium and large cities of Europe are major concerns today, being one of the biggest contributors the vehicles used for transportation of people and goods. Simultaneously, to reduce costs and improve design and production flexibility, the automotive industries are replacing mechanical links with electronic systems, leading to the so-called X-by-wire systems. This paper relates with these concerns and trends and presents an on-going project to adapt accordingly a small vehicle, initially based on an internal combustion engine, which will be transformed in an electric vehicle named Veículo Eléctrico Isento de Licença de condução - VEIL. In this initial phase, the focus is placed on the accelerator control system, already designed with an X-by-wire architecture in mind. In future work, the VEIL mechanical links will be replaced progressively by electronic actuators to arrive at a full X-by-wire car.

Keywords: Electric Vehicle, Traction Control, X-by-Wire, Electronic Accelerator Control, CAN network.

1. Motivation

Mobility in European Union has doubled between 1970 and 2000, traveling each person, in average, about 35Km per day. This implies several demands in the transportation sector, namely the increasing utilization of oil derivatives, because the most common transportation mean are vehicles with Internal Combustion Engine (ICE). Other consequence of mass utilization of ICE vehicles is the increase of pollution emission, especially greenhouse effect gases (GEG), which must be prevented if we want sustainability of the planet.

In Portugal, the transportation sector accounts for 30% of GEG emissions, being the sector with greater growth in the last decade (about 70%). Route traffic accounts for about 80% of all transportation and the individual passenger transportation sector 50% from route traffic [1].

The pollution emission of ICE vehicle is one of the major sources of urban pollution, especially in the medium and large cities and is an increasing problem that must be dealt with. On the other hand, electric vehicles (EVs) present zero emission of pollutants locally, being 97% cleaner than ICE cars (including pollution in electric central power plants associated to battery recharging) [2]. If batteries are recharged using renewable sources, then there is no pollution associated to this solution. An EV, during one year of average utilization, emits in average, 8 Kg less of Carbon Hydrates, 6 Kg of Nitrogen Oxide and 90 Kg of Carbon Monoxide. The EVs are silent, gentle to drive and of high working efficiency while being basically non pollutant during its lifetime.

On the other hand, when considering the design of a new car, it seems adequate to follow the most recent trends in vehicle design, namely the X-by-wire paradigm [4]. This corresponds to replacing all mechanical links in a car by electronic actuation, bringing along a great potential to reduce costs and improve the design and production flexibility. With this approach, it is possible to generate more compact and ergonomic designs, to simplify the assembly, to reduce the costs of components, to integrate advanced control features at the level of dynamic behaviour, and possibly other advantages. The down side is that X-by-wire systems are inherently safety-critical, thus requiring a high level of fault-tolerance. This must be adequately planned in the system control architecture, making use of redundancy as well as error detection and recovery capabilities.

The inclusion of an X-by-wire architecture will be planned from the beginning, but the control modules will be added as the subsystems are added to the vehicle. This paper focuses on the accelerator control which already includes an adequate network interface, namely the Controller Area Network (CAN). This network will be the basis for the distributed vehicle control systems.

In the next section we present the EV platform, and in section 3 we analyse the vehicle dynamics. The communication architecture is discussed in section 4, followed in section 5 by the description of the traction control system. After that we present the VEIL estimated performance, based on MatLab/Simulink simulations, making concluding remarks in the last section.
2. VEIL Platform

Our EV is based on an ICE car, a LIGIER 162 GL (see Figure 1), which has small dimensions, thus ideal for urban traffic, 2 seats and a luggage volume of 400 dm$^3$. The original engine was a Lombardini 4 stroke diesel engine, with 505 cc, 5.4hp, maximum rotation of 3100 rpm and 15.1 Nm (at 2340 rpm).

![Figure 1 – Driving license free car– LIGIER 162 GL.](image)

For the transformation of the original vehicle in EV we choose the configuration in Figure 2.

![Figure 2 – Resulting Electric Vehicle (after transformation).](image)

In this stage we replace the ICE by an Induction Motor (IM), controlled by a Variable Frequency Drive (VFD). The VFD combines a three phase diode rectifier with a three phase Pulse Width Modulation (PWM) inverter, through a DC link. The fuel tank is replaced by a pack of batteries with 96V. There are plans to use supercapacitor in the near future to use regenerative braking. The VFD is fed directly through its DC link with reversible chopper DC-DC to raise the tension of a pack of batteries for a compatible voltage level (550V - 800V).

The chosen VFD is a MOVIDRIVE compact, a vectorial controller from SEW-EURODRIVE, targeted for industrial and commercial use and designed to work with IM or Permanent Magnets Synchronous Motors (PMSM), working in the four quadrants. The frequency converter is designed for variable speed AC motors-drive (with speed feedback), with voltage or current vector control. Our choice was for current control, because it enables, together with speed control, a high dynamical response.

As we present in next section the chosen motor was an IM with the following characteristics: 400 V, 50 Hz, 4 kW, 2860rpm, with high resolution encoder directly coupled to the motor shaft.

3. VEIL Dynamic Analysis

Considering a vehicle of mass $m$ (see Figure 3), the opposing forces to the vehicle motion are: the rolling resistance force ($F_{RR}$) due to friction of the vehicle tyres on the road; the aerodynamic drag force ($F_{D}$) due to the friction of the body moving through the air; and the climbing force ($F_{I}$) that depends on the road slope.

The total tractive effort force ($F_T$) is the sum of the resistive forces, as in expression (1):

$$F_T = F_{RR} + F_{D} + F_{I}.$$  \hspace{1cm} (1)

At low speeds and in asphalt road, the main force opposing to the vehicle movement is the $F_{RR}$, which is much greater then $F_{D}$. At higher speeds the $F_{D}$ is the main resisting force, mainly because it is proportional to the square of the vehicle speed. The resultant force from the climbing angle, $F_{I}$, depends only on the slope angle, $\theta$, being independent on the vehicle speed and from the road type.

The $F_{RR}$ force, as in (2), is the sum of the rolling resistance force of each wheel, function of the coefficient of rolling resistance ($\mu_{RR}$) and of the vehicle weight. The value of this coefficient can easily be determined through the measurement of the force necessary to pull the vehicle with very low constant speed. The typical values for $\mu_{RR}$ may vary between 0.015, for conventional tires, and 0.005 for tires developed specially for EV [4] [5].

$$F_{RR} = \mu_{RR} \cdot mg.$$  \hspace{1cm} (2)

The aerodynamic drag is proportional to the density of the air, $\rho$, to the drag coefficient ($C_D$), to the vehicle frontal area ($A_F$) and to the square of the vehicle speed relatively to the wind ($V_W$), as express in (3) [5] [6]:

$$F_{D} = \frac{1}{2} \rho \cdot C_D \cdot A_F \cdot V^2.$$  \hspace{1cm} (3)

The Figure 3 – Representation of the forces applied to the vehicle.
It is verified, that the power applied to the motor, necessary to overcome the drag, increases with the cube of the speed. It must also be noted that the air density is function of the atmospheric pressure and the air temperature.

The weight component of the vehicle, according to roadway slope, corresponds to a force that opposes the motion, being a function of the climbing angle $\theta$ and the vehicle mass $m$, such as in the next expression:

$$ F_i = mg \cdot \sin(\theta). \quad (4) $$

The load torque $T_R$ results from a set of vehicle motion resistant forces ($F_R$) in the motor referential, accounting the wheel radius $r$, and the transmission gearbox ratio $i$, is represented by the expression:

$$ T_R = \frac{r}{i} F_R. \quad (5) $$

The mechanical equation that describes the dynamic behaviour of the electrical motor, in the motor referential, is given by the expression:

$$ T_m - T_s = J_m \cdot \frac{d\omega_m}{dt}, \quad (6) $$

where $\omega_m$ is the angular speed and $T_m$ is the motor torque. The total moment of inertia associated to the vehicle ($J_T$) (in the motor referential) is given by the expression (7), being equal to the sum of the moments of inertia from engine ($J_e$), wheel ($J_r$) and the one associated with the vehicle ($J_v$) that is a function of the road characteristics [3].

$$ J_r = J_m + J_r + J_v, \quad (7) $$

The moment of inertia corresponding to the mass of the vehicle is defined by the expression (8), where $\varepsilon$ represents the slipping of the wheels.

$$ J_v = \frac{1}{2} m \left( \frac{r}{i} \right)^2 (1-\varepsilon), \quad (8) $$

The selection of the electric motor to the vehicle traction, on good conditions of performance, must be based on the knowledge of diverse information, being the most relevant the following: number of functioning quadrants, torque for all range of angular speeds (characteristic $T_s = f(\omega)$), operation speeds, acceleration and deceleration requested.

4. Integration in an X-by-wire architecture

X-by-wire architectures are distributed by nature, interconnecting sensors, actuators and controllers in the vehicle by means of adequate data networks, replacing mechanical links [8]. In our case, the link between the accelerator pedal and the engine is replaced by such an electronic link. Thus, the accelerator has an electronic sensor attached that transmits the pedal position to the motor control system – VFD (see Figure 4).

There are currently many networks available, suited for distributed vehicle control systems, e.g., TTP, FlexRay, TT-CAN, CAN and Byteflight. Some of them present different compromises between cost, fault-tolerance support, operational flexibility, bandwidth and access delays.

The exchange of information between the subsystems of our EV (sensors, actuators, VFD) is accomplished trough a Controller Area Network (CAN). This network was originally proposed by Bosh, in Germany, in the 80’s, with main application in ICE vehicles [7].

The main characteristics of CAN network that justify its wide deployment are: (a) low cost; (b) high efficiency in data bus use; (c) long distance transmission (up to 10 km); (d) high information data rate (at most 1 Mbit/s); (e) robust detection of errors and automatic transmission of corrupted messages; (f) unique message ID, identifying information type and priority; (g) it makes the distinction between temporary and permanent errors, disconnecting in this way nodes that present permanent faults.

The maximum bit rate transmission speed is 1MBits/s and the distance between equipments is at most 10 km, not achievable simultaneously. For instance, we can transmit with a bit rate of 1 MBit/s in 40 meters, but if the distance is 1 km the bit rate is reduced to a maximum of 40 kbit/s.

The numerous advantages that CAN network present makes it one of the most widely used networks that is widespread in the automobile industry, aeronautical industry – the most demanding in safety and fault tolerance – and in industrial control.

In our system, the option was for CAN, given its low cost, high robustness and high flexibility. However, the fault-tolerance support is relatively limited and the real-time properties can be degraded by specific type of failures, such as babbling idiot. Therefore, the CAN protocol will be later complemented with higher protocols such as FTT-CAN or FlexCAN, to achieve adequate levels of dependability and timeliness while delivering a good flexibility.
The electronic accelerator will include adequate CAN interfaces, built on top of common components to keep costs low and speed the development process. Further subsystems will be added later, taking advantage of the flexibility granted by the CAN protocol.

5. Traction Control System

The traction control system (TCS) is based on a set of sensors and actuators and the software which includes the algorithms for traction control of the EV. To make the transformation in EV, the original mechanical elements (accelerator, brake and transmission gearbox) were changed by electrical/electronic systems, maintaining the original interaction vehicle-driver (pedals, shift selector, etc.).

The original transmission system was based on a continuous movement gearbox and the interaction between driver and vehicle is only based in two pedals (accelerator and brake), and a forward/reverse movement selector. In the EV, the motor speed control is achieved by varying the frequency of the power supply applied to the motor, and changing the phase sequence for the movement selector.

To implement the TCS it is necessary information about the pedals positions and from the movement selector. The sensors used in the pedals are precision potentiometers. These sensors change their resistance function of cursor position, being ideals for measuring rotation movements and widely used in the automobile industry, namely in almost all modern ICE vehicles.

The potentiometer connected to the accelerator pedal senses its position, determining in this way the requested speed. From the potentiometer movements, timing and position, the algorithm in the TCS also detects the driving dynamic, (for instance, city driving or rapid passing through) which permits the system to respond with an adequate acceleration ramp, function of the driver requests.

The Acquisition and Communication Module (ACM) is based on a Microchip microcontroller that has an integrated CAN platform and some ADCs, needed to get the information from the sensors. The necessary software to make data acquisition, data processing, velocity calculus (acceleration ramps), construction of command messages and VFD communication, is placed in the microcontroller memory. A typical message consists of three bytes with the following information: start order, the pretended speed/position set point and the rotation direction. This system connects reliably sensors and actuators, allowing for real-time processing and a rapid response from the traction system. The ACM construction is modular, allowing his replication through all the EV, controlling the EV subsystems (for instance, batteries, solar panels, dc-dc converters, supervisor and event data logger). In this way we can expand easily the communication network, allowing for a full and global management of the EV. In the near future, our approach allows for a quick change of the remaining mechanical systems by electric/electronic ones.

The IM control strategy is integrated on the VFD. The used scheme is based on vector-control, in order to force the evolution of the stator currents, being the motor torque control done by field orientation, according to the block diagram showed in Figure 5. In this dynamic control it is necessary to sense the rotor speed and stator currents.

The required speed, given by the accelerator pedal position, is compared with the rotor speed (given by an encoder), permitting the computation of the necessary motor torque to reach motor the intended set points. This calculus is done by a Proportional-Integral controller. The controlling pulses of the IGBT's gates are obtained by comparing the estimated currents, to achieve the requested torque, and the absorbed motor currents (see Figure 5).

![Figure 5 – Vector-control scheme.](image)

6. Estimated Performance

The presented results were done on Matlab/Simulink, simulating the VEIL dynamical model, presented in section 3 and the dynamic model of the electric drive (IM plus VFD).

The implemented model had in account the characteristics of the electrical drive, the transmission ratio of the gearbox ($i = 10$), the wheel radius ($r = 26$ cm), the full load vehicle mass ($m = 500$ kg) and the moments of inertia from the vehicle, from the motor and from the wheels.

In Figure 6, it is presented the expected performance

![Figure 6 – VEIL speed.](image)
of the VEIL in terms of speed on plain road ($\theta = 0^\circ$),
where the resistant forces are: the rolling resistance force
in the wheels and the aerodynamic force. It is showed
that the VEIL can reach 42.5 km/h in 40 sec and can
accelerate from 0 to 25 km/h in approximately 3 seconds.
In the speed graph is visible the influence of the $F_{DA}$
increase with the increasing speed, restricting in this way
the maximum achievable speed. While the $F_{RR}$ is constant
the $F_{DA}$ increases with the square of the speed (see Figure
7).

![Figure 7 – VEIL road load forces.](image)

The model was tested in a normalized test circuit, where
the ECE15 cycle was used. The obtained results are
presented in Figure 8. It was verified that in the first half
of the urban circuit (until 100 sec) the VEIL can follow
all the requested speeds and accelerations, but in the last
part, the VEIL does not reach the maximum speed of the
test circuit (50 km/h). This limit in maximum speed of
the VEIL is derived from the actual ratio of gearbox that
does not permit to reach above 42.5 km/h.

![Figure 8 – ECE15 urban-enhanced cycle VEIL response.](image)

![Figure 9 – Speed, Road Load Forces of the VEIL in Slope Roadway.](image)
Finally we analyze the VEIL capacity to start in a roadway with $\theta = 10^\circ$, $20^\circ$, $30^\circ$ and $45^\circ$ of slope, where the principal actuating force is the climbing force, $F_I$. The results for diverse climbing angles $\theta$ where meted together and showed in Figure 9. We verified that the forces $F_{RR}$ and $F_{DA}$ are the ones that have lesser influence and the force $F_I$, which derives from the roadway inclination, is the main restriction for the VEIL motion. In Figure 9.a) is showed that VEIL, with our proposed electrical motor drive and corresponding controller, can pull out in a roadway with $45^\circ$ of inclination and stabilize at around 8 km/h after 2 sec. This test is very important, because in our major cities we can found some high inclination roads, for instance in garage accesses, where typical values can vary between $30^\circ$ to $40^\circ$.

7. Conclusion

This paper presents the VEIL platform and justifies its interest mainly because it is a vehicle with atmospheric zero pollution. This platform will be used in various projects of the DEE-ISEC as a test bed for diverse technological aspects, e.g., motor/converter power train, batteries, aiming at improved autonomy and/or speed/acceleration control.

In this project phase, foresees that, with the selected electric motor drive and the electronic accelerator implemented, the VEIL can reach 42.5 km/h in 40 sec and can accelerate from 0 to 25 km/h in approximately 3 seconds. The VEIL project is essentially aimed to be used in the urban circuit, where the legal speed limit is 50 km/h. The urban vehicle must have a good acceleration response and a high slope roadway start capacity. In this work it was verified that the VEIL can pull out in the slope roadway, having very good results in these situations, with the maximum inclination of $45^\circ$.

In the VEIL simulation study it was verified that, at low speeds (urban circuit cases) the force that most opposed to vehicle motion is the rolling resistance, because it is independent of the vehicle speed and the drag force is a function of square speed. The drag force takes particularly importance in applications that involve superior speeds, foreseen in future VEIL developments.

The estimated performance must be validated in the following phase, only waiting the delivery of the special battery pack.

References


