

Development of Power Control Unit for Compact-Class Vehicle

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ABSTRACT

Toyota Motor Corporation has developed the new compact-class hybrid vehicle (HV). This vehicle incorporates a new hybrid system for the improvement of fuel efficiency. For this system, a new Power Control Unit (PCU) is developed. The feature of the PCU is downsizing, lightweight, and high efficiency. In expectation of rapid popularization of HV, the aptitude for mass production is also improved. The PCU, which plays an important role in the new system, is our main focus in this paper. Its development is described.

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INTRODUCTION

Mobility is a foundation to human social and economic life. Automotive vehicles are a key contributor to the mobility we enjoy today. However, automotive vehicles are also a contributor to issues of global warming and air pollution through tailpipe emissions of CO₂ and pollutants. To combat these issues, the urgent task of automotive development is environmental consciousness: high fuel efficiency, and low emissions. To solve this task, Toyota has been working to develop and popularize Hybrid Vehicles (HV). In 1997, 1st generation HV, the world's first mass produced HV, debuted. Its fuel efficiency was twice as much as gasoline engine vehicles. In 2003, a high voltage system using a boost converter was introduced to 2nd generation HV, which achieved high power and high fuel efficiency. In 2009, 3rd generation compact-class HV debuted. Increasing the engine displacement and the power of motor, both the power and fuel efficiency at high speed cruising was improved. Apart from the hybrid systems power train, Toyota is a leader in further improving efficiency through the reduction of size and weight of each unit produced.

Now the 4th generation HV, the first vehicle adopting TNGA (Toyota New Global Architecture), has debuted. Through the reduction in vehicle component size and weight, lowering the center of gravity and the stature, the 4th generation HV achieves high fuel efficiency (40.8km/L, JC08), and a pleasurable driving experience. For this hybrid system, a 4th generation power control unit (PCU) has been newly developed (Fig 1). The PCU has achieved further reduction in size, the weight and the electronic energy loss than previous generations. This paper explains the specific technologies of the 4th generation PCU to enable this improvement.



Fig.1. The 4th generation PCU

PCU SPECIFICATIONS AND STRUCTURE

HV System Specifications

The configuration of the new hybrid system is shown in Fig.2. The basic configuration is same as the previous model. However, a major change is the mounting position of the main and auxiliary batteries enables improvements in an increase in luggage area and the lower center of gravity of car. The battery mounting positions of 4th generation hybrid system is shown in Fig.3.

The specifications of the system are shown in Table.1. The fuel efficiency is improved around 18.2%(JC08) by following items.

- Improvement of thermal efficiency of gasoline engine
- Reduction in the electronic loss of HV system components
- Reduction in the current by the operation of motor at higher speed

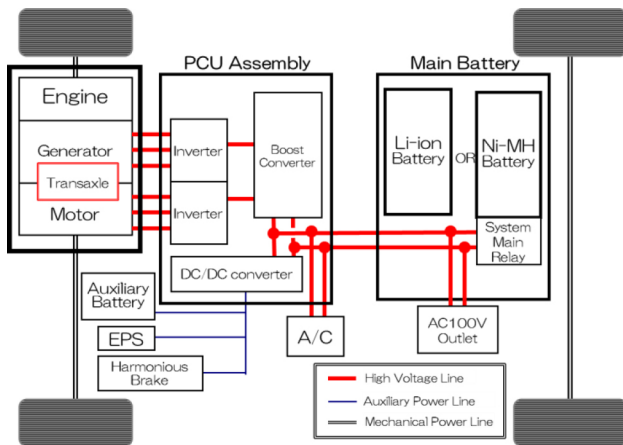
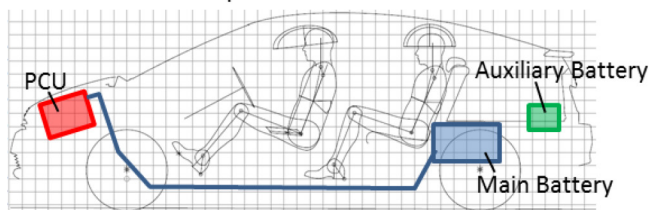
Fig. 2. Composition of 4th generation HV system

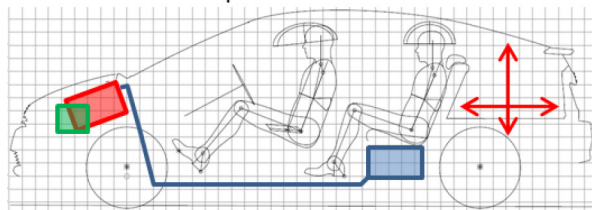
Table 1. Specifications of HV system

	Previous model (3 rd generation)	New model (4 th generation)
Boost Voltage	650V	600V
System max. output	100kW	90kW
Motor max. output	60kW	53kW
Motor max. rotation speed	13900rpm	17000rpm
Engine displacement	1.8L	1.8L
Engine max. output	73kW	73kW
Improvement ratio of fuel consumption	-	18.2%

<3rd Generation Compact-Class HV>



<4th Generation Compact-Class HV>

Fig. 3. Placement of 4th generation HV system

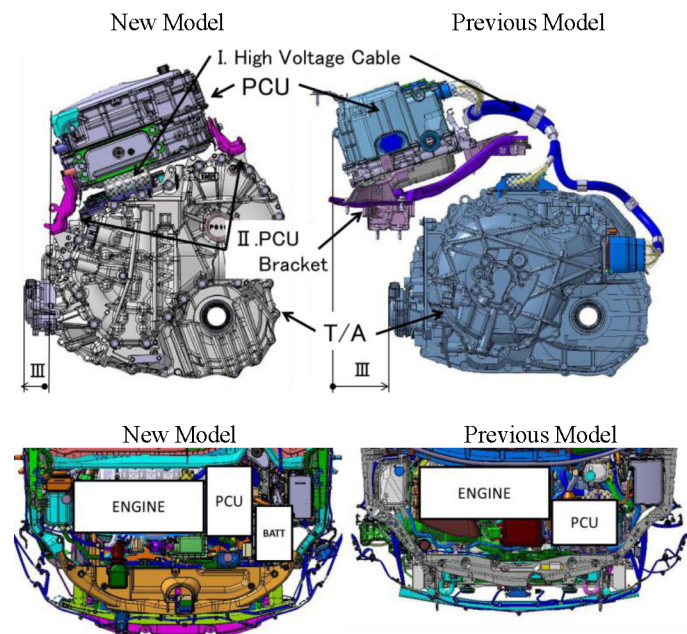
PCU Mounting

PCU mounting space, following the concept of TNGA, was not developed independently for every car type, but in consideration of applications to the many models. Thus, the PCU was mounted upon the transaxle (T/A) directly (Fig.4). Other than the above, the advantage of this mounting is following.

- Reduction in the length of the high voltage cable (lightweight)
- Simplification of the bracket (downsizing and lightweight)
- Robustness for front collision damage which lead to insulation deterioration of PCU

The main technical problem of mounting PCU on the T/A directly is engine vibration transferred to the PCU. To resolve this problem, following structures are adopted.

- To reduce transferred vibration, a rubber bushing is added to the bracket.
- To withstand the vibration, an absorbing structure has been adopted for signal connection terminals.
- Highly resistant electronic parts for vibration are adopted.
- To minimize resonance, the circuit board has been mounted with a narrow pitch using elastic washer to decrease stress from high rigidity housing.

Fig. 4. 4th generation PCU mounting

PCU Specification

Despite a decrease in total power output due to downsizing, the max output density has improved approximately 50% over the previous generation. The high output density is achieved through reduction of component weight and volume.

Table 2. PCU specifications [1]

	Previous model (3 rd generation)	New model (4 th generation)
Max total output	177.8kVA	162.2kVA
Max boost voltage	650V	600V
Motor max current	170Arms	180Arms
Generator max current	88Arms	75Arms
Weight	13.5kg	11.9kg
Volume	11.2Liters	6.8Liters
Max output density	15.9kVA/Liter	23.7kVA/Liter

According to the optimization of the PCU layout, the volume is reduced by 33% and the mass by 12%, as shown in Table.2. Main improvement items are following.

- I. Adoption of double-sided cooling module
- II. Reduction in capacitance of the capacitor through the improved boost converter controllability
- III. Removal of snubber circuit due to lowering voltage surge by the low inductance structure.

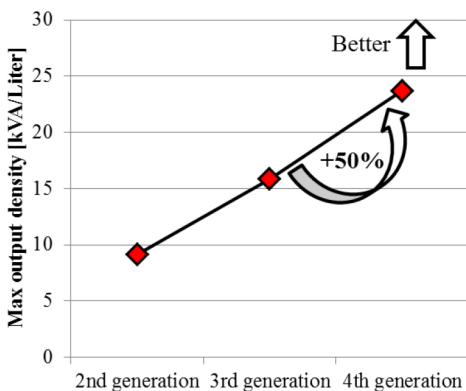


Fig.5. Comparison of specifications

PCU Structure

The PCU structure is shown in Fig.6. The PCU consists of inverter for generator/motor, boost converter and DC/DC converter. The new PCU structure has improved applicability between vehicle models and is downsized over previous generations.

The PCU has improved applicability over previous model due to the adoption of a new power module with. The double-sided cooling structure of the power module (Fig.7) is different from single-sided cooling structure used in previous generation. The double-sided structure improves the applicability of the cooling structure between vehicles platforms. The stack quantity of double-sided structure is adjustable to correspond with various vehicle sizes. So we call this assembly the Power Stack(P/S). The P/S consists of Power Cards, the cooler, insulating plates, thermal conductive grease, compression plate spring, and spacers. The Power Card(P/C) is the resin-molded package including IGBT (Insulated Gate Bipolar Transistor), FWD (Free Wheeling Diode), heat sink, and terminals.

A concern of the P/S is the increase in heat flux per unit area from integrating the power devices into the Power Cards. However this issue is mitigated through the improved heat transfer efficiency of the double-sided cooling structure of the P/S.

The PCU is also downsized from previous generations by functional integration. The fastening structure is changed from bolt tightening to welding; the quantity of fastening structures are decreased by 67%. To further save space, the diameter of bolts are decreased in size. The signal line wiring harnesses (W/H) are integrated with the each component. These changes improve manufacturability and enable downsizing of the PCU. With the improvements described above, the PCU achieved 33 % reduction in volume(Fig.8).

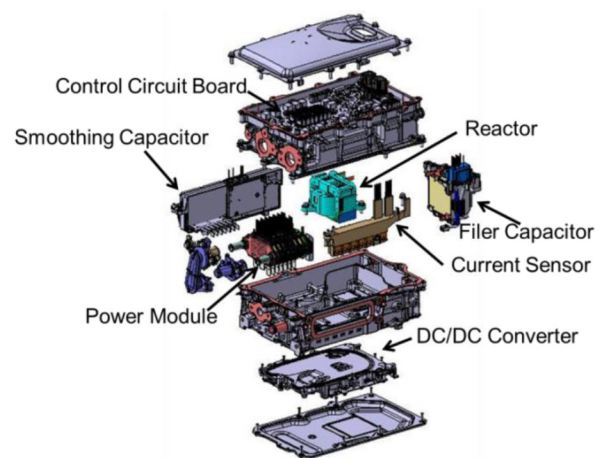


Fig.6. PCU Structure

Double-sided cooling structure Single-sided cooling structure

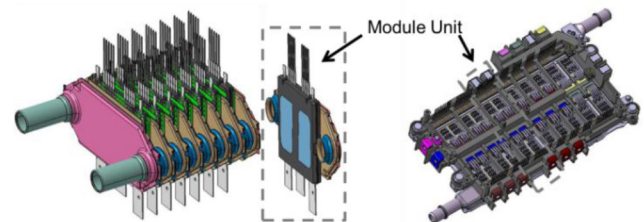


Fig.7. Cooling structure

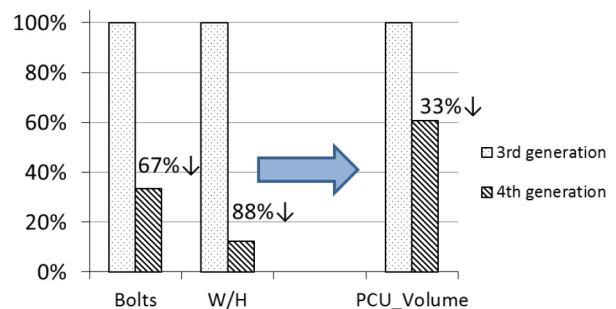


Fig.8. Comparisons of previous and new model

NEW TECHNOLOGY OF EACH COMPONENT FOR THE LIGHTWEIGHT AND DOWNSIZING

In this chapter, we discuss the development for the light weighting and downsizing of the PCU structure and components.

Power Module

Conventional Structure of Power Module (3rd generation)

Fig.9 shows the structure of the 3rd generation power module which adopted the single-sided cooling method. The power module consists of IGBTs, FWDs, insulating plates and a cooling plate. The cooling performance is improved by no interruption of heat conductive grease. But this module has been developed not suitably for the application to various vehicle models but for the compact-class