Performance Characteristics of the First, State-of-the-art Electric Vehicle Implemented in Chile

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Abstract
The first, state-of-the-art electric vehicle implemented in Chile is presented. The vehicle uses a high specific power brushless dc motor, high performance switching power supplies, and a non-polluting battery charger. The car transformed to an EV was a double cabin, Chevrolet LUV truck, with an actual gross weight of 1,920 kg (720 kg in the front and 1,200 kg in the rear). This vehicle is similar in size and shape to a Chevrolet S-10. Some of the performance characteristics of this EV are: maximum speed, 120 km/h; acceleration, 0-65 km/h in nine seconds; efficiency, 4 km/kWh (0.25 kWh/km). The car can carry five passengers comfortably seated inside the double cabin. The traction motor was connected directly to the conventional mechanical transmission, which allows the vehicle to run, in the third speed, at 120 km/hour. The other speeds allow to make different experiments in the prototype, like to reach higher speeds, more acceleration, or to be able to climb more difficult hills. All the instrumentation for the driver panel was implemented digitally, given information about inverter temperature, motor temperature, battery current, battery voltage, ampere-hours used, actual torque, and rpm of the motor. The car has been running about 1,500 km., and has demonstrated to be very reliable.

Introduction
Some cities in Chile, like Santiago the capital, are one of the most contaminated in the world, mainly for the large amount of Diesel and gasoline propelled ICE. In Santiago there are more than 12,000 buses for public transportation, and a number of around 700,000 vehicles of many kinds. During winter, the smog contamination reaches levels so high that some days more than 50% of the vehicles are not permitted to run on the streets. Many industries are also forced to stop production for the same reason. Despite this situation the authorities seem to ignore the problem, because they do not see any practical solution in the near future. Trying to change the mind of the authorities, the Catholic University of Chile, with the help of some industries like GM-Chile, Sonnenschein, Tramcorp (Trading Motors Corporation), CGE (Compañia General de Electricidad), BMV Industrias Eléctricas, Research Government Funds through Fondecyt and others, begun to transform a conventional ICE truck to an electric vehicle. The vehicle used for this transformation was a double cabin truck Chevrolet model "LUV" [1], which is shown in figure 1. This vehicle was selected because of the following reasons: **a)** it is a double cabin vehicle which, like most passenger cars, allows to carry five passengers comfortably; **b)** it has a strong chassis, which allowed to install the battery pack with a simple spring reinforcement; **c)** it is a

very common vehicle in Chile, and hence conventional piece parts are cheap and easy to find; and **d)** it has lot of room in the engine compartment, which allowed to install all the electric and electronic equipment inside with no big trouble.

Figure 1
The Chevrolet "LUV" Electric

The actual gross weight of the vehicle is 1,920 kg. (720 kg. in the front and 1,200 kg. in the rear). It uses 26 lead-acid batteries, Dryfit Traction Type from Sonnenschein, with a capacity of 50 Ah, 12 Vdc. The batteries are located 5 in the front, and 21 in the rear. The traction equipment was implemented with a brushless dc motor from Unique Mobility (CaliberEV 53) [2]. The motor was installed and connected to the original mechanical transmission, which allows the vehicle to run, in the third speed, at 120 km/hour. The other speeds are optional, and allow to make different experiments in the prototype, like to reach higher speeds (4^{th} and 5^{th} speed), more acceleration (2^{nd} speed), or to be able to climb more difficult hills (1^{st} speed). In flat surface, the vehicle is able to start in 5^{th} speed. The third speed is the normal driving speed, and the acceleration from zero to 65 k/h is reached in only nine seconds. The energy consumption under city driving conditions is only 0.25 kWh/km, which allows to cover a range of 65 km. at 80% DOD. Until now, the vehicle has covered more than 1,500 km without any problem. Battery charger, auxiliary power supply and other minor components are from Solectria Corporation [3]. All the digital instrumentation of the vehicle was designed and implemented at the Department of Electrical Engineering, Catholic University of Chile. Mechanical parts were made at the Department of Mechanical Engineering. The complete transformation was made at the Tramcorp facilities.

Main Power Circuit

The Figure 2 shows the Main Power Circuit of the converted Chevrolet LUV. The Auxiliary Power Supply is a DC-DC converter, which generates 13,2 Vdc nominal from the main battery pack. To balance the original weight in the engine compartment of the vehicle, five of the 26 batteries were installed in the front. The battery charger was installed in the rear, with the charging terminals in the same place were originally was the pipe of the fuel engine supply. The power inverter was located in the upper side of the engine compartment, and the traction motor (not shown in Figure 2) at the bottom. The photographs of Figure 3 a), and 3 b) show the installation of the traction motor and inverter respectively. The Soft Start in Figure 2 avoids the inrush current during the ignition process. The Ah meter allows to know the state of charge of the main battery.

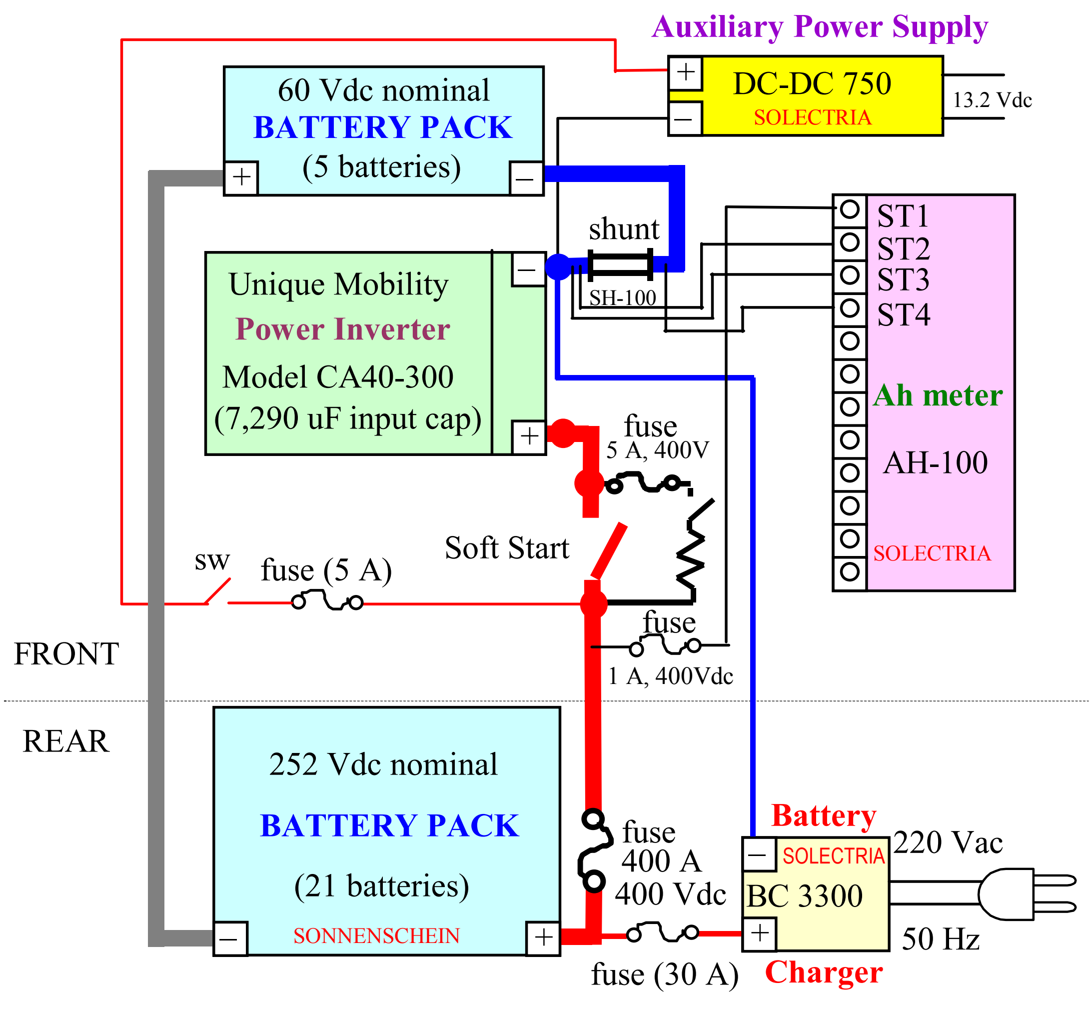
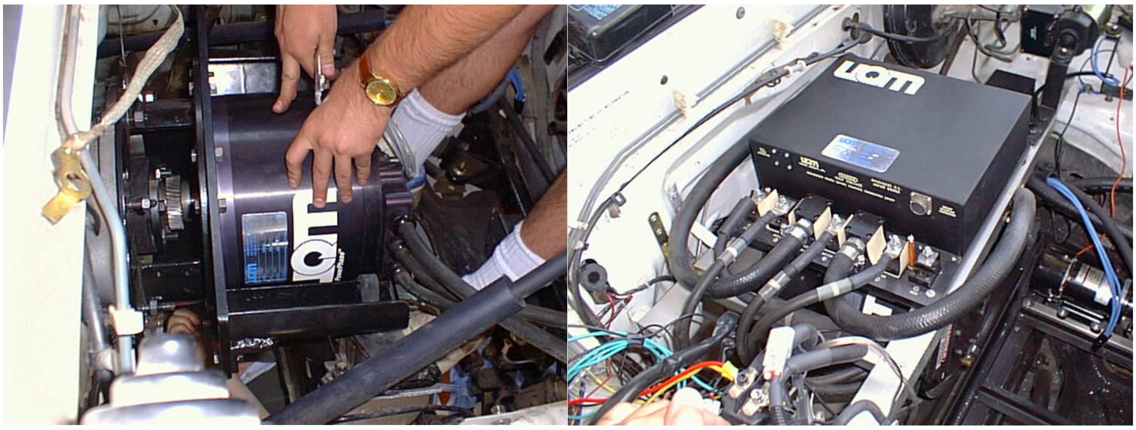


Figure 2
Chevrolet LUV Power Circuit



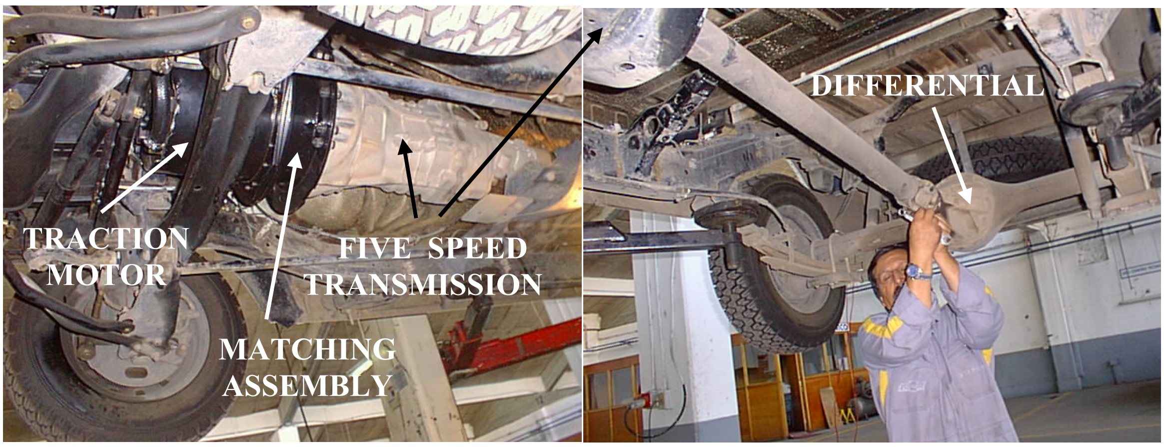
a) b)

Figure 3

Installation of the Traction Motor (a), and Inverter (b)

Power Wheel Transmission

The figures 4 a) and b) show pictures of the power wheel transmission. As it was already mentioned, the original five-speed mechanical gearbox was not removed, allowing to make different experiments with the EV. However, the clutch system was eliminated, and then, it is not possible to make mechanical speed changes when the vehicle is running. In any case, that is not required, because the new traction motor gives 1.5 times more torque than the original engine. Besides, this high torque can be obtained from zero speed to 2,200 rpm, compared with the internal combustion engine, which gives its maximum torque at 3,000 rpm only. The maximum torque of the new brushless dc motor (between zero and 2,200 rpm) is 240 Nt-m. The original engine was able to give a maximum of 160 Nt-m, but only at 3,000 rpm. The direct connection from the traction motor to the wheels (through a selectable gear reduction from the mechanical five-speed transmission), allows an excellent acceleration in third speed (0 to 65 km/h in 9 seconds), and an acceptable maximum speed of 120 km/h. At that speed, the traction motor runs at 6,150 rpm. This value is far from the maximum rating of the brushless dc motor (7,600 rpm).



FRONT **REAR**

Figure 4

Power Wheel Transmission Pictures

Microcomputer Control Installation

As the control system is made of fragile digital circuits and microprocessors, it was required to install it inside the cabin. However, it was also required to keep the cabin carefully clean, and free of bulky equipment. To satisfy the two requirements, the main microprocessor was installed in the place originally used for cassettes and glasses. The Photographs in Figures 5 a), b), c), and d), show a sequence of the microcomputer installation inside the passenger cabin. In 5 a) the aluminum box built for the controller is displayed; in 5 b) the electrical connections of the controller are shown; in 5 c) the LED indicators already installed, and in Figure 5 d) all the electronic equipment adequately finished.

Figure 5
Microcomputer Control Installation

The UQM (Unique Mobility) microcomputer shown in Figure 5 has many functions: control of the ignition key; control of the acceleration pedal and regenerative braking; and control of the forward and reverse direction. It also receives the position signal from the brushless dc traction motor, and sends the PWM signals to the power inverter. During ignition, the microcomputer activates the “Soft Start” sequence to avoid undesirable inrush currents. In Figures 5 c) and 5 d), the “forward-neutral-reversal” switch is also shown.

Panel Instrumentation

A digital instrumentation, using the original analog panel, was designed and implemented. In the new digital panel, there is information about motor temperature, motor speed in rpm, battery current, battery voltage, inverter temperature, and reference torque. In an additional instrument, there is information about ampere-hours used. In the Figure 6, the new digital panel is displayed. In the bottom right of the same figure, the old analog panel is being shown for comparison. The only original instrument in the new panel is the analog speedometer. The A·h meter (from Solectria Corporation), was installed as shown in Figure 6.

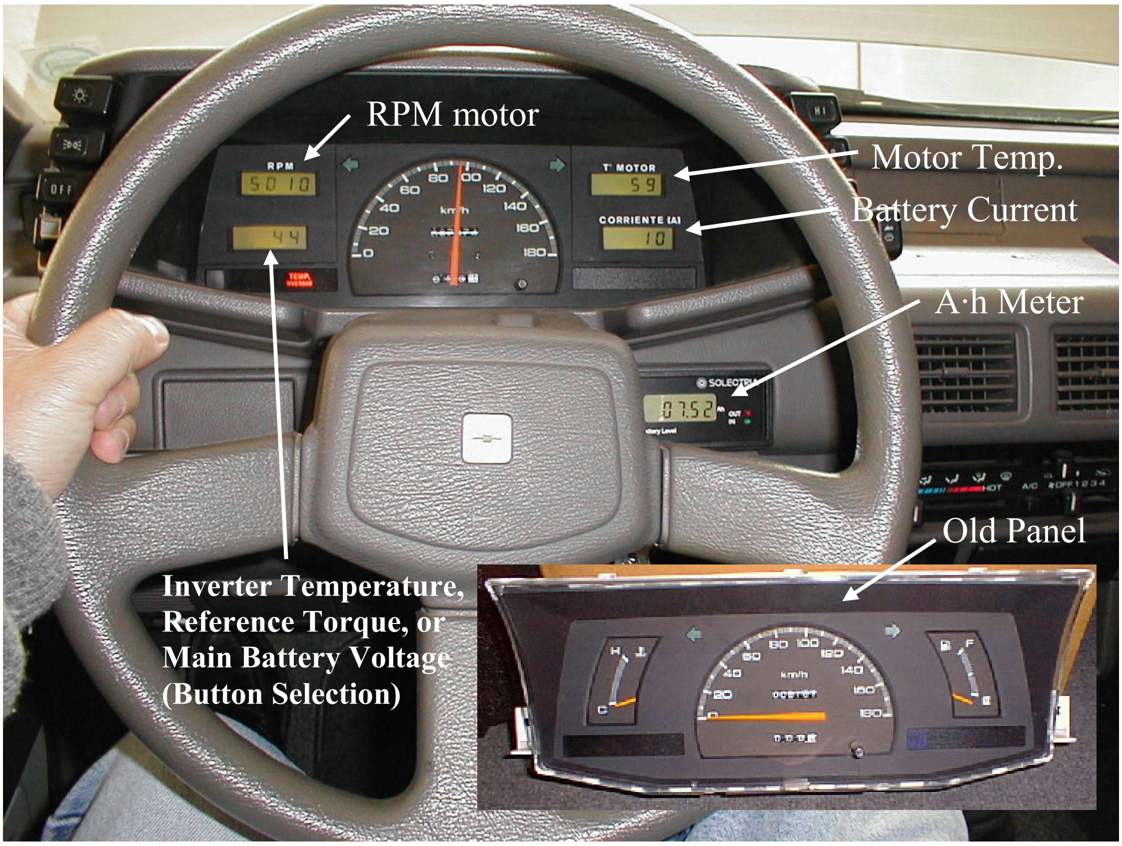
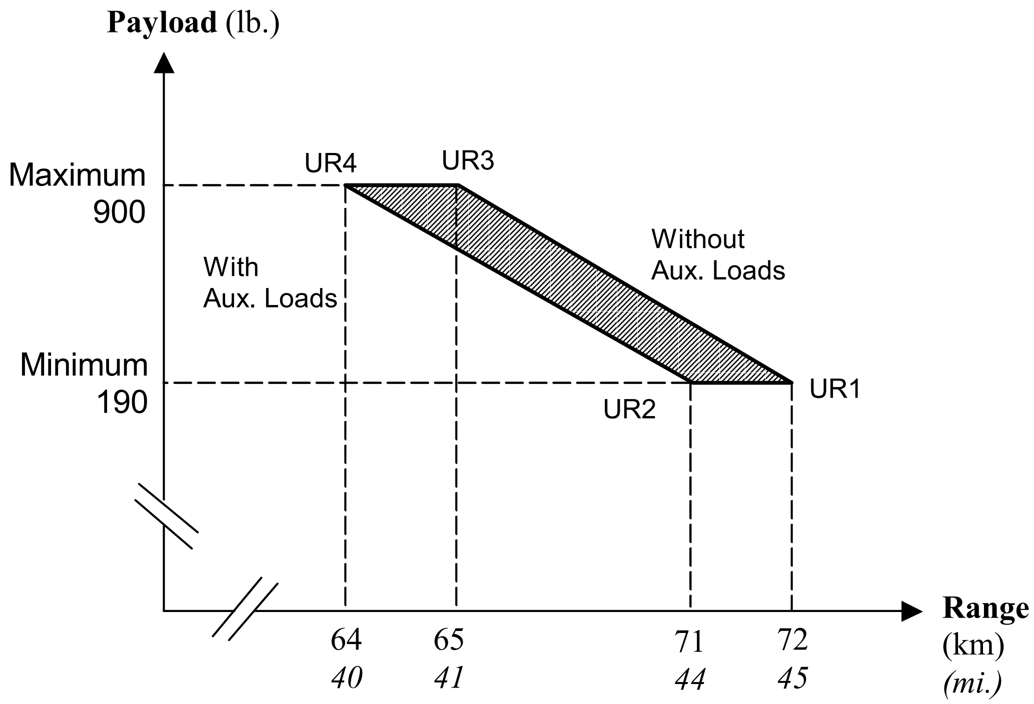


Figure 6
Digital Panel Instrumentation

For the design and operation of the digital panel, a dedicated microprocessor was used. All the variables are compared with maximum and minimum reference values. If one of the numbers is out of range (for example inverter over temperature), the display begins to fluctuate ON and OFF alternatively. In this way, the driver is advised, and can take some action to solve the problem. The digital display located at the bottom-left of the panel is a "selectable display". It allows the driver to choose the variable he or she wants to see. In this way, the number of parameters to be checked, is not limited by the number of displays. The selection is made by pushing a small button, which allows to see the *inverter temperature*, the *reference torque command,* or the *main battery voltage*. Later on, more variables will be added to this "selectable display".

Performance EV Tests

The EV was tested to check its performance using a standard procedure for electric vehicles, developed by Southern California Edison. This method is explained in a special report entitled "Electric Vehicle Test Procedure" [4]. One of the tests described in that report is the "Urban Range Test", which permits to know the range of the vehicle following four vehicle tests configurations: 1) *UR1*, conducted with minimum payload (driver only), and with no auxiliary loads; 2) *UR2* with minimum payload, and all auxiliary loads; 3) *UR3* with no auxiliary loads but with maximum payload; and 4) *UR4* with maximum payload, and all auxiliary loads. In the case of the Chevrolet LUV, the maximum payload was defined with a load of 900 pounds, including the driver. The Urban Range Test allows to plot the "EV Range Envelope", which defines the vehicle range according with UR1-UR4. This test assumes that the battery has been discharged from full to around 90% DOD. The Figure 7 shows the Range Envelope for the Chevrolet LUV. The vehicle does not have air conditioning system, and hence the auxiliary loads in this vehicle do not have an important effect on the range.



Test	UR1	UR2	UR3	UR4
Payload (lb)	190	190	900	900
AC kWh/km	0.25	0.253	0.277	0.28
Range (km)	72	71	65	64

Figure 7
EV Range Envelope and Efficiency of the Chevrolet LUV

The most interesting result in this test is the efficiency of the vehicle, because the range is more a matter of the battery type (in this case, the battery is a pack of 26 units in series, 50 Ah, 12 Vdc, Dryfit Traction type, from Sonnenschein). The efficiency, showed in AC kWh/km in the table of Figure 7, is quite the same as vehicles like the Ford Ranger, and the Chevrolet S-10.

Freeway tests have not been performed yet. However, the vehicle is able to run at 120 km/h in third speed (the third speed is the normal driving speed for all conditions). In third speed, the vehicle is able to accelerate from zero to 65 km/h in eleven seconds with full payload (900 pounds). With only the driver, the same speed is reached in only nine seconds. The gross weight of the vehicle is 4,260 lb. (1,600 lb in front, and 2,660 lb in the rear). The battery pack weights 1,160 lb (220 in front, and 940 in the rear).

Battery Monitoring System (BMS)

A BMS System is being designed and installed in the vehicle. This system will allow to follow the behavior of each battery in the time. The BMS will measure each battery voltage and temperature, and the instantaneous current of the pack. Then, the information will be processed and studied to know how the particular location of each battery affects its performance. The system has galvanic isolation, and uses analog multiplexers to send the information to a digital microcomputer.

Conclusions

The development of the first, state-of-the-art electric vehicle implemented in Chile was presented. The vehicle uses a high specific power brushless dc motor, high performance switching power supplies, and a non-polluting battery charger. The car transformed to an EV was a double cabin, Chevrolet LUV truck, with an actual gross weight of 1,920 kg (720 kg in the front and 1,200 kg in the rear). This vehicle is similar in size and shape to a Chevrolet S-10. Some of the characteristics obtained with this EV are: maximum speed, 120 km/h, acceleration, 0-65 km/h in nine seconds, efficiency, 4 km/kWh (0.25 kWh/km). The vehicle can carry five passengers comfortably seated inside the double cabin, and has demonstrated a good performance during its first 1,500 kilometers of tests.

Acknowledgments

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