Oral Presentation

The 7th TSME International Conference on Mechanical Engineering
13-16 December 2016

AME0020

Performance Improvement of Existing Electric Motorcycles in Thailand by Modifying Battery from Lead Acid Battery to Li-ion Battery

Ratanarodcharoen. S[1], Ruangjirakit. K[1,*], Kaewtatip. P[1], Laoonual. Y[1], Tangamchit. P[2], and Limthongkul. P[3]

[1] Department of Mechanical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi, 126 Pracha-uthit Rd., Bang Mod, Thungkhru, Bangkok, 10140, Thailand
[2] Department of Control System & Instrumentation Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi,
126 Pracha-uthit Rd., Bang Mod, Thungkhru, Bangkok, 10140, Thailand
[3] National Metal and Materials Technology Center (MTEC)
114 Thailand Science Park (TSP), Phahonyothin Rd., KhlongNueng, KhlongLuang, PathumThani, 12120, Thailand
[*] Corresponding Author: kitchanon.rua@gmail.com, +66 (0) 95 801 9797, 66 (0) 2470 9111

Abstract

This research aims to study causes of electric motorcycles (e-MCs) are not popular in Thailand and feasibility of improvement performances of e-MCs in order to promote e-MCs are popular in Thailand. Changing battery type is one method to investigate these causes. Li-ion batteries are acquired based on some criteria to evaluate its charging/discharging characteristics and compare with those of lead acid battery. As battery characteristic data from experiment, Li-ion battery has specific energy more than lead acid battery and it can spend charging time less than that. On behalf of e-MCs, it, which equipped Li-ion battery, has more driving range and less charging time when compare with those of which equipped lead acid battery, as data from experiment in laboratory. However, batteries for e-MCs are necessary to manage and control by an efficient battery management system (BMS) to prolong its lifetime and avoid to be damaged.

Keywords: Battery management system, Electric motorcycles, Lead acid battery, Li-ion battery.

1. Introduction

Currently, there are many countries have focused on a high level of carbon dioxide (CO2) emission problem. The International Energy Agency (IEA) has studied the problem and proposed an IEA 2014 plan, which has one target to reduce an energy intensity (EI) from transportation sector by 22 percent in 2020 compared with that in 2009 by improving fuel economy, using electric vehicles, and using biofuels for transportation [1].

In case of Thailand, according to collection data about energy consumption of the Ministry of Energy , Thailand (MOE), the final energy consumption is about 100,000 kilotons of energy (ktoe) in 2016 and it has been forecasted that it would continuously increase to 187,142 ktoe in 2036 based on business as usual case (BAU case) as shown in Fig. 1 [2]. The MOE has studied this problem and proposed the Energy Efficiency Development Plan 2015 (EEDP 2015) which has a target to reduce the EI from all sectors by 30 percent in 2036 compared with that in 2010. Transport sector was expected that it would decrease the most EI by 58 percent of all expected reduction as shown in Table. 1 [3]. According to one target of EEDP 2011, it has planned to reduce EI form transportation sector by an increase the number of registered e-MCs to be 70 percent of the total number of registered motorcycles in Thailand [4].

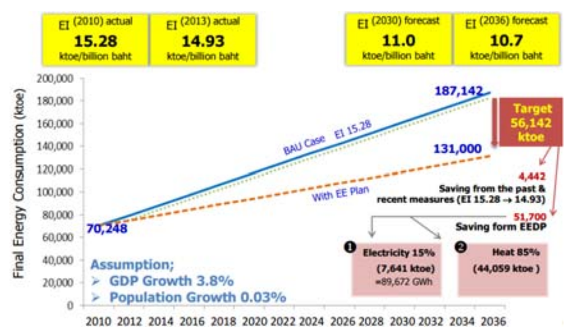

Fig. 1 Energy consumption in the past and future demand trend of BAU case against with that of EE plan case [2]

Table.1 Expected reduction energy consumption by sectors [2]

	Expected Enegy Saving by Economic sector	Total (ktoe)	Total (%)
EE1	Enforcement of energy conservation standard in designated factory/building	5,156	10%
EE2	Building Energy Code (BEC) for the new buildings	1,166	2%
EE3	Energy Labeling (HEPs & MEPs)	4,149	8%
EE4	Energy Efficiency Resource Standard (EERS) for large energy producers and distributors	9,524	18%
EE5	Financial Incentives and support for energy performance achievement	991	2%
EE6	Promoting greater use of LED	500	1%
EE7	Energy saving measures in transport sector	30,213	58%
	Total (ktoe)	51,700	100%

2. Current status and performances of existing electric motorcycles in Thailand

According to registered vehicle statistics of the department of land transport [5], motorcycle is the most used vehicle in Thailand, which has more over 20 million units or 55 percent of all registered vehicles as shown in Fig. 2. However, the current actual proportion of e-MCs was less than 0.01 percent of all registered motorcycles in 2016 and its number decreases every year. According to data obtained from research title "Evaluation of Electric Motorcycle Driving Behaviors Comparing with Conventional Engine Motorcycle in Thailand" [6] and focus group meetings, the main reasons that e-MCs are not popular in Thailand are Thai people have anxiety about driving range per charging less than user's expectation, long battery charging time, and maximum speed less than user's satisfaction.

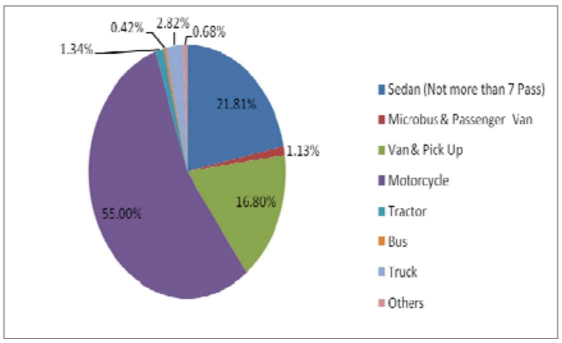

Fig. 2 Proportion of all registered vehicles in Thailand as September 2016 [5]

For improvement performances of e-MCs as the aims of research, it can be noticed that battery related to first two reasons. If battery can be improved, Thai people will use e-MCs instead of conventional motorcycle. As Pike Research, (2012), most e-MCs equip lead acid battery even e-MCs in Thailand and small portion equipped is Li-ion battery [7]. Therefore, changing battery type from lead acid to Li-ion is one method to deal with problems. For third reason, according to rider's riding behavior, when they ride conventional motorcycle, they usually drive at high speed but most e-MCs have maximum speed less than conventional motorcycle. In order to let e-MCs become popular in Thailand, unless driving range per charging and battery charging time, maximum speed also should be improved. Improving performances e-MCs does not achieve only user's expectation and satisfaction but it also meets registration regulation in Thailand, which is mentioned later.

2.1 Experimental performances of existing electric motorcycle in Thailand

An EVT model Viz is chosen as a studied e-MC in this research. It equips motor power 1.5 kW, five packs of 12V 20Ah lead acid battery and it can drive 60 km per charging and accelerate speed to 60 km/hr as advertised by supplier. The EVT-Viz will be evaluated driving range per charging and maximum speed. Tests are performed on chassis dynamometer based on two driving modes: NEDC (only urban mode, UDC, as shown in Fig. 3) [8] and maximum speed mode. For test preparation according to TIS 2350-2551 (2008) (Thai): Motorcycles: safety requirements; emission from engine, level 6 [9], firstly, the EVT-Viz has to weigh. Then set aero dynamics drag force, rolling resistances, and wind resistance as same as real driving condition. Third step, install two ETAS ES411 modules with batteries for obtaining energy consumption data of the EVT-Viz while testing as shown in Fig. 4. Finally, Fix the EVT-Viz on rollers of chassis dynamometer as shown in Fig. 5.

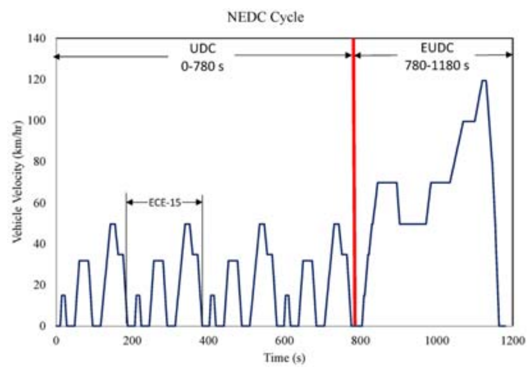

Fig. 3 Characteristics of NEDC

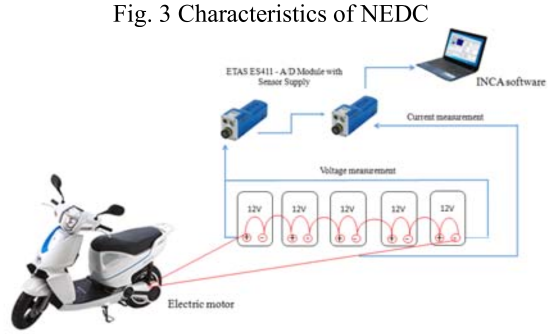

Fig. 4 Installation of ETAS ES411 modules on EVT-Viz

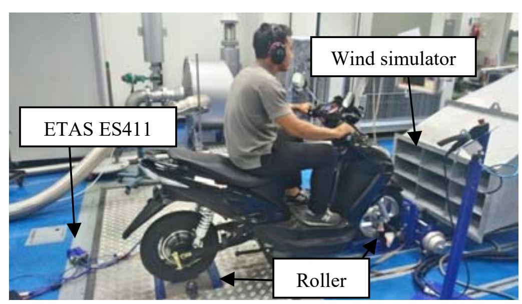

Fig. 5 Experimental setup electric motorcycle on roller of chassis dynamometer

As data obtained from test as shown in Fig. 6 and Fig. 7, driving range per charge of the EVT-Viz based on NEDC mode is 26.6 km. While maximum speed of the EVT-Viz starts to decrease until less than 45 km/hr since testing time is 4,800 seconds or 1.33 hours. On that time, it can drive 23.29 km. However, test based on maximum speed mode, a maximum speed of the

EVT-Viz is 52.71 km/hr and it can drive at maximum speed for 1,000 seconds or 0.28 hour then maximum speed decreases until less than 45 km/hr.

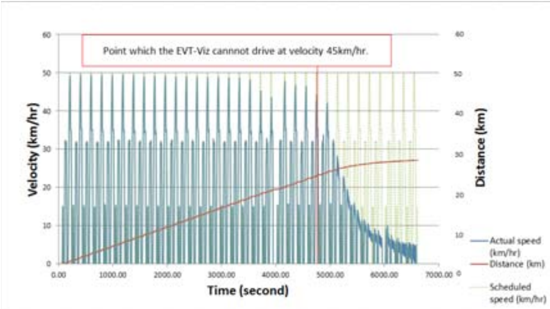

Fig. 6 Speed and distance of the EVT-Viz versus test times based on NEDC driving mode

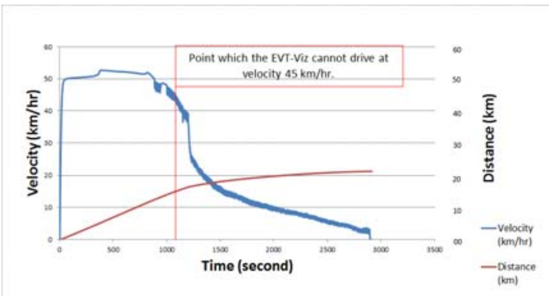

Fig. 7 Speed and distance of the EVT-Viz versus times based on maximum speed driving mode

2.2 Registration regulation in Thailand

According to the registration regulation proposed by Department of Land Transport, Thailand, e-MCs that can register in Thailand must to have electric motor that has power exceed 500 Watts and maximum speed does not less than 45 km/hr [10]. According to experimental performances from previous chapter and power of electric motor of EVT-Viz, it can be noticed that it can be registered in Thailand.

However, users still have anxiety about its driving range because it have less driving range per charging than theirs expectation and conventional motorcycle and battery charging time about 7-8 hours. Therefore, in order to promote e-MC in Thailand, it is necessary to improve its driving range and charging time. There are many methods to investigate with these problems, but this research will changing battery type from lead acid battery to Li-ion battery.

3. Feasibility of performance improvement of existing electric motorcycle based on user's anxiety and registration regulation in Thailand

Since users have the anxieties about driving range of existing e-MCs in Thailand and battery charging time, changing battery type is one method that used to investigate those problems. As analysis the studied e-MC, currently used battery is VRLA battery, model DJW12-20. It has specification. This research will evaluate characteristics of current battery at room temperature and acquire new Li-ion batteries, which have higher performances than current battery.

3.1 Experimental characteristics of lead acid battery

Currently used battery was evaluated its capacity and charging/discharging time at different charging/discharging rates by the MACCOR Series 4000, which can provide the high level of accuracy and time resolution [11]. Two characteristics are evaluated because battery's capacity and charging/discharging time are related to driving range and battery charging time. The current battery will be performed tests on four test conditions as shown in Table. 2.

Step for battery testing, firstly, wires for voltage and current measurement have to connect between battery and the MACCOR series 4000. Then program all parameters for tests into MACCOR software according to four test conditions.

Table. 2 Four test conditions

		Charging rate	Discharging rate
Capacity testing	Recommended rate	0.10C	0.10C
	Usage condition	0.15C	1.00C
Charging rate testing		0.20C	0.10C
		0.50C	0.10C
		1.00C	0.10C
		2.00C	0.10C
		3.00C	0.10C
Discharging rate testing		0.10C	0.20C
		0.10C	0.50C
		0.10C	1.00C
		0.10C	2.00C
		0.10C	3.00C

Analysis in this research will not analyze battery characteristics in constant voltage step because in order to improve battery charging time, fast charging is necessary. Fast charging is only applied in first charge phase (constant current step) [12] so this research will analyze only constant current step. According to testing data as shown in Fig. 8 - 9, the currently used battery has capacity 13.14Ah or 65.7% of rated capacity (20Ah), not including capacity when float charging, which specified by supplier, when charging at recommended, while it spends charging time 6 hours 34 minutes. For charging at usage condition, it has capacity only 13.64Ah or 68.2% of 20Ah and it spends charging time 4 hours 33 minutes. Additional, its capacity decreases when charging at rates higher than usage condition rate, although charging time also decreases. As experimental data, it can be noticed that current lead acid battery cannot apply fast charging because its capacity does not reach 70%SOC whether charging at any rates [12].

On behalf of discharging characteristics as shown in Fig. 10 - 11, as discharging at the slowest rate (0.1C), it has capacity only 15.57Ah or 77.9% of 20Ah. As same as charging behavior, its capacity and discharging time decreases when discharging at rates higher than 0.1C such as discharging at 1.0C, it has capacity only 10.47Ah or 52.4% of 20Ah and discharging time is only 32 minutes.

AME0020

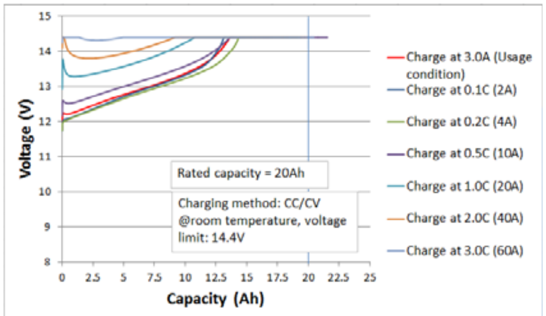

Fig. 8 Capacity of lead acid battery when charging at different rates

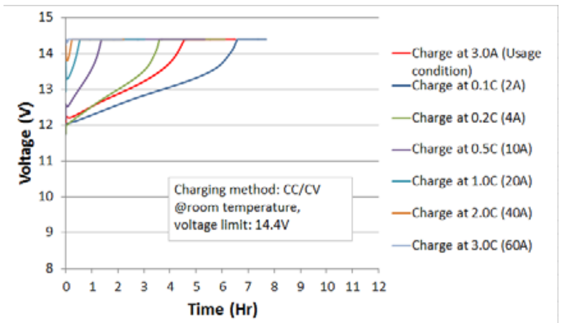

Fig. 9 Charging time of lead acid battery at different rates

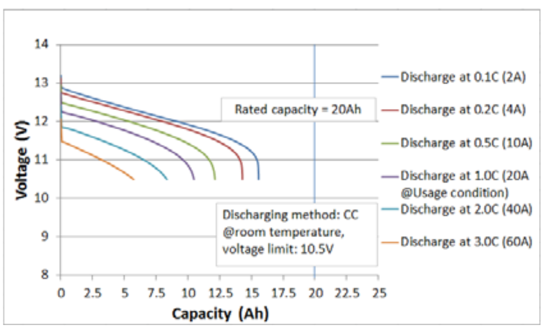

Fig. 10 Capacity of lead acid battery when discharging at different rates

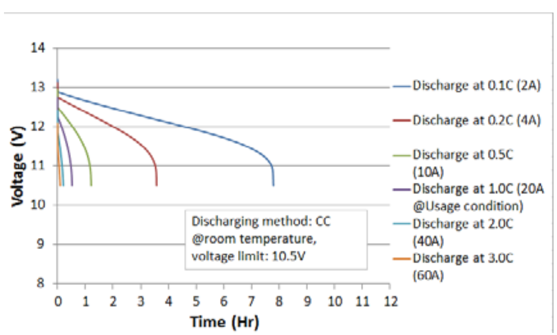

Fig. 11 Discharging time of lead acid battery at different rates

As all experimental data are summarized, current lead acid battery has capacity lower than specification. Moreover, its capacity also decreases less and less when charging at higher rates, although charging time will reduce when charging at higher rate. However, current lead acid battery is not suitable for e-MCs in future because it cannot apply fast charging in order to improve battery charging time purpose. Therefore, changing battery type from lead acid battery to Li-ion battery is necessary.

3.2 Acquiring Li-ion batteries

Many e-MCs have equipped Li-ion battery instead of lead acid battery in worldwide [7] because Li-ion battery has advantages more than lead acid battery and others, although cost is higher [13]. However, price of Li-ion battery has projected decline in the future [14].

Acquiring Li-ion battery in this research aims to improve performances of e-MCs so, Li-ion battery is acquired will have performances and advantages more than current lead acid battery. Thus, criteria are necessary to set for selection Li-ion battery for improvement purpose as shown in Table.3

Table. 3 Criteria for Li-ion battery selection

Items	Criteria	Current used battery	Criteria for selection Li-ion batteries
1	Space (W x L x H)	Can fit the existing space	Can fit the existing space
2	Total voltage	60 V	60 V ± 6 V
3	Total capacity	20 Ah	More than 20 Ah
4	Total weight	30 kg	Less than 30 kg
5	Charging rate	0.15C at current condition	Can be charged at rate more than 0.15C
6	Discharging rate	1.00C at current condition	Can be discharged at rate more than 1.0C
7	cycle life	About 750 times	More than 750 times

There are 10 Li-ion batteries are observed However, only four Li-ion batteries (in black box) meet the criteria as shown in Table. 4. However, acquiring just for evaluation performances and behavior of Li-ion battery thus, battery will be purchased one pack per brand. Because of business problems, there is only AA power portable corp that can be purchased.

AME0020

Table. 4 Li-ion batteries are observed and which meet criteria

No.	Specification data		Current lead acid battery	AA power portable corp	Powerstream	GBS	Lishen	Vpower	AA power portable corp	Topband	NEC	Topband	AA power portable corp
1	Battery type		Lead acid	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion	Li-ion
2	No. unit can be fitted in existing space		5 packs	5 packs	5 packs	19 cells	19 cells	2 packs	5 packs	5 packs	8 packs	14 cells	24 cells
3	Total voltage		60.0 V	64.0 V	64.0 V	60.8 V	60.8 V	72.0 V	64.0 V	64.0 V	66.0 V	44.8 V	60.0 V
4	Total capacity		20 Ah	20 Ah	22 Ah	20 Ah	20 Ah	30 Ah	25 Ah	25 Ah	5 Ah	30 Ah	10 Ah
5	Total energy		1200 Wh	1280 Wh	1408 Wh	1216 Wh	1216 Wh	2160 Wh	1600 Wh	1600 Wh	330 Wh	1344 Wh	600 Wh
6	Total weight		30.0 kg	15.0 kg	13.8 kg	13.3 kg	13.0 kg	18.0 kg	15.25 kg	13.0 kg	4.57 kg	15.4 hg	7.4 kg
7	Total specific energy		40.0 Wh/kg	85.3 Wh/kg	102.0 Wh/kg	91.4 Wh/kg	93.5 Wh/kg	120 Wh/kg	105.0 Wh/kg	123.1 Wh/kg	72.2 Wh/kg	87.3 Wh/kg	81.1 Wh/kg
8	Charging current rate	Normal continuous	0.15C	1.00C	0.18C	0.50C	0.30C	N/A	N/A	N/A	2.00C	N/A	N/A
		Maximum continuous	N/A	3.00C	0.90C	N/A	3.00C	N/A	0.50C	N/A	4.60C	0.50C	0.50C
9	Discharging current rate	Normal continuous	1.00C	N/A	0.45C	0.50C	0.30C	N/A	N/A	N/A	N/A	N/A	N/A
		Maximum continuous	N/A	2.00C	1.80C	3.00C	6.00C	1.30C	2.00C	N/A	4.60C	5.00C	2.00C
		Maximum pulse	N/A	10.0C <10s	4.50C @30s	N/A	8.00C @30s	N/A	N/A	N/A	5.40C @1s	8.00C	N/A
10	cycle life		>750 times	>1000 times	>1200 times	1500 times	2500 times	>500 times	1000 times @0.20C	N/A	7500 times @0.80C	2000 times	1000 times @0.20C

Note: 1. Red sign is represented characteristic does not meet criteria.
2. Blue sign is represented characteristic is not given by supplier.

3.3 Experimental characteristics of Li-ion batteries

Li-ion battery that be purchased will be evaluated its capacity and charging/discharging time based on four testing conditions and steps as same as tests of current lead acid battery.

As testing result as shown in Fig. 12, Li-ion battery has capacity 21.42Ah or 107.1% of rated capacity (20Ah), which is 157% more than that of current lead acid battery when charging at usage condition. Moreover, its capacity does not significantly decreases when charging at higher or lower rates. As Fig. 13, Li-ion battery can fully charge in 19 only minutes and about 14 minutes for 70%SOC (fast charging), if power supply has enough power output (charging at 3.00C)

On behalf discharging behavior, as experimental data has shown in Fig. 14 – 15, Li-ion battery has capacity 21.57Ah or 107.9% of 20Ah, which is 138.5% more than that of current lead acid battery when discharging at the slowest rate and its capacity still remains capacity whether discharging at higher or lower rates. For discharging time, it can discharge in about an hour that more than two times of that of lead acid battery at 1.0C.

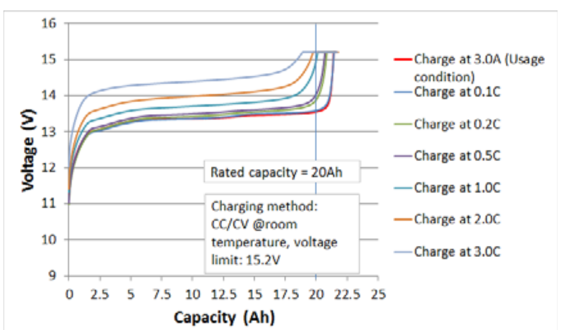

Fig. 12 Capacity of Li-ion battery when charging at different rates

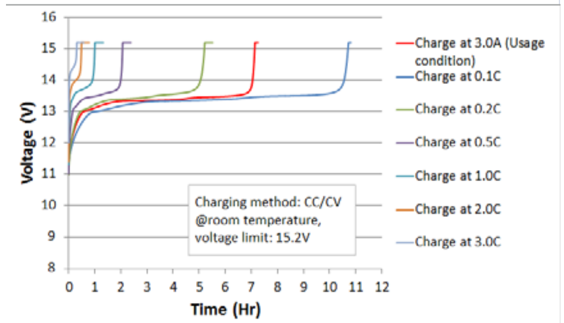

Fig. 13 Charging time of Li-ion battery at different rates

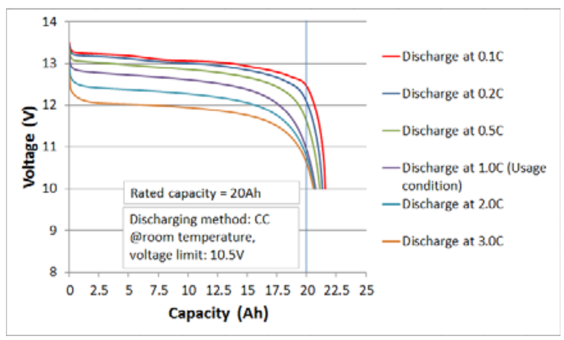

Fig. 14 Capacity of Li-ion battery when discharging at different rates

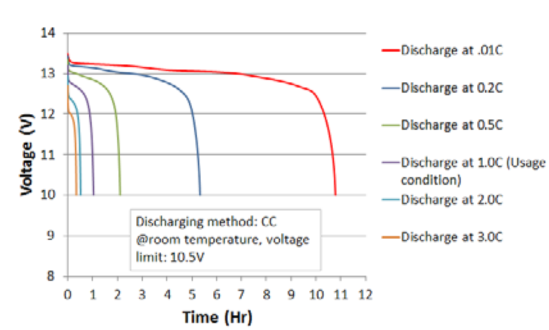

Fig. 15 Discharging time of Li-ion battery at different rates

According to all results of Li-ion battery testing, Li-ion battery has capacity more than that of current lead acid battery both charging and discharging. Moreover, Li-ion battery can spend charging time only 19 minutes, if have enough power supply (60 Amperes). For discharging time, it is also more than that of current lead acid battery by 50% even it is discharging at any rates (0.1C to 3.0C).

3.4 Experimental performances of existing electric motorcycle which equipped Li-ion batteries

In Thailand market, there is one e-MC that equipped Li-ion battery and electric motor, has specifications as shown in Table. 5.

Table. 5 Specification of Toyotron model TX-1. Source from www.toyotron.com

Specification	
Motor power	3000 Watts
Battery type	60V 36Ah Li-ion battery
Maximum speed	50 – 60 km/hr
Maximum range	45 – 60 km

Performance of TX-1 was obtained from testing that performed based on condition as same as that of testing in section 2.1. As Fig. 16 – 17, TX-1 has driving range little more than 80 km per one charging when testing on NEDC mode and maximum speed is about 60 km/hr when testing on maximum speed mode.

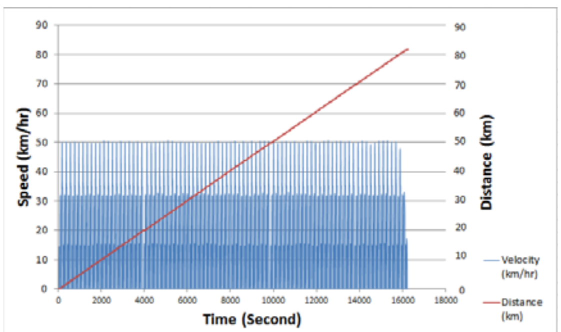

Fig. 16 Speed and distance of the TX-1 versus test times based on NEDC driving mode

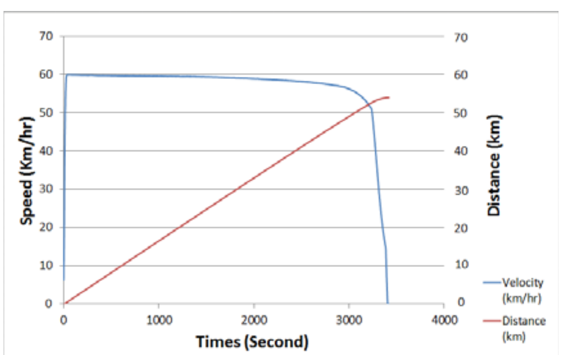

Fig. 17 Speed and distance of the TX-1 versus test times based on maximum driving mode

4. Conclusion

Most existing e-MCs in Thailand have three main problems: less driving range, long battery charging time, and limited maximum speed. Changing battery type of e-MCs from lead acid battery to Li-ion battery is one method to deal the problems. As test performances of e-MCs based on NEDC (only urban mode), e-MCs equipped Li-ion battery has driving range more than that of which equipped lead acid battery and it spends battery charging time less than that according to battery characteristic evaluation. However, it is well known that battery is very important for e-MCs so it should be handled as well. Design an efficient battery management system (BMS) is one way for handling battery. It will make battery prolongs lifetime and avoid battery to be damaged from overcharging.

5. References

[1] IEA, *Energy Technology Perspectives 2012 Pathways to a Clean Energy System,* p. 63 (2012)

[2] The ministry of energy of Thailand, *Thailand Energy Efficiency Development Plan (2015 - 2036),* p. 6 (2015)

[3] The ministry of energy of Thailand, *Thailand Energy Efficiency Development Plan (2015 - 2036),* p. 10 (2015)

[4] The ministry of energy of Thailand, *Thailand Energy Efficiency Development Plan (2011 - 2030),* p. 28-29 (2011)

[5] The department of Land, Transport Statistics Sub-Division, Transport Planning Division, *Registered vehicles by fuels,* URL: http://apps.dlt.go.th/statistics_web/fuel.html, accessed on 28 August 2016

[6] Trinurak P. (2016). Evaluation of Electric Motorcycle Driving Behaviors Comparing with Conventional Engine Motorcycle in Thailand, paper presented in *EVteC & APE Japan 2016,* Yokohama, Japan.

[7] Pike Research. (2012), *Electric Motorcycles and Scooters: Market Drivers and Barriers, Government Policies, Technology Issues, Key Industry Players, and Global Demand Forecast,.* URL: http://www.navigantresearch.com/wp-assets/uploads/2012/12/EMOT-12-Executive-Summary.pdf, accessed on 28 August 2016

[8] dieselnet.com, *Emission Test Cycles ECE 15 + EUDC/NEDC,*URL; https://www.dieselnet.com/standards/cycles/ece_eudc.php, accessed on 15 October 2016

[9] Thai Industrial Standards Institute (TISI), *TIS 2350-2551 (2008) (Thai): Motorcycles: safety requirements; emission from engine, level 6.* URL: https://law.resource.org/pub/th/ibr/th.cs.2350.t.2551.pdf, accessed on 18 October 2016

[10] Department of land transport, *Rules how to inspect the car. And ACTION The establishment of licensed vehicle inspectors. 2555,* URL: http://www.ratchakitcha.soc.go.th/DATA/PDF/2555/E/175/10.PDF, accessed on 19 October 2016

[11] MACCOR, Inc, *Series 4000 Automated Test System,* URL: http://www.maccor.com/ProductDocs/Data%20Sheet%20for%20Series%204000%20Test%20System.pdf, accessed on 19 October 2016

[12] BATTERY UNIVERSITY, *BU-401a: Fast and Ultra-fast Chargers,* URL:

AME0020

http://batteryuniversity.com/learn/article/ultra_fast_chargers, accessed on 20 October 2016

[13] BATTERY UNIVERSITY, *BU-107: Comparison Table of Secondary Batteries*, URL: http://batteryuniversity.com/learn/article/secondary_batteries, accessed on 27 October 2016

[14] INSG Insight, *The Global E-bike Market 2014*, URL: http://www.insg.org/%5Cdocs%5CINSG_Insight_23_Global_Ebike_Market.pdf, accessed on 28 August 2016