Evaluation of an Electric Vehicle Performance under Different Modes of Operations: Experimental Study

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Abstract

In recent years, Electric Vehicles (EVs) have become a production viable and effective mode of efficient transportation. Electric Vehicles (EVs) can provide increased fuel economy and reduced harmful emissions over convention technology vehicles. In this study, the electric vehicle (EV) was tested to check its performance using a certain procedures. The tests described in this study are "No Load Tests", "Load tests" and "On-road Performance Evaluation Tests". All these tests allow evaluating the power and energy consumption by the electric vehicle during different modes of operations. The battery voltage and current were recorded during the different tests to allow plotting the requirements. The vehicle has been demonstrated to be very reliable and all the presented tests showed excellent results regarding system behavior and efficiency. Some of the performance characteristics of this Electric Vehicle are: maximum speed is nearly about 60 km/h at the top gear with 1.78 m/s^2 acceleration. The vehicle can carry two passengers comfortably seated inside cabin. The DC traction motor was connected directly to the conventional mechanical transmission, which allows to give 15 HP at 3200 rpm, and 72 Volt input and that is more reliable and suitable for the tested vehicle. For the constructed electric vehicle, the available and suitable type of batteries is the US 8VGC XC deep cycle lead acid batteries for the 8 V 170 amp hours (AH). According to the calculations, we were able to fit eight batteries in our vehicle. This would give a battery pack of 10.88 kWhr. We have them configured in two rows of eight series connected batteries creating a battery pack of 64 V and 170 AH. All the instrumentation for the driver panel was implemented digitally, given information about battery current, battery voltage, and rpm of the motor.

Key Words: Electric Vehicles, Performance Evaluation, DC Electric Motor, Lead Acid Battery.

1. Introduction

Vehicles have improved over long years. They became more versatile, better in performance and more comfortable without increasing the purchase cost, which has lead to unprecedented increase in number of vehicles on the road; this increase in the number of vehicles together with raising understanding of their environmental impacts and sustainability provided motivation for current discussion on future mobility [1]. However, most researchers attempt to present an enhancement processes in an attempt to find answer of this problem. In recent years, a significant interest in alternative vehicles such as Battery Electric Vehicles (BEVs) and Hybrid Electric Vehicles (HEVs) have arisen globally due to the pressing environmental concerns and skyrocketing price of oil [2].

Electric vehicles (EVs) have existed for over a hundred years. At the start of the 20th century electric vehicles must have looked a strong contender for future road transport [3] due to the environmental and economical issues which provide a compelling impetus to develop clean, efficient, and suitable vehicles for urban transportation [4].
When they were invented, they immediately provided an economical and reliable means of transportation. However, electric vehicles were plagued by poor range and short-lived batteries. Today, a renewed interest in environment and energy independence has compelled industry and government to again pursue electric vehicle designs. These designs focus on improving the range, efficiency, and durability of EVs [5].
Electric vehicles have improved their performance and made suitable for commercial and domestic use during the last decades. Nevertheless, pure electric vehicles still have not achieved ranges comparable to that of gas powered conventional vehicles, this problem, due to the low energy density and specific energy contained in most electric batteries compared to that of gasoline, is resolved in hybrid vehicles by combining high energy density of gas or hydrogen and high efficiency of electric drive systems [6]. Finally, the electric vehicles (EVs) can be safer than oil-powered vehicles [7].

2. Vehicle Testing (Practical Work)

2.1 Introduction

The vehicle testing was carried out in the Vehicle Research Laboratory, Automotive and Tractors Engineering Department, Faculty of Engineering, Minia University. The different tests were carried out using the protocol in the Code of world Regulations
The following section presents the results obtained from the experimental work carried out in this study. Extensive testing was carried out over a prolonged period of time.

2.2 Performance Evaluation Tests

The electric vehicle (EV) was tested to check its performance using a certain procedures. The tests described in this study are "No Load Tests", "Load tests" and "On-road Performance Evaluation Tests". All these tests allow evaluating the power and energy consumption by the electric vehicle during different modes of operations. The battery voltage and current were recorded during the different tests to allow plotting the requirements. These tests assume that the battery has been discharged from full to around 80% of the full charge state. The most interesting results in this study are the power and energy consumed by the vehicle.

2.3 No Load Tests (Primary Tests)

In these tests, the vehicle operates without any loads acting on the wheel, while the volt and current drained from the battery and consumed by the vehicle were recorded. In addition, the battery volt, current and power was measured during a short period of time.
Figure (1) shows the variation of battery voltage, battery current and battery power versus vehicle speed at no load on the wheel. With respect to battery voltage, it has been shown that increasing of vehicle speed resulted in a decrease in the voltage due to the drain of the battery because it operates without a recharging source.
The battery current decreases with the increasing of vehicle speed; this is also due to the increasing of the load with vehicle speed increased.

On the other hand, the power consumed by the vehicle increased due to increasing the vehicle speed because of the increasing of internal resistance of the transmission set.
Figure (2) shows the variation of battery voltage, battery current, battery power and energy consumed versus time. This test was carried out during a short period of time to evaluate the state of the battery along the time of operation. It is observed that the battery voltage, current and power reduced along the period of operation, on the other hand the amount of energy consumed increased.

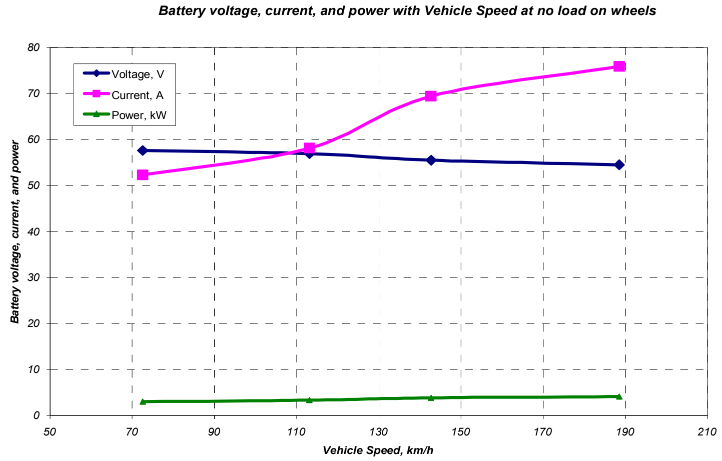

Figure (1) Battery current, voltage and power with vehicle speed, at no load on the wheel.

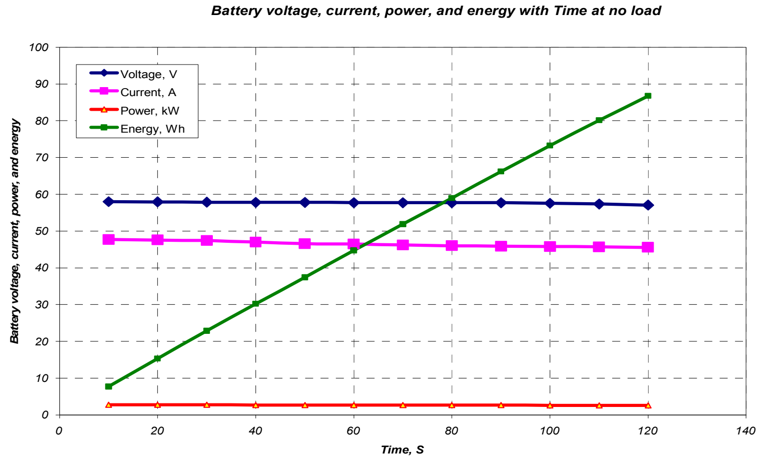

Figure (2) Battery current, voltage, power, and energy during a short period of time.

Another tests were carried out at the mode of no load acting on the vehicle are the battery voltage, current, power and energy consumed with different gearshifts versus time. The following figures 3, 4, 5and 6 illustrates the variations of battery voltage, current, and the power and energy consumed by the vehicle during a certain period of time with a different gear shifts at no load acting on the vehicle during the tests. Finally, a comparison between power and energy consumed by the vehicle at different gearshifts was presented and the results show that the increasing of vehicle speed resulted in increasing of power and energy consumption as shown in figures 7 and 8. Moreover, the average power and energy consumed during the tests at the cases of different gear shifts were calculated, and the figures 9 and 10 show the results. Table (1) shows the average power and energy consumption by the electric vehicle with different gearshifts at no load affected on the wheels.

Gearshifts	1st Gear	2nd Gear	3rd Gear	4th Gear
Power (kW)	2.968	3.027	3.229	3.856
Energy (Wh)	53.028	53.972	57.514	67.301

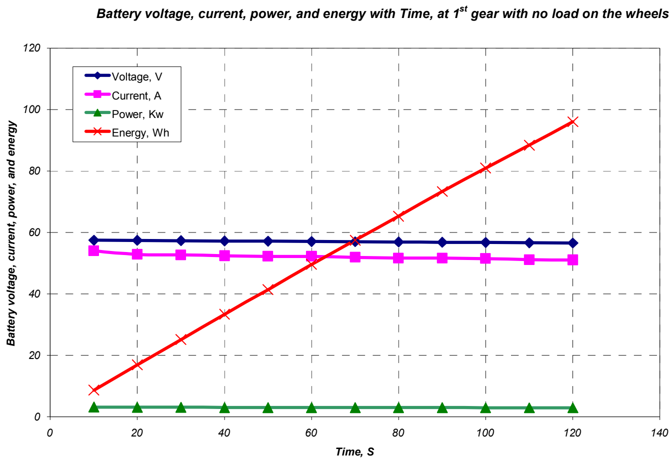

Figure (3) Battery voltage, current, power, and energy with Time, at 1st gear with no load on the wheels

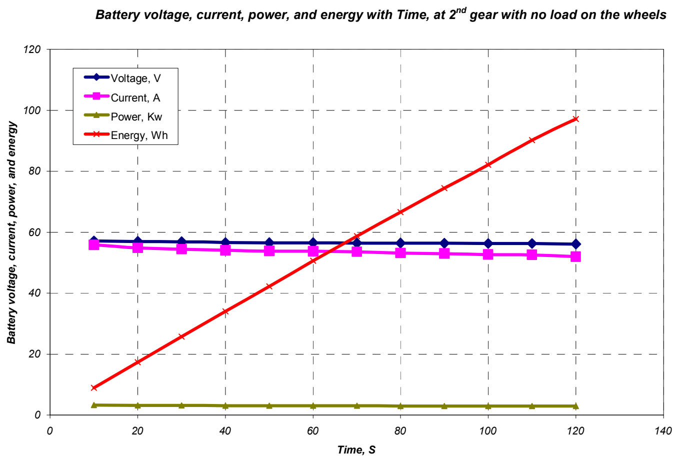

Figure (4) Battery voltage, current, power, and energy with Time, at 2nd gear with no load on the wheels.

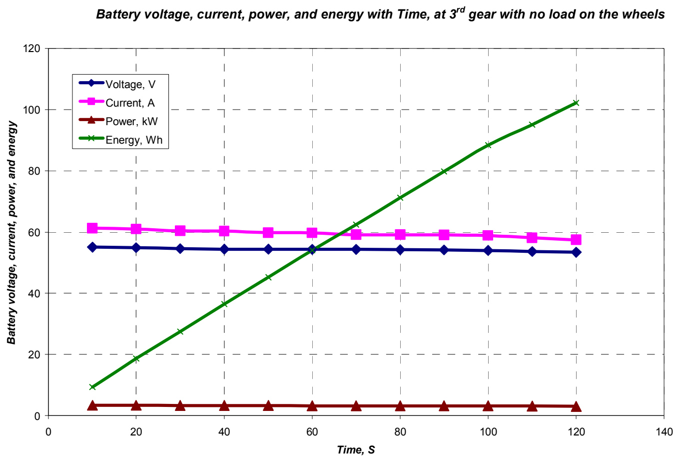

Figure (5) Battery voltage, current, power, and energy with Time, at 3rd gear with no load on the wheels.

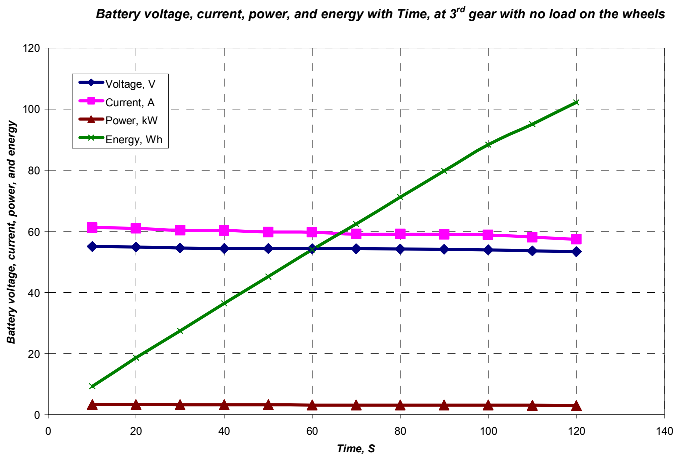

Figure (6) Battery voltage, current, power, and energy with Time, at 4th gear with no load on the wheels.

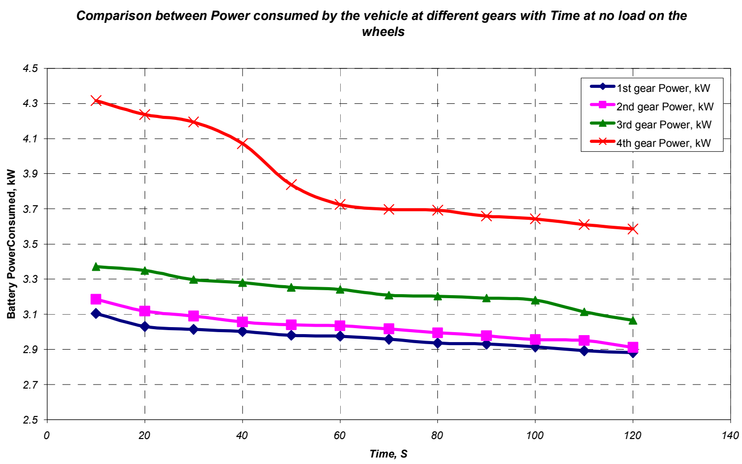

Figure (7) Comparison between Power consumed by the vehicle at different gears with Time at no load on the wheels

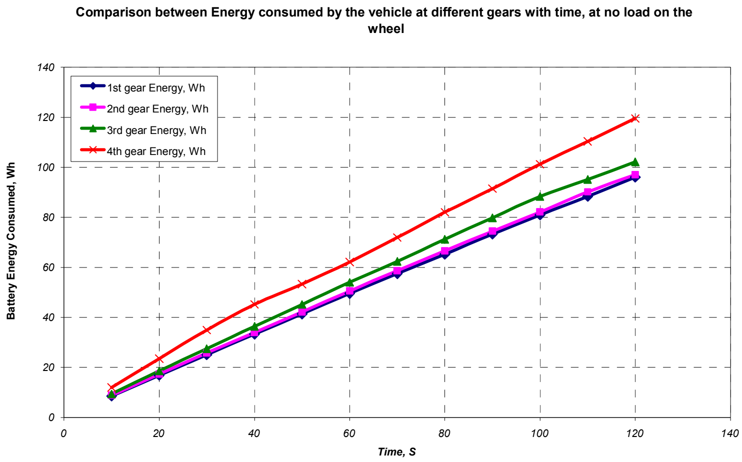

Figure (8) Comparison between Energy consumed by the vehicle at different gears with time, at no load on the wheel

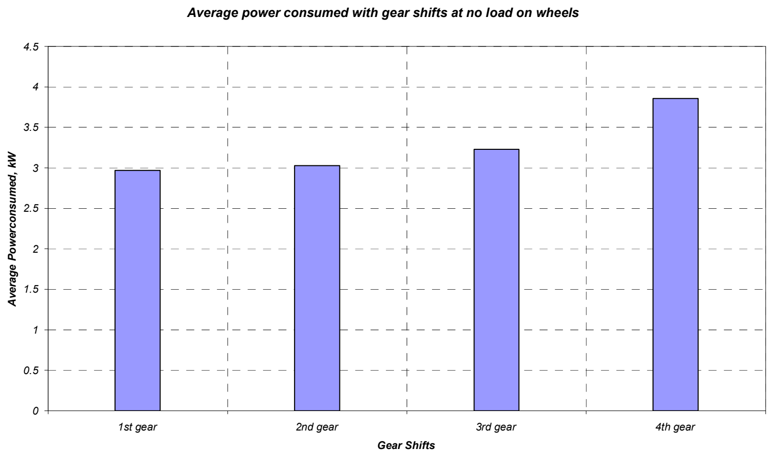

Figure (9) the average power consumed with gearshifts at no load on wheels.

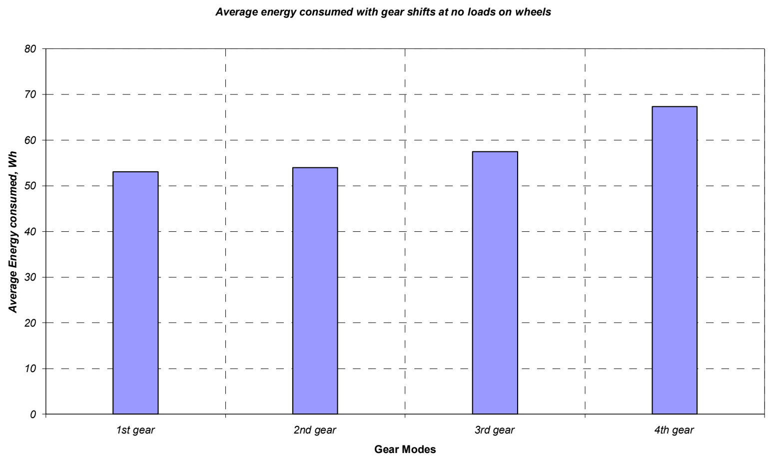

Figure (10) the average energy consumed with gearshifts at no loads on wheels.

2.4 Chassis Dynamometer Tests (Load Tests)

The same tests described in the previous case were conducted on a chassis dynamometer to simulate the vehicle loading action during the tests. In this case, the rolling resistance only was considered as the load acting on the vehicle and the voltage, current, power and energy consumption were recorded according this condition.

Figure (11) show the relations between battery voltage, current and power with vehicle speed at a certain load condition (rolling resistance only was considered). It is observed that the battery voltage decreased with increasing the vehicle speed due to the drain mechanism of the battery without recharging source. In addition, the battery current increased as the vehicle speed increases to compensate the energy consumed to overcome the motion resistance of the vehicle. Finally, the power consumption significantly increases with vehicle speed.

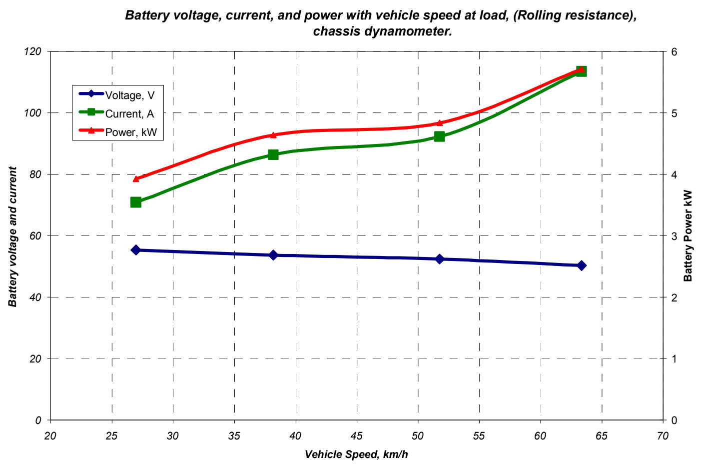

Figure (11) Battery voltage, current, and power with vehicle speed at load, (Rolling resistance)

In addition, a set of tests were carried out at the mode of load condition acting on the vehicle are the battery voltage, current, power and energy consumed with different gearshifts versus time. Figures 12, 13, 14 and 15 illustrates the variations of battery voltage, current, power and energy versus time at different gear shifts. The load considered in this case is the rolling resistance, which simulated by using the chassis dynamometer device. Moreover, a comparison between the power and energy consumption by the vehicle during the selected period at different gear shifts were carried out and the following figures 16 and 17 demonstrate these variations and the results show that the increasing of vehicle speed resulted in increasing of power and energy consumption. Finally, the average power and energy consumed during the tests at the cases of different gear shifts were calculated, and the figures 18 and 19 show the results.

Table (2) shows the average power and energy consumption by the electric vehicle with different gearshifts at load considered from rolling resistance.

Gearshifts	1st Gear	2nd Gear	3rd Gear	4th Gear
Power (kW)	3.655	3.929	4.115	4.342
Energy (Wh)	64.740	69.505	70.202	73.756

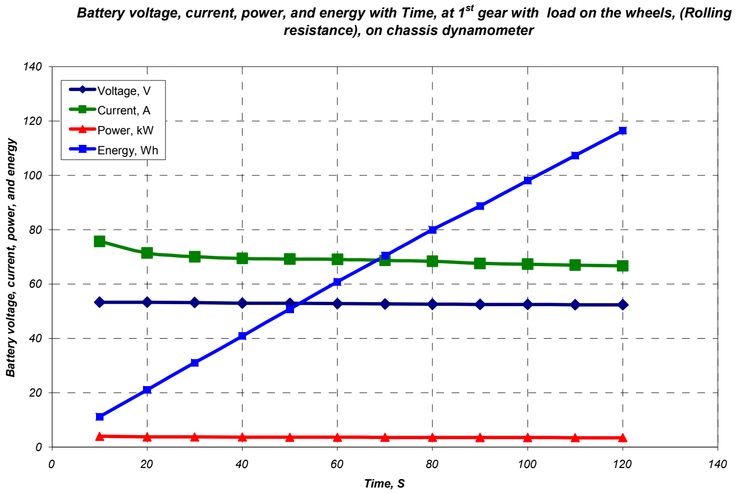

Figure (12) Battery voltage, current, power, and energy with Time, at 1st gear with load on the wheels, (Rolling resistance)

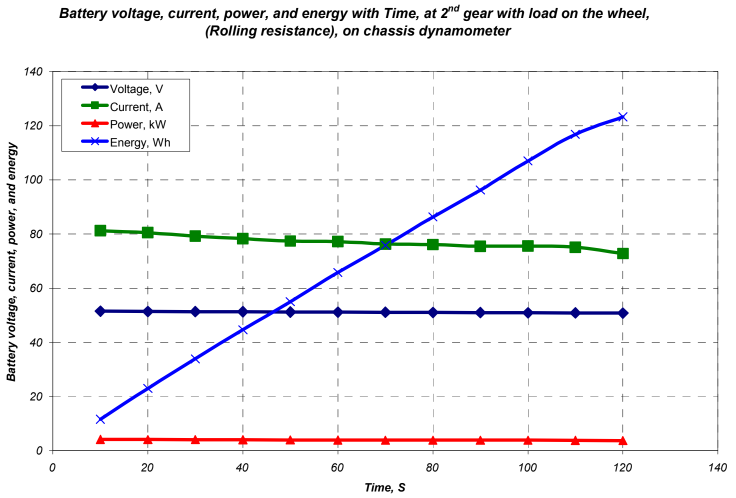

Figure (13) Battery voltage, current, power, and energy with Time, at 2nd gear with load on the wheel, (Rolling resistance)

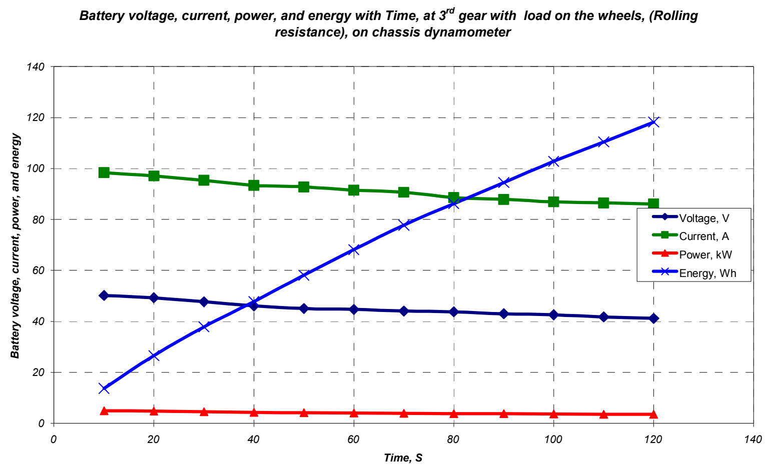

Figure (14) Battery voltage, current, power, and energy with Time, at 3rd gear with load on the wheels, (Rolling resistance)

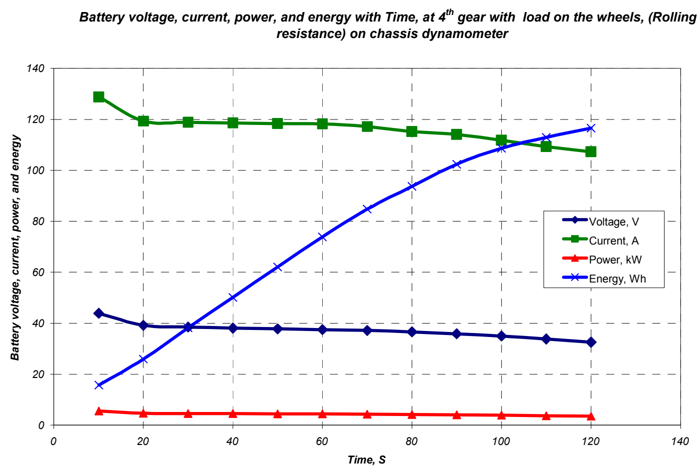

Figure (15) Battery voltage, current, power, and energy with Time, at 4th gear with load on the wheels, (Rolling resistance)

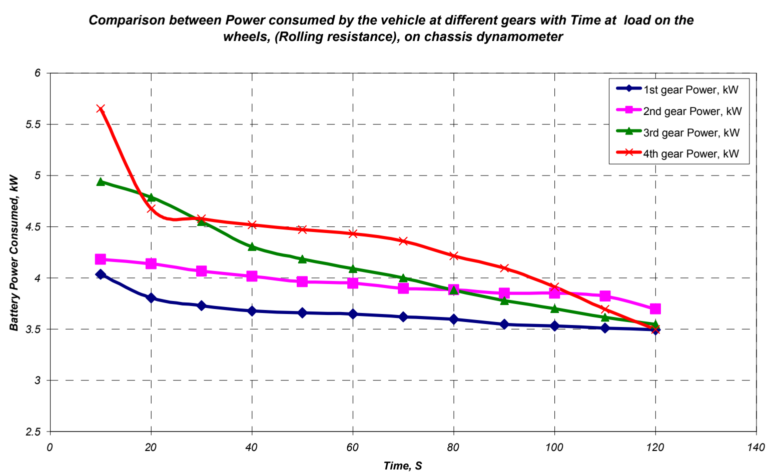

Figure (16) Comparison between Power consumed by the vehicle at different gears with Time at load on the wheels, (Rolling resistance)

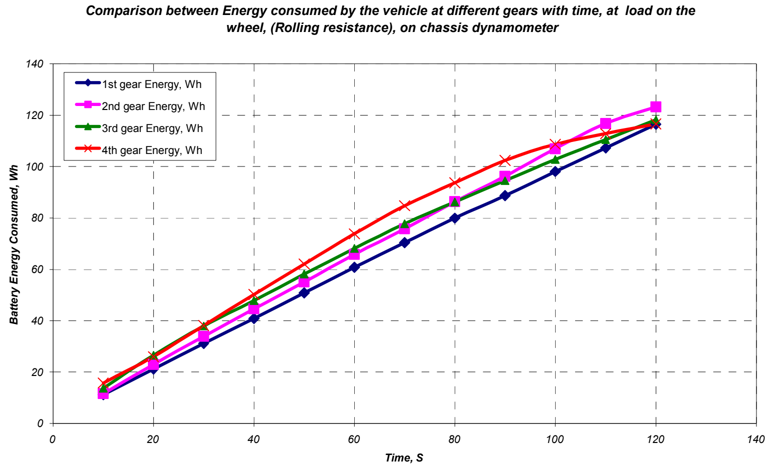

Figure (17) Comparison between Energy consumed by the vehicle at different gears with time, at load on the wheel, (Rolling resistance)

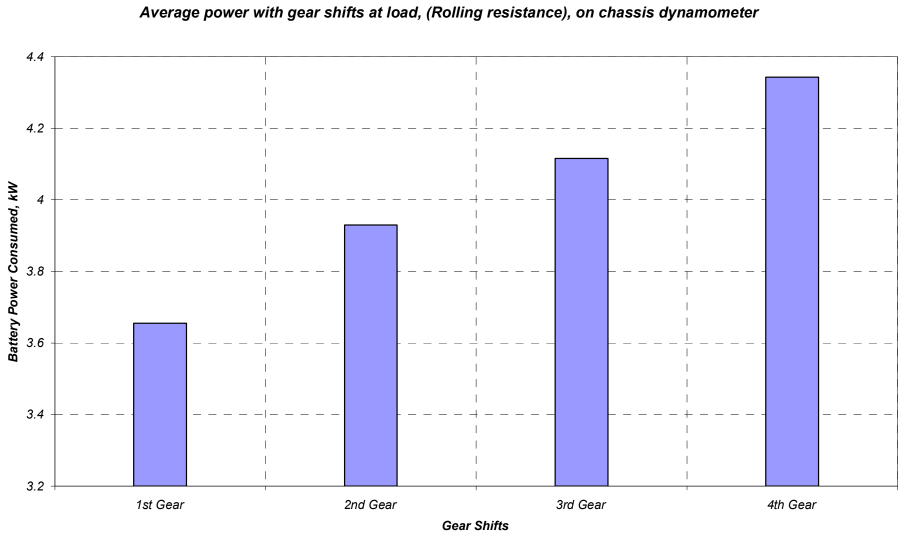

Figure (18) Average power with gear shifts at load, (Rolling resistance)

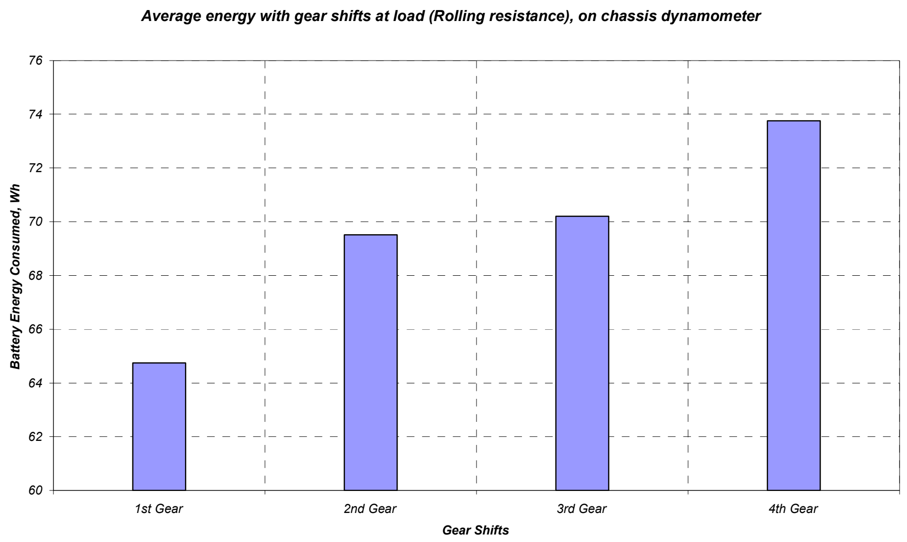

Figure (19) Average energy with gear shifts at load (Rolling resistance)

2.5 On-road Performance Evaluation Tests

On-road evaluation of the implemented electric vehicle (EV) was conducted to determine the battery characteristics, power and energy consumed by the vehicle during the normal driving. Road testing was carried out at the faculty car parks and this enables us to accelerate up to about 60 km/h by the tested vehicle. These tests have been introduced, for power and energy consumption certification of the implemented electric vehicle at different modes of operations according to road conditions. The test represents a driving pattern, which includes a repetition of a basic cycle composed of idle, acceleration, deceleration, and stop modes and the main characteristic parameters of this cycle are 600 sec. duration, maximum speed 43 km/h and average speed was nearly 28.5 (km/h). The test was carried out on the vehicle and the amount of battery voltage, current, power and energy were recorded. In addition, the vehicle speed and time during the test were taken into account. Figure (20) shows the vehicle speed profile over the duration of the test cycle. The results show that, the vehicle speed changes during the duration of the cycle according to road conditions. As this shown the vehicle started the cycle at speed of 0 (km/h), and then increased due to the acceleration according to the road conditions, then the vehicle speed decreased due to the deceleration, this deceleration may be because the using of the brakes or due to an obstacles or for preparing to stop. From the results, the maximum speed, which the vehicle reached, is 43 (km/h), and the average speed was 28.5 (km/h). Figure (21) show the variation of battery voltage versus time as a function of vehicle speed during the test. It is observed that the battery voltage decrease along the period of the test due to the drain of the battery without recharging sources.

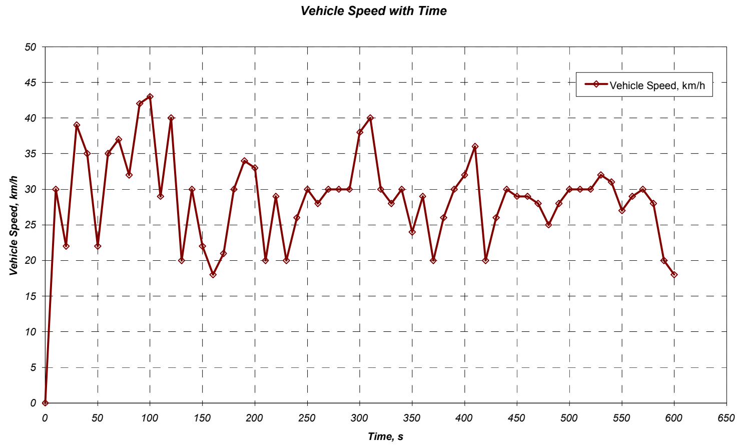

Figure (20) vehicle speed with time (On-road test)

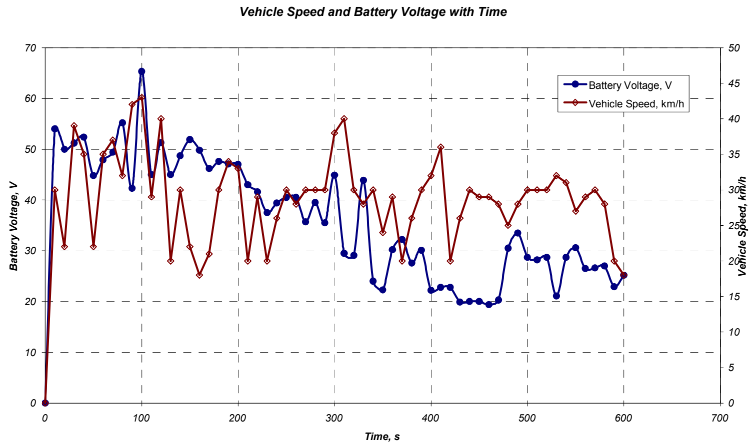

Figure (21) battery voltage with time as a function of vehicle speed (On-road test)

Figure (22) show the variation of battery current versus time as a function of vehicle speed. It is observed that the consumption of battery current increase with the vehicle speed increase because of the increasing of the road resistance acting on the vehicle during motion.

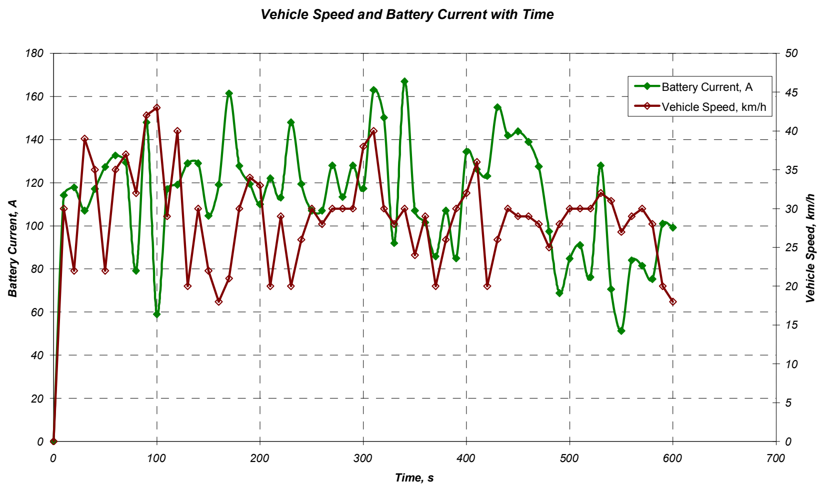

Figure (22) battery current with time as a function of vehicle speed
(On-road test)

Figure (23) show the variation of battery power consumed by the vehicle during the test versus time as a function of vehicle speed. It is observed that the power decrease along the period of the test due to the drain of the battery.

Figure (24) show the variation of battery energy versus time as a function of vehicle speed. The results obtained that the energy consumption increased with the time of usage.

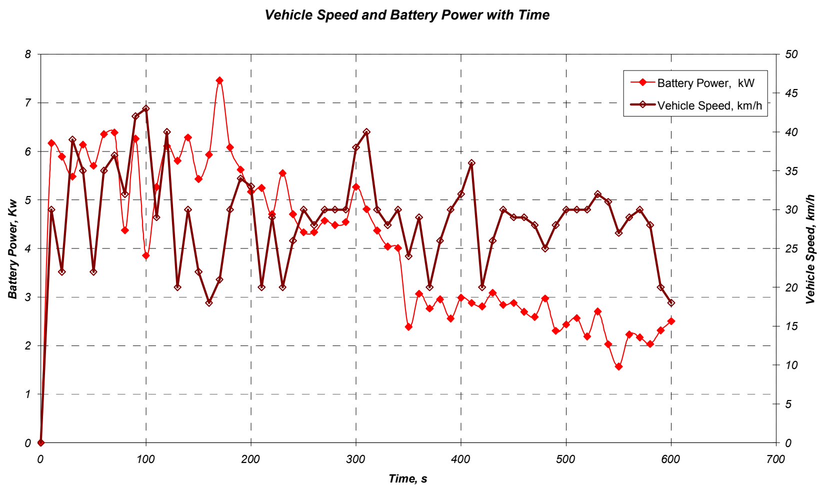

Figure (23) battery power with time as a function of vehicle speed
(On-road test)

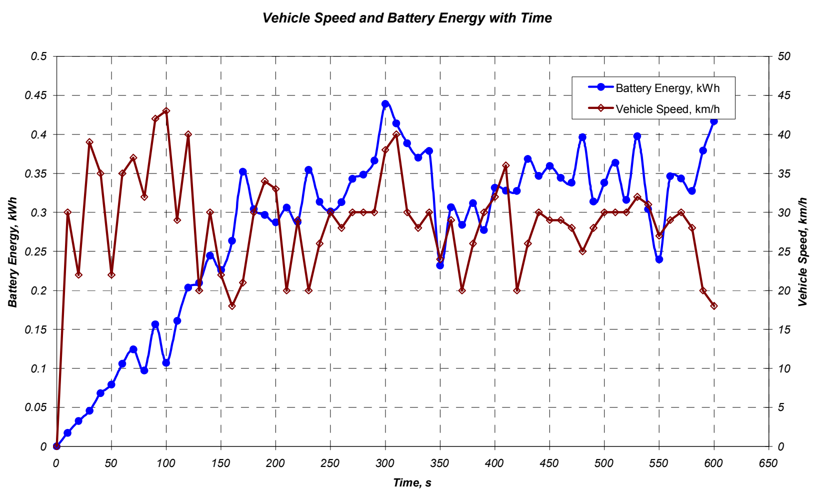

Figure (24) battery energy with time as a function of vehicle speed
(On-road test)

From the results obtained, we can conclude that the average power and energy where the implemented electric vehicle can consumed. Then, a long the presented test and according to its characteristics the power and energy consumption during this period were as the following table. Table (3) shows the average power and energy consumption by the electric vehicle at on-road test for performance evaluation.

Power (kW)	4.025
Energy (Wh)	277.730

2.6 Maximum Speed Tests (On-road Tests)

These tests depending on conduct the vehicle at different gearshifts and trying to reach the maximum speed of the vehicle at every gearshift.

During these tests, the time, vehicle speed, battery voltage, battery current, battery power and battery energy were recorded until the vehicle reached to the maximum speed.

At the first gear the vehicle reached about 38 (km/h) and the duration of the test was 30 sec. Figure (25) show the variation of battery voltage, current, power and energy with time as a function of the vehicle speed at the first gearshift. The results obtained that the maximum acceleration of the vehicle during this case was 1.23 m/s^2.

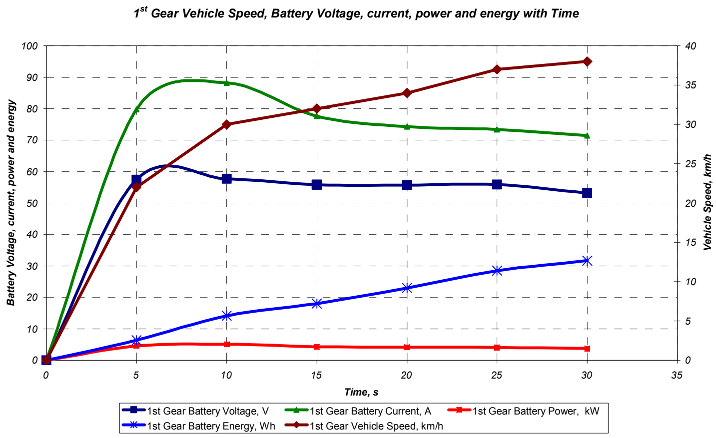

Figure (25) battery voltage, current, power and energy with time as a function of the vehicle speed at the first gearshift.

At the second gear the vehicle reached about 43 (km/h) and the duration of the test was 30 sec. Figure (26) show the variation of battery voltage, current, power and energy with time as a function of the vehicle speed at the first gearshift. The results obtained that the maximum acceleration of the vehicle during this case was 1.56 m/s2. At the third gear the vehicle reached about 52 (km/h) and the duration of the test was 30 sec. Figure (27) show the variation of battery voltage, current, power and energy with time as a function of the vehicle speed at the first gearshift. The results obtained that the maximum acceleration of the vehicle during this case was 1.78 m/s2. At the fourth gear the vehicle reached about 58 (km/h) and the duration of the test was 30 sec. Figure (28) show the variation of battery voltage, current, power and energy with time as a function of the vehicle speed at the first gearshift. The results obtained that the maximum acceleration of the vehicle during this case was 2.06 m/s^2.

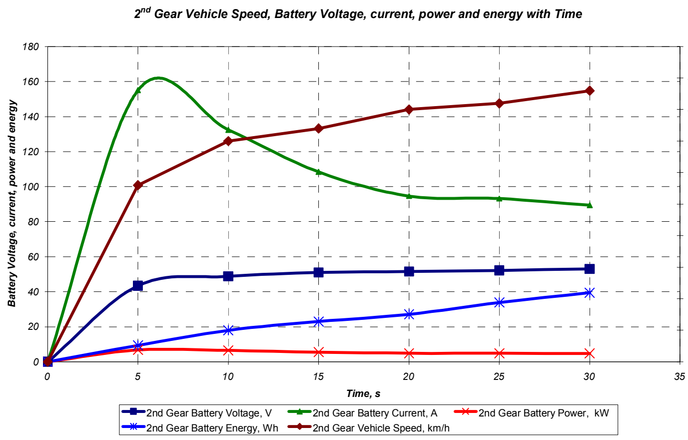

Figure (26) battery voltage, current, power and energy with time as a function of the vehicle speed at the second gearshift.

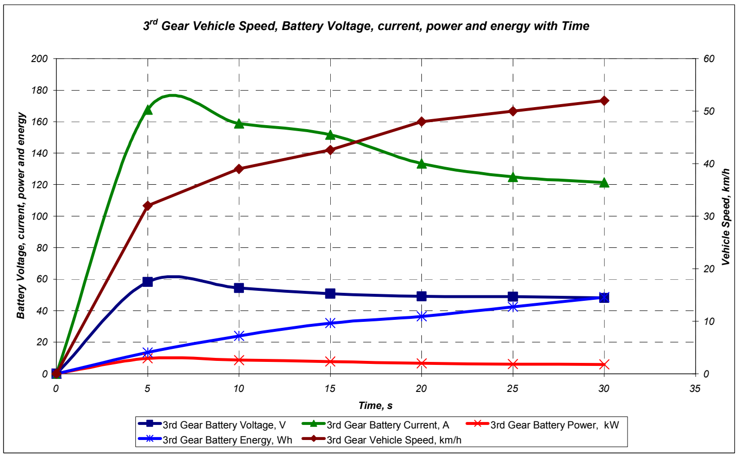

Figure (27) battery voltage, current, power and energy with time as a function of the vehicle speed at the third gearshift.

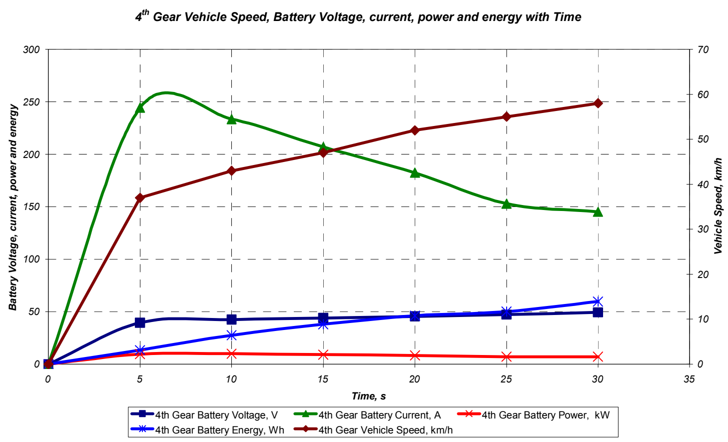

Figure (28) battery voltage, current, power and energy with time as a function of the vehicle speed at the fourth gearshift.

Finally, the average power and energy consumption by the vehicle during this test were determiner and the following figures show these results.
Table (4) shows the average power and energy consumption by the electric vehicle with different gearshifts at maximum load tests.

Gearshifts	1st Gear	2nd Gear	3rd Gear	4th Gear
Power (kW)	3.720	4.740	6.372	7.347
Energy (Wh)	17.389	21.516	28.165	33.591

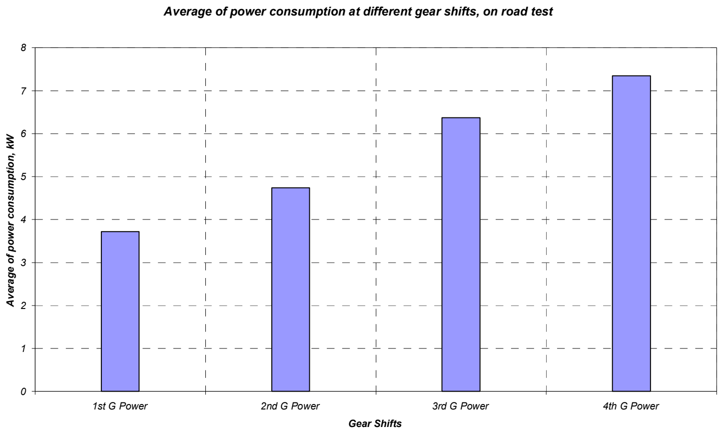

Figure (29) average power consumption at different gearshift.

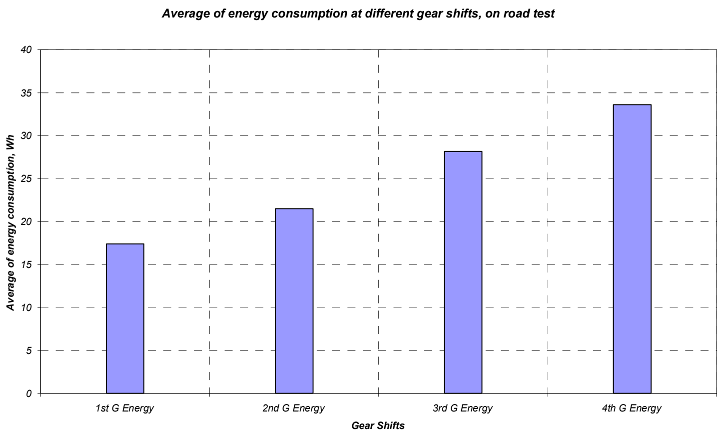

Figure (30) average energy consumption at different gearshift.

3. Conclusion

This paper makes an attempt to evaluate a battery electric vehicle and studying its performance under different operating conditions. The study results have shown that, the electric vehicle can meets the consumer expectations as well as environmental issues and benefits, and other impacts like noise or local air-pollution. The vehicle has been demonstrated to be very reliable and all tests presented showed excellent results regarding system behavior and efficiency. The tested vehicle has a maximum speed of about 60 km/h at the top gear with 1.78 m/s^2 acceleration. The vehicle can carry two passengers comfortably seated inside its cabin.

References

[1] Essam M. M. Allam, Nabil M. Hammad, Ahmad A. A. Saad, Shawki A. Abouel-Seoud, " A Small City Series Hybrid Electric Vehicle : Performance Evaluation", EET-2007 European Ele-Drive Conference Brussels, Belgium, May 30 – June 01, 2007.

[2] Yuliang Leon Zhou "Modeling and Simulation of Hybrid Electric Vehicles", master of applied science in the Department of Mechanical Engineering University of Victoria, 2007.

[3] James Larminie, John Lowry, " Electric Vehicle Technology Explained", Book, John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex PO19 8SQ, England.

[4] Iqbal Husain, "Electric and Hybrid Vehicles", Design Fundamentals, Book, Boca Raton London New York Washington, D.C, Published in the Taylor & Francis e-Library, 2005.

[5] Dimosthenis C. Katsis "Development of A Test bed For Evaluation of Electric Vehicle Drive Performance", Masters of Science in Electrical Engineering, August 27, 1997 Blacksburg, Virginia

[6] Micah Ortúzar, Juan Dixon (SM IEEE) and Jorge Moreno "Design, Construction and Performance of a Buck-Boost Converter for an Ultracapacitor-Based Auxiliary Energy System for Electric Vehicles", Department of Electrical Engineering Pontificia Universidad Católica de Chile Casilla 306, Correo 22, Santiago.

[7] United States. Environmental Protection Agency (EPA). Transportation and Air Quality Transportation and Regional Programs Division. EPA420-F-00-034, March 2002.