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Research Article

PERFORMANCE ANALYSIS OF AN ELECTRIC CAR WHEN USING DIFFERENT BATTERY TYPES

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ABSTRACT:
This research focused on the performance analysis of an electric car when using different battery types. The electric car was built specified for the experiment. It was equipped with a 5 kW BLDC motor. The lithium-iron phosphate battery and deep cycle lead-acid battery with equal capacity of 48V 120 Ah were selected. The electric car was tested on a chassis dynamometer with two modes of testing, there were twice run of five urban cycles, and continuous drive on urban driving cycle until the electric car unable to reach 50 km/h. While testing, the electric power analyzer was conducted for recording various electric data. The results showed that the electric car when using lithium-iron phosphate battery could respond to reach the target velocity curve profile better than when using deep cycle lead-acid battery. In addition, the driving range per charge of the electric car using lithium-iron phosphate battery was longer as well.

Keywords: *Battery, Electric car, Performance, Urban driving cycle*

1. INTRODUCTION

Global warming is the unusual rapid increase of earth's average surface temperature. In this phenomenal, the emission of CO_2 playing the most prominent role, and driven largely by the transportation sector [1]. From this point, it has led to the setting of a carbon reduction framework in the transportation sector by related agencies. One solution is that to replace internal combustion engine vehicles on the road by electric vehicles. The CO_2 emissions from combustion of the engines will be significantly reduced, especially in the cities that have a lot of vehicles [2]. Because electric vehicles use electric motors instead of combustion engines, and use batteries instead of fuel as its energy source, So, there are not any combustion on the vehicles. However, the driving distance of electric vehicles depend on designs, sizes, and types of battery. Therefore, battery is the primary factor to the price, size, weight, and performance of vehicles. Battery life is also one of the limitations of electric vehicles [3]. There are several types of batteries such as Lead-acid battery, Nickel Metal hydride (Ni-MH) battery, and many different types of Lithium batteries. However, each battery type has its own specific characteristics both advantages and disadvantages [4]. Some research preferred that Molten Salt (Na-NiCl2) is best in the point of view of energy consumption [5]. However, suitable battery selection for electric vehicles, especially for the modified vehicles, it should be considered in many terms of usages, also can see in Fig. 1.

Wojciech Gis et al. [6] have studied the energy consumption for electric passenger cars on the chassis dynamometer with NEDC and FTP driving cycles. While Sam van Goethem et al. [7] have tested the performance of battery electric buses on a test track with SORT procedure and the UNECE R101. But, they found that some influencing factors such

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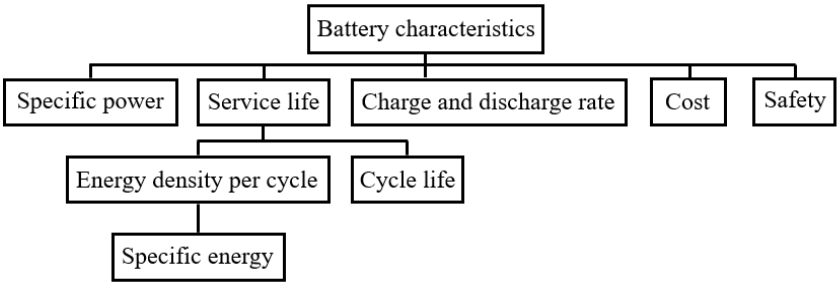


Fig. 1. Battery characteristics. [2]

as temperature, speed profile, and cycle length errors caused by the driver could hardly or not be controlled. To get a better understanding of these influences and the effect they have on the results, the test should be repeated in an environment where all parameters can be controlled.

Because of several error factors may have caused by human, Ilyès Miri el at. [8] have developed an accurate computer-based model for estimating EV energy consumption under the given driving cycles. MATLAB/Simulink software was used for BMW i3 modelling according to the real BMW i3 car. For controlling precise speed of vehicle in accordance with the driving cycle, PI controller was developed and used instead of human. The model has demonstrated accuracy with less than 6%. At the same way Mizutani, N. et al. [9] have developed a robotic driver for controlling vehicle speed instead of human. The robotic driver was comprised of linear actuator for the throttle and brake pedals, as shown in Fig. 2(a). Thereafter, running tests were performed using the robotic driver with vehicle on chassis dynamometer, as shown in Fig. 2(b). The result showed better speed control performance.

(a) Robotic driver on a driver position.

(b) Vehicle setup for the experiment.

Fig. 2. Vehicle speed control by a robotic driver. [9]

Other than researching on energy consumption point of view for electric vehicles, the comparison between battery electric car (BEV) and internal combustion passenger car (ICEV) in terms of their energy consumption on the test route also have been done. The results shown that BEV's consumption was 68% lower than ICV's energy consumption [10]. While Zdzislaw Chlopek et al. [11] have investigated on the chassis dynamometer with standard driving test cycles: 8 UDC, 10 EUDC, 6 FTP-72, 5 Stop and Go, and 8 PIMOTUT1, as shown in Fig. 3. The results demonstrated that the electric vehicle used average about 64% less energy than the conventional one.

(a) Renault Kangoo Express Z.E. (BEV) (b) Renult Kangoo 1.5 dCi (ICEV)

Fig. 3. Vehicles use for tests on chassis dynamometer. [11]

The battery is one of the main factors affecting the performance of electric vehicles. The research therefore focused on the performance characteristics of an electric car when using different battery types. The experiment was performed on a chassis dynamometer with urban cycle run under the UNECE R101 regulation. The two types of lithium-iron phosphate battery and deep cycle lead-acid batteries with equal capacity were selected for supplying electric energy to the car.

2. METHODOLOGY

2.1 Electric car

This research focused on the performance characteristics of the electric car when using different battery types. The electric car was built specified for the experiment. Its frame made from steels supported by 4 wheels with suspension system, drive and turn by front wheels. Equipped with a 5 kW DC brushless motor and a fixed gear ratio for its drivetrain. The car has 2 seats, the battery pack was placed at the back of the seats between left and right of rear wheels. The details are as in Table 1.

Table 1: Details of the electric car.

Item	Specification
Overall dimension (L × W × H)	3.04 m × 1.65 m × 1.37 m
Mass (Without battery and driver)	700 kg
Wheel base	2.00 m
Motor	BLDC motor 5kW
Gear ratio	1.88 : 1
Differential gear ratio	4.08 : 1
Tire size	205/50 R16

For the sources of electric power, the lithium-iron phosphate battery and deep cycle lead-acid battery at equal capacity of 48V 120 Ah were selected and used in this research. The details of these two types of batteries are as in Table 2.

Table 2: Details of battery packs used with the electric car.

Type of battery	Property	Battery pack size (W × L × H)	Mass (kg)
Deep cycle lead-acid	12V 120Ah × 4 (4 Series)	0.50 m × 0.80 m × 0.23 m	150
Lithium iron phosphate	3.2V × 345 Cells (23 Parallel, 15 Series)	0.59 m × 0.62 m × 0.48 m	75

2.2 Driving cycle

In the experiment, it is very difficult to drive the electric car for testing with several cycles on the real road. Because the traffic situation is uncontrollable, every driving cycle will not be the same pattern, which will be affected to the incomparable results [7]. Therefore, in this research the electric car was tested on the chassis dynamometer under the standard driving cycle which called New European Driving Cycle (NEDC). The driving profile is shown in Fig. 4. Noted that, the electric car used in this research was just able to reach the maximum speed of 60 km/h. Therefore, in this research the car was tested only upon the urban cycle driving profile which the maximum speed is just 50 km/h.

2.2.1 Regulation No. 101

The experiment with an electric car in this research has performed under the regulation No. 101 [12]. This regulation is the uniform provisions concerning the approval of passenger cars powered by an internal combustion engine only, or powered by a hybrid electric power train with regard to the measurement of the emission of carbon dioxide and fuel consumption and/or the measurement of electric energy consumption and electric range. The regulation is also applicable for vehicles powered by an electric power train only with regard to the measurement of electric energy consumption and electric range.

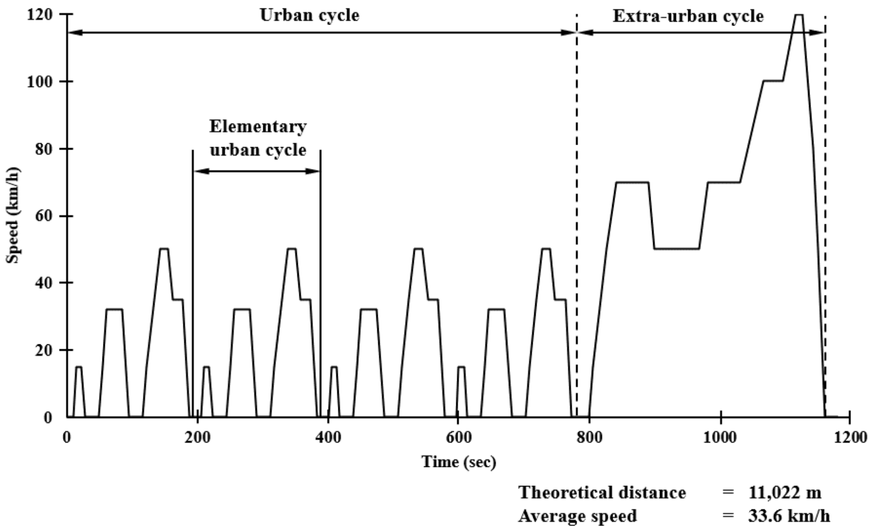


Fig. 4. New European Driving Cycle (NEDC). [12]

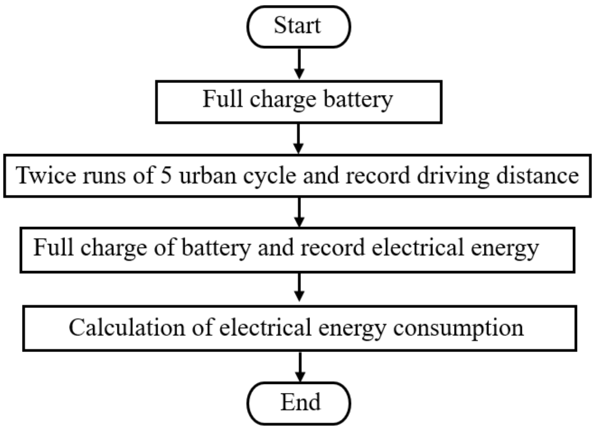


Fig. 5. Flow chart of the electrical energy consumption experiment.

2.2.2 Electric energy consumption

For the electric energy consumption, this research has followed upon the Annex 7 - Method of measuring the electric energy consumption of vehicles powered by an electric power train only [12]. The procedure can be expressed as a flowchart diagram in Fig. 5.

The electric energy consumption “C” is defined by the formula as shown in equation (1) [12]. The electric energy “E” should be in Watt hour (Wh). Also, the charging time must be recorded in the test report.

$$C = \frac{E}{D_{test}} \tag{1}$$

2.2.3 Electric range

For the driving range of the electric car, this research has followed upon the Annex 9 - Method of measuring the electric range of vehicles powered by an electric power train only or by a hybrid electric power train [12]. The procedure can be expressed as a flowchart in Fig. 6.

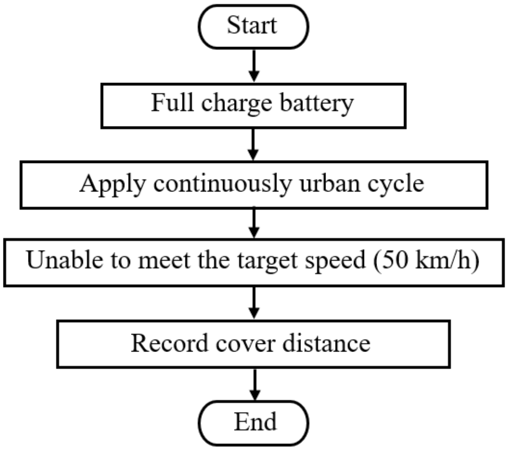
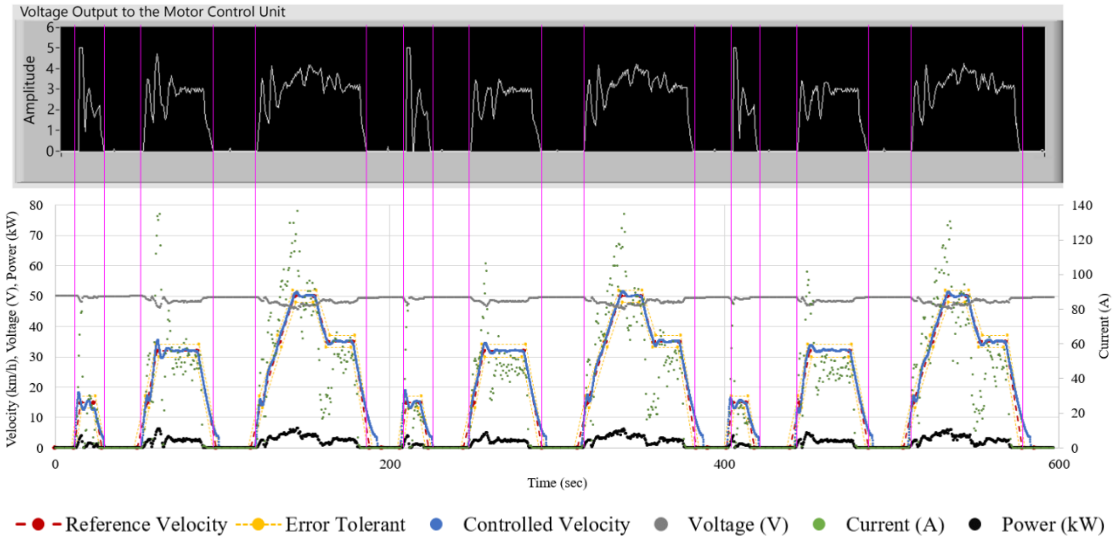


Fig. 6. Flow chart of the electric range experiment.

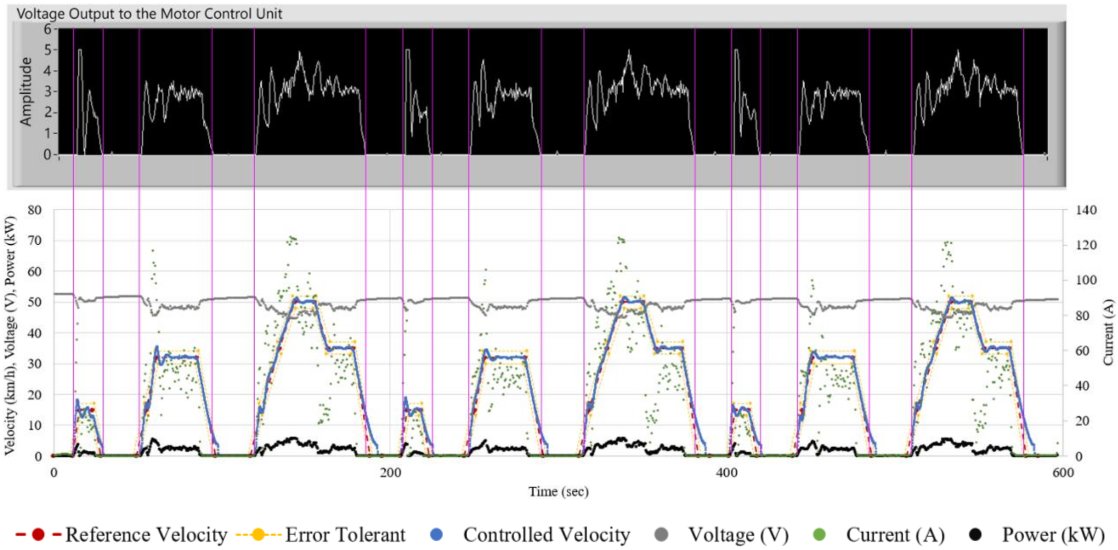
2.3 Experimental setup

For the performance characteristics analysis, the electric car was tested on a chassis dynamometer with urban cycle under the UNECE R101 regulation as explained above. The experiment consists of 2 modes of testing, which were 1) twice run of the cycle made of five elementary urban cycles (Annex 7), and 2) driving continuously urban cycle until the electric car unable to meet the target speed up to 50 km/h (Annex 9).

In the experiment, to control the velocity of the electric car followed the velocity profile as shown in Fig. 4 by human with many cycles is seem to be impossible. To control the speed of a test car accurately within the limited error tolerance band and approach the target speed as close as possible. It is better to do that by programmed robot instead of human [9]. Therefore, the National Instrument USB-6008 Data Acquisition Card was applied for controlling the acceleration and speed of the car by sending signals to a motor controller unit instead of pressing the accelerator pedal by human. It was programmed according to the urban cycle profile of driving cycle using feedback signal from the speed sensor. While testing, the driving distance and velocity were recording by the chassis dynamometer software. The electric energy consumption and various electric data of the electric car were recorded by Fluke 435 Series II power analyzer.



(a) a car powered by lithium-iron phosphate battery.



(b) a car powered by deep cycle lead-acid battery.

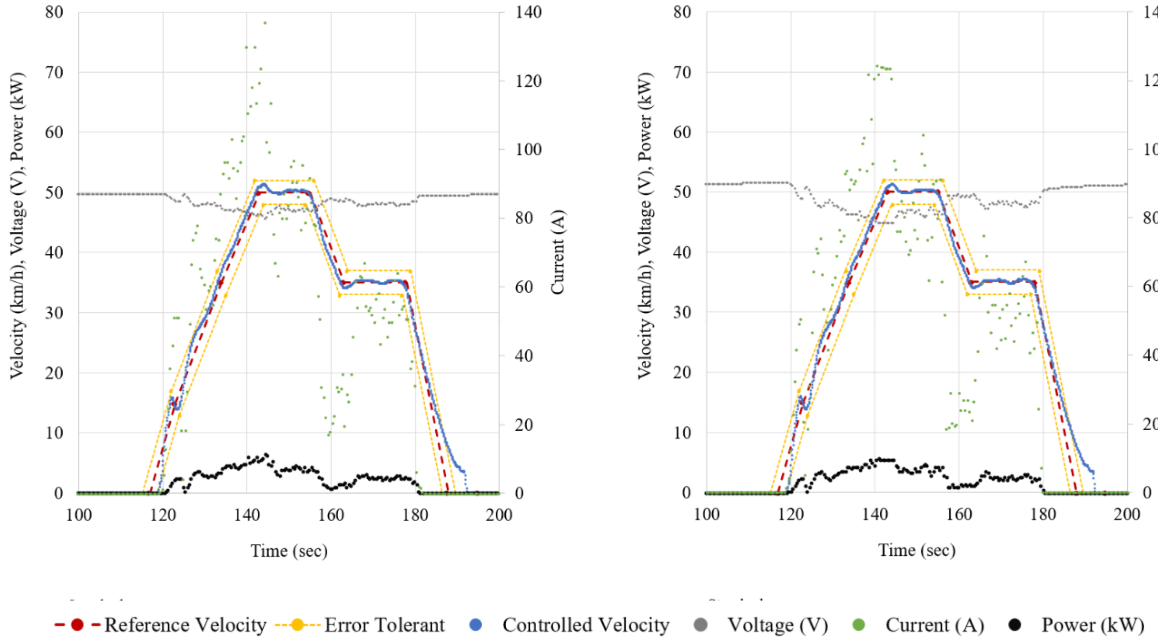
Fig. 7. Results of urban cycle testing.

3. Results and Discussion

The experimental works with an electric car were carried out on a chassis dynamometer instead of running on a real road. Because the testing condition is needed to be controlled. The results of each testing and analysis are shown as follows.

3.1 Results for speed control upon the driving cycle

For the testing of electric car under urban cycle of driving, the speed of the car has to be aligned with the standard speed profile as shown in Fig. 4. To control speed of the car the car precisely, the National Instrument USB-6008 data acquisition card has been used for controlling the speed pedal instead of pushing by human force. The two types of batteries, lithium-iron phosphate and deep cycle lead-acid batteries were used, and compared the different results between them. In this testing we have focused on how each battery type responds to the reference velocity profile of the car, and how each battery discharge electric current to the system. The results are shown in Fig. 7 as follows.



(a) (b)

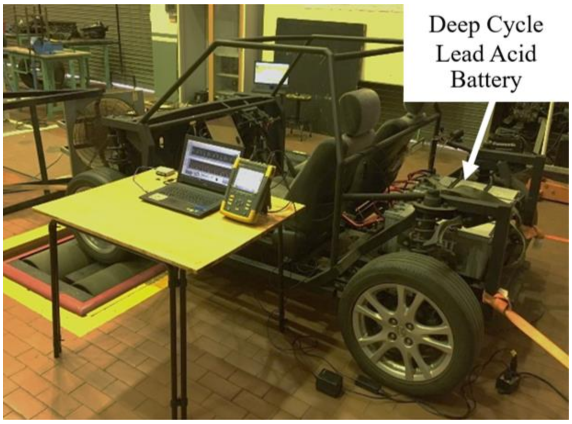
Fig. 8. Comparison results of urban cycle testing, (a) a car powered by lithium-iron phosphate battery, and (b) a car powered by deep cycle lead-acid battery.

Considering the results in Fig. 7 both (a) and (b), before the driving test has started, both types of batteries were fully charged followed the reference procedure [12]. In case of speed or velocity in overview, both lithium-iron phosphate battery and deep cycle lead-acid battery could supply adequately electric power for the car to run followed the reference velocity profile within 2% of error tolerant well.

From Fig. 8, show the close-up data for comparing the results of urban cycle testing. The electric voltage of lithium-iron phosphate battery when has fully charged will be around 50.4 V, for deep cycle lead-acid battery will be around 52.0 – 52.6 V. However, when the car requires high electric power to approach the target speed, the lithium-iron phosphate battery could discharge electric voltage (V) higher than the deep cycle lead-acid battery. It was the same way when looking at the electric current. It is obviously that the peak electric current (A) supplied by lithium-iron phosphate battery was higher than that of supplied by deep cycle lead-acid battery. This could reflect that the lithium-iron phosphate battery should be better responded to the acceleration and speed control than the deep cycle lead-acid battery one. In the same way, if consider the voltage output from NI DAQ device which is the input parameter to the motor control unit, see Fig. 7., the higher voltage represents the higher acceleration rate needed to reach the target velocity. So, it could be implied that if the driver gave the same acceleration input, the car powered by lithium-iron phosphate battery could give a better respond to the driver than the car powered by the deep cycle lead-acid battery.

From these results when compared together at the same battery capacity. It can be short concluded that lithium-iron phosphate battery has more advantage than deep cycle lead-acid battery, especially acceleration response of the vehicle.

(a) a car powered by lithium-iron phosphate battery



(b) a car powered by deep cycle lead-acid battery

Fig. 9. Experimental setup on a chassis dynamometer.

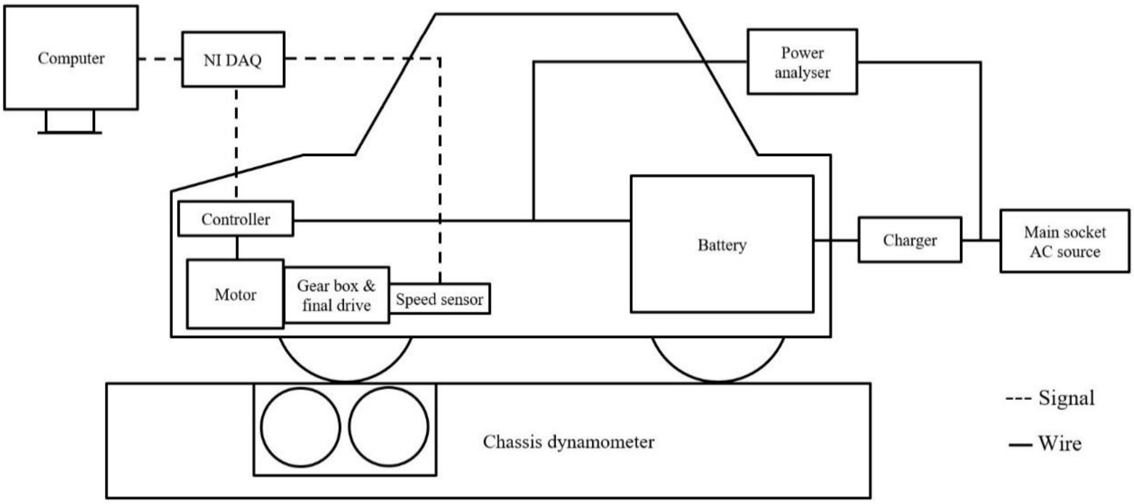


Fig. 10. Experimental setup diagram.

3.2 Results for energy consumption

In this section, the tests were performed in accordance with the procedure described in Annex 7 to UN-ECE Regulations 101 [12]. The electric car was tested on a chassis dynamometer by driving twice of the cycle which made of five elementary urban cycles as shown in Fig. 9. After that, the battery having been charged according to the charging criteria. Meanwhile, the battery charging energy consumptions were recorded. The results are shown in Table 3 as follows.

Table 3: Results for energy consumption when the car powered by lithium-iron phosphate battery and by deep cycle lead-acid battery.

	Lithium-iron phosphate battery			Deep cycle lead – acid battery		
No. Test	Electric energy charging (Wh)	Energy consumption (Wh/km)	Charging time (min)	Electric energy charging (Wh)	Energy consumption (Wh/km)	Charging time (min)
Run 1	882	86.73	48	1001	98.43	143
Run 2	912	89.68	52	1005	98.82	136
Run 3	869	85.45	51	939	92.33	125
Average	887.67	87.28	50.33	981.67	96.53	134.67

The results in the Table 3 show the average energy consumption of the electric car when powered by lithium-iron phosphate battery and when powered by deep cycle lead-acid battery, there were 87.28 Wh/km and 96.53 Wh/km, respectively. It is obviously that lithium-iron phosphate battery has lower energy consumption than deep cycle lead-acid battery of about 10.6%. Iclodean1, C. et. al. [5] also found different energy consumption when the electric car using different battery types. In this referred case, four different battery types have also different battery mass varied 173 kg to 534 kg. And the results were carried out by performing AVL simulation (Virtual road simulation). However, the different energy consumption was not varied according to the battery mass. Therefore, the mass of battery might not be the main impact to the energy consumption. As our result, the car was tested on a chassis dynamometer, and battery pack was placed at the rear while the car is a front-wheel drive type, see Fig. 9 and 10. Therefore, the different battery mass in this work might not be the cause of different energy consumption. But, if considering the time spent for battery charging, the lithium-iron phosphate battery took just about 50 minutes for fully charged, while the deep cycle lead-acid battery took about 135 minutes. With the lithium-ion phosphate battery, charging is much faster than the deep cycle lead-acid battery. Considering together with the experimental setup diagram in Fig. 10, the amount of electric energy charged to the batteries was measured before flowing through the charger. Therefore, the efficiency of charger, and charge/discharge characteristics of batteries might affect the total energy consumption as well. For example, the longer charging time could mean to larger energy loss at the charging devices as heat loss, as the general losses in operation of a transformer. However, these assumptions should be confirmed by conducting an experiment.

3.3 Results of electric range

After battery having been charged according to overnight charge procedure until the end of charge criteria. The tests were performed in accordance with the procedure described in Annex 9 to UN-ECE Regulations 101. The electric car was tested on a chassis dynamometer by driving continuously urban cycle until the electric car unable to meet the target speed up to 50 km/h. Noted that, both lithium-iron phosphate battery and deep cycle lead-acid battery have the same capacity, 48V 120Ah.

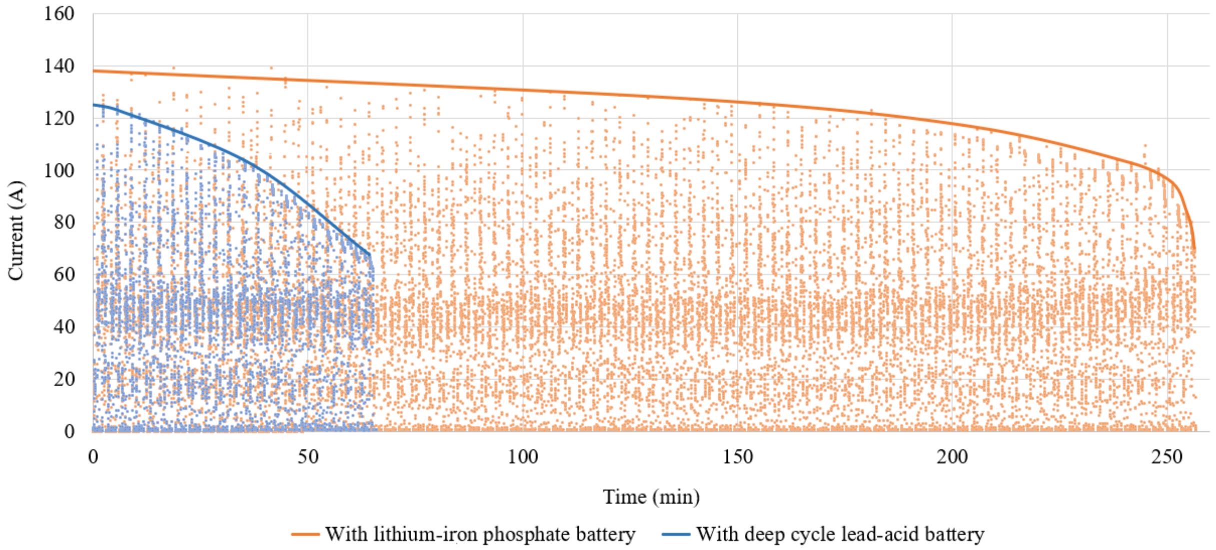


Fig. 11. Comparison of the current drop while tested electric range.

Table 4: Results of electric range test.

No. Test	Lithium-iron phosphate battery		Deep cycle lead - acid battery	
	Cycle	Cover distance (km)	Cycle	Cover distance (km)
Run 1	76	80.46	15	15.26
Run 2	77	81.75	16	16.88
Run 3	79	83.89	14	14.83
Average	-	82.04	-	15.66

The results shown in Table 4, when testing with the deep cycle lead-acid battery. After approximately 15 urban cycles, the car could not reach the target velocity due to the battery could not supply sufficient electric power. So, the average cover distance was 15.66 km as its electric range. While the lithium-iron phosphate battery could supply sufficient electric power continuously until 77 cycles. The average cover distance was 82.04 km as its electric range. See also the results of current dropped while the electric car was running, between lithium-iron phosphate battery and deep cycle lead-acid battery in Fig. 11. It is largely different between them; the electric current of deep cycle lead-acid battery was dropped so quick. This is the specific characteristic of lead-acid battery based that the users should be known. The usable capacity of battery will be dropped quite large from the nominal capacity according to the discharge current, the larger discharge current will be resulted in smaller battery capacity [13]. While the lithium-iron phosphate battery has not much usable capacity dropped although operating at large discharge current [14, 15].

4. CONCLUSION

In general, when think about batteries, it has been known that the lithium-based battery should be performed better than lead-acid based battery. But, how different in details are not known very well. Furthermore, the gap of price difference always made users hesitate about battery selection. In this research, the results showed that the electric car when using lithium-ion phosphate battery could respond to meet the velocity curve profile of urban cycle better than when using deep cycle lead-acid battery. The electric energy consumption when using lithium-ion phosphate battery was lower than when using deep cycle lead-acid battery approximately 10%. And surprisingly that the electric range of the electric car when using deep cycle lead-acid battery was very short when compared with the lithium-iron phosphate battery one, 15.66 km for deep cycle lead-acid battery, and 82.04 km for lithium-iron phosphate battery. These quantitative results would be the helpful information for the users as mentioned above. However, these results are just made the experiments on a chassis dynamometer. And the running of the test car only performed based on urban cycle of the New European Driving Cycle (NEDC) [12]. Further experiments and investigations in other aspect and criteria should be performed and discussed later, such as investment and value.

NOMENCLATURE

C energy consumption, Wh/km
D_{test} distance covered during the test, m
E electric energy, Wh

REFERENCES

[1] Hannappel, R. The impact of global warning on the automotive industry, AIP Conference Proceedings, Vol. 1871, 2017, pp. 1-6.
[2] King Mongkut's University of Technology Thonburi. Electric vehicle technology and innovation research report, 2017, KMUTT, Bangkok.
[3] Laoonual, Y. Assessment of electric vehicle technology development and its implication in Thailand, Research report, 2013, King Mongkut's University of Technology Thonburi and National Metal and Materials Technology Center, Bangkok.
[4] Siphakhakon, A. and Techakittiroj, K. Electric vehicles: principle and design, 2013, Chulalongkorn University Printery, Bangkok.
[5] Iclodean1, C., Varga, B., Burnete, N., Cimerdean, D., Jurchiș, B. Comparison of different battery types for electric vehicles, IOP Conf. Ser.: Mater. Sci Eng. Vol. 252, 2017, pp. 1-8.
[6] Gis, W., Zółtowski, A., Bochenska, A. Testing of electric vehicle in driving cycles, Journal of KONES Powertrain and Transport, Vol. 19(4), 2012, pp. 1-15.
[7] Goethem, S.V., Koornneef, G., Spronkmans, S. Performance of battery electric buses in practice: energy consumption and range, TNO Innovation for life, 2013, pp. 1-25.
[8] Miri, I., Fotouhi, A., Ewin, N. Electric vehicle energy consumption modelling and estimation – A case study, International Journal of Energy Research, Vol. 45(1), 2021, pp. 501-520.
[9] Mizutani, N., Matsui, H., Yano, K., Takahashi, T. Vehicle speed control by a robotic driver considering vehicle dynamics for continuously variable transmissions, Journal of Robotics and Mechatronics, Vol. 30, 2018, pp. 300-310.

[10] Braun. A. and Rid, W. Energy consumption of an electric and an internal combustion passenger car. A comparative case study from real world data on the Erfurt circuit in Germany, Transportation Research Procedia, Vol. 27, 2017, pp. 468-475.
[11] Chłopek, Z., Lasocki, J., Wójcik, P., Badyda, A.J. Experimental investigation and comparison of energy consumption of electric and conventional vehicles due to the driving pattern, International Journal of Green energy, Vol. 15, 2018, pp. 773-779.
[12] United Nations, Regulation No. 101, Agreement, 2013, United Nations, Geneva.
[13] Kung Long Batteries Industrial. Sealed Lead-Acid Batteries Technical Manual, Taiwan, URL: https://www.master-instruments.com.au/files/knowledge-centre/manufacturers-data/sla_batteries_technical_manual_ed2_1_.pdf, accessed on 04/02/2021.
[14] Carrilero, I., Alonso, J., Pereirinha, P.G., Anseán, D., Viera, J.C., González, M., Lithium Iron Phosphate and Lithium Titanate Oxide cell performance under high power requirements of electric bus applications, paper presented in 2018 IEEE Vehicle Power and Propulsion Conference (VPPC), 2018, Chicago, USA.
[15] AIMScorp. LiFePO4 Instruction Manual, Nevada, URL: https://invertersrus.com/wp-content/uploads/2018/12/Aims-LiFePO4-Lithium-Battery-Manual.pdf, accessed on 04/02/2021.