

Development of New IGBT to Reduce Electrical Power Losses and Size of Power Control Unit for Hybrid Vehicles

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ABSTRACT

One way to improve the fuel efficiency of HVs is to reduce the losses and size of the Power Control Unit (PCU). To achieve this, it is important to reduce the losses of power devices (such as IGBTs and FWDs) used in the PCU since their losses account for about 20% of the total loss of an HV. Furthermore, another issue when reducing the size of power devices is ensuring the thermal feasibility of the downsized devices. To achieve the objectives of the 4th generation PCU, the following development targets were set for the IGBTs: reduce power losses by 19.8% and size by 30% compared to the 3rd generation. Power losses were reduced by the development of a new Super Body Layer (SBL) structure, which improved the trade-off relationship between switching and steady-state loss. This trade-off relationship was improved by optimizing the key SBL concentration parameter. Size was reduced by adopting a new environment-friendly IGBT surface electrode structural design that enabled double-sided solder packaging. This approach ensured thermal feasibility caused by the higher current density due to the smaller design. A Reduced Surface Field (RESURF) structure was adopted for edge termination. To improve the robustness of the breakdown voltage, an optimum RESURF concentration balance was designed which also contributed to the IGBT's downsizing. These developments successfully reduced both the loss and size of the IGBTs, thereby reducing the size and loss of the new PCU, and helping to improve the fuel efficiency of Toyota's 4th generation HVs.

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INTRODUCTION

After the most recent wave of global motorization, vehicles have become a key part of the foundation supporting societies and economies around the world. However, vehicles are also a reason behind environmental issues such as global warming due to CO₂ emissions and air pollution. For this reason, automakers regard the development of Hybrid Vehicles (HVs) and other fuel-efficient, low-emission environmentally friendly vehicles as an urgent task. Toyota Motor Corporation has a long history of developing and popularizing fuel efficient HVs as one measure to help resolve these issues. It is also making progress in the development of Electric Vehicles (EVs), Plug-in Hybrid Vehicles (PHVs), and Fuel Cell Vehicles (FCVs). All of these vehicles are powered by motors that are controlled by a Power Control Unit (PCU). Figure 1 shows the system structures of some vehicle types that use a PCU. Hybrid technology is widely adopted in each vehicle type.

The role of the PCU is to convert Direct Current (DC) from the battery or Fuel Cell (FC) stack into Alternating Current (AC), for the motor. In addition, when the system is regenerating energy, the PCU

also converts AC from the motor to DC, and supplies that current to the battery (Fig. 2). Therefore, reducing the power conversion loss of the PCU is important to improve the fuel efficiency of an HV. As shown in Figure 3, the power devices used in the PCU of a two-motor HV with a boost converter include 14 Insulated Gate Bipolar Transistors (IGBTs) and 14 Free Wheeling Diodes (FWDs).

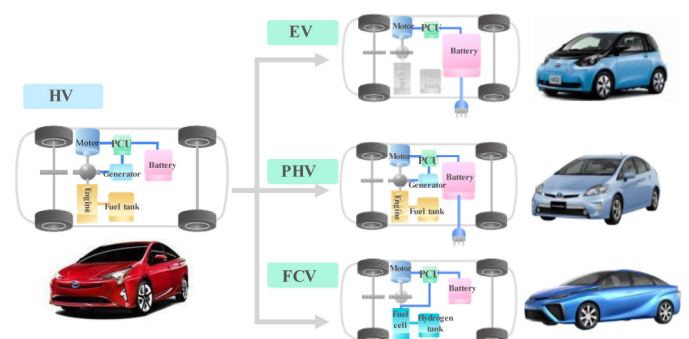


Figure 1. Outline and structure of vehicles installed with a PCU

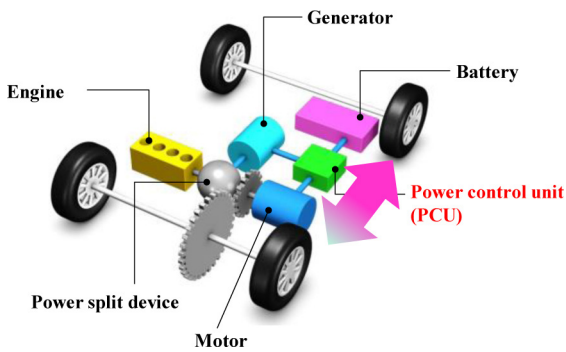


Figure 2. The Toyota Hybrid System (THS).

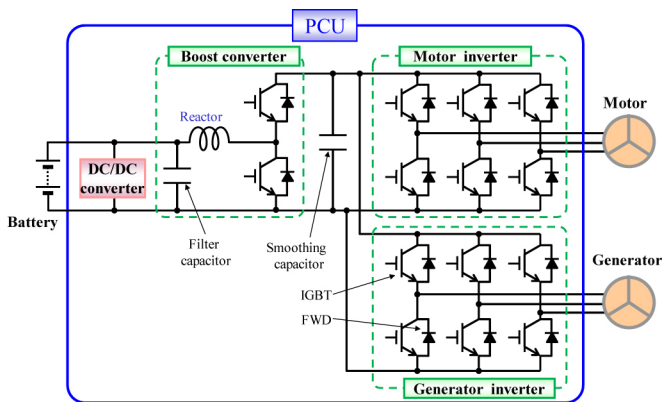


Figure 3. Internal circuits of PCU.

Power losses of the IGBTs' and FWDs' used in the PCU account for about 20% of the total losses of an HV (Fig. 4). Therefore, higher PCU efficiency can be achieved by reducing power device losses.

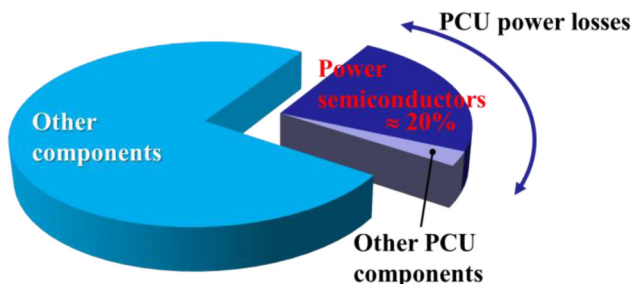


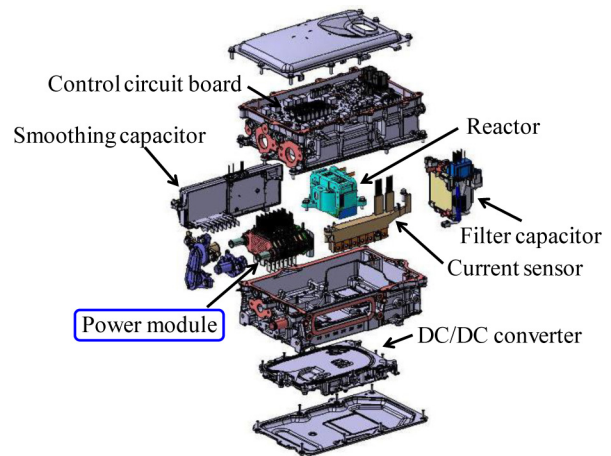
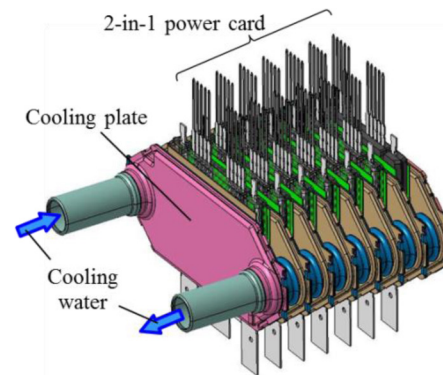
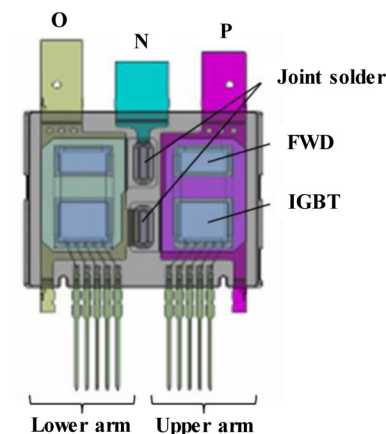
Figure 4. Breakdown of power losses of an HV.

Measures to reduce the size and weight and to lower the center of gravity and installation positions of powertrain components in the fourth generation of Toyota's HVs have helped to enhance driving enjoyment while also improving fuel efficiency up to 40.8 km/l in the JC08 test cycle. This paper describes the new structure of the 4th generation IGBTs that were developed to help further reduce the size, weight, and loss of the HV system.

IGBT INSTALLATION LOCATIONS, REQUIREMENTS, AND DEVELOPMENT TARGETS

This section describes the general installation locations and requirements for IGBTs and the development targets of the 4th generation PCU. Figure 5 shows the internal structure of the 4th

generation PCU. The IGBTs are mounted on a 2-in-1 power card structure of the power module inside the PCU. Two sets of IGBT and FWD pairs are located on the upper and lower arms (Figs. 6 to 8).

Figure 5. Structure of 4th generation PCU.Figure 6. Structure of 4th generation power module.Figure 7. Structure of 4th generation 2-in-1 power card.

When the PCU converts DC to AC or AC to DC, the current flow is repeatedly switched ON and OFF by the IGBTs. Power losses that occur during this switching process are converted to heat. There are two types of loss: steady state loss when the IGBT is switched ON and the current flows through it, and switching loss that occurs during the switching process (Fig. 9). It is important to reduce both of these losses. Furthermore, reducing the size of the IGBTs also helps to