

## **Development of New Hybrid City-Buses**

Atsushi Ohshima <sup>1</sup>

<sup>1</sup> *Hino Motors, Ltd., Hybrid Vehicle Development Div.  
3-1-1, Hino-dai, Hino-shi, Tokyo, 191-8660, Japan  
[atsushi.ohshima@hino.co.jp](mailto:atsushi.ohshima@hino.co.jp)*

---

### **Summary:**

In December 2015, our company developed a new hybrid city bus with a new system and unit, which fuel economy was improved. Following technologies are adopted in order to improve fuel economy; adopting of new hybrid units changing the powertrain layout, engine downsizing, adopting of Automated Manual Transmission. Also, optimization of hybrid control which realized the improving fuel economy significantly. The cooperation of the major bus users, verification tests were conducted and its high fuel-saving was demonstrated. This paper explains component and control of new hybrid system and shows the results of verification tests.

*Keywords: bus, heavy-duty, HEV(hybrid electric vehicle), Japan, parallel HEV*

---

### **1. INTRODUCTION**

In recent years, the effects of air pollution and global warming have become worldwide issue. Since vehicle emissions are one key factor contributing to these environmental changes, countries are implementing increasingly strict vehicle emissions and fuel economy regulations in the world. In our company, hybrid buses with improved fuel economy have been mass-produced since 1991 in order to reduce exhaust gas emissions.

Aiming for even more dramatic fuel economy improvement, new hybrid city bus(Fig.1) was developed. The proportion of electric energy to driving energy; electric energy ratio was expanded, by renovating the hybrid system and the unit on the basis of the accumulated technology by many years of experience in new model. Also, engine was

downsized and Automated Manual Transmission (AMT) was adopted for transmission.

This paper explains the methods for fuel economy improvement and the results of verification tests throughout one year by the major bus users are shown.



Fig.1 New Hybrid City-Bus

### **2. DEVELOPMENT GOAL AND APPROACH**

#### **2.1. Development Goal**

Fuel Economy Improvement: 40% over baseline conventional diesel models.

## 2.2. Development Approaches

In order to achieve the development goal, hybrid system and powertrain units were need to be changed. The development approaches are the followings.

- 1) Development of new hybrid units
- 2) Increase of the regenerative energy by changing layout of powertrain
- 3) Optimization of hybrid control
- 4) Downsizing engine
- 5) Low speed of engine during shift change by AMT

## 3. SYSTEM CONFIGURATION

### 3.1. Vehicle Specifications and Powertrain Configuration

Table.1 shows vehicle specifications of new hybrid city bus and previous one. Fig.2 shows structure of hybrid system.

A parallel hybrid system arranged coaxially with the diesel engine and motor/generator were adopted in new model. Its performance was assured in previous model. One of the most noticeable point is the clutch was positioned between the engine and the motor/generator which enable to disengage automatically during driving. Thus, during deceleration, new model enables to regenerate energy equivalent of engine pumping loss . And during starting, it can drive only by motor. In addition, adopting AMT for transmission enabled to both easy-drive and fuel economy improvement. The details of the hybrid system is described in Chapter.4.

Table.1 Vehicle specifications

|                         | Previous Model            | New Model                                 |
|-------------------------|---------------------------|-------------------------------------------|
| Gross Vehicle Weight    | 15,280kg                  | 14,365kg                                  |
| Vehicle Size (L×W×H) mm | 10,525×2,490×3,285        | 10,555×2,485×3,105                        |
| Engine                  | 6-cylinder inline(7.684L) | 4-cylinder inline (5.123L)                |
| Transmission            | Manual Transmiion(5speed) | Automated Manual Transmission (6speed)    |
| Motor                   | Induction Motor (41kW)    | Permanent Magnet Synchronous Motor (90kW) |
| Battery                 | Ni-MH(4.8kWh)             | Ni-MH(7.5kWh)                             |

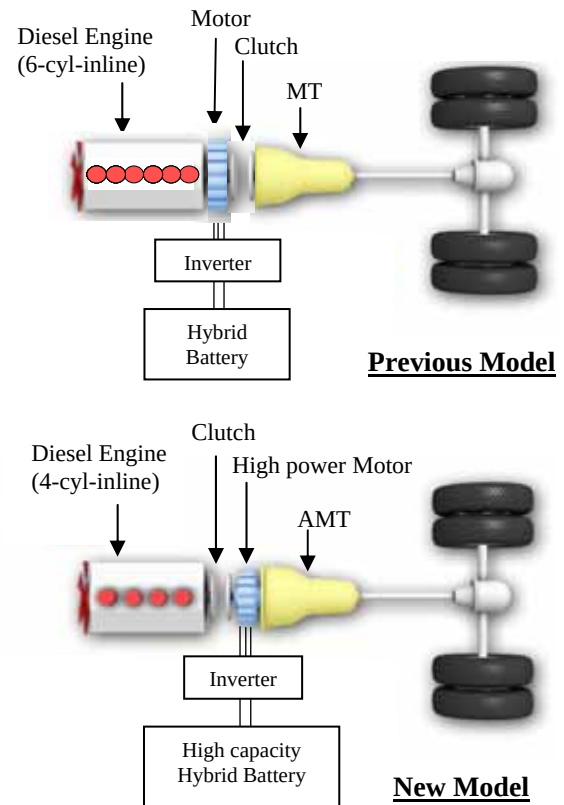


Fig.2 Constitution of new hybrid system

### 3.2. Hybrid System Output Target

Hybrid system output target was 90kW.

Fig.3 shows deceleration output histogram of actual route bus operation data. It shows that 90 kW covers 97% of the frequency(Fig.3) and can

regenerate enough energy. And also 90kW enables the vehicle to drive only by motor power.

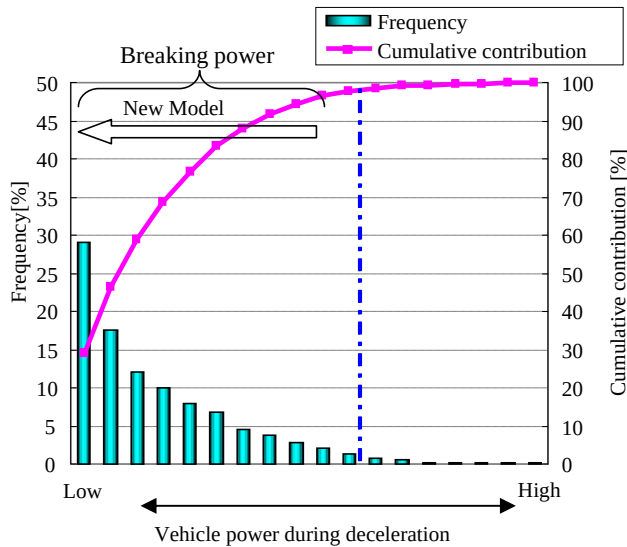


Fig.3 Distribution of vehicle power during deceleration

### 3.3.New Hybrid Units

With increasing hybrid system output, new units were developed. High efficient synchronous motor, which is compact, expanding max power and oil cooled structure, is adopted. Inverter is compact and water cooled structure. With increasing hybrid system output, capacity of hybrid battery is expanded. By positioning inverter which was mounted on the roof to rear right side of the underfloor, as shown in Fig.4, overall height has been lowered. It enables the new model bus to operate various circumstances such as narrow town route.

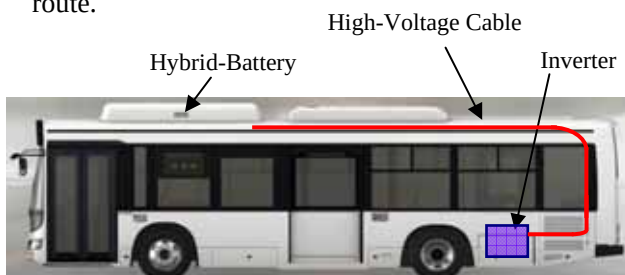


Fig.4 Arrangement of hybrid component

## 4. DEVELOPMENT CONTENTS

### 4.1. Increase of the Regenerative Energy

By positioning the clutch between the engine and the motor/generator, the new hybrid bus enables following control. And increase of regenerative energy was certificated.

1) Separating the motor/generator from the engine power by the clutch during regeneration

2) Regeneration of very low speed range

Very low speed range is defined as the range less than idling speed.

Fig.5 shows the regenerative energy of new hybrid city bus and the previous one during deceleration. The new hybrid city bus regenerated energy equivalent of the engine pumping loss (①) and the kinetic energy in the very low speed range (②).

Fig.6 shows the result of regenerative energy of the demonstration test by operating routes. New model regenerative energy was increased by 60% compare to the previous one.

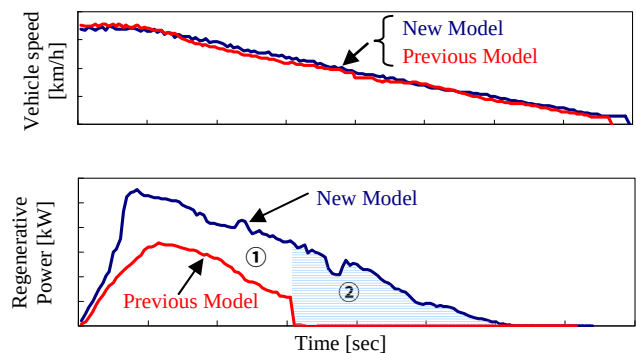


Fig.5 regenerative energy during deceleration

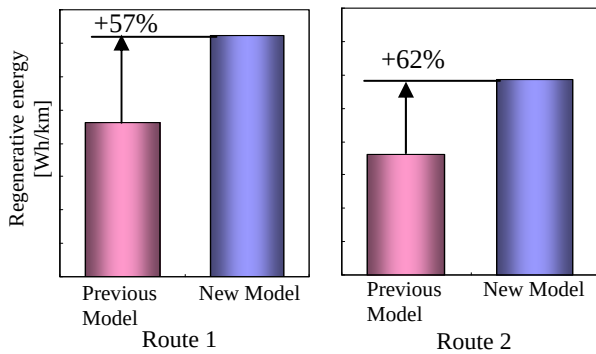


Fig.6 Improvement of regenerative energy

## 4.2. Optimization of Hybrid Control

### 4.2.1. Adoption of Motor Starting

Changing layout of powertrain enables vehicle to start by motor power.

There are two patterns of way when hybrid vehicle starts. One is Motor starting, and the other is torque assist starting.

Motor starting; engine speed keeps idling speed to maintain engine accessory drive (Fig.7).

Torque assist starting; this reduced engine load during starting by the motor.

Since the fuel consumption at the start needs about 60% of the total fuel consumption, it is hypothesized that motor starting can be suitable for route buses than the torque assist starting. Fig.8 shows the result of simulation of the fuel efficiency of motor starting and torque assist starting with the same amount of discharge, average vehicle speed is different. The internal evaluation pattern was used. From Fig.8, it is found that the motor starting has higher fuel efficiency than the torque assist starting. The lower the average vehicle speed is, the more effective fuel efficiency is. This is because low speed pattern has a lot of starts and stops. It is confirmed that motor starting is suitable

for the route bus whose average vehicle speed is very low at 10-15km/h.

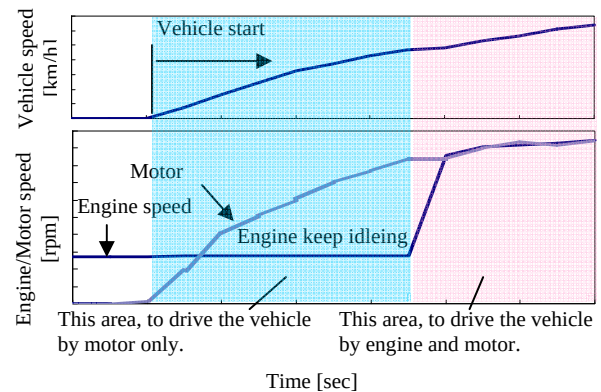


Fig.7 Driving data by motor

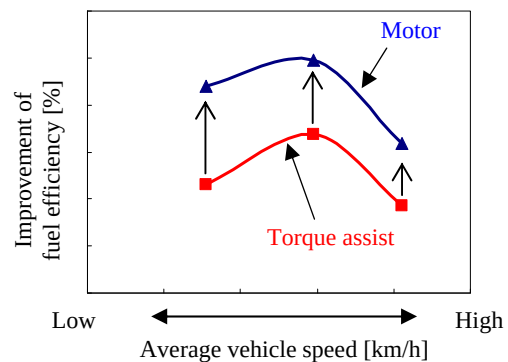


Fig.8 Fuel efficiency of start the vehicle by Motor and Torque assist

### 4.2.2. Standardizing of 3-shift Start

General city bus usually starts with 2-shift. While new model adopted 3-shift starting and improved more fuel economy in addition to the motor starting.

Generally, 3-shift start, compared to 2-shift, reduces traction power during vehicle start. However, as shown in Fig.9, new model can start with 3-shift in general city route because of the characteristics of low-speed torque of motor. Furthermore, 3-shift start can reduce energy needed to start, for it can reduce rotational inertia about 1t. Thus 3-shift motor starting is standardized as a starting-gear in the new model.

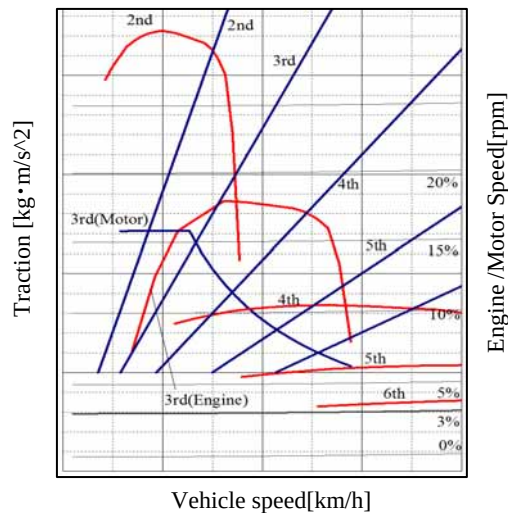


Fig.9 Torque-Speed curve of engine and motor

### 4.3. Engine Downsizing

Engine is downsized to 5.123L (4-cyl-inline) from 7.684L (6-cyl-inline), the previous engine. Motor torque assist, optimal transmission gear ratio and differential gear ratio make new model compatible high fuel economy with power performance.

### 4.4. Low Speed of Engine During Shift Change by AMT

AMT was adopted in the new model. Low engine speed can be achieved by vehicle control, which shift change speed must be lower than a designated speed. This control contribute to improve fuel economy. Engine speed trends to be high during shift change at the Manual Transmission because of engine speed is decided by driver's operation. This was one of key factors affected to much fuel consumption.

## 5. Verification and Result

### 5.1 Internal evaluation

All the technological innovations in order to improve fuel economy described in Chapter.4 were gathered in the new hybrid bus, verification test was conducted.

Internal evaluation patterns were used, that simulates city route patterns(A, B) and suburban pattern(C).

### 5.2 Result

Fig.10 shows the Verification result of each evaluation pattern. The new model hybrid achieves 40% fuel economy improvement in each evaluation pattern over the baseline diesel model.

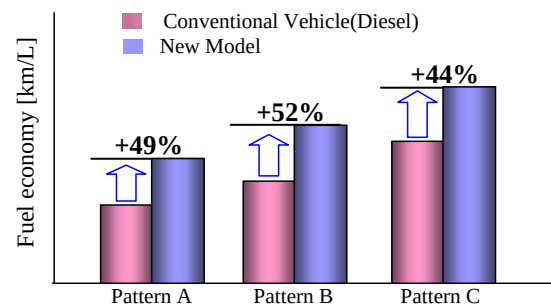


Fig.10 Fuel economy improvement of the pattern

### 5.3 In use evaluation

One-year user demo was conducted and also new model hybrid achieves 40% fuel economy improvement.

Fig.11 shows the result of user demo.

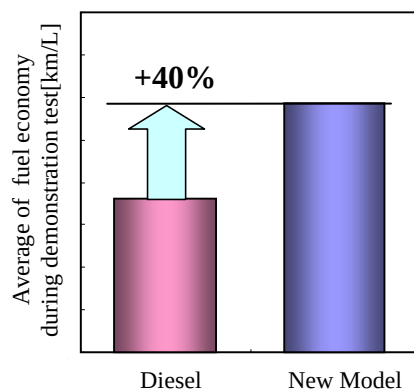


Fig.11 Result of the demonstration test

## Author



**Atsushi Ohshima** is a hybrid system engineer, Hino Motor, Ltd. Mainly in charge of hybrid bus system since April, 2013. He acquired a master of a mechanical engineering at Mie University in Japan in March, 2013.

## 6. Conclusion

New model hybrid city bus achieved 40% fuel economy improvement by various innovations such as powertrain including engine, hybrid system and unit, and optimal hybrid control.

Our company continues to accumulate various technologies and develop hybrid city bus, aiming to further more performance improvement.

From this new model, we expected "hybrid" city bus to be standard in the world.

## Acknowledgement

We appreciate the great cooperation of monitor user bus company.

## Reference

- [1] Satoshi Uemura, et al: Development of New Hybrid City-Buses, JSAE Proceedings, No.14-15A, pp.318-321 (2015)