

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 Toyota Hybrid System II (THS-II) to improve fuel efficiency. For this system we have developed a new power control unit (PCU) that features size reduction, light weight, and high efficiency. We have also improved the ability to mass produce these units with the expectation of rapid popularization of HV. The PCU, which plays an important role in THS-II, is our main focus in this paper. Its development is described.

INTRODUCTION

Mobility is the base of the human society and economic activity, and widely contributes to society. Meanwhile, it has also brought the important issues of global warming and air pollution induced by CO₂ emissions. Therefore, the development of environment-conscious vehicles that are fuel-efficient and have low-emissions is an urgent task today. To solve these issues, Toyota has been working to develop and popularize Hybrid Vehicles (HV). The debut of 1st generation HV-the world's first mass produced HV- was in 1997, doubled fuel efficiency compared with the gasoline vehicles. In 2003, a high voltage system using a boost converter was introduced as 2nd generation HV, achieving high-power and low-fuel consumption.

The new compact-class HV has been developed this time as a leader of 3rd generation HV, achieving the highest global standards, 50 mpg (US comb.) with high-power and low-fuel consumption. This HV system has the newly developed 3rd generation power control unit (PCU), and is optimized to make the most of the performance of a 1.8L engine and a high-speed, high-

power motor. This PCU contributes to downsizing the motors by increasing the maximum system voltage from 500V to 650V, also improving the system efficiency. A direct cooling type has been employed into cooling system of Intelligent Power Module (IPM), achieving size reduction and lighter weight by greatly improving the cooling efficiency. This size reduction and lighter weight easily enables the PCU adoption into multiple models, enabling the rapid popularization of HV. In addition, the structure design focused on ease of mass production and increased quality. This paper explains the specific technology of this 3rd generation PCU.



Fig. 1 The 3rd generation PCU

PCU SPECIFICATIONS AND STRUCTURE

HV System Specification – The new HV system has increased the maximum voltage of the boost converter from 500V to 650V, as shown in Fig.2. The higher voltage enabled the use of a high-speed, high power of motor with motor speed reduction device. The higher boost voltage leads to downsizing and system efficiency improvement. Table1 shows the specifications of HV system. Motor maximum output has been increase to 60kW, improving the power performance.

Higher system efficiency improves fuel consumption by around 14% at 100km/h.

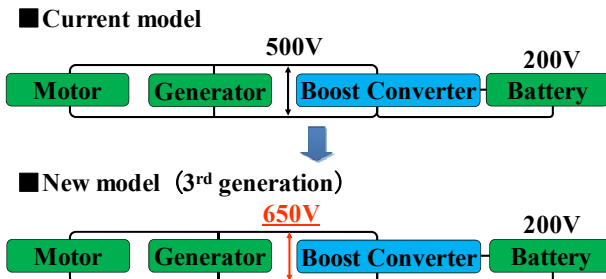


Fig. 2 Composition of HV system

Table 1 Specification of HV system

	Current model	New model
Boost Voltage	500V	650V
System max output	82kW	100kW
Motor max output	50kW	60kW
Motor max rotation speed	6000rpm	13000rpm
Improvement ration of fuel consumption	-	14% @100km/h

PCU Specification - The table2 shows the PCU specifications. The PCU max output has been improved around 10%. The RMS, current of the motor inverter has been reduced from 230A(rms) to 170A(rms) by using higher boosted voltage and the motor speed reduction device. The reduced current enables loss reduction and power semiconductor downsizing. In addition, volume is reduced by 37% and mass by 36% due to the newly developed IPM direct cooling, thinner capacitor film,

Table 2 Specification of PCU

	Current model	New model
Max Total Output	KVA	162
Max Boost Voltage	V	500
Generator max current	Arms	75
Motor max current	Arms	230
Incoporated main components	-	Boost converter Generator inverter Motor inverter DC/DC converter A/C inverter
Weight	kg	21
Volume	Liters	17.7

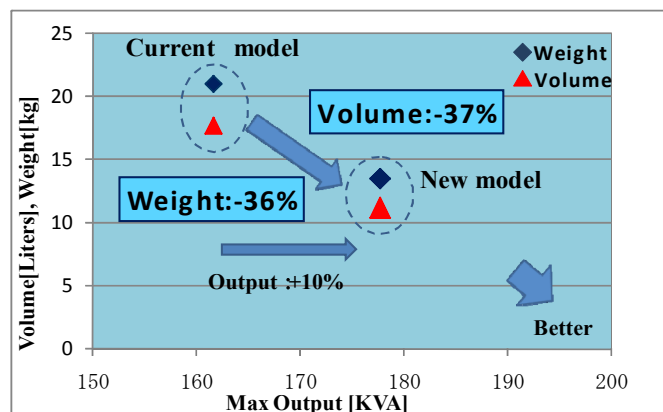


Fig. 3 Size reduction, light weight of New PCU

improvement of DC/DC converter power density and the optimization of the layout of units, as shown in Fig3.

Fig4 shows the electrical loss comparison of the PCU for the current model and that for the new model. The loss has been decreased by 25% by utilizing trench-gate type, thinner IGBTs, switching speed improvement and current reduction by breakdown voltage improvement, and optimization of switching frequency.

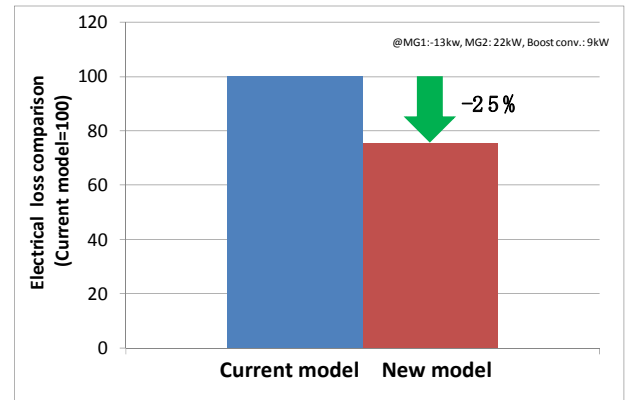


Fig. 4 PCU Electrical loss Comparison (vs. Current model)

PCU Structure for Mass Production Improvement - This figure below shows the PCU structure diagram. PCU consists of inverter for generator/motor, boost converter and DC/DC converter. The size and weight of the 3rd generation PCU structure is reduced by integrating similar parts that used to be separate. Ease of mass production is increased by reducing the number of components, assembly points, and the number of grease spreading. The current model had a separate IPM for generator/motor and one IPM for boost converter. In the new model these IPMs have been integrated. Using the direct cooling type eliminated the grease between IPM and the case, improving the cooling efficiency. Grease spreading and bolt tightening were omitted by integrating the reactor and lower case.

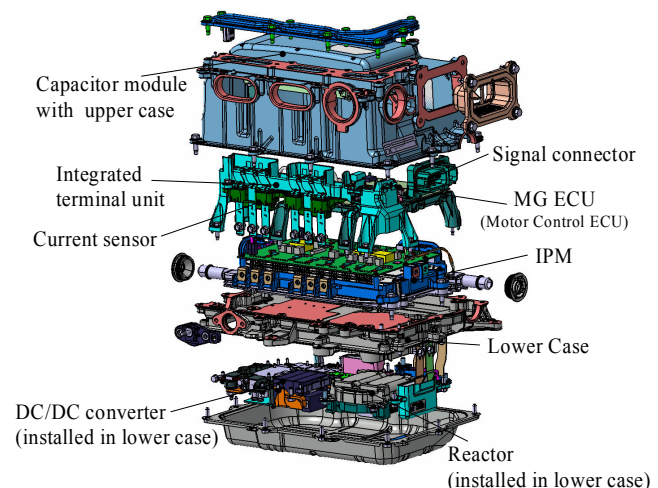


Fig. 5 Structure of the 3rd generation PCU

In addition, the number of components was reduced by integrating generator /motor /input terminal units. A signal connector eliminated the wiring harness and its brackets by directly implementing the signal connector to the MGECU.

Consequently, compared to the current model the number of components in the assembly process (including IPM) has been reduced by 23%, bolts by around 34%(excluding MGECU), and the number of grease spreading from 3 times to 1 time. In addition, assembly automation ratio has been boosted to 82% by the structure design. The result is it is easier to mass produce the PCU.

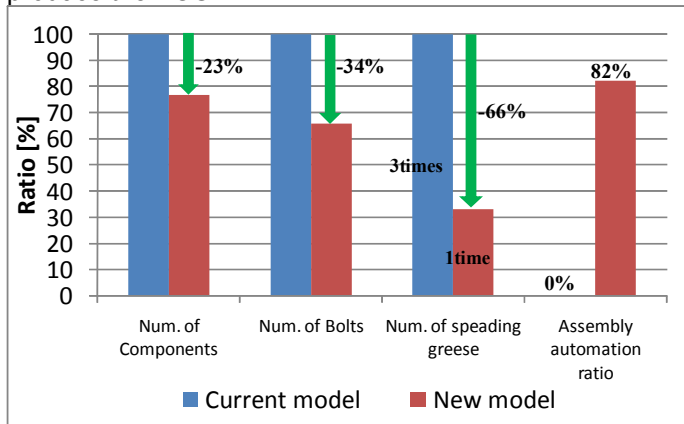
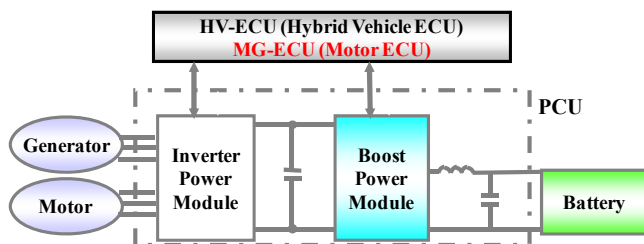


Fig. 6 Improvement of the mass productivity

Inverter, Boost Converter Controller - The current model had the Motor/Generator control ECU (MG-ECU), controlling MG1/MG2 inverter and boost converter, integrated with the ECU (HV-ECU) for the vehicle control. Therefore a large number of signal wires controlling PCU needed to be arranged in the engine compartment. The new model combines the MG-ECU and PCU, eliminating the signal wires and reducing weight.

Current model



New model

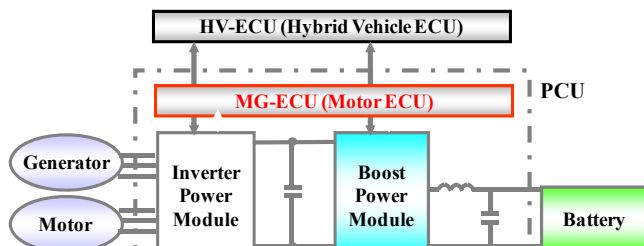


Fig. 7 Inverter, Boost Converter Controller

NEW TECHNOLOGY OF EACH COMPONENT

Intelligent Power Module (IPM) - The IPM consists of the high voltage power module and the control circuit. The power module contains the heat sink for improving the cooling performance, the insulating substrate for assuring insulation, and the power semiconductor, Insulated Gate Bipolar Transistor (IGBT) and Free Wheel Diode (FWD) for switching large current by an external control signal. Since the 1st generation, the IPM had been mounted with grease onto the heat sink (Fig.8). However in the 3rd generation the cooling efficiency has been improved by developing the direct cooling type (Fig.9). Also a new technology has been established, which assures a thermal shock resistance without using copper alloy with low coefficient of linear expansion.

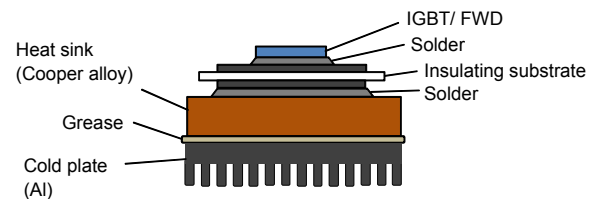


Fig. 8 A cross section of the 2nd generation module

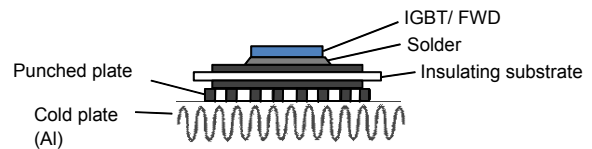


Fig. 9 A cross section of the 3rd generation module

Power Module - The 2nd generation IPM used a boost converter to make it possible to increase the input voltage into the IPM. Consequently, the current output of the IPM decreased. Therefore the number of IGBTs decreased which downsized the IPM.

To achieve a further downsizing of IPM, it was necessary to reduce the size of power semiconductors by improving the cooling efficiency as well as reducing power loss of the power semiconductors.

As mentioned before, in the previous cooling structure, the grease between a heat sink and a cold plate had high thermal resistance (Fig 10).

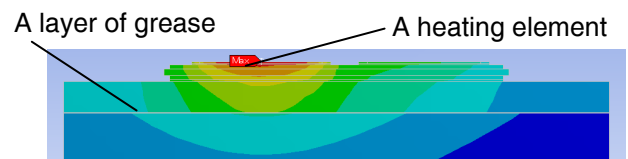


Fig. 10 Heat distribution of the conventional cooling structure (2nd generation)