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The Strong Hybrid System for Motorcycles

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Abstract

The strong hybrid system is one of the best solutions to reduce the exhaust of carbon dioxide from vehicles. However it could be believed too big and too complicated for motorcycles. Yamaha develops the strong hybrid motorcycle "HV-X" with an unique power unit which consists of a 4-stroke 250cm^3 single cylinder engine and two 300V AC motors with a planetary gear set in the simple one-room construction with the highly stiffened casing. They are controlled by the HV-X control system which contains a hybrid control unit (HCU), a motor control unit (MCU), a generator control unit (GCU), an engine control unit (ECU) and some battery management controllers (BMC) to attain 60% or less exhaust of carbon dioxide without a degradation of drive performances, but better acceleration. The paper introduces substances of the HV-X hybrid control system.

Keywords: HEV (hybrid electric vehicle), motorcycle, planetary gear

1 Introduction

Generally speaking, the motorcycles have better fuel economy than the automobiles. It does not mean that the motorcycles have better propulsion system. It is owing simply that the motorcycles is smaller and lighter than the automobiles..
Also, we realize that people may think the motorcycles being not so prestigious and socialized because of not having sophisticated behaviours with noises, exhaust gas emissions, fuel economy and sometimes riding manners.
On the other hands, people thinks less fuel consumption and generous response of the accel-grip means less drive performance. Any image of the inferior performance particularly weak acceleration kills the products.

1.1 Why hybrid motorcycle

The strong hybrid system can improve noises, fuel economy, and reduce exhaust gas emissions and carbon dioxide dramatically without a degradation of specific motorcycles' emotional charms on riding feeling such as acceleration and manoeuvrability. Those advantages can innovate social image of the motorcycles much better. Further the hybrid motorcycle will contribute the traffic safety through letting riders behave matured manners.

1.2 What comes with the hybrid motorcycle

The strong hybrid system can cut the exhaust of carbon dioxide 40% or less, then twice of the fuel economy can be met. The hybrid system can depart from your family and neighbours quietly and smoothly without any sounds, gasses, and vibrations. Once getting into highway, the hybrid system can make one higher grade acceleration, no time lag response, seamless cruising, and rocket-like power at any speeds when the wide open throttle (WOT) happens. The hybrid system can maintain high efficiency under any driving conditions since no clutch, no shift-mechanism, no mechanical continuous variable transmission

(CVT), and no torque converter. The strong hybrid system can run forever until the fuel tank dry up.

2 Construction of the hybrid motorcycle “HV-X”

The strong hybrid system has been installed into a motorcycle called “HV-X”. The HV-X consists of a hybrid power unit, a battery pack including the battery management controllers (BMC), inverters and a fuel tank.

2.1 Construction of the vehicle

The construction is shown in figure 1. The prospects are shown in figure 2.

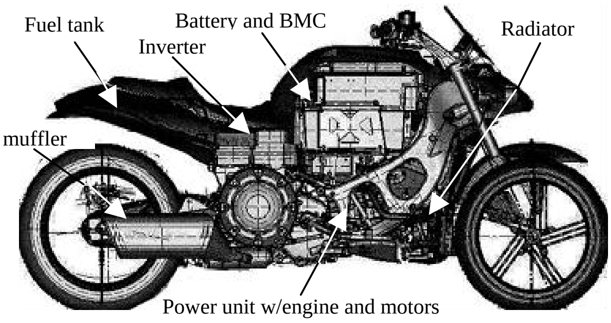

Figure 1 Construction of the HV-X

Figure 2 Prospect of the HV-X

The power unit is placed onto the centre of the vehicle. It contains an engine and two motors with a planetary gear system. The final speed reduction set is located at the left side of the rear arm sustaining the rear wheel. The exhaust pipe and muffler are placed at the right side of the rear arm. The battery and BMC are located in between knees of the rider just like a fuel tank of conventional motorcycles. The inverter is put onto the power unit directly for shortening the power and cooling line. The fuel tank is located on the rear wheel like a rear-fender. The double deck radiators are located in front of the power unit. A brief specification of the HV-X is shown in table 1.

Table 1 Specification of the HV-X

Name of the vehicle	HV-X	Y-400cm^3	Y-500cm^3
Type of the power unit	Strong hybrid 23kW	4st. single cylinder 23kW	4st. single cylinder 28kW
Type of the traction battery	Lithium Ion 84cells 300v-5.7Ah	Not applicable	Not applicable
Length	2200mm	2175mm	2195mm
Width	750mm	780mm	775mm
Height	1100mm	1185mm	1445mm
Wheelbase	1600mm	1565mm	1580mm
Seat height	740mm	780mm	800mm
Tire size	F17/R17”	F14/R13”	F15/R15”
Weight w/1G’ including battery	258kg	221kg	222kg
Weight balance	F55/R45%	No data	F54/R46%
CG height	446mm	No data	451mm

2.2 Construction of the power unit

The power unit consists of a 4-stroke 250cm^3 single cylinder engine, two 300V 3-phase alternating current synchronous motors, and gear trains including the planetary gear system. The construction is shown in figure 3. The prospect is shown in figure 4.

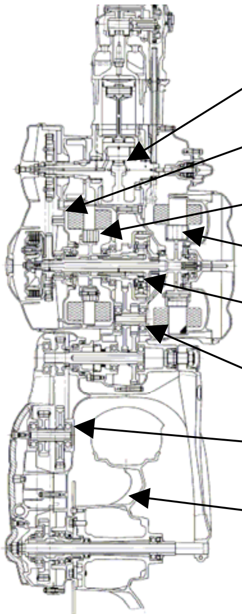

Figure 3 Construction of the power unit

Figure 4 Top view of the cut power unit

The internal combustion engine (ICE) consists of the cylinder head, cylinder body, piston, connecting rod, and crankshaft coming from the Yamaha 250cm^3 scooter. The left end of the crankshaft has a primary speed reduction sprocket and chain which connecting to the carrier of the planetary gear system to transmit torque between the carrier and crankshaft. The motor 1, which mainly acts as a generator, is placed coaxially onto the carrier shaft. The rotor of the motor 1 is connected to the sun gear of the planetary gear system. The motor 2 takes both roles of a motor and/or a generator flexibly depending on the balance of power consumption and preservation, is placed coaxially onto, and at the right side of the planetary gear system. The rotor is connected to the ring gear of the planetary gear system. The ring gear has not only internal gear shape to engage with the planetary gears but also has external gear to engage with the 2ndary speed reduction. The 2ndary speed reduction is firmly connected to the rear wheel through the final speed reduction, as a single-gear ratio transmission with neither clutch nor shifting mechanism.

A brief specification of the power unit is shown in table 2.

Table 2 Specification of the power unit

Type of hybrid	Strong series-parallel	
Combined power	23kW at 120km/h	
Combined torque	67Nm at 50km/h	
Engine	Motor 1	Motor 2
Single cyl. 4st 249cm^3 B66mm-S73mm	Internal permanent magneto 3 phase alternate current synchronous	
Max. power 15kW at 7000rpm	Max. power 10kW at 10000rpm	Max. power 15kW at 7000rpm
Max. torque 24Nm at 5000rpm	Max. torque 21Nm at 10000rpm	Max. torque 69Nm at 2000rpm
Max. speed 7500rpm	Max. speed 12000rpm	Max. speed 7500rpm
Water cooling	Water and oil cooling	Water and oil cooling

2.3 Specification of the planetary gear system

The power combination of the series-parallel hybrid is arranged by the planetary gear system.

The planetary gear system acts like a policeman who controls the power from the motor to the engine for engine activation, from the motor to the wheel for propulsion, from the engine to the motor or from the wheel to motor for generating, and sums the power of engine and motors at the inter-section of the power transmission. This planetary gear system can split the engine torque 70% versus 30% constantly.

Some photos of the planetary gear set are shown in figure 5.

A brief specification of the planetary gear system is shown in table 3.

Figure 5 Planetary gear set (carrier/left, ring/right)

Table 3 Specification of the planetary gear set

Item of the planetary gear system	
Ring gear engaged pitch diameter	109.2 mm
Planetary gear carried diameter	76 mm
Sun gear engaged pitch diameter	42.8 mm
Rate of the engine operation	0.712
Rate of the electric transmitted operation	0.288

3 Hybrid mechanism

The fundamental function of the power unit is the same as any well-known strong hybrid systems of passenger cars [1][2]. What is so distinctive is the mechanism of the power unit including timing, prioritizing and/or balancing on combined output power and internal energy storage [3].

The configuration of the power flows based upon the hybrid mechanism, is shown in figure 6.

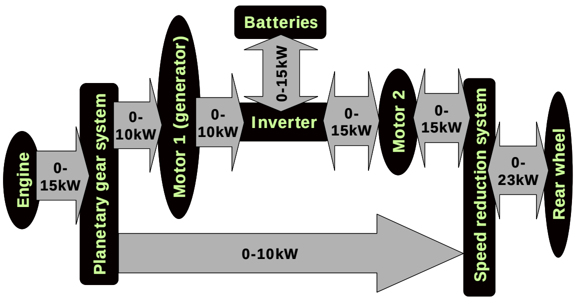

Figure 6 Configuration of the power flows

Though the planetary gear set splits the engine torque 70% versus 30% constantly, the rotational speed of the planetary gear set is controllable through the engine and motor 1. Then the engine power can be divided into 0 through 10kW for series operation and direct operation

The motor 1, inverter, battery, and motor 2 shall work just as a series hybrid operation. The motor 1 mainly acts as a generator. The generated power from motor 1 is divided to or assumed from the battery and motor 2. In case of power requested from the motor 2 is lower than the power from the motor 1, the power can be split into response for the request from motor 1 and charging current for the battery. In case of requested power from the motor 2 is higher than the power from the motor 1, the power can be assumed from the motor 1 and discharging current from the battery as the response for the request.

At the ring gear, the power can be combined, and then transmitted to the rear wheel.

As a note, in case of these samples, to understand easily, the loss of each actuation is ignored.

To start from the standstill, the motor 2 starts to rotate. As it is connected to the rear wheel directly, the vehicle moves immediately and quietly. On the other hand, as the engine shall be stopped, the motor 1 will rotate with certain controlled speed based upon the planetary gear system theory. In case of the engine activation required, the motor 1 shall be controlled to rotate the crankshaft of the engine for obtaining enough torque and speed to start the engine.

The mechanism of the power flow at the start from the standstill is shown in figure 7.

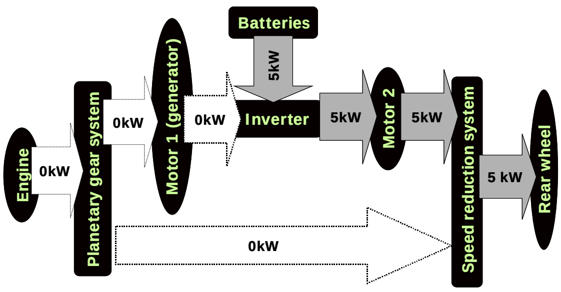

Figure 7 Sample power flow at start

In case of the wide open throttle required, the engine highly activates with the available best efficiency, and the motor 1 shall act as a generator to transform the mechanical power to the electric power as the ECVT. The mechanism at the wide open throttle is shown in figure 8.

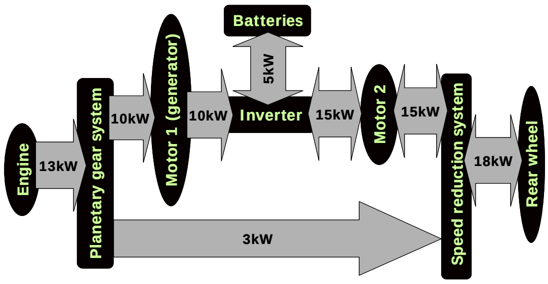

Figure 8 A sample power flow at wide open throttle

To keep running continuously as long as the petroleum fuel remains, no power goes in and out to the battery. So in that case, to perform best fuel efficiency, the ratio of the power flow via series operation versus engine direct operation shall be figured out by the hybrid system. The ratio will be kept by the hybrid system through maintaining the engine throttle, the speed and torque of the Motor 1 with the power flow shown in figure 9.

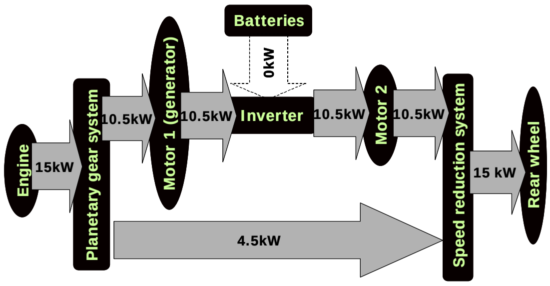

Figure 9 A sample power flow at cruising.

Upon the start from the stand still, accelerating with wide open throttle, cruising, and deceleration, various type and/or rate of the energy flow makes five operation mode shown in table 4.

Table 4 The operational mode of the hybrid system

mode	operation
PEV	Electric propulsion only w/o engine activation (power comes from battery only)
PHEV	Power comes from petroleum fuel and battery (parallel hybrid)
ECVT	Power comes from petroleum fuel only (series-parallel hybrid)
Charging	Engine generates battery energy
Re-charging	Motor regenerates battery energy at downhill and/or deceleration.

4 Contents of the strong hybrid control system

The strong hybrid control system is described with hardware layout and software chart.

4.1 Contents of the hardware

There are four principle hardware contents. They are the battery management controller (BMC) , the motor control unit (MCU) , the generator control unit (GCU) and the engine control unit (ECU). The BMC controls battery and also communicates with the HCU. The HCU is the supervisor to manage the vehicle for less fuel consumption, cleaner exhaust gases and better acceleration by controlling the MCU, GCU and ECU. The MCU controls the motor 2 and the GCU controls the motor 1 through the inverter. The engine is fully driven by wire. The ECU controls the fuel injector, throttle valve and ignition.

The layout of the principal components is shown in figure 10.

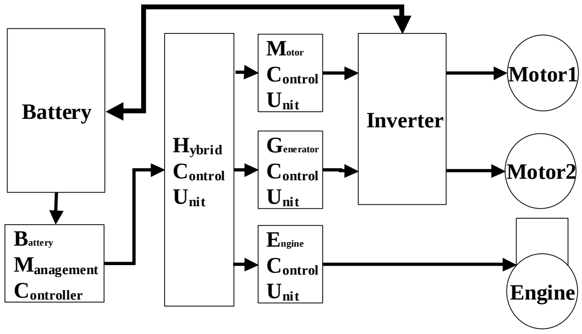

Figure 10 The principle components of the hybrid system

Including above principle components, plenty of sensors, actuators and other various parts are required for the HV-X to run smoothly, efficiently and quietly. The entire hardware system layout is shown in appendix A.

4.2 Contents of the software

The hybrid control software system acts three main parts. The 1st part is the state of charge (SOC) control. The SOC is maintained with 40% through 60% for the vehicle to be able to run as long as the petroleum fuel remains. The 2nd part is the good manoeuvrability control. Impressive acceleration from standstill, seamless extension to the top speed, no time lag and rocket-like power at any speed when the WOT happens are the most important value for motorcyclists. The hybrid system will force two motors to catch up the rider's willingness.

The 3rd part is the best efficiency control. Mainly four maps figure out the best control of the engine throttle and generator speed. They are "generator map", "engine performance map", "accel-angle versus requested torque versus velocity map", and "engine speed versus requested torque versus velocity map". The fundamental system flow is shown in figure 11.

Based upon the present battery SOC and vehicle speed, the current ampere demand is calculated in the SOC control part. The calculated ampere demand, the riders accel-grip indication and vehicle velocity, extract necessary generator torque for charging through three-dimensional efficiency map in the best efficiency control part. The necessary generator torque means additional engine requested torque so that the throttle adjustment is found in the engine map. Then the throttle order is fixed. These requested torque and vehicle velocity extract most efficient engine speed through another three-dimensional map in the best efficiency control part. Then the generator speed order is fixed.

According to the engine map with the measured throttle position and engine speed, the engine output torque is estimated. The necessary driving force is extracted from the vehicle driving performance chart. The driving force and throttle adjustment make requested torque for good manoeuvrability. The requested torque and estimated engine torque fix the motor torque order.

The entire system flow is shown in Appendix B.

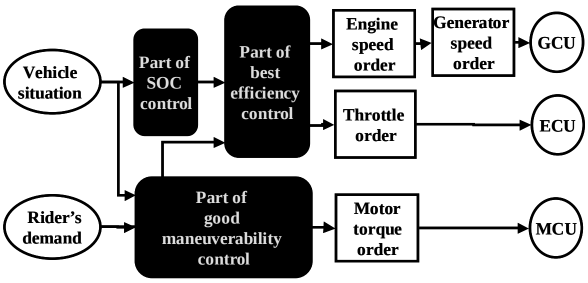

Figure 11 The fundamental system flow of the hybrid system

5 Results and Discussion

Generally speaking, engines are evaluated with maximum power/torque, BMEP, BSFC, and so on as on the dynamometer. However in case of the hybrid, the power unit is evaluated with the acceleration, top speed, and fuel economy with the combined power sources on the chassis dynamometer [4]. The configuration of the test equipments is shown in figure 12. The hybrid parameters are shown in table 5.

Table 5 The hybrid test parameters

item	parameters
Motor 1	Motor1 speed for engine to start cranking
	Engine speed for engine to start firing
Engine	Engine torque for engine to start firing
	Min. engine torque at engine firing
	Max.engine torque at engine firing
BMC	SOC

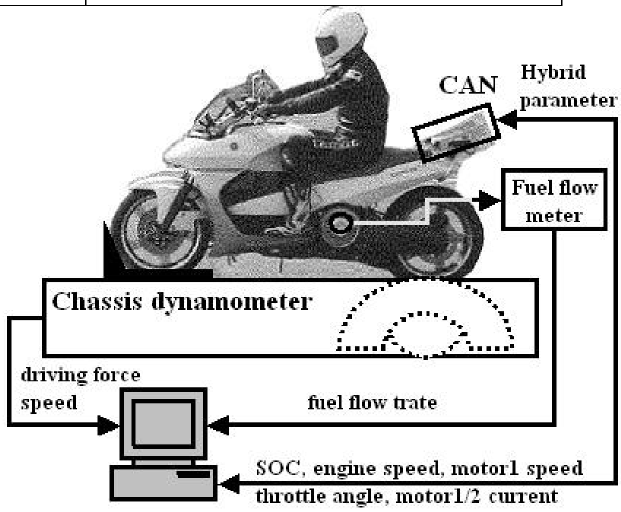

Figure 12 The test configuration of the hybrid vehicle

5.1 Driving performance

The performance of hybrid vehicles is figured by continuous and/or limited period performance. The continuous performance means that the vehicle can run as long as the petroleum fuel remaining in the fuel tank. The limited period performance means that the power unit uses both full power of the engine and battery through the motor 2. Therefore, the vehicle can perform while the battery energy remained.

5.1.1 Vehicle driving performance diagram

The driving performance test has been done on the chassis dynamometer to utilizing the test parameters shown in table 4. The test result is shown in figure 13. The HV-X has better and/or same performance with Y-400cm^3 under continuous performance.. Further the HV-X outputs superior power in limited period performance.

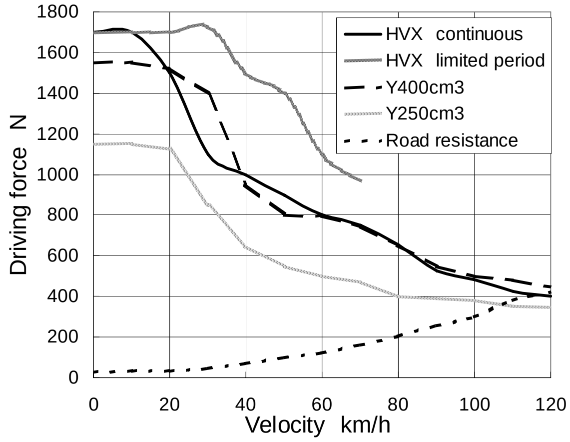

Figure13 The HV-X driving performance diagram

5.1.2 Acceleration

The acceleration performance is measured by limited period performance. The acceleration is evaluated by the time of reaching 400m distances with wide-open throttle (WOT). The result is shown in Fig. 14. The power unit in the “HV-X” reaches 400m distance 1.5 seconds faster than the Yamaha 400cm^3 scooter, and 3.6 seconds faster than the Yamaha 250cc scooter.

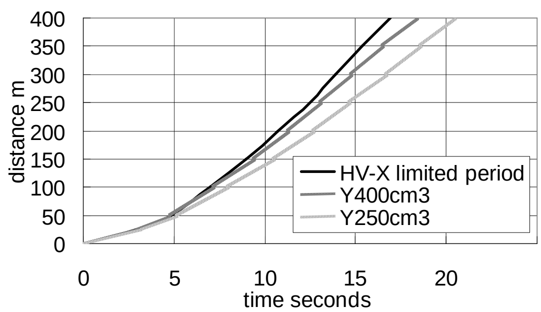

Figure 14 The acceleration performance of HV-X at 0-400m WOT test.

5.2 Fuel efficiency

Whenever we drive a vehicle, there are some goes, stops and speed changes in the trip. In case of happening any stops, starts and speed changes, the ratio of the power flow via electric continuous variable transmission (ECVT) versus engine direct operation is controlled to keep better fuel efficiency. Simultaneously, the battery SOC is altering as well. It means depend upon the SOC and amount of the power goes in and out to the battery, the fuel consumption may become different. As the fuel economy of hybrid shall be evaluated by petroleum fuel consumption only [5][6], the difference has to be eliminated. To coincide with the condition, the following procedure is taken to figure out the fuel economy with the practical driving patterns called mode-fuel-consumption:

1. (1) Scale X-axis with the difference of battery capacity between before and after mode driving.
2. (2) Scale Y-axis with the measured fuel economy.
3. (3) Put points at (difference, fuel economy) per a mode driving.
4. (4) Make a regressive line with all points.
5. (5) The fuel economy of the practical driving patterns called mode-fuel-consumption is the point of intersection at the regressive line and Y-axis.

As the typical driving patterns, the ECE40 is taken. The comparison of the fuel consumption between the HV-X and Y250cm^3 is shown in figure 15.

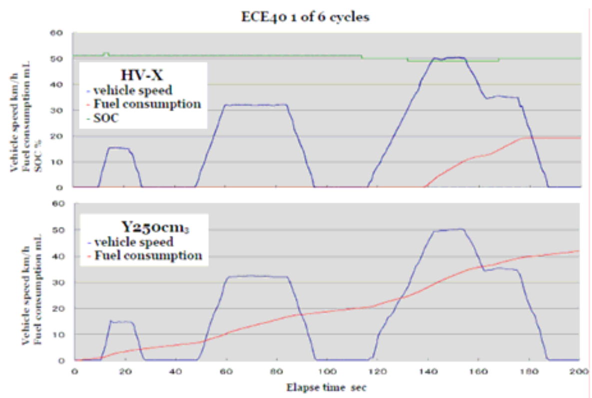

Figure 15 The comparison of fuel consumption at ECE40 between HV-X and Y250cm^3

As the practical motorcycle driving pattern, the urban commute mode is taken. The urban commute has been figured out for this project. The urban commute mode came from measured data by running through a real city. The mode pattern is shown in figure 16.

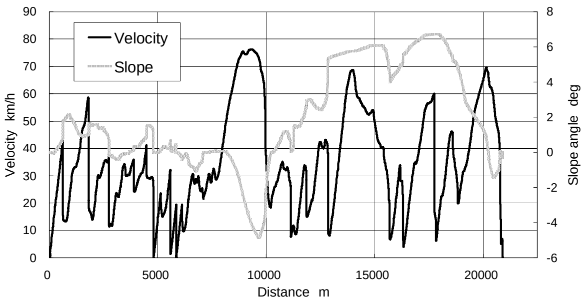

Figure 16 The urban commute mode

The comparison of the fuel consumption between the HV-X and Y250cm^3 is shown in figure 17.

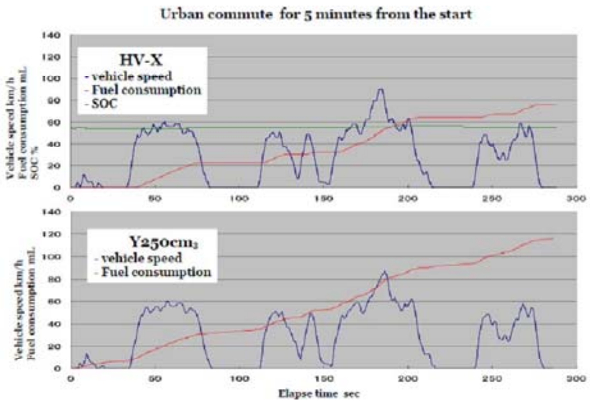

Figure 17 The comparison of fuel consumption at Urban commute mode between HV-X and Y250cm^3

These results including the WMTC mode, are shown in figure 18. The power unit of HV-X attains 40 through 100% better fuel economies compared with the Yamaha 250cc scooter.

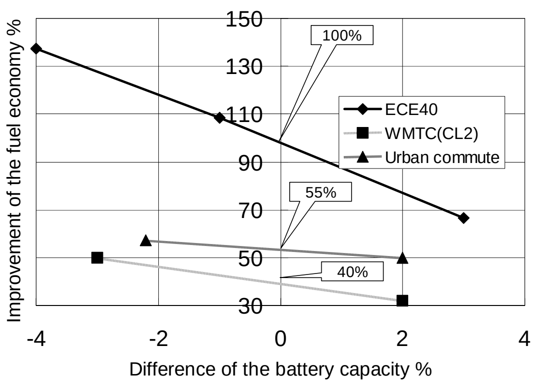

Figure 18 The improvement of fuel efficiency by the hybrid system with the HV-X versus Y250cm^3

6 Conclusion

The strong hybrid system for the strong hybrid motorcycle "HV-X" embodies 5 different driving modes to accomplish better fuel economy and driving feeling. One is the mode of Pure-EV. Two is the mode of Parallel Hybrid. Three is the mode of Series Hybrid and/or Electric Continuous Transmission. Four is the mode of generating.
Five is the mode of re-generating.

These combinations attain:

(1) The strong hybrid motorcycle "HV-X" make better acceleration comparing with same type of motorcycle which has one class bigger displacement.
(2) The strong hybrid motorcycle "HV-X" attain 100% better fuel efficiency at the ECE40 mode, 40% at the WMTC mode and 55% at the WMTC mode comparing with same type of motorcycle which has same displacement.

That is all about the summary and conclusion of the project. However, several subjects still remain, such as weight, cost, and so on. We would like to solve them, and certainly proceed further in the research and development.

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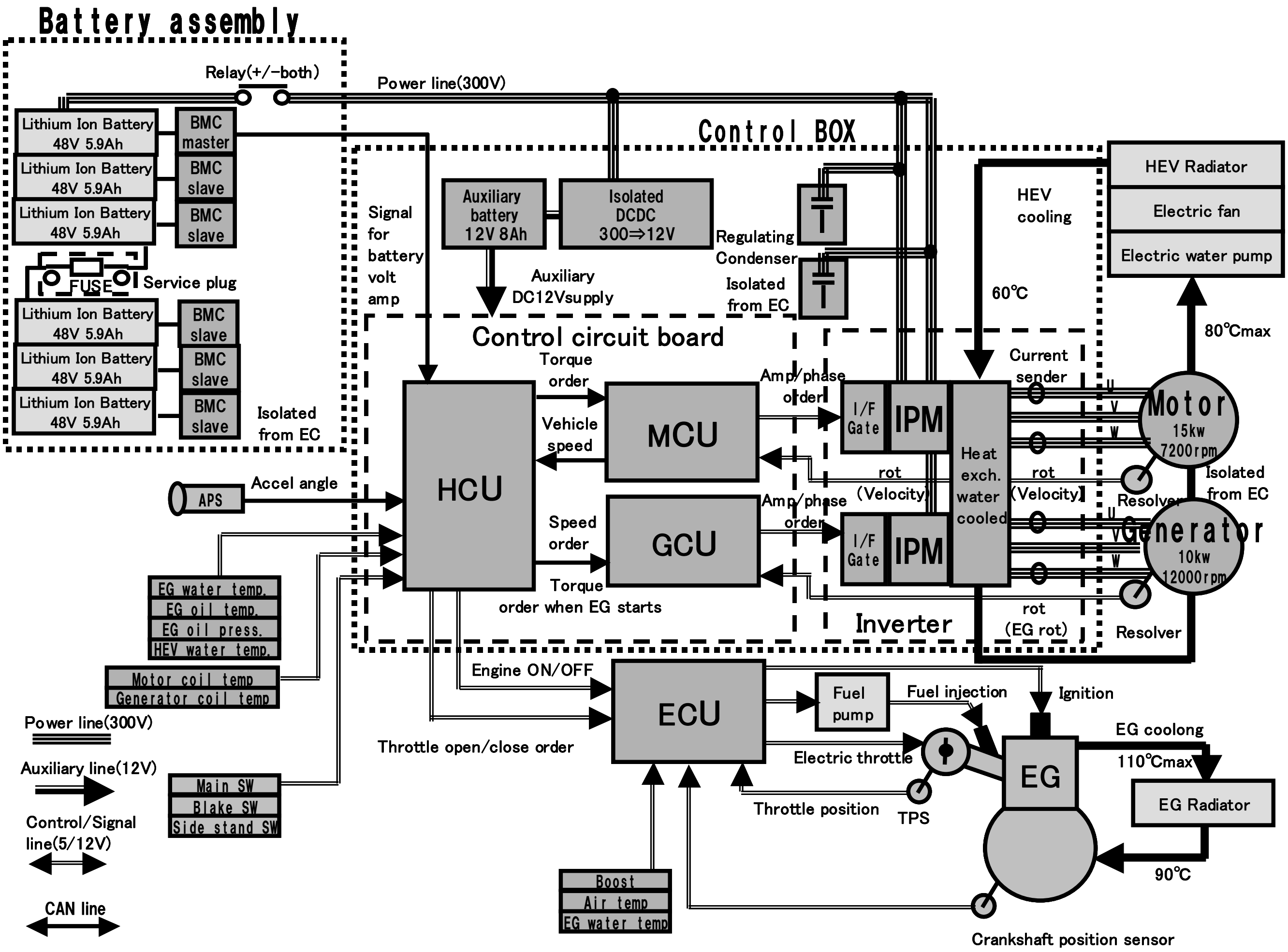
Appendix A The entire hardware layout of the HV-X



Appendix B The entire control system flow of the HV-X