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Advances in the Electric Vehicle Project-VEIL Used as a Modular Platform for Research and Education

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Abstract

This paper presents the recent advances of the author's electric vehicle project, named VEIL. This vehicle constitutes a platform that is being used in several projects at Electrical Engineering Department of the Engineering Institute of Coimbra (DEE-ISEC), Polytechnic Institute of Coimbra, as a test bed for diverse electric vehicle technological aspects research and development, like multiple sources energy management, battery monitoring systems, power electronic DC/DC converters, motors and drives, fault-tolerant modular control architecture, and communications and control network. It is also being used as an educational platform in electric vehicles and electrical engineering at ISEC and for technology demonstrations. Some experimental driving results with those advances are also presented.

Keywords: NEV (neighbourhood EV), education, battery management, data acquisition, vehicle performance.

1 Introduction

Present's world economy is strongly tied to people and goods mobility. However, most of this mobility is oil based, leading to very serious problems like shortage and price rise of crude oil in a near future, economic and energetic dependency, global and local pollution with the corresponding health problems and the foreseen global warming of the planet, and traffic congestion. Electric Vehicles (EV) and Hybrid Electric Vehicles (HEV) can play a fundamental role in the solution to those problems, since the electric traction is the key to advanced and sustainable transports, as acknowledged by the International Energy Agency (IEA).

At the Electrical Engineering Department of the Engineering Institute of Coimbra (DEE-ISEC) the authors have started the ongoing VEIL project to convert a small vehicle, initially with an internal-combustion engine (ICE), into an electric vehicle. On the next sections, the VEIL project will be shortly described as well as some of the recent improvements. Experimental driving results are presented and some conclusions are extracted.

2 The VEIL project and its previous state

In Europe, on average, each person covers a 35 km distance per day, distributed by 5.5 journeys and 52% of the journeys do not exceed 3 km [1]. Furthermore, in urban cycle driving, a small car is easy to move and park. Taking this into consideration, together with a small budget, it was chosen an ICE licence free car, a *LIGIER 162 GL* (Fig. 1), for the VEIL project. It has small dimensions, thus being ideal for urban traffic, two seats and a luggage volume of 400 dm^3, weighting only nearly 350 kg. The original engine was a

Lombardini 4 stroke diesel engine, with 505 cm^3, 5.4 hp, maximum rotation of 3100 rpm and maximum torque of 15.1 Nm (at 2340 rpm).
VEIL stands for "*Veículo Eléctrico Isento de Licença de condução*", meaning *Licence Free Electric Vehicle*. It constitutes a platform that is being used in several projects as a test bed for diverse EV technological aspects such as motor&drive power train, batteries and other storage/energy sources, speed&acceleration control, improved autonomy, *x-by-wire* systems, and CAN and FTT-CAN protocols.

Figure 1: VEIL in action at ISEC campus.

2.1 The VEIL platform

The VEIL platform is an electric vehicle including embedded electronic systems, a communication network, actuators and sensors [2]. In the first step conversion process, volume and weight were gained. The ICE weighted 80 kg, being also removed the refrigeration system, exhaust pipe and gas tank, with an estimated weight of 35 kg. Taking all into account it were withdrawn 115 kg of components that can be replaced by batteries, Supercapacitors (SCs), photovoltaic panels (PVs), motor and power electronic devices to maintain the original vehicle weight. The planed power scheme of the VEIL project is shown in Fig. 2.

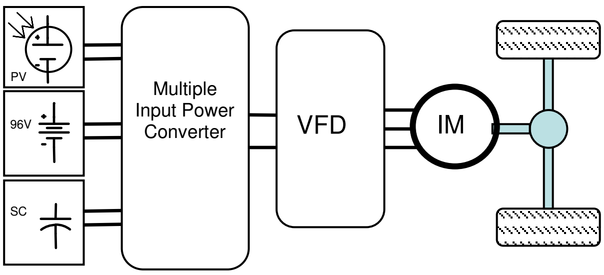

Figure 2: Power Scheme

The embedded system communication is based on a Controller Area Network (CAN). The CAN network is used to exchange data between network modules, used to collect information about internal state of the VEIL platform and to transmit control messages between sub-systems.

2.2 Energy Storage systems

The original diesel tank was replaced by a pack of batteries with 96V (see Fig. 3). The first chosen batteries are of NiMH type, which presented, at the project starting time, a good quality-price relationship for our EV.
We use two banks in parallel, each with eight batteries in series, with total weight of 48 kg.

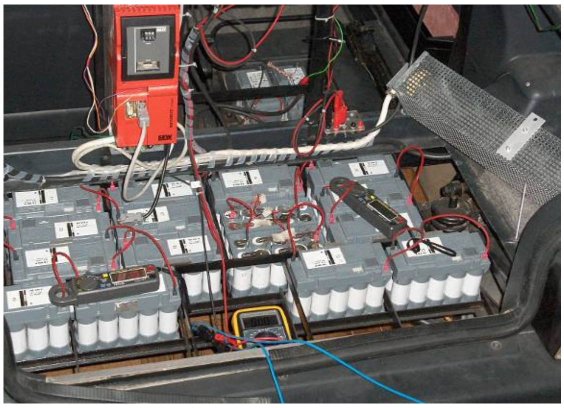

Figure 3: NiMH batteries and VFD assembled on the vehicle luggage compartment

2.3 Motor and drive

The ICE was replaced by an Induction Motor (IM), in Fig. 4, controlled by a Variable Frequency Drive (VFD), in Fig.3.

Figure 4: Details of the EV Platform (IM)

The electrical motor is an industrial/general purpose IM with the following characteristics:

400 V, 50 Hz, 4 kW, 2860 rpm, with a high resolution encoder directly coupled to the motor shaft.
The VFD combines a three phase diode rectifier with a three phase Pulse Width Modulation (PWM) inverter, through a DC link. The VFD is fed directly through its DC link with a Buck-Boost DC/DC converter (96V / 600V) (see Fig. 6) to raise the voltage of a pack of batteries for a VFD compatible voltage level (550V - 800V).

2.4 DC-DC Converter

The 1st DC-DC converter (Fig. 6) raises the voltage from 96V to 600V DC to the VFD DC bus. To implement a bidirectional converter the Half-Bridge DC-DC configuration is chosen. The DC-DC converter can work in the following modes: OFF, buck, boost or half-bridge [2][5].

2.5 Communication network

As mentioned before, CAN is the data network used to exchange information between the subsystems of the VEIL, allowing for real-time processing and a rapid response from the traction system. CAN is one of the most widely used networks in the automobile industry, aeronautical industry (the most demanding in safety-critical aspects) and in industrial control. In [3] it was presented a fault-tolerant modular control architecture for the VEIL electrical vehicle equipped with x-by-wire sub-systems.
To fully control the EV, the traction control system (TCS) needs to gather information about the pedals positions and from the movement selector (see Fig. 5). The energy flow between motor and energy sources is monitored by a high level controller named Energy Management System, EMS, with the following main objectives: optimize drive range, to assure functioning parameters within bounds (e.g. continuous control State of Charge (SOC) of battery banks) and to provide for longevity of all subsystems. The last presented [4] development in the VEIL platform was the implementation of the Multiple Energy Sources Monitoring System. This is very important to correctly manage and control the power flow in the vehicle.

3 Recent advances in the VEIL

The first experimental results of the VEIL project were presented in [2]. As was then concluded, there was a clear need for some improvements. The VEIL Project is a platform in evolution for development and research, education and technology demonstrations. After its first stage of development, the first prototype has undergone

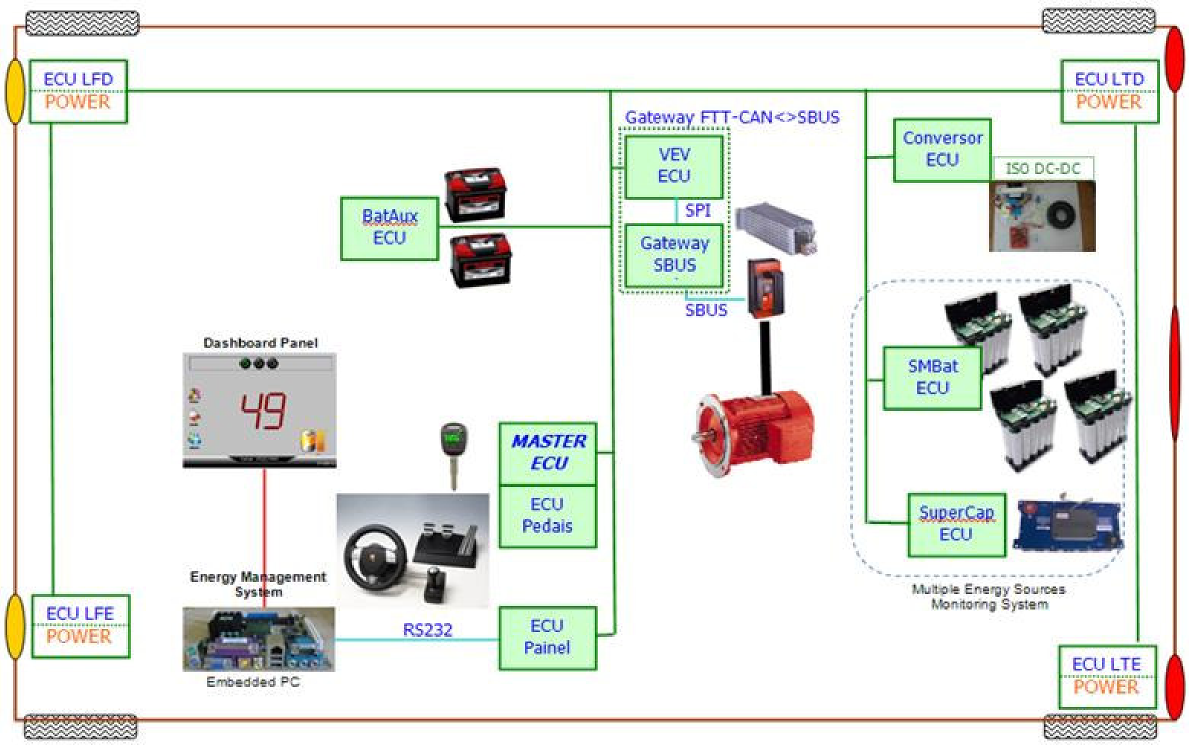

Figure 5: Control System architecture with sensors, actuators and processing units
(some of the components shown differ from the presently used).

some improvements, in particular, the development of a new and more powerful DC/DC converter to be used with the batteries or with the SCs, in parallel with the previous one, and the evolution in the network communication, specially with the monitoring sources and new traction control algorithm. It was also mounted an embedded PC and a 7’’ touch screen for faster development and debugging as well as for user information (Fig. 6). As it was not, until now, found a satisfactory PV panels solution to apply in the vehicle’s roof it was not implemented. Nevertheless, an two axis solar follower with PV panels has been developed, that can be used to replace the on board PV panels for energy management studies when the vehicle is parked [6].

3.1 The battery monitoring system

A battery EV essential sub-system is one that can monitor and report the correct status of individual batteries in the each bank.

The VEIL battery monitoring system [4] is implemented with an ECU (build around a PIC18F2680) connected to the main CAN network that acts as a Master to a sub-network constituted by a group sensors with a physical and isolated CAN layer, as depicted in Fig. 7.

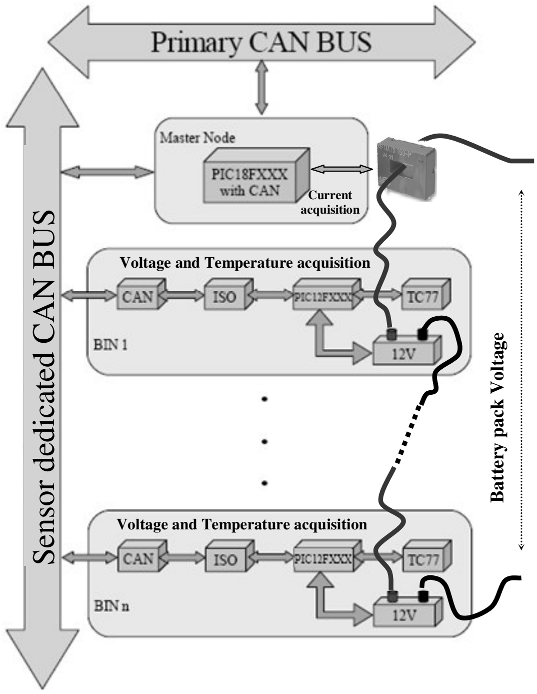

Figure 7: Architecture for one battery bank sensor network.

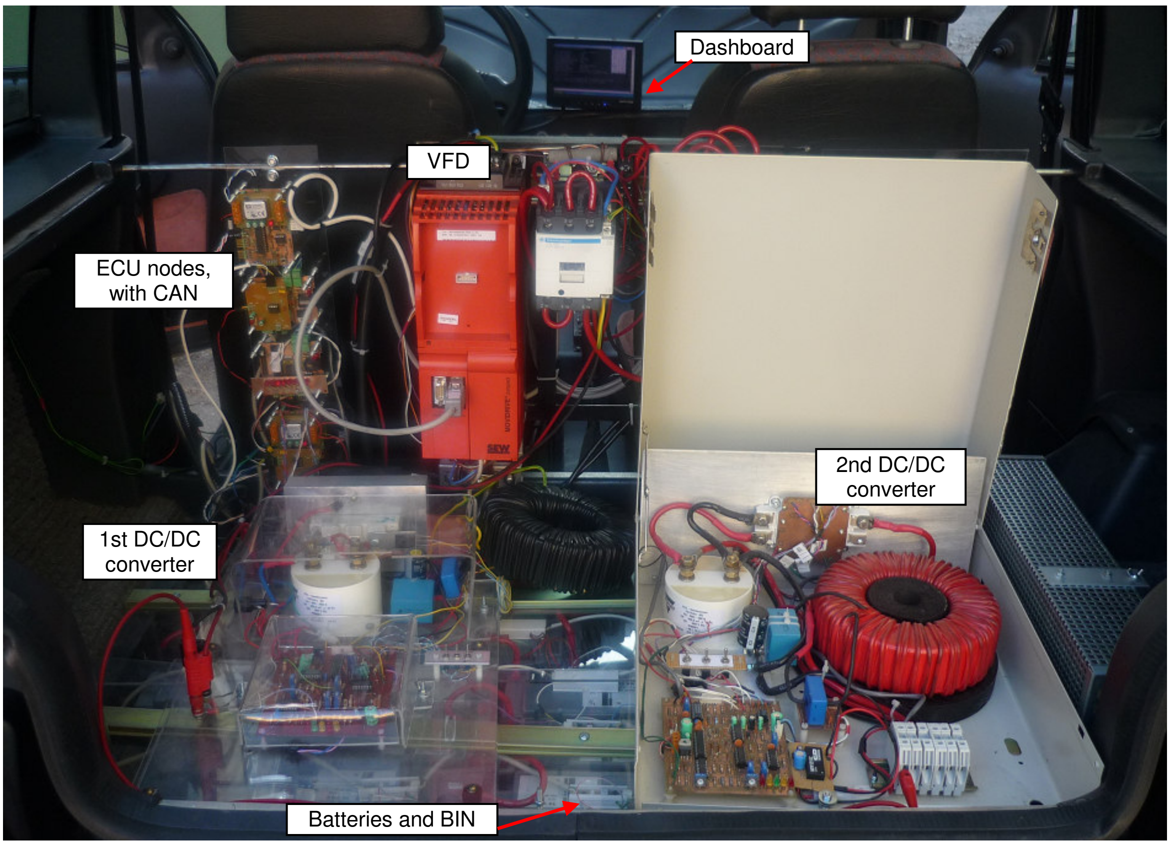

Figure 6: VEIL luggage compartment: DC/DC converters, VFD, batteries banks with battery monitoring system, ECU nodes, touch screen dashboard (in debugging mode).

A sensor node, named BIN – Battery Interface Node, as seen in Fig. 8, is attached to each battery of the bank and is build around a very small microcontroller – PIC12F683 – that senses the individual voltage and temperature, and was designed to have extra low cost.

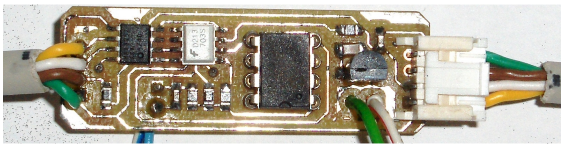

Figure 8: BIN – an add-on battery voltage and temperature acquisition module (48×15 mm).

The modules are digital electrically isolated and connected by a CAN transceiver that is fed by the main sensor network module board – Master Node (Fig. 7). The use of flash memory microcontrollers guaranties flexibility and upgradeability. The upper communication layers are all implemented by software. The Master ECU module for each sensor network battery bank acquires the bank current through a Hall Effect sensor (closed loop), and collects data (voltage and temperature) from the BINs.
The algorithm of the running software in these modules is:

```
Initializations;
1:  Wait for request;
    Acquire voltage and temperature;
    Compose frame (data + CRC);
    Wait x milliseconds for correspondent slot;
    Send frame;
    goto 1;
```

This system is very flexible and modular, and with minor changes can also monitor other battery banks, PV or SC modules.

3.2 Improved communication network and data storage and visualization

The VEIL communication network uses a CAN network, with a higher level protocol FTT-CAN [7], and the choice made was thoroughly explained in [2].
Since FTT-CAN has a dual phase cycle (two windows, one for synchronous messages and other for asynchronous ones) it is straightforward to add to the network new messages (corresponding to new functionalities) with guaranteed timeliness and also sporadic messages corresponding to events or alarms that do not possess periodic characteristics.

The implemented network, with the nodes identified, is depicted in Fig. 5, were each Electronic Control Unit (ECU) is implemented with a single board computer, build around the PIC18F2680 microcontroller, and some additional hardware, being all used parts commercial off-the-shelf (COTS) components. This microcontroller has an integrated CAN controller, and the board has modular construction, allowing its replication through all the EV. It is important that the communication network can be easily expanded, allowing a distributed management of the EV.

The messages exchanged in the FTT-CAN network are listed in the following paragraph.
Master ECU – is the FTT-CAN master node, that controls all communication in the network; produces the Elementary Cycle Trigger Message;
Pedais ECU – reads pedals positions and produces the Accelerator and Brake position;
SMBat1 ECU– read individual battery voltage and temperature from bank 1, and also the current; produces individual and global values of voltage, current and temperature;
SMBat2 ECU– same as SMBat1, but for bank2;
Painel ECU - gathers all available information and send it trough RS232 link to the PC; receives from PC information about cruise control and limit velocity and produce the corresponding messages to the network;
Gateway FTT-CAN<>SBUS – responsible for exchanging messages between CAN network and VFD;
The Supercap, BatAux and Ligths ECUs are in the process of implementation.
It constitutes also an objective of the VEIL project, to develop and implement a complete *x-by-wire* strategy for the vehicle. In order to do that, some more ECUs and specific hardware have to be deployed, but only after a complete analysis from the dependability point is complete.

In our opinion a modern electric vehicle must have a completely digital dashboard, displaying relevant information in a fashion and perceptible way.
The dashboard panel provides all the relevant information about the vehicle conditions. It will present both raw information (e.g. vehicle velocity, motor power, voltage or SOC of batteries bank and high-voltage DC-link, batteries energy, etc), integrating also the data to provide information like autonomy, trip length, average speed etc. It can also be configured to set alarms related to some variables, e.g. when the battery energy lowers bellow a given threshold.

Since the car is equipped with a PC it was decided to implement the dashboard with customizable looks that each driver can, from a defined set, choose. The software was programmed in Processing, an Object Oriented Programming language based on Java.
One example of the look implemented is showed in Fig. 9. Since we have a 7" TFT display with touch screen, the driver can activate various functions by touching the corresponding button, e.g., enter in cruise control mode.
When the car is ON, a data-logging mechanism is running in the Dashboard software, recording voltage, currents and temperatures collected from the battery monitoring system, and wheel speed, VFD DC-Link voltage, current, temperature and status from various messages that are gathered by the Painel ECU. All of this is recorded in a CSV file and is available for later analysis.

3.3 A new DC/DC converter for higher power or SCs

To increase the power available in the VFD DC link and to use the SCs in order to maximize the regenerative braking energy storage and to give the EV a greater ability in acceleration mode, a new DC/DC power converter was developed (2nd DC/DC converter in Fig. 6).
This converter has a more powerful power switch (a Semikron SEMIX252GB126HD) that can deal with currents up to 240A and 1200V. As the IGBTs module has an integrated thermal sensor it was set a thermal shutdown to protect the power circuit.
The desirable inclusion of the converters on the system, namely for SCs full utilization, is not yet accomplished. The next step is to provide high level control to the converters. To allow that, the DC-DC converter must be connected to the data network (based on FTT-CAN), permitting the control of each converter using data received through an ECU like the ones already used in VEIL to perform other tasks. With this new functionality the SCs bank, or other sources, can be included and a more complete energy and power management can be performed.

4 Some new experimental results

With the new DC/DC converter, the battery monitoring system and the improved communication network, the performances of the VEIL were quite enhanced. Some of the performed tests results will be presented next. To perform the tests it was used the circuits at ISEC campus, presented in Fig. 10.

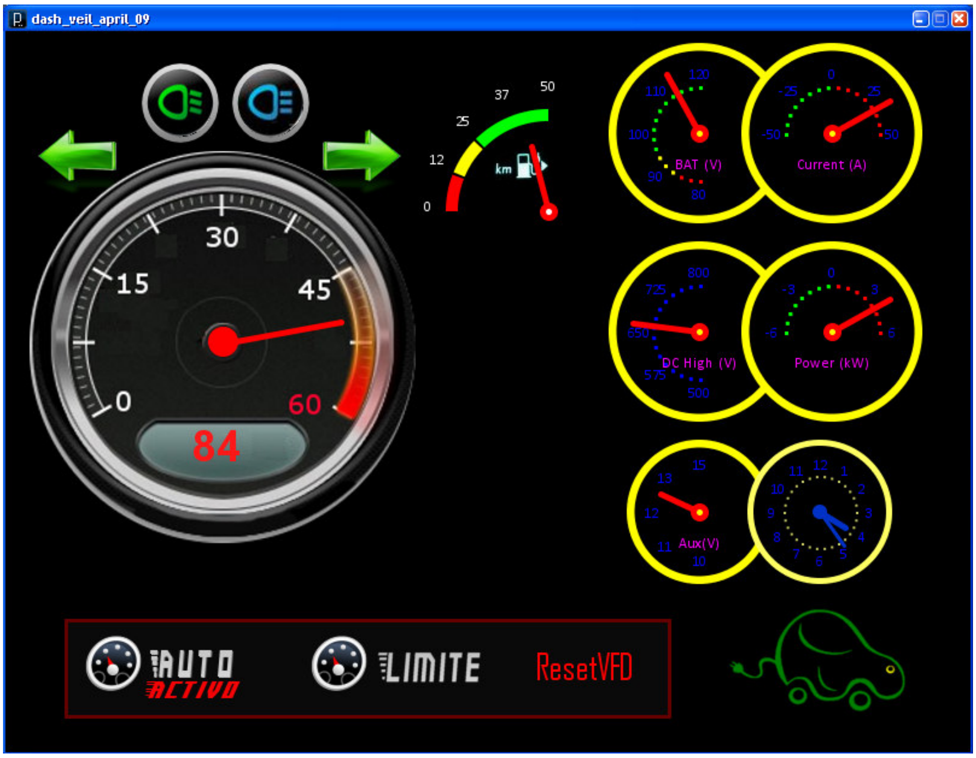

Figure 9: One possible layout for VEIL Dashboard.

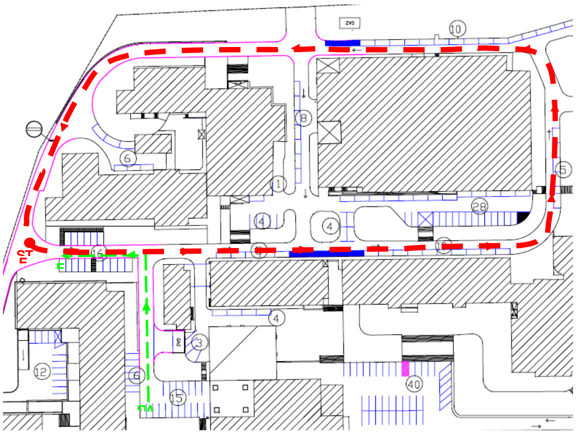

Figure 10: Circuit tests at ISEC campus.

The red circuit (closed one) is for cruise control and autonomy tests and the green one for ramp climbing.
On the analysis of the results, it should be bear in mind that this vehicle is limited to a 4 kW motor and 45 km/h, by law. Also, the used batteries, by manufacturer restrictions and embedded fuse are limited to 25 A (30 A during 5 s, and 50 A during 0.5 s), which considering the two batteries banks, allows only a 50 A current (60 A maximum, for 5 s), that is around 5 kW, considering a perfect charge balance between the two banks.
All the next shown results present data gathered by the battery monitoring system and the communication network and stored during the road tests in the VEIL embedded PC.

4.1 Maximum speed

In Fig. 10, it can be seen that a maximum target speed of 50 km/h, slightly higher than the legal 45 km/h limit, is reached in about 25 s.
It might seem a modest acceleration, but the acceleration ramps are adjusted to avoid that the batteries voltage sharply decrease. It is also important to notice that the simulated results [8] for the power at 50 km/h constant speed, 4.3 kW, are in very good accordance with the measured ones, and that for an acceleration of the vehicle from standstill to 50 km/h in 8 s, like in the NEDC cycle, considering a 70% efficiency for the present VEIL power chain, the electrical power demand would be around 50 kW, which is very far away from what is available now and can be used by the 4 kW IM. However, the maximum acceleration can be improved with a careful control of the batteries and with the complete inclusion of the SCs when the Energy Management System, EMS, is fully developed. On the other hand, it can also be seen that at constant 50 km/h, the present batteries current are reaching its limits, and the SCs can only improve the transient performance.

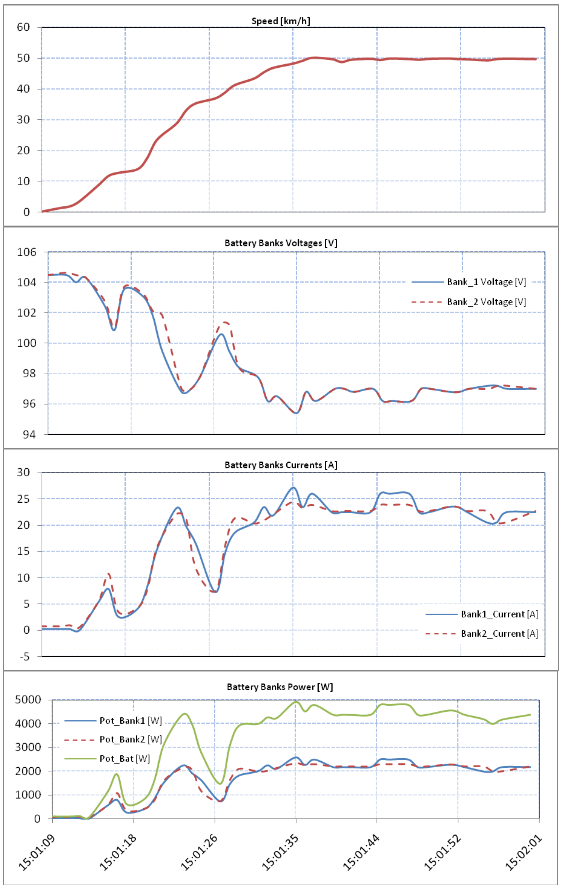

Figure 10: Some maximum speed test results.

4.2 Ramp climbing

The VEIL climbs the chosen ramp (Fig. 11) with no problem. However at the end of the ramp, at about 40m, there is a junction (90 ° curve) which prevents the speed to increase further. Anyhow, at that point, the batteries current is already on the limit and it can be also seen an important voltage decrease in the battery banks.

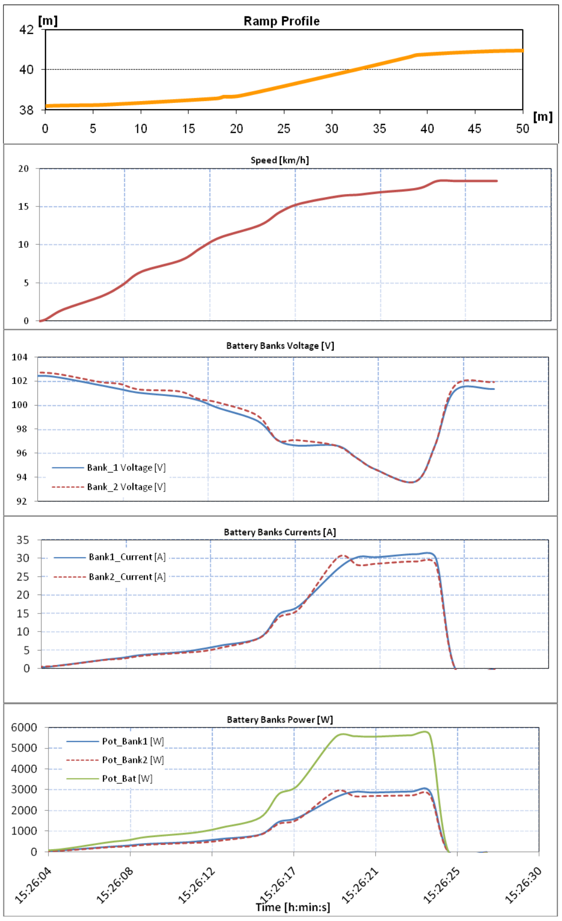

Figure 11: Ramp climbing test results.

4.3 Cruise control and autonomy

In Fig. 12, it can be seen a 5 laps trip around the ISEC circuit, accounting for 2.5 km, with a set point speed of 20 km/h. It must be said that, for security reasons, it is difficult to keep a higher constant speed due to some bend curves at the test circuit, as can be seen in Fig. 10.

The VEIL performs perfectly the circuit with the cruise control set speed. The energy consumption for the ~2.5 km was 170.5 Wh that means a 42.5 km autonomy for these conditions (2 passengers, 160 kg), 20 km/h constant speed at ISEC campus). With regeneration energy recover, considering the efficiency of the full power chain, this value can reach 45.3 km. The regenerative brake gives a very smooth and powerful brake, complemented by a mechanical brake. This system prolongs the life of the brake system and permits the reuse of energy generated by the electrical brake.

The autonomy for 50 km/h constant speed, flat road and with only the driver, is expected to be around 33.7 km [8].

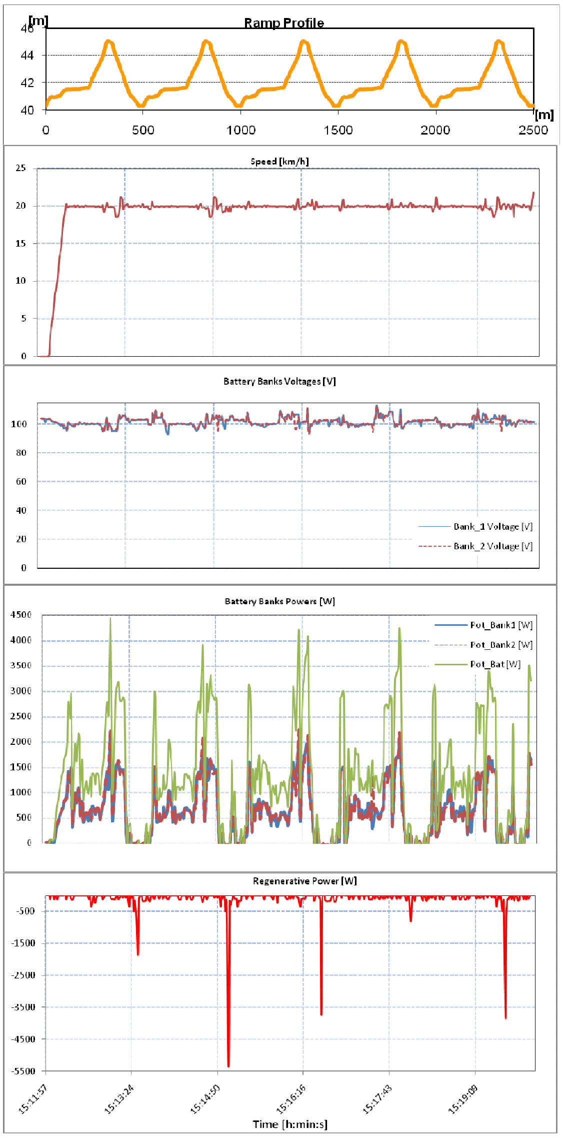

Figure 12: Some cruise control and autonomy tests.

4.4 Battery charge monitoring

The battery monitoring system through the VEIL communication network is fully functional, allowing the real time monitoring of each batteries bank and individual batteries (and data registration for offline analysis), allowing the battery management system and the energy management system to take control of its tasks. In Fig. 13, it can be seen a partial slow charge (2 A to 3 A) of the two battery banks. In the first two graphics it is shown the voltage and the current evolution of the two battery packs, and in the last two, the individual temperatures of bank 1 and bank 2, respectively. It can be seen here that the bank 2 batteries temperatures were starting to rise and passing the charge temperature. Bank 2 power supply was then cut so that the temperatures do not pass the recommended limits. The battery temperatures were also verified using a thermal camera, as in Fig. 14.

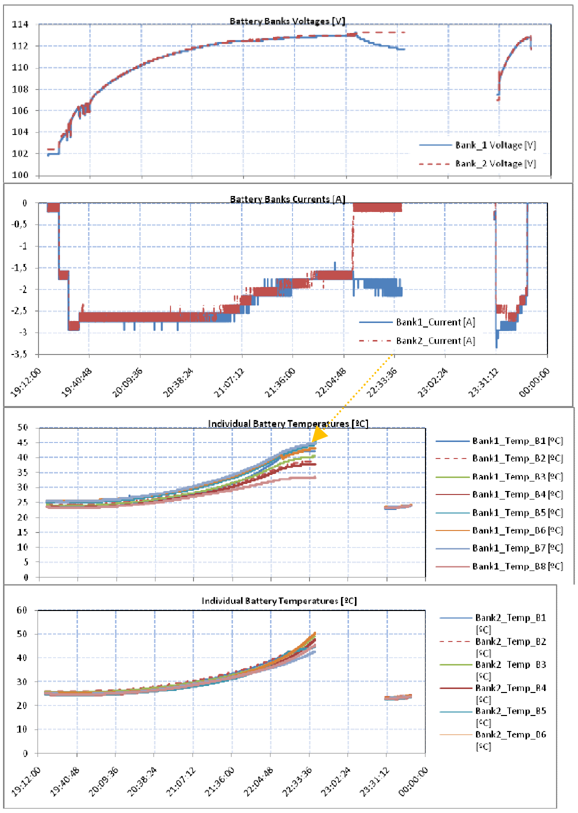

Figure 13: Battery charge monitoring.

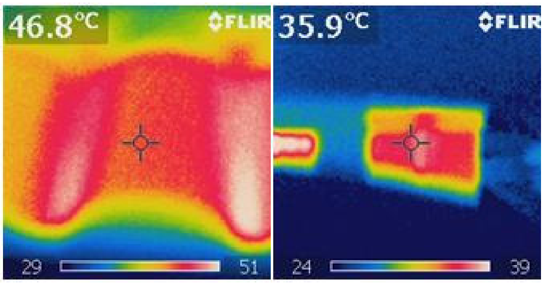

Figure 14: Battery temperature verification.

5 Conclusions

The VEIL Project is an ongoing electric vehicle platform for development, research, education and for technology demonstrations. After its first stage of development, the platform has undergone some improvements, increasing the vehicle performances, and approaching the present power sources and motor limits, as it was shown. It is a project that deals with most of the issues of the electric vehicles, like energy sources monitoring, (multiple) energy source(s) management, communication network, power electronics development, with a modular perspective and pursuing all the development lines at the same time, rather than focus only in one of the EV aspects at a time. Some aspects still to be further improved: a fully battery management system, with intelligent charge and discharge control and considering different energy sources (single-phase, three-phase, but also regenerative energy and SCs charge and discharge), the high level multiple energy sources management and the multiple energy converters management, improve the fault tolerant network.

One interesting characteristic of the VEIL project is that our EV is experimenting what might be one of the future characteristics of EVs: instead of being a “once upon a time built car”, like the ICE cars, they might very likely became “Upgradable Electric Car”. For example, when the batteries reach its life time, they could be replaced by more powerful and with more capacity ones, and perform upgrades in the software and firmware. Like today’s PCs.

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