

Small Size Power Control Unit for 2020 Model Year FIT

Hitoshi NISHIO¹Yasuhiko KONDO²Yuichiro UENO²Kenichi NONAKA³Yukiya KASHIMURA³Kenichi TAKEBAYASHI³

ABSTRACT

Honda has developed a third-generation power control unit for compact cars for the 2020 model year FIT.

Downsizing was achieved by employing RC-IGBTs in the power semiconductors used in the power module, which is the main component of the power control unit. This reduced the longitudinal length by 12%. The control boards that were divided into a motor ECU (control board) and a gate driver (drive circuit board) in the second-generation unit were integrated to reduce the wire harnesses that connect each board, achieving further downsizing. The capacitance of the capacitor was reduced by 50% by enhancing the current followability of voltage control unit control. The application of these technologies realized development of a PCU with output power up to 267 kVA that achieves a volume of 8.5 L even with the 12 V DC-DC converter incorporated into the PCU, which enables mounting in a compact car.

1. Introduction

Global warming and air pollution due to CO₂ emissions while driving continue to be issues associated with the spread of automobiles.

One means of addressing these issues is the electrification of automobiles to reduce exhaust gas. In 2013, Honda developed a two-motor hybrid system named the SPORT HYBRID Intelligent Multi-Mode Drive (i-MMD) system⁽¹⁾. The i-MMD system realizes the three drive modes of EV drive mode, which drives the vehicle by the motor mainly using electric power supplied from a high-voltage battery; Hybrid drive mode, which drives the vehicle by the motor using electric power supplied from the engine operating as a generator; and Engine drive mode. The power train consists of an engine, an electric coupled Continuously Variable Transmission (CVT) incorporating traction and generator motors, a Power Control Unit (PCU), and an Intelligent Power Unit (IPU).

The PCU functions to convert the electric power from the high-voltage battery, traction motor, and generator motor, and influences the motor output power and fuel

economy. The first-generation two-motor hybrid (GEN1) PCU was mounted on a frame fixed to the body inside the engine compartment.

A second-generation two-motor hybrid (GEN2) PCU was developed in 2016 to enhance ease of installation inside the engine compartment and support higher power density⁽²⁾. This GEN2 PCU was mounted directly on the transmission to achieve a compact layout within the engine compartment. This made it possible to mount a 12 V battery inside the engine compartment of various vehicles, thereby contributing to expanded cabin space.

A third-generation two-motor hybrid (GEN3) PCU was developed in 2018. This GEN3 PCU incorporated the 12 V DC-DC converter, which was built into the IPU mounted in the rear of the vehicle for the GEN2 PCU, into the PCU mounted in the engine compartment⁽³⁾.

Vehicles equipped with Honda's i-MMD system have conventionally been medium- and large-sized vehicles such as sedans and SUVs. In order to further expand electrification, Honda pursued development with the goal of mounting in compact models such as the FIT (Fig. 1). Honda also set vehicle development targets for compact

¹ Innovative Research Excellence Power Unit & Energy

² Honda Motor Co., Ltd.

³ Keihin Corporation

cars based on its original “Man Maximum, Machine Minimum” philosophy that seeks to maximize the space used by humans, and incorporated the 12 V DC-DC converter, which was built into the IPU mounted in the rear of the vehicle in the GEN2, into the PCU mounted in the engine compartment. Compact cars have little available mounting volume inside the engine compartment as shown in Fig. 2, so the GEN2 system could not be mounted as is.

This called for an even smaller third-generation two-motor hybrid (GEN3S) PCU for compact cars⁽⁴⁾.

The development target was set as a configuration that reduces the longitudinal length by 10% and achieves a mounting volume of 8.6 L while incorporating the 12 V DC-DC converter.

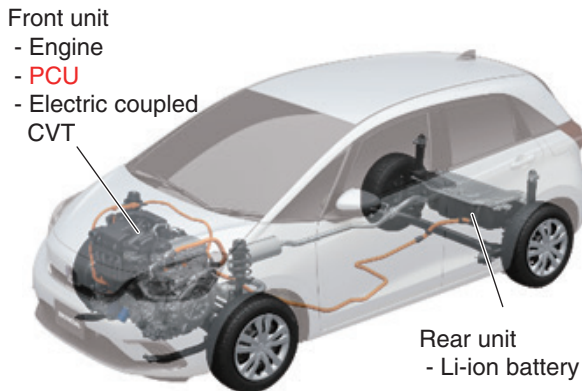


Fig. 1 Position of PCU in SPORT HYBRID i-MMD

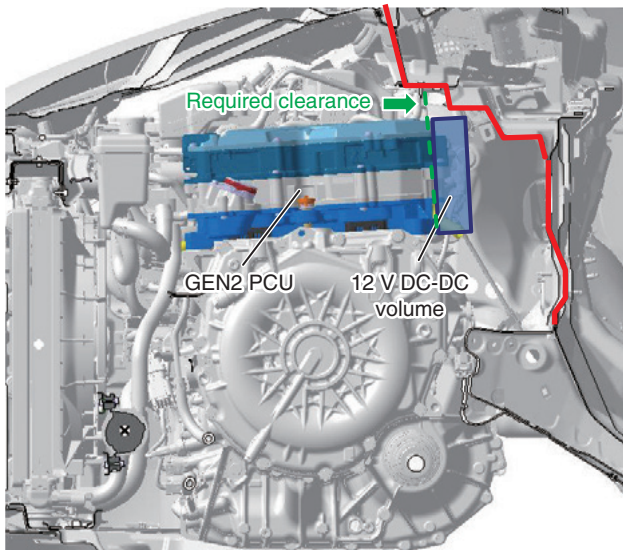


Fig. 2 Layout of PCU in SPORT HYBRID i-MMD

Table 1 Comparison of GEN2 and GEN3S specifications

Item	GEN2	GEN3S
Maximum total output power [kVA]	388	267
Maximum boost voltage [V]	700	570
Motor maximum output current [Arms]	320	270
Generator maximum output current [Arms]	155	155
DC-DC converter output voltage [V]	-	12
DC-DC converter maximum output current [Arms]	-	140
Volume [L]	8.9	8.5
Weight [kg]	14.3	13.4

2. Introduction of Small-size PCU for FIT

Figure 3 shows the PCU components.

The main component of the GEN3S PCU is an Intelligent Power Module (IPM) consisting of two inverters that drive the motors, a VCU that controls to the optimal voltages, and a control board (ECU) that performs integrated control of those parts. The IPM layout arranges the traction motor, generator motor, and VCU power semiconductors over the entire top surface of the water jacket, with the control board placed directly on top of those parts. A voltage smoothing capacitor, an inductor (booster circuit part), and a current sensor for detecting energizing current are also provided, and a 3-phase connector for direct connection with the motor built into the transmission is located close to the side surface. Also, the above-mentioned 12 V DC-DC converter is incorporated into the PCU.

As the goal is mounting in compact cars, the available mounting space in the vehicle is narrower than before. In addition, Table 1 shows that the demanded output power is less than that for GEN2.

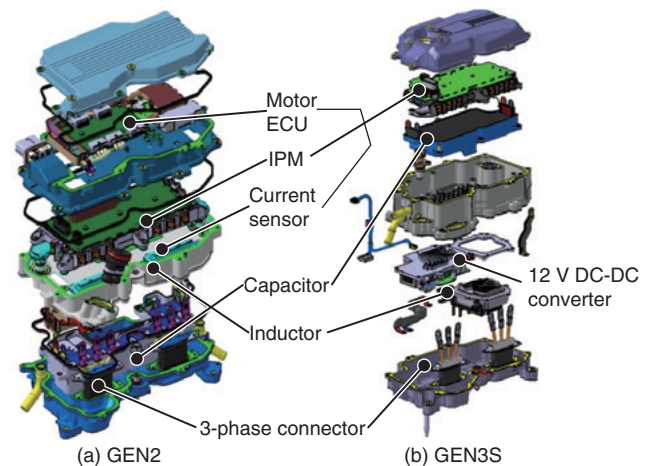


Fig. 3 Exploded view of GEN2 and GEN3S PCUs

The internal parts can be downsized in accordance with the demanded specifications, but further size reduction is needed for each part in order to newly incorporate the above-mentioned 12 V DC-DC converter. Therefore, the increase in parts incorporated into the PCU was supported by integrating components to reduce the number of parts. As a result, the longitudinal dimension was reduced by 12% and, even incorporating the 12 V DC-DC converter, the volume was reduced by 4.4% compared to the GEN2, which achieved the targets (Fig. 4).

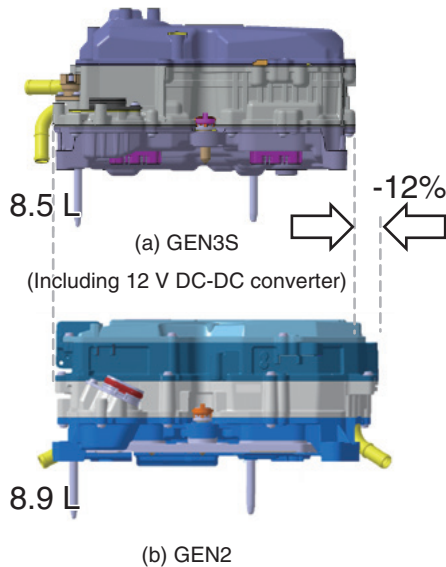


Fig. 4 Comparison of GEN2 and GEN3S sizes

3. Main Technologies

PCU components with a large space factor include the power module (PM), capacitor, control board, and the wire harnesses used to transmit the various signals.

The PM has semiconductors arranged in a plane, so, including the housing that comprises the circuit, this determines the longitudinal length of the PCU. In addition, the capacitor accounts for a large portion of the volume of the PCU lower part in the GEN2, so this volume was reduced in order to incorporate the 12 V DC-DC converter.

Furthermore, the control boards were divided in the GEN2, so these elements including the wire harnesses were reduced and parts were integrated to downsize the PCU.

The main technical developments are the following three points:

- (1) Adoption of reverse-conducting insulated gate bipolar transistors (RC-IGBTs) as the semiconductors mounted in the PM;
- (2) Integration of the control boards; and
- (3) Reduction of the capacitor capacitance.

3.1. Power Module Downsizing

High output power has been demanded of traction motors for hybrid systems, so IGBTs and diodes have been used as the silicon power semiconductors that function as the drive switching elements. The size of the PM in which these semiconductors are mounted determines the length of the PCU, so RC-IGBTs were adopted in the GEN3S PCU.

Figure 5 shows an overview of the RC-IGBT structure.

Conventional inverters for vehicles mount the IGBT and diode separately, with the temperature sensor that measures the semiconductor temperature mounted over only the IGBT.

The newly developed RC-IGBT is a new semiconductor device that has both IGBT and diode areas within the same semiconductor as shown in Fig. 5 (b). This enables the IGBT to also operate as a diode. By providing IGBT and diode areas within the same semiconductor, the breakdown voltage holding areas (guard ring) for each of the conventional IGBT and diode semiconductors can be shared, which reduced the semiconductor size.

In addition, the conventional configuration had a temperature sensor for overheat protection on the IGBT side but not on the diode side, so overheat protection for the diode was performed by estimating the temperature from the temperature sensor on the IGBT side. This method, however, has large estimation deviation compared to direct measurement of the semiconductor temperature using a temperature sensor. This made it necessary to limit the operating temperature range in consideration of this deviation relative to the upper limit operating temperature of the semiconductor, which called for a larger diode size than necessary. Use of an RC-IGBT extended temperature protection using the mounted temperature sensor to the diode area, which allowed reduction of diode size to the least size needed.

Figure 6 shows the effects. Sharing the guard ring needed by each semiconductor reduced the guard ring area by 33% and the diode area was also reduced by 64%, achieving a 30% reduction in the overall semiconductor area. This reduced the longitudinal length of the PM by 12%, which contributed to downsizing the PCU.

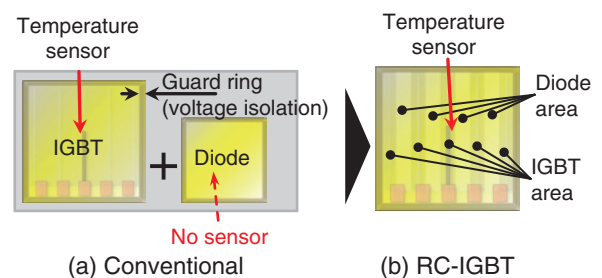


Fig. 5 Comparison of conventional chips and RC-IGBT chip structures

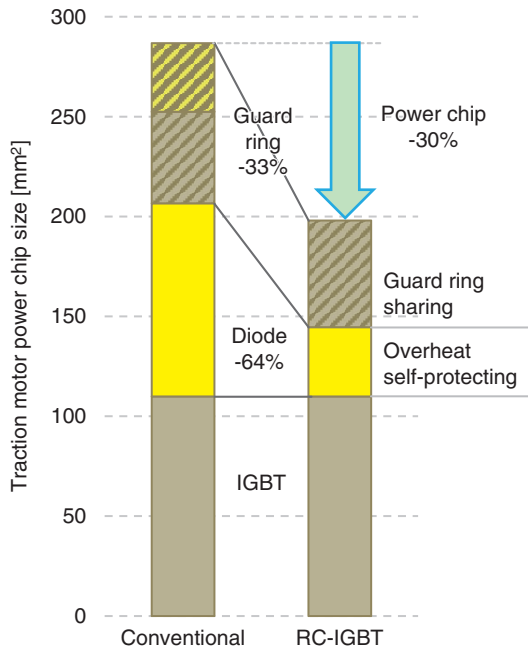


Fig. 6 Comparison of conventional and RC-IGBT semiconductor areas

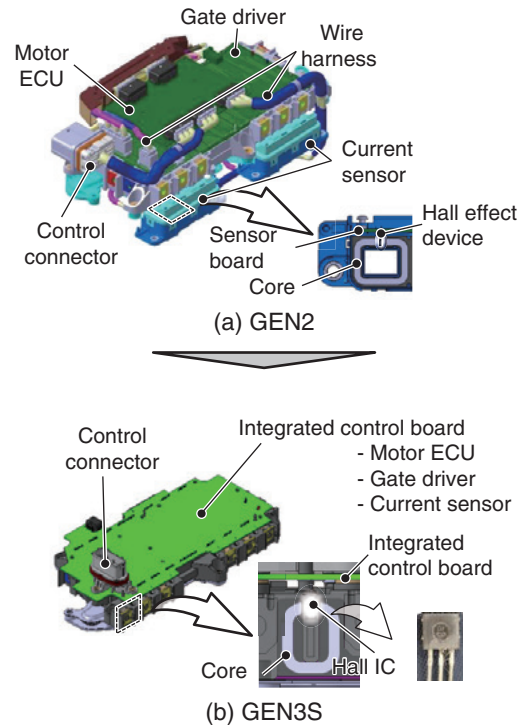


Fig. 7 Comparison of GEN2 and GEN3S circuit structures

3.2. Downsizing through Integration of Control Boards

The IPM sends commands from the motor ECU to the gate driver, and the VCU, motors, and generator inverter are driven according to those commands. In addition, current and voltage sensors for control are also connected to the IPM. In the GEN2 PCU, these parts were mounted on separate boards and connected to the motor ECU via wire harnesses. Connection with an external ECU consisted of connection to the PCU via a control connector, and then connection with the boards inside the PCU via wire harnesses. Figure 7 shows a comparison with the conventional structure.

When developing the GEN3S PCU, these parts were integrated to reduce the PCU volume.

The connector that receives external commands was mounted directly on the board to reduce the wire harnesses. This connector is connected to the integrated control board by signal pins.

The motor ECU and the gate driver were combined into an integrated control board. This board was achieved through such advances in circuit mounting technology as higher density compared to the conventional gate driver, and use of a single-package voltage sensor circuit. The previously divided motor ECU and gate driver boards were also integrated and mounted on the PM.

In addition, the conventional current sensor consisted of a magnetic flux core, a Hall element for measuring magnetic flux, and a board that controls these parts. However, this current sensor function is realized by the combination of

a magnetic flux core built into the PM case and a Hall IC mounted on the integrated control board. The structure has seven sensors as before, and was realized by the precision of collective assembly and development of technology for correcting the sensors post-assembly. This reduced the height by 50% (Fig. 8).

3.3. Reduction of Capacitor Capacitance

While the capacitor accounted for half of the overall height in the GEN2 PCU, enhancement of VCU control technology enabled a 50% reduction of capacitance. Thermal issues associated with capacitance reduction were addressed by modifying the cooling channel.

The capacitor functions as the VCU voltage source. It is

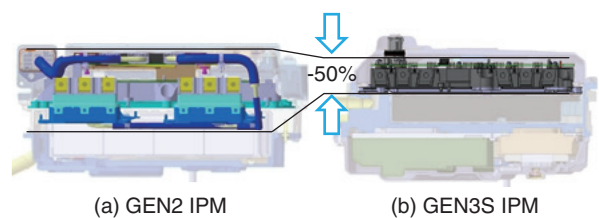


Fig. 8 Comparison of GEN2 and GEN3S IPM structures

not an ideal power source, however, and when the inductor current fluctuates, the voltage also fluctuates due to the influence of the internal impedance. This voltage fluctuation influences the control, with the result that the current fluctuation increases. The voltage fluctuation width is specified to help prevent an increase in the inductor current fluctuation, and a capacitor with a large capacitance was used in the GEN2 PCU to smooth the voltage.

To support the increase in voltage fluctuation, current control, cascade control of voltage control, a disturbance observer, a duty estimation calculator, and a duty cancel calculator were newly developed for VCU control. Use of these technologies suppressed the voltage resonance gain over a wide frequency range and reduced the AC component of the load current. This VCU control enabled capacitance reduction by 50% as shown in Fig. 9.

Reducing the capacitance of the capacitor, however, increases the internal impedance. This increases the self-heating value, but was addressed by modification of the cooling channel. The capacitor has a low heating value, so it is cooled by natural heat dissipation instead of water, and is susceptible to heat from the external environment. As the capacitor materials determine the heatproof temperature of the capacitor, the total of the temperature heated by the environment and the self-generated temperature due to energization, which are temperature rise factors, should be the heatproof temperature or less. Since the PCU is mounted in the engine compartment, it has a large temperature rise due to the environment.

In the structure used since the GEN2 i-MMD with the PCU mounted directly on the transmission, the capacitor was located below the IPM as shown in Fig. 10 (a), making it susceptible to transmission and engine heat. The GEN3S PCU uses a structure that surrounds the capacitor with a cooling channel as shown in Fig. 10 (b) to reduce the influence of this external environment heat.

In the GEN2 structure, cooling water entered from the vehicle front side, passed through the PCU interior, and was discharged from the vehicle rear side. In contrast, the GEN3S collects the cooling water inlet and outlet on the

vehicle front side, which allowed reduction of the cooling pipes inside the engine compartment and helped to reduce the occupied engine room space.

The capacitor is not directly water-cooled, but is surrounded by the cooling channel, which helps to prevent external thermal influence. Figure 11 gives an overview of the reduction in capacitance.

Capacitor self-heating increased by two times or more, but the external thermal influence was reduced by 46%, so the upper temperature reached could be reduced to less than or equivalent to that of the conventional structure.

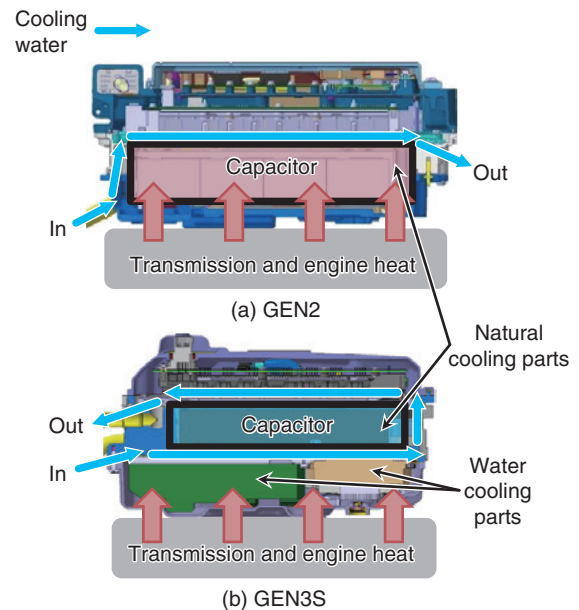


Fig. 10 Difference of capacitor structures

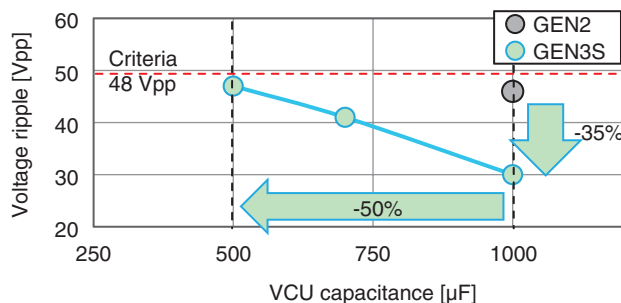


Fig. 9 Comparison of GEN2 and GEN3S VCU capacitance

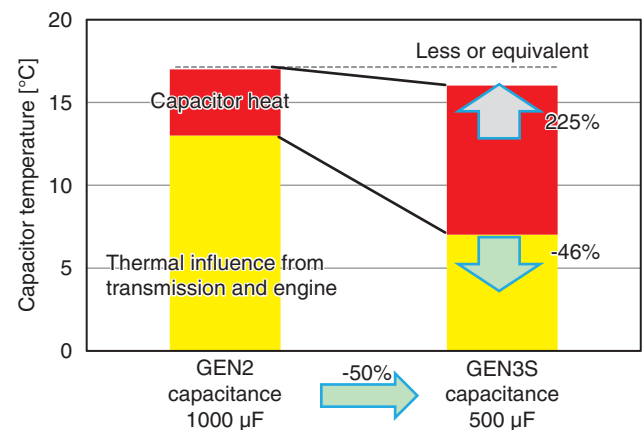


Fig. 11 Comparison of GEN2 and GEN3S capacitor temperatures

4. Conclusion

The following technical developments achieved the PCU downsizing targets with the goal of mounting the i-MMD system in a compact car.

- (1) Adoption of RC-IGBTs as the power semiconductors reduced the longitudinal PM length by 12%.
- (2) Integration of the control boards and current sensors reduced the IPM height by 50%.
- (3) Development of VCU control and adoption of a new cooling structure reduced the capacitance of the capacitor by 50%.

These technologies realized development of a PCU with output power up to 267 kVA that achieves a volume of 8.5 L even with the 12 V DC-DC converter incorporated into the PCU, thereby enabling mounting in a compact car.

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■ Author ■



Hitoshi NISHIO



Yasuhiko KONDO



Yuichiro UENO



Kenichi NONAKA



Yukiya KASHIMURA



Kenichi TAKEBAYASHI