The possibility of installing extra battery to improve hybrid to EV-like vehicle in Bangkok traffic

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The possibility of installing extra battery to improve hybrid to EV-like vehicle in Bangkok traffic

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This study presents the result of improving Prius, generation3, to be likely more electric vehicle by increasing Prius' battery capacity and running the experiment durring rush-hour of Bangkok traffic condition. The data collecting methods and route selection will be shown. Prius' behavior will be explained along with Toyota hybrid system (THS) is used to explain and compare the improved behavior of having the extra battery and the consumption result is shown and analyzed in this paper.
KEY WORDS: Toyota hybrid system, Prius , Prius Plus, Bangkok traffic,% State of charge, Extra battery

1. Chapter

1. INTRODUCTION

The characteristic of Bangkok traffic that has low traveling speed, high instantaneous acceleration, high taking off and stop count allows Toyota hybrid synergy driving system (THS) to operate in the pure electric mode in full time until the %SOC of the battery is lower than 25%, the speed exceeds 64Km/h and the % acceleration paddle is over 50% of the Hybrid system indicator bar. Therefore, under the congestion in Bangkok traffic, increasing the battery capacity is the solution to reduce emission and fuel consumption, because the efficiency of the driving motor at the low speed is higher than inter combustion engine (ICE) and charging the extra battery from residence's electricity gains higher efficiency than converting gasoline to electricity by gasoline engine which occurs when Prius has low %SOC and needs engine to generates the electric back. As long as, the capacity of the battery is increased, the pure electric mode is also extended. Thus, this paper investigates the result of converting Prius, Generation 3, to behave more similarly to electric cars under Bangkok city traffic pattern by installing an extra battery ($LiFePO_4$), 40Ah capacity, parallel to the Prius's battery. The result of the study will illustrate the advantages of having extra battery. The first is to point out consumption behavior that is improved by the extra battery. The second is to express the difference of total energy consumptions.

1.1 Specification

Power train

Engine Model	2ZR-FXE, 4-cylinders in line Atkinson
Displacement	1798 CC
Max. output	98 hp @ 5200 RPM
Max.Torque	105 hp @ 4000 RPM
MG1,MG2 Max system Voltage	650VAC permanent magnet AC
MG2 Max. power	80hp(60Kw)
MG2 Max. Torque	207-546 N.m

Table 1, power train's specification [1]

1.2 Hybrid system'

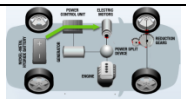
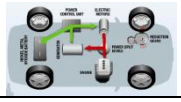
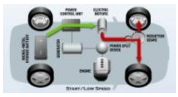
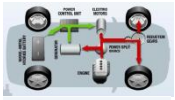
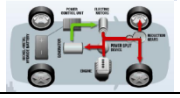
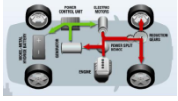
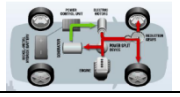
The table 2 shows the information of the basic Prius battery and the extra battery.

Category	HV Prius	PHEV Prius
Type of battery	Ni-MH (Nickel Metal Hydride)	LiFePO$_4$ (lithium iron phosphate)
Voltage(V)	201.6V	48V converted to 201.6V
Capacity	6.5Ah	40Ah
Charging method	By engine only	By 220V AC wall socket only
picture		 Enginer

Table 2, Hybrid system specification [2],[3]

1.3 THS fundamental operation modes

Prius' power train system consists of so many components, such as MG1, MG2, Power split Device (PSD), Engine, battery, inverter and converter, etc., which required such a complex logic to control the system. Therefore, THS can be illustrated in the basic fundamental operation behavior by the table 3 below which informs how each component operates in each mode.[4]

Operation Mode	Engine	MG1	MG2	HV battery	Picture
Stop stage					
High % SOC	-	-	/	Discharge	
Low % SOC	/	/	/	charging	
Speed below 64 Km/h					
High %SOC	-	-	/	Discharge	
Low %SOC					
Low load	/	/	/	Charge	
High load	/	/	/	-	
Speed higher than 64 Km/h					
Low Load	/	/	/	Charge	
High Load	/	/	/	-	

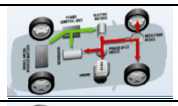
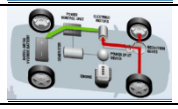
High Power	/	/	/	discharge	
Regenerative	-	-	/	Charge	

Table 3, THS operation modes [4]

Note High %soc (% state of charge) : battery has %SOC higher than 25%
Low %soc : battery has %SOC lower than 25%

Assuming the %SOC is still high, when a common Prius is in the heavy traffic, the THS operation mode usually stays on the pure electric mode (Speed below 64 Km/h mode) which consumes electricity from the battery. Every time the %SOC of battery is drained lower than 25% (2 bars of battery indicators), the engine will be started up and charge the battery back until the %SOC reaches 37.5%(3 bars of battery indicator). If Prius is still in the traffic that has velocity below 64Km/h, Prius battery will be changed and discharged as a cycle around 25-37.5%SOC which makes Prius operate similarly to a usual ICE. [4]

1.4 Principle of the extra battery

The Figure 1 illustrates the alternative direction of current flow. Every time the Prius battery does not reach 75% SOC, the extra battery will still keep charging Prius battery and also supply power to the main THS system in the same time when Prius' battery is weak. If the THS operation modes is applied to Bangkok traffic pattern, adding the extra battery will certainly prolong the Stop Stage mode and High% SOC at speed below 64Km/h mode which both use pure electric to propel the whole system. [5]

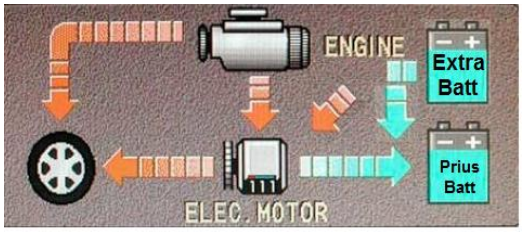


Figure 1, alternative direction of current flow [5]

2. chapter

Methodology

In order to point out the total consumption and the difference between the two Prius' consumption behaviors which is effected by extending battery capacity, electrical power and fuel consumption are required to be collected in real time by a data logger along with speed-time data. The experiment is conducted by driving two Prius vehicles following each other and measures the data under Bangkok traffic. For this paper, the normal prius is called Prius and the Prius with the extra battery is called Prius Plus.

In term of running the experiment in Bangkok traffic, the problems of limited time and short vehicles borrowing period, the representative route that was choosen was Pattanakarn-Rama9-Phetchaburi which has the speed-time data as in the Figure2 and the selected route's parameters is compared with Bangkok driving cycle from 2006 [6] as the table4.

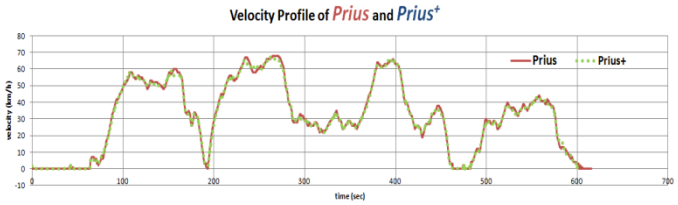


Figure 2, test route's speed-time data of Prius and Prius Plus

Parameters	Our Route	Bangkok driving cycle
Vmax	68 km/hr	62 km/hr
Average Speed	31.43 km/hr	28.8 km/hr
% of idle	15.66 %	37.7%
% Acc	9.18 %	15.3 %
% Dec	8.09 %	23.8 %
0 < V <10	7.53 %	9.3%
10 < V <20	4.84 %	23.6%
20 < V <30	19.60 %	10.3%
30 < V <40	18.03 %	28.3%
V > 40	33.81 %	28.6%

Table 4, compared traffic parameters

Although some parameters may different from the Bangkok driving cycle, the route is the main road that cuts through the center of the well-known Bangkok's congestion traffic and also is considered as a metropolitan area. [7]

For the fuel consumption, the air mass flow and air fuel ratio (AFR) are collected for calculating total usage of fuel by data logger, Innovate LM2. AFR is sensed by O_2 sensor at the tail pipe in the Figure3. In order to analyze the data, percent of acceleration paddle, engine RPM, load PCT, and vehicle speed also need to be collected.

Figure 3, Oxygen sensor and Data logger Innovate LM2 [5]

From the Figure4, the extra battery modules are installed parallel to the Prius battery. The position is between after the switch main relay (SMR) and before the Inverter/converter and A/C system. For measuring the electric power consumption the two current sensors are equipped. The first one measures the charging and discharging current due to Prius battery which is the blue sign named A. The second one measures the total charging and discharging current of the whole THS system which is the red sign, B.

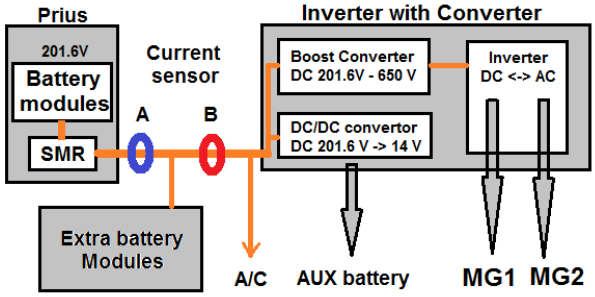


Figure 4, Hybrid power train map [2]

In the experiment, Prius is equipped just only sensor A and Prius Plus is equipped Both A and B. Even though the Prius battery voltage rapidly fluctuates around 230V, the voltage is assumed to be at 230V because of the high voltage safety operation policy.

3 chapter

Result and discussion

From the 10 minutes result data trip in figure 5, these two graphs have 4 parameters; charging and discharging current at the main wire, velocity of the vehicles and Engine RPM, which are used for analyzing the THS operation mode. For the better understanding, the data from the second 59.1 to 192.1 will be analyzed as a sample.

At the beginning of the trip, Prius and Prius Plus were in the same operation mode, speed below 64km/h, which were shown by the main discharge line(red). After the velocity increased, the both engines were started up to support torque for the acceleration but ,notice that, Prius Plus could stay in the pure electric mode longer than Prius. And after that between second 107.2 to 164.6, the velocity began to constant. Prius Plus could perform driving in the speed below 64km/h mode (pure electric mode) all along the constant speed. In the other hand, the Prius, RMP still rose every time the %SOC was low or when a little acceleration occurred because the battery was not be able to provide the electric power for driving.

To compare the effect of the extra battery on engine RPM, the RPM line (blue) of the Prius Plus runs in the engine high efficiency operation band more constantly than the Prius' RPM. This behavior enhances the fuel economy and reduces emission.

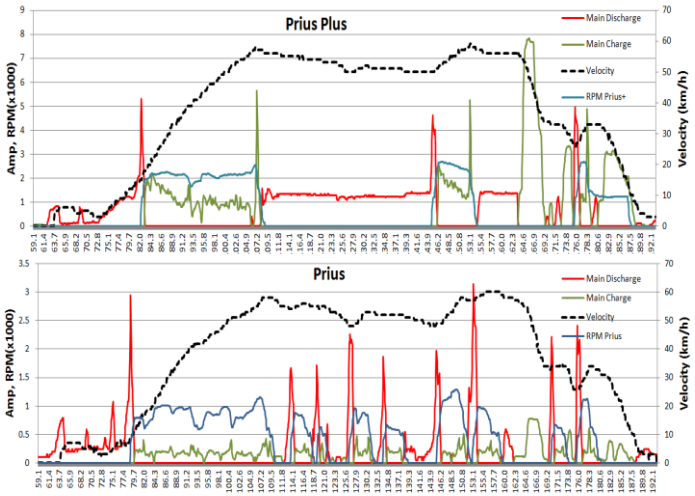


Figure 5 compared 4-parameter of Prius and Prius Plus

From the experiment, there was a pure electric driving occurred at the whole 2.53 minutes micro-trip which had the top speed at 43.1 Km/h. This Prius Plus stayed in the speed below 64km/h mode (pure electric driving mode) for the whole trip. From the, the forth micro-trip was shown to analyze and point out consumption behavior that was improved by extending the capacity of the battery. Even though some errors occurred during the vehicle-following test, such as the different acceleration and velocity, the improved behavior was expressed clearly in Figure 6. The Prius Plus graph shows a 100% in the speed below 64km/h with high %SOC mode (pure electric driving mode).

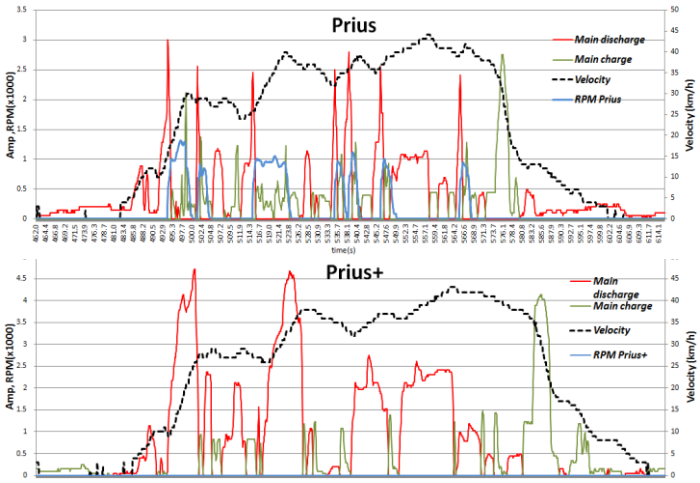


Figure 6, 2.53 minutes, 4th micro-trip of Prius Plus

According to the similarlity of the speed and the acceleration of the Prius and Prius Plus in the figure 10, the Prius Plus can be accelerated by electricity for every acceleration and the speed in this trip is below 64km/h which means Prius' engine is started because of low %SOC.

The Figure 7 shows that the higher %SOC of the battery, the stronger electric power can be released to accelerate the car. Since, the weak battery cannot provide enough power to support the acceleration, the engine has to be started to supply the torque.

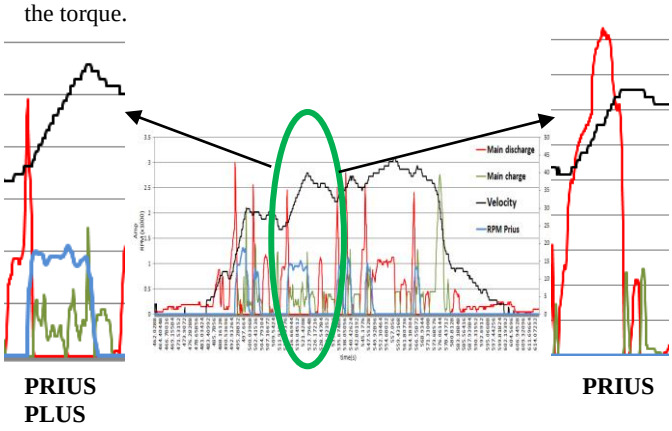


Figure 7, improved behavior

The electricity and fuel consumption for this pure electric drive micro-trip are shown in the Figure 8. The bar graphs compare the quantity of using electricity to fuel between Prius and Prius Plus in the 444.72m of micro-trip. Prius consumed 0.021l of gasoline which is equal 21.24 km/l and Prius Plus consume 100% of electricity (0.0382KWh) which trends to behave more likely to EV vehicle. According to the Enginer's claims, the 40Ah battery can provide a pure electric drive for 16Km and 32Km for blended distance. The total energy input of Prius was 659.30 kJ from fuel and Prius Plus consumed 332.91kJ from electricity as in the figure12.

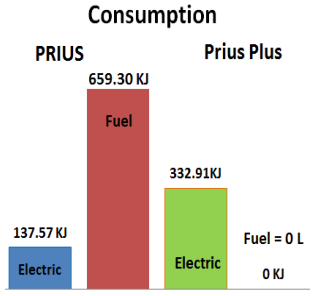


Figure 8 ,comparison of pure electric micro trip consumption

As the result of following two Prius vehicles test, the distance between two vehicles was maintained constant in order to keep the driving-wheel energy to be as the same as possible, however, the result total input energy of Prius and Prius Plus is still different. This issue is caused by the better performance of motor compared to the efficiency between ICE and motor power trains.

For the whole trip, the total consumption between Prius and Prius Plus is shown in the Figure 9. The first graph shows the km/l that Prius and Prius Plus consumed. The second graph shows kWh/km of the electric consumption.

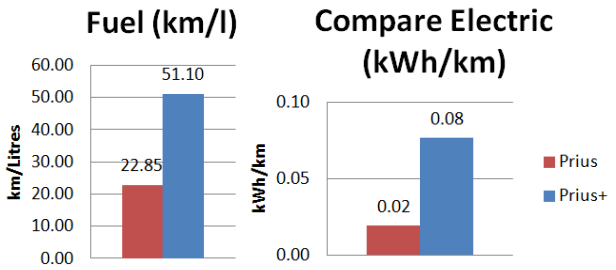


Figure 9, total consumptions comparison

From the result in the Figure 10, it ensures that the extra battery will be effective for THS system when the driving speed is lower 64km/h.

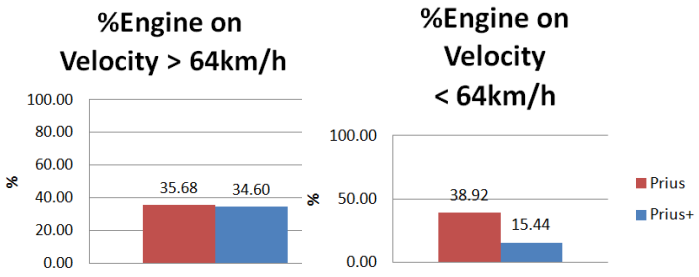


Figure 10,
%Engine on of the Prius and Prius Plus in Velocity over 64km/h mode and velocity below 64km/h mode

4. chapter

CONCLUSION

Prius, Generation 3, can be more fuel economy in Bangkok traffic congestion by increasing the size of 6.5Ah hybrid battery or shift the cycling charging-discharge range (25-37.5%SOC) higher and wilder, in order to keep the THS in pure electric drive mode longer and get MG2 to assist the engine. The Higher %SOC of the battery, the stronger electric power can be released to drive the wheels. The weak battery cannot provide enough power to support the acceleration, the engine has to be started to supply the torque. Thus, the idea of adding extra battery to Prius can extend the pure electric driving mode of hybrid vehicle (speed below 64km/h with high %SOC mode and stop stage with high %SOC mode) is practical. The extra battery will be very effective for THS system only if the average speed is lower than 64km/h and during low acceleration or cruising speed. Unless the driver applies EV mode, the pure electric driving will be able to perform higher acceleration but the max velocity will be limited at 48km/h.

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