

Development of Power Control Unit for 2009 Model Year INSIGHT

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ABSTRACT

A Power Control Unit (PCU) has been developed for the Integrated Motor Assist (IMA) system employed in the new model INSIGHT. The development aimed to reduce the overall size, height, and weight of the PCU in order to realize a layout that positioned it under the floor of the rear trunk. Contiguous positioning of the DC-DC converter and the inverter in the PCU has reduced the area required for mounting the unit, in addition to enabling the DC-DC converter input filter to be removed and the number of terminals reduced. This has contributed to the realization of size and cost reductions. The total height of the DC-DC converter has been reduced through the use of copper wire printed on a substrate for part of the main transformer winding wire, contributing to the reduced height of the PCU. The use of a smoothing capacitor with the electrostatic capacity reduced by half enabled reductions in size and cost. In addition, the use of beam leads for the internal wiring of the transfer-molded power module (TPM), together with connections made by direct lead bonding (DLB), enabled the production process to be simplified and costs reduced.

1. Introduction

Today, there are further heightened demands for technology to reduce the amount of CO₂ contained in automobile emissions and enhance fuel economy in order to reduce the greenhouse gases that bring about global warming. Hybrid systems are one method used to address these issues, and the proprietary IMA system developed by Honda has been installed in the first-generation INSIGHT, CIVIC Hybrid, and ACCORD Hybrid. The IMA has lower fuel consumption than conventional gasoline-fueled vehicles, and can be expected to yield a CO₂ reduction effect if its use becomes widespread. This will necessitate a simultaneous reduction in cost and enhancement of marketability as a product, and there is demand, therefore, for a PCU that can satisfy those conditions.

Technologies to enhance product marketability (reduced size, reduced weight) and achieve lower cost are used in the PCU, the unit component of the IMA that handles power conversion, and these technologies are described in the following.

2. Development Goals

Development of the IMA system installed in the first-generation INSIGHT, CIVIC Hybrid, and ACCORD Hybrid was carried out with a focus on fuel economy performance, and the system has evolved accordingly. Apart from the first-generation INSIGHT, these vehicles are built on four-door sedan bodies and the intelligent power unit (IPU) is installed behind the rear-seat backrests. Because of the IPU layout, a hole could not be opened through the IPU to enable configuration of a continuous open space from the trunk through to the rear passenger compartment. Therefore, cars equipped with the conventional IMA did not support loads consisting of long cargo items.

The IPU for the IMA installed in the new model INSIGHT was intended for use in a subcompact-sized five-door hatchback body with split-folding rear seatbacks. In order to realize this layout, development used the previous IMA technology as a base while seeking to reduce size and weight as much as possible, and it was necessary to install the unit under the floor of the trunk

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room (Fig. 1).

In conjunction with smaller size and lower weight, a reduction in the PCU cost was also sought as a development objective.

Reduced size, weight, and cost of the PCU were sought by various means. The internal layout of the PCU was optimized, shared parts were adopted, and new structures were adopted for the inverter and DC-DC converter.

Figure 2 shows the exterior appearance of the IPU. Figure 2(a) shows the former structure, and Fig. 2(b) shows the new structure.

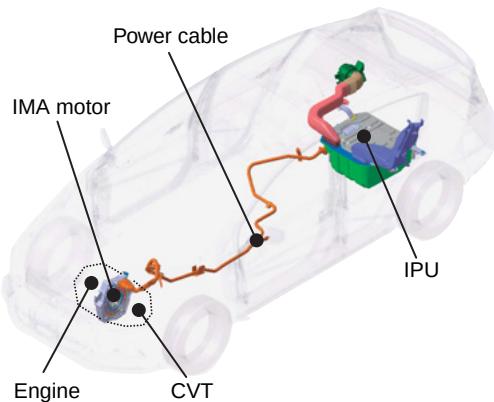


Fig. 1 Configuration of IPU

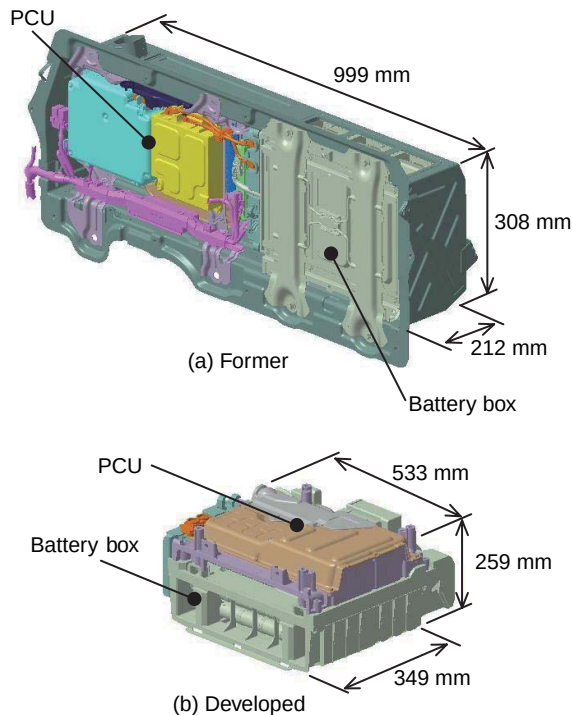


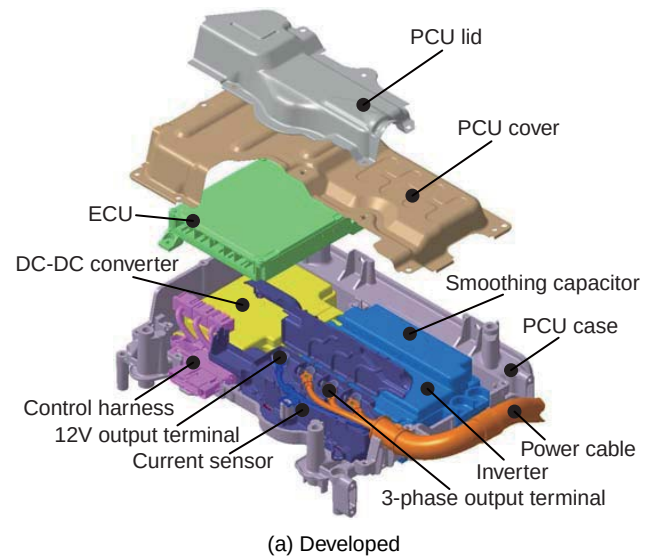
Fig. 2 Comparison of IPU

3. Technology for Reduced Size and Lower Cost

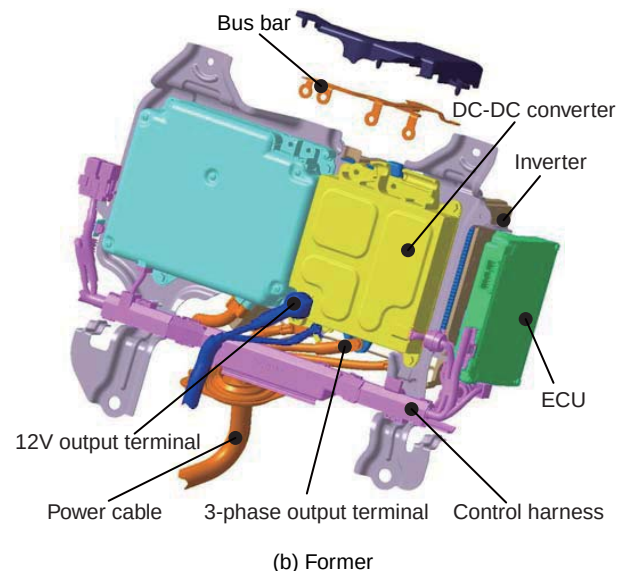
3.1. Structure of the PCU

The PCU consists of the inverter, the DC-DC converter, the electronic control unit (ECU), the current sensor, and the control harness that connects these components. It functions to control power conversion between the IMA system's high-voltage battery and the motor and to supply load power of 12 V. At the same time, electromagnetically shielded construction and a power distribution mechanism are also necessary for the PCU.

Figure 3 shows the exterior appearance of the PCU. Figure 3(a) shows the new structure and Fig. 3(b) shows the former structure.



(a) Developed



(b) Former

Fig. 3 Comparison of PCU

3.1.1. Electromagnetically shielded construction

Since the PCU has an internal high-voltage switching circuit, there is a possibility that switching noise could affect the vehicle. Electromagnetic shielding is therefore necessary. The former PCU had its inverter, DC-DC converter, and ECU enclosed in separate metal cases for that reason [Fig. 3(b)].

The newly developed PCU is simultaneously shielded overall by the PCU case and cover, which is constructed to limit the conduction or radiation of switching noise generated by the inverter, the DC-DC converter, or the ECU. As a result, the covers for the inverter and DC-DC converter could be made from the minimal amount of resin, contributing to the reduction in size and weight.

The new system also adopted a power cable that has the motor cable and 12-V output cable contained inside aluminum piping. This enabled power-cable shields, PCU cover, and PCU case to be electrically connected to provide total shielding for the IMA high-voltage unit in a structure that could be achieved simply and under low cost [Fig. 3(a)].

3.1.2. Power distribution mechanism

The component units of the PCU that are supplied power from the high-voltage battery are the inverter and the DC-DC converter. In the former configuration, the inverter and DC-DC converter were located facing each other so that a bus bar was needed to connect their high-voltage input portions [Fig. 3(b)]. In the new configuration, the PCU has the DC-DC converter located close beside the inverter. Providing power in this configuration enabled the DC-DC converter input bus bar to be removed, together with use of a smoothing capacitor for the inverter, so as to reduce the capacity of the DC-DC converter's filter capacitor. These steps were taken to reduce the PCU size and lower its cost [Fig. 3(a)].

In the former configuration, the inverter and DC-DC converter each had their own output terminal for 3-phase output and 12-V output, respectively. The cable connections and wiring took up a large area [Fig. 3(b)]. The new configuration PCU, by contrast, has added output terminal functionality to the current sensor so that the 3-phase current output from the inverter and the 12-V output from the DC-DC converter can be contained compactly, contributing to the reductions in size as well as in the cost of the shield construction described earlier [Fig. 3(a)].

These technologies enabled the PCU footprint area to be contained within the projected top surface area of the battery box. The IPU could therefore be contained between the car body's side frames, enabling it to be installed beneath the trunk room floor. This approach realized the five-door hatchback body layout.

3.2. Inverter

The IMA system is equipped with an inverter to drive the DC brushless motor. This component performs high-

voltage DC and 3-phase AC power conversion. The basic structure of the inverter includes a power semiconductor module that performs high-voltage, high-current switching, a control board with switching control, protection, and communications functionality, a smoothing capacitor to handle smoothing for the high-voltage input section, a high-voltage wiring case using an insert-molded bus bar, a heat sink, and a cover. The exterior appearance of the former inverter and the developed inverter are shown in Fig. 4.

3.2.1. Reduction of inverter smoothing capacitor capacity

The inverter is equipped with a smoothing capacitor to reduce the DC input voltage and current fluctuations.

The electrostatic capacity of the smoothing capacitor influences the voltage build-up rate during system malfunctions, and to reduce the electrostatic capacity, it is also necessary to shorten the protection response time. This inverter has a response time 27% shorter than before, thus enabling realization of a 50% reduction in electrostatic capacity, relative to the former inverter, as well as a reduction in cost.

Thin polypropylene film is used as a material for the capacitor device. This contributes to the 45% reduction in capacitor size as well as reduction in weight. Figure 5 shows the former capacitor and the newly developed capacitor.

3.2.2. DLB structure of TPM inner wiring

Figure 6 shows the exterior appearance of the inverter's power semiconductor module, with the former structure shown in Fig. 6(a) and the new structure in Fig. 6(b). The power semiconductor module uses a TPM

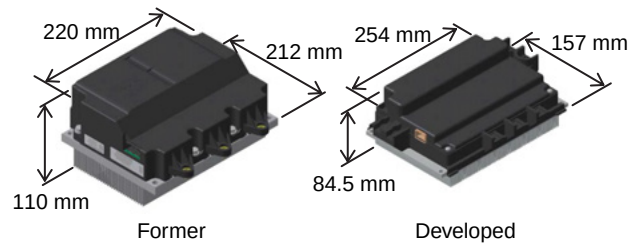


Fig. 4 Comparison of inverter

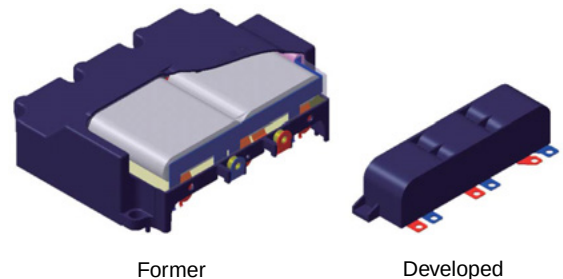


Fig. 5 Comparison of capacitor

structure that packages one phase of the 3-phase current.

The interior of the TPM houses the power devices (IGBT and diodes), the insulated substrate, and the bus bar. A DLB structure has been adopted [Fig. 6(b)] in order to connect the power devices and the bus bar electrically. The former structure used wirebonding [Fig. 6(a)] to connect the power devices and bus bar, and this accounted for a large part of the power semiconductor module manufacturing process. The DLB method simplifies that process and enables a cost reduction^{(1), (2)}.

3.2.3. Increasing the allowable junction temperature in the power devices

The power devices generate heat due to the passage of electric current, and this raises the junction temperature. If the rise exceeds the allowable temperature, damage will result. The rise in temperature can be limited by increasing the area of the power devices, but this method raises the cost. The device area should therefore be kept as small as possible.

The newly developed product has adopted DLB, as described above, and the increased reliability has succeeded in lifting the allowable junction temperature 17%. The devices are now capable of carrying a 38% larger electric current with the same device area as that of the former device.

Use of the above technology has reduced the size of the power semiconductor module to 60% of the former device.

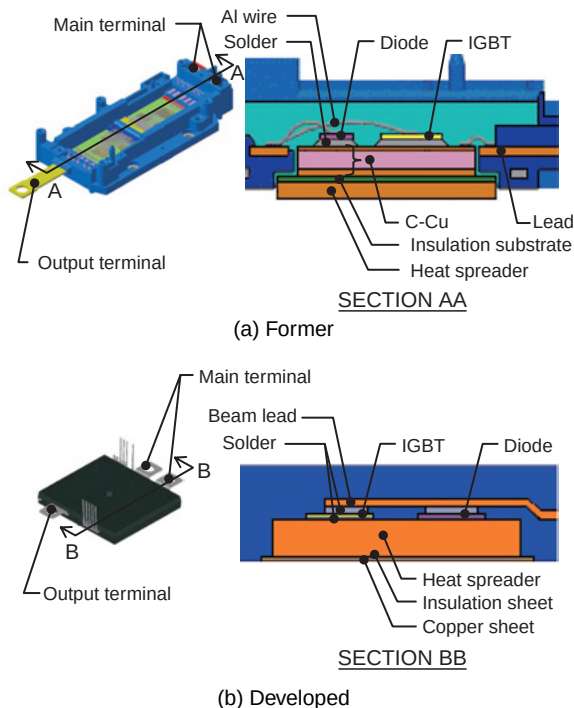


Fig. 6 Comparison of power module

3.3. DC-DC Converter

Vehicles equipped with IMA systems use a DC-DC converter to supply 12-V auxiliary load power. This device is composed of a high-voltage switching device, a transformer, a rectifier diode, a choke coil, a filter, a connecting bus bar, a heat sink, and a control board.

Figure 7 shows a comparison of the exterior appearance of the former converter and the newly developed converter.

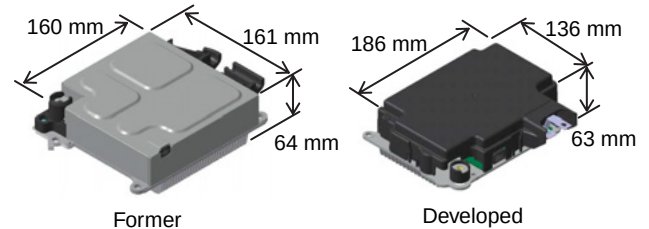


Fig. 7 Comparison of DC-DC converter

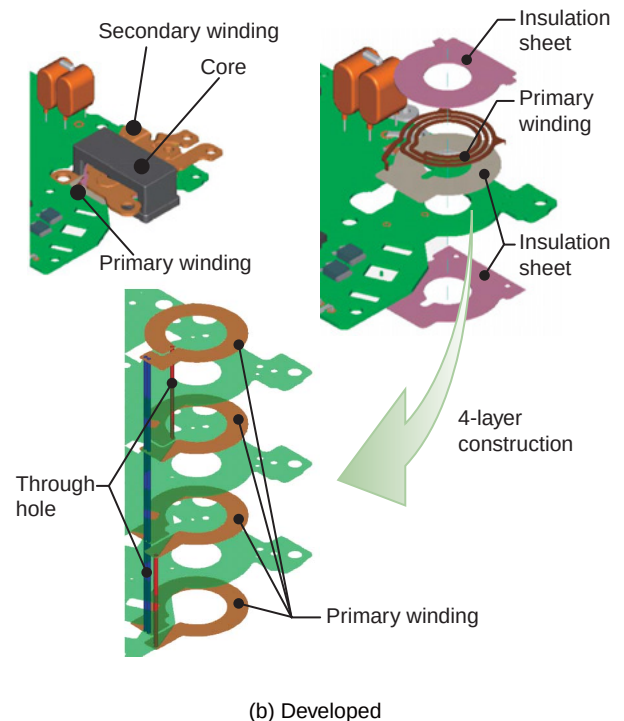
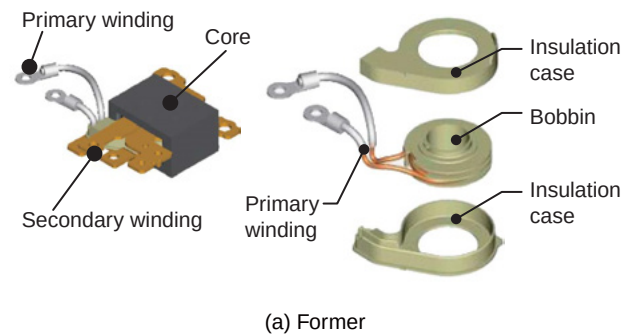


Fig. 8 Comparison of transformer

3.3.1. Transformer winding wire structure

Figure 8 shows the exterior appearance of the transformer. Figure 8(a) is the former structure while Fig. 8(b) is the new structure.

The primary winding wire in the former transformer was a single-core copper winding wire wound on a bobbin, as shown in Fig. 8(a). The electrical connection, therefore, was made with screws holding the wires to a terminal, thereby necessitating an additional connecting process other than the soldering process used with circuit components on printed circuit board, and complicating the manufacturing process. The primary winding wire in the new structure, as shown in Fig. 8(b), is made up of a printed circuit board with conductive patterns in coil form equivalent to a total of two turns in 4 layers, together with copper sheet equivalent to three turns. This enables the electrical connections to be made by the same soldering process used for circuit components on the printed circuit

board, so that the manufacturing process is simplified and reduced in cost⁽³⁾.

In the former structure, using the necessary number of turns in the primary winding wire resulted in a greater total height. With the new structure, however, the use of a printed circuit board also contributes to the reduction in the height of the DC-DC converter.

3.3.2. Reducing the high-voltage input filter circuit

The former DC-DC converter had a filter circuit of the kind shown in Fig. 9 in order to mitigate disturbance noise in the high-voltage input portion of the device. In the newly developed device, the location of the DC-DC converter inside the PCU case has been optimized so that the ferrite-core filter and Y-capacitor in the input portion could be eliminated, and the electrostatic capacity of the DC-DC converter input filter capacitor has been reduced 60% relative to the former device.

3.3.3. Enhanced efficiency

In order to achieve the desired fuel economy performance, it was necessary to help prevent the degradation of power conversion efficiency resulting from the PCU unit being made more compact. Another important factor is enhancement of device and circuitry efficiency in the power conversion portion.

The former device included a resonant snubber circuit on the secondary side in order to employ a rectifier diode with low withstand voltage and low loss. The newly developed device, however, uses a circuit to limit surge voltage due to switching on the primary side instead, enabling use of a still lower-loss rectifier diode. As a result, efficiency increases of 0.5% to 1% were achieved in the normal range of use. The reduction of losses also contributed to a 30% reduction in the weight of the heat sink. Figure 10 shows a comparison of efficiency.

The use of these technologies realized a 46% reduction in weight and 3% reduction in volume in the DC-DC converter, compared to the former device.

4. Conclusion

Development of the PCU for the new model INSIGHT achieved the following items relative to the former PCU:

- (1) In the inverter, the capacity of the smoothing capacitor was reduced by 50% by increasing the speed of over-voltage detection. The use of DLB for the wiring and a 17% increase in the allowable junction temperature realized a 40% reduction in the volume of the power semiconductor module without sacrificing efficiency. As a result, the weight was lowered 36% and the volume reduced by 35%.
- (2) The DC-DC converter weight was reduced by 46% and its volume reduced by 3% by converting part of the transformer winding wire to printed circuit form, adopting a low-loss rectifier diode, and optimizing the

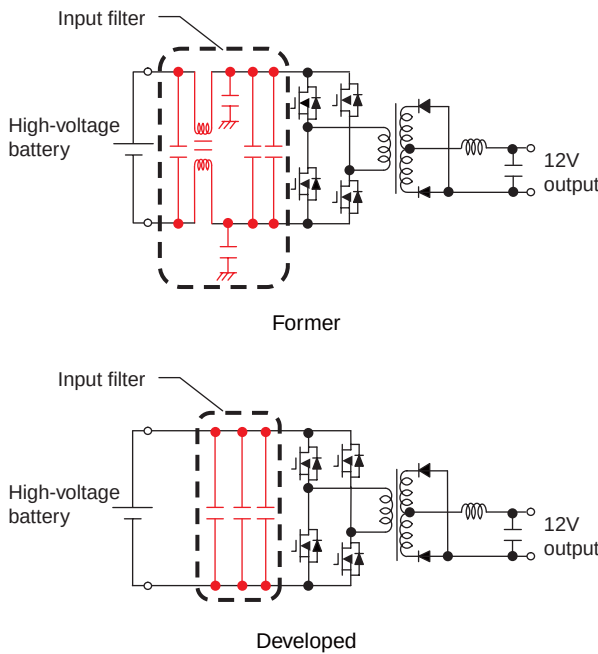


Fig. 9 Comparison of input filter

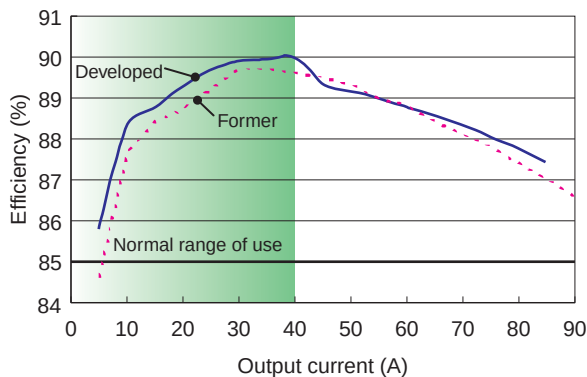


Fig. 10 Comparison of conversion efficiency

internal layout of the PCU to reduce the input filter.

- (3) In the PCU, the electromagnetically shielded structure and power distribution mechanism were optimized. In the inverter, the smoothing capacitor electrostatic capacity was reduced and a DLB structure was adopted. In the DC-DC converter, a new structure was adopted for the transformer winding wire and the input filter was reduced. These measures enabled reductions in cost.

As a result, the overall PCU height was reduced by 41%, its weight was reduced by 31%, and its volume was reduced by 10%.

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