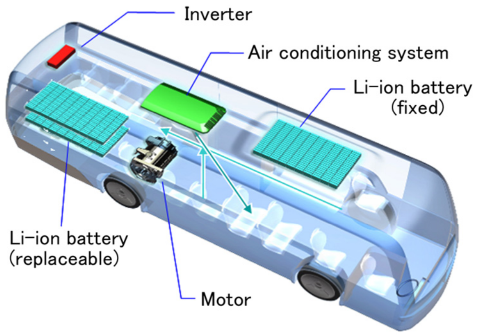
Development of Highly Efficient Power Train for Large Electric Buses on Regular Routes



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To achieve a low-carbon society, Mitsubishi Heavy Industries, Ltd. (MHI) is currently developing an electric power train consisting of batteries, a motor, and an inverter for use in large electric buses of a highly public nature that run on regular routes. The widespread use of large electric vehicles is thought to be a development of the distant future, because the capacity of the batteries required for electric vehicles usually increases with the vehicle weight. However, large electric buses on regular routes can be used in practical operations without mounting a large battery because approximately 80% of all routes in urban Japan are shorter than 15 km.

1. Vehicle Concept

To enable an early market launch, MHI selected the low-floor, 65-passenger series hybrid bus made by Mitsubishi Fuso Truck and Bus Corporation (MFTBC) as the base vehicle and decided to collaborate with MFTBC in the joint development of large electric buses on regular routes. As shown in **Figure 1**, the low-floor bus runs on a motor that is powered by electricity generated by an engine and then stored in a battery. By replacing the engine with a combination of rechargeable, replaceable batteries and developing an appropriate way to manage the batteries, large electric buses that do not need large-capacity batteries can be used on regular routes. MHI mounted its Li-ion batteries, drive motor inverter, and an electric air conditioner on the bus to provide a highly efficient electric power train, with the result that the total energy management improved the rate of electric consumption (travel distance per unit of power consumed), thereby further reducing CO_2 emissions and improving the operability with a small capacity battery.

2. Solutions to Improve the Rate of Electric Consumption by Total Energy Management

The following outlines some of the solutions discussed to improve the rate of electric consumption through total energy management.

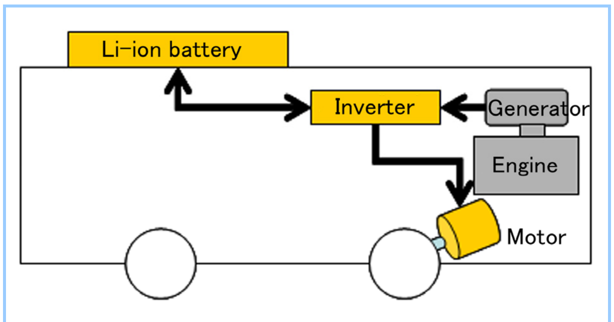


Figure 1 Series hybrid bus

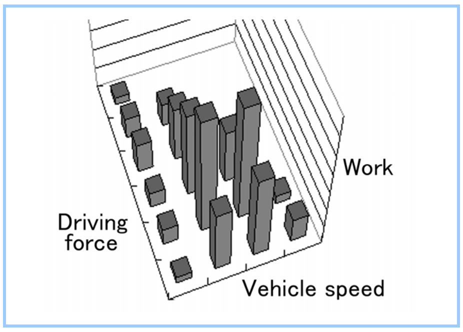


Figure 2 Distribution of the workload during operation on practical routes

2.1 Drive Motor Inverter

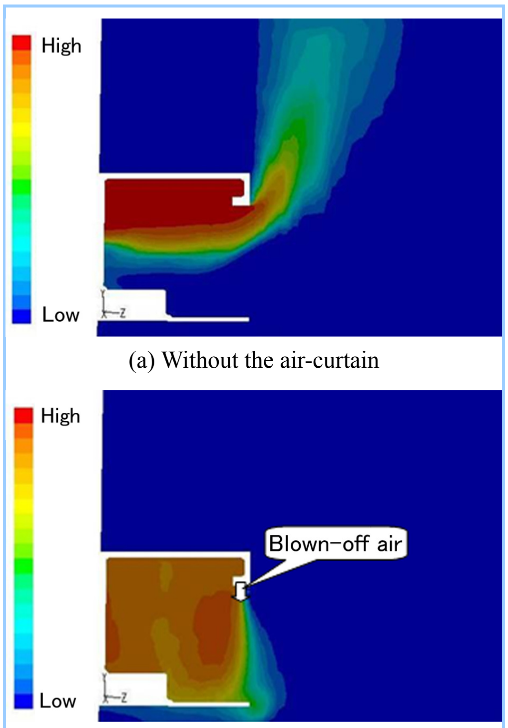
For the drive motor inverter, a solution can be designed specifically for regular-route buses, and for enhancing the performance of the device itself. Although the routes of regular-route buses vary from one operation route to another, the buses do not move randomly like general vehicles do, and their running and stopping patterns are similar. Consequently, the drive motor work does not deviate markedly from the distribution shown in **Figure 2**. Therefore, the rate of electric consumption can be improved, for example, by setting the best efficiency of the motor in the region where the work is greatest.

2.2 Reducing Power Consumption for Air Conditioning

Table 1 shows conventional solutions for reducing the air conditioning power consumption and the effects of the solutions. When compared with measures for altering the heat conduction and heat radiation of the vehicle itself, the following solutions were far more effective in reducing the air conditioning power consumption: (1) a "door-air-curtain" can be used to prevent heat from entering or leaving the bus when the door is opened at stops, which is a situation peculiar to regular-route buses; and (2) exhaust heat can be recovered from the drive motor inverter to secure a heat source for heating air.

Figure 3 shows an example of an analysis of the effect of the door-air-curtain mentioned in solution (1). The air-curtain blown from the upper portion of the door significantly reduces the outflow of heat during heating, but has little effect during cooling.

Regarding solution (2), the greatest weakness of electric vehicles is the lack of a heat source for heating; this said, vehicles equipped with an internal combustion engine use exhaust heat from the engine. Therefore, recovering the exhaust heat from the drive motor inverter is an effective countermeasure.



(a) Without the air-curtain

(b) With the air-curtain

Figure 3 Effect of the door-air-curtain

Table 1 Solutions to reduce the air conditioning power consumption and effects thereof

Solution		Reduction in the air conditioning power consumption	
		Cooling	Heating
Improved heat insulation for the vehicle body	(%)	–3	–9
High-barrier double-insulating glass	(%)	–9	–4
High solar reflective coating	(%)	–2	-
Door-air-curtain	(%)	-1	–15
Exhaust heat recovery	(%)	-	–16

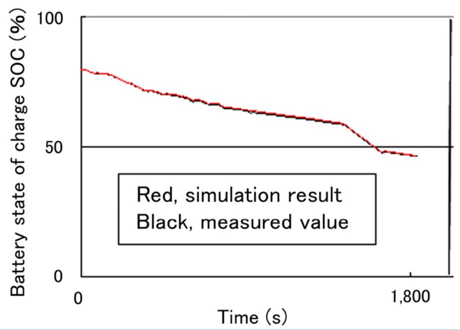


Figure 4 Comparison of the simulation results and measured values

3. Driving Simulator and Validation Thereof

MHI developed a driving simulator as a tool for evaluating highly efficient power trains. To validate its accuracy, MHI used an existing motor inverter and batteries, and applied a load equivalent to that of legal driving mode on a test bench. The simulation outcomes and measured values of the remaining battery power are compared in **Figure 4**. The difference between the simulated and measured values was less than 1%, showing excellent agreement and confirming the simulator as an evaluation tool for highly efficient power trains.