

Development of High-output, Portable External Power Output System for Use with Next-generation Environment Vehicles

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ABSTRACT

The external power output device EE90i (the Power Exporter 9000) that provides new value with the capability for obtaining electric power from next-generation vehicles was developed. Through use of the Power Exporter 9000, next-generation vehicles will be able to utilize electrical output at the location where it is needed, allowing the use of those vehicles as mobile power sources that can provide electrical output.

The Power Exporter 9000 has realized a form factor that allows loading the unit into the trunk of a CLARITY FUEL CELL by means of applying downsizing and weight-saving technologies for engine generators. The engine generator's inverter technology and heat-dissipating construction were then used to achieve stable electric output with quality equivalent to grid power as well as high output of 9 kVA. Furthermore, compliance with the Guidelines of Charge/Discharge System for Electric Vehicle V2L DC version has enabled connectivity and compatibility with next-generation vehicles that have external power output function and that are not only from Honda but also from other manufacturers. The general usability of the CLARITY FUEL CELL for connection with external power output devices was also heightened by following the above guidelines in the design. These technologies were found to offer prospects for a method of developing a society that builds national resilience against natural disasters and realizing the hydrogen society that is Honda's aim.

1. Introduction

Since the Great East Japan Earthquake of 2011, there has been heightened concern with preventing and mitigating the effects of natural disasters, and the National Resilience Basic Plan was adopted by Cabinet decision⁽¹⁾. The use of fuel cell vehicles (FCV), electric vehicles (EV), and other such next-generation vehicles that have functionality for generating and storing large amounts of electric power as moving electric power sources is one method that is anticipated for building a resilient society. Realizing a moving electric power source necessitates using the vehicle for electric power at the destination, and the EE90i (Power Exporter 9000, hereafter PE9000) was developed as a portable external electric power source for that purpose. The utilization in a wide variety of scenes such as during disasters or other emergencies, and for outdoor activities and other such purposes is anticipated, and the PE9000 is required to have a high output. The PE9000 was therefore configured to provide output of 9 kVA, making it lower

than the vehicle end's maximum value (10 kW), which is specified as the upper limit in the second clause of Article 199 in an Interpretation of Technical Standards of Electric Installation⁽²⁾. Configuring it for portability and high power output, the PE9000 provides new value to next-generation vehicles as mobile power sources that can provide electrical output.

At the same time, Honda is using the concepts of “generate,” “use” and “get connected” with hydrogen energy for its aim of realizing a hydrogen society with zero CO₂ emissions. The hydrogen used in FCVs can be generated from renewable energy, and they do not emit any CO₂ when they are used. Hydrogen can be stored and transported with high energy density, and is therefore receiving attention as a next-generation energy that has excellent energy security properties. In the Strategic Roadmap for Hydrogen and Fuel Cells⁽³⁾, the Japanese government has further set a dissemination target for increase to about 800,000 FCVs by the year 2030⁽⁴⁾. This indicates that future use of hydrogen energy is expected to expand. This development is targeted

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at the realization of a hydrogen society by enabling the FCV and PE9000 to “get connected” for energy production.

This paper will describe the three characteristics introduced in the PE9000 of compact lightweight portability, a high output source of high-quality electric power, and mutual compatibility with vehicles, and it also touches on the power output technology in the CLARITY FUEL CELL.

2. Development Goals

2.1. Development Concept and Performance Requirements

Figure 1 shows a conceptual image of the hydrogen society that is Honda’s goal. The aim is to realize a hydrogen society by the three concepts of (1) “Generate” hydrogen from renewable energy using the Smart Hydrogen Station⁽⁵⁾, (2) “Use” hydrogen by driving an FCV that uses the hydrogen, and (3) “Get connected” with hydrogen by using the PE9000 to connect the vehicle with electrical equipment (Vehicle to Load, hereafter V2L) and using the Power Manager HEH55⁽⁶⁾ to connect with grid power at home and other such locations (Vehicle to Home, hereafter V2H). The purpose in developing the PE9000 was to provide new value in “connecting” based on the concept of “connect with cars, extend into people’s lives.”

Figure 2 shows an external view of the PE9000. With “Inter-Blended” as the keyword, the unit has a clean design that harmonizes with the environment. The look was also harmonized with the design of the CLARITY FUEL CELL, creating a unified appearance for the system.

The hydrogen society that is Honda’s goal.

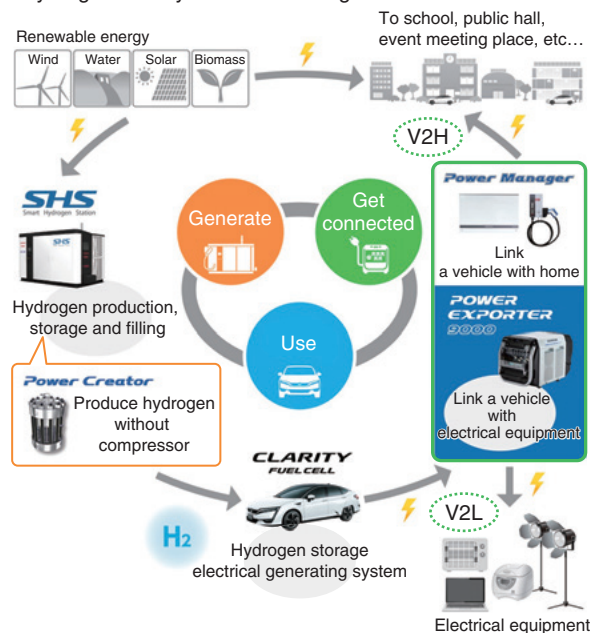


Fig. 1 Conceptual diagram of realization of hydrogen society

The following aspects of performance were defined as goals of development in order to utilize the PE9000 as a method for realizing a hydrogen society and strengthening resilience against natural disasters.

- (1) That it have portability to enable carrying the unit;
- (2) That it have power output at high capacity and high quality equal to those of grid power sources;
- (3) That it have high general usability that makes it possible to connect with a lot of next-generation vehicles.

2.2. System Configuration and Characteristics

Figure 3 shows a configuration diagram of the external power output system. The DC power supplied from the next-generation vehicle is converted into AC power by the PE9000, which supplies the electricity to electrical equipment. The system is set up so that when the next-generation vehicle is a Honda CLARITY FUEL CELL, the internavi system can be interposed to enable one to check the power supply status on a smartphone or other such device, not only at the multi-information display (MID) of the vehicle but also at a remote site.

Table 1 shows the main specifications of the PE9000. The PE9000 incorporates the following characteristics.

- (1) Downsized, lightweight, and portable type

Active use of technology for making an engine generator compact and lightweight achieved high power output of 9 kVA within a size and mass that can be loaded into the



Fig. 2 External view of Power Exporter 9000

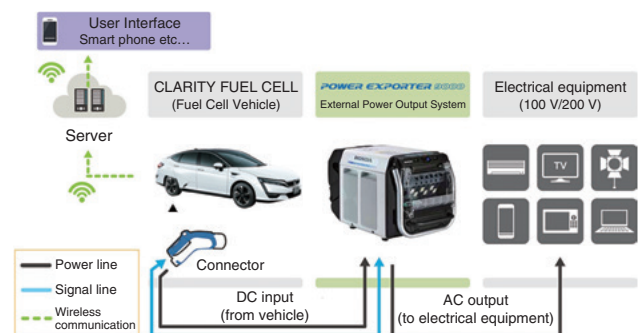


Fig. 3 System configuration of external power output system

Table 1 Specifications of Power Exporter 9000

Item	Specification
Rated output power	9 kVA
Output voltage	100 V/200 V
Dimension (L/W/H)	755 mm × 387 mm × 438 mm
Mass	50.8 kg
Sound power level	L_{WA} 57 dB
Applicable standard	V2L Guidelines for DC system

trunk of a CLARITY FUEL CELL. The handle and wheel construction further assure portability by one person after the unit has been unloaded from a vehicle.

(2) High power output and high quality power source

The layout of electric unit and cooling fan were optimized so as to efficiently cool the heat-generating components of the onboard electric unit. This arrangement permitted a design capable of providing a stable energy supply even during high power output. Inverter design technology⁽⁷⁾ was used in the engine generator to achieve high quality electricity output.

(3) Compatibility with vehicles

Conforming with the charge/discharge system guideline V2L DC for electric vehicle⁽⁸⁾ (V2L Guidelines) ensures compatibility with next-generation vehicles that come with the external power feeding function, including those of other manufacturers. Either EV or FCV can be selected in terms of the zero CO₂ emission, but the advantages of high power output are maximized when connected with an FCV, which has a longer cruising range than an EV as of June 2016. The approximately seven days' worth of general household electricity is available to be provided when connected with a Honda CLARITY FUEL CELL⁽⁹⁾. The adoption of a user interface that is suited to a V2L system provides the design with high usability.

This paper will introduce the developed technology that achieves the above three characteristics.

3. Introduction of Developed Technology

3.1. Technology for Compact, Lightweight, and Portable Type

The unit was designed to have a power/weight ratio yielding a major advantage over other manufacturers (Table 2). This was done by aiming for high power output of 9 kVA and case construction with exterior dimensions that allow the unit to be mounted in a CLARITY FUEL CELL trunk in combination with weight (60 kg or less)⁽¹⁰⁾ that allows it to be loaded and unloaded by two adult males. The unit also incorporates unique measures to reduce the burden on users when moving the unit alone and when loading or unloading it from a vehicle. The following will introduce the technology for making the unit more compact and lighter weight together with ease of handling and the collision energy absorbing structure of the unit when loaded in a vehicle.

Table 2 Compare power/mass ratio with competitors

Name	Power (kVA)	Mass (kg)	Power/Mass ratio (VA/kg)	Portable or not
Honda PE9000	9	60 (Target)	150 (Target)	Portable
Nichicon Vehicle to Socket	3*1	73	41	Not portable
Mitsubishi MiEV power BOX	1.5	11.5	130	Portable
AESC LEAF to 100V	1.5	12	125	Portable

*1: At the time of external power output.

3.1.1. Subdividing and packaging the inverter and converter

The inverter and converter are the main functional components of the PE9000, and they are major components in terms of weight and volume. The PE9000 is composed of five electric units including inverters and converters. The 9-kVA output is not treated as a single unit. Instead, an inverter with 6 kVA of output and an inverter with 3 kVA of output are each treated as single units, and three converter units with 3 kVA of output each are combined to support 9 kVA of power output. This subdivision into units enables the layout to be configured with a large degree of freedom.

Figure 4 shows the inner composition of the PE9000. The basic layout consists of the inverter and converter, and the remaining functional components were configured as described below.

- (1) Electric parts used for control are placed in the upper part of the unit
- (2) Electric parts used for output are placed in the front part of the unit
- (3) Discharging connectors are housed in the back part of the unit
- (4) Cooling fans are placed on the sides.

With the components configured in this way, the external dimensions allowed the unit to fit inside the trunk of the CLARITY FUEL CELL.

3.1.2. Lightweight, high-strength frame

In order to assure the strength to withstand normal handling while reducing the unit's weight, aluminum pipe that is lighter in weight and stronger was chosen as the frame material. Figure 5 shows the frame structure and the distribution of exterior forces applied to it. The structure is designed so that exterior forces are concentrated on the main frame, eliminating the need for brackets and other such parts. Steps were also taken to concentrate functions by attaching functional components directly to the pipe frame so that the number of component parts can be reduced, making the unit lighter in weight. Where the weight of the frame parts as a percentage of the total unit weight for

another Honda generator of similar weight (EU28is) is 54.8%, the figure for the PE9000 is 32.7%.

3.1.3. Converter construction

The input voltage range of the PE9000 is wide as it varies from 150 V to 450 V, and this system requires a converter that can convert constant direct voltage. Figure 6 shows a converter section. Although the converter makes up a large part of the system's weight and volume, the circuit boards were made in a 2 substrates piling composition, thereby reducing the surface area and allowing the converter to be made more compact and the case to be made lighter in weight. The components are also subjected to resin mold processing to assure their water resistance and vibration resistance. Since this system is not equipped with a major source of vibration such as an engine, it is less likely to be exposed to a vibrating environment than a conventional engine generator. Steps were therefore taken to optimize the resin molds for strength, with the result that the space between the top and bottom boards could be left hollow instead of being filled with mold material for strength, and this further reduced weight. Since this is a hollow structure, only the sides of the circuit boards that have parts on them are given the mold treatment. The solder side does not come into contact with mold material, which helps prevent solder-cracking resulting from a difference in rates of thermal expansion between the solder material and mold material. Ventilation holes were opened in the hollow part of the structure in order to limit moisture absorption by the circuit boards. These technologies achieved the unit's greater compactness and lighter weight of converter.

The above packaging, lightweight high-strength frame, and converter technologies yielded a high power output with a maximum of 9 kVA, while containing the PE9000 in a case 755 mm × 387 mm × 438 mm (total length × total width × total height) in size with a total unit weight of

50.8 kg (power/weight ratio: 177 VA/kg). Thus, the unit was made to enable loading in a CLARITY FUEL CELL trunk.

3.1.4. Handling performance

In addition to making the unit more compact and lighter in weight, functions intended for high handling performance were also added. In order to achieve a balance between stability while the unit is stationary and operability while it is being carried, a new wheel structure features a wheel that only touches the ground when the unit handle is lifted up.

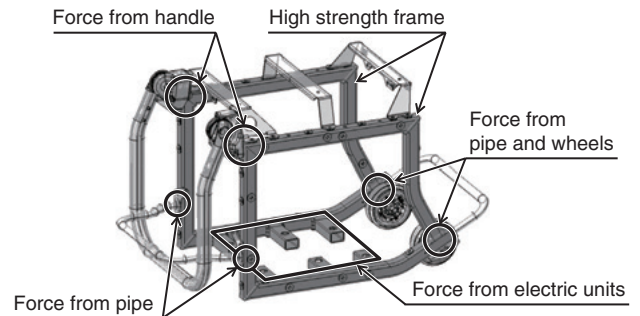


Fig. 5 Force receiving points on high strength frame

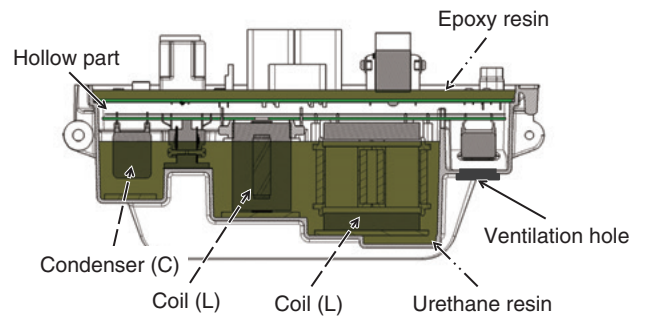


Fig. 6 Section of converter

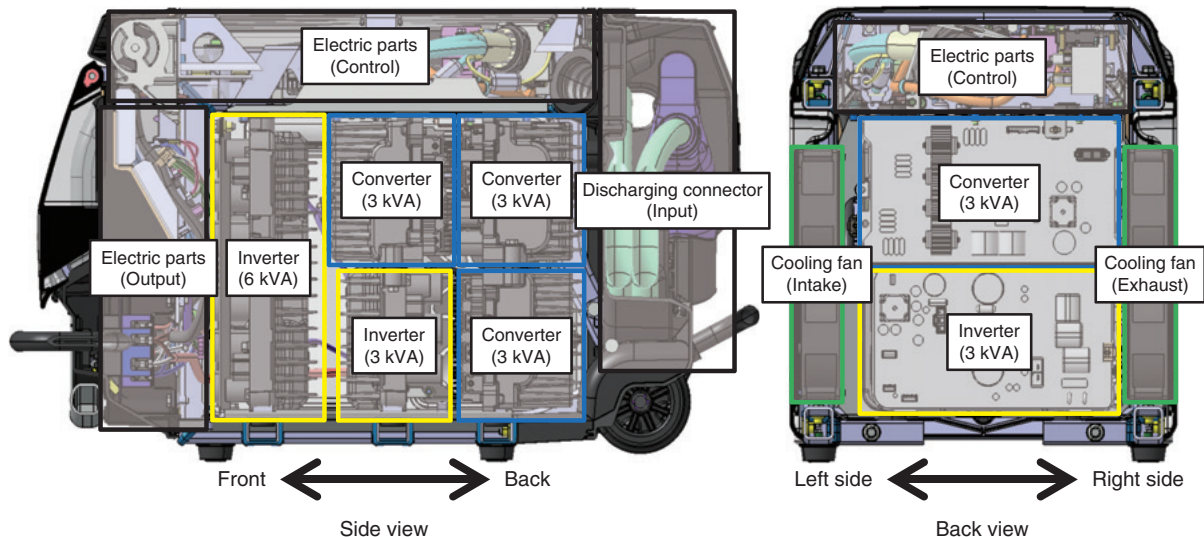


Fig. 4 Inner configuration of Power Exporter 9000

Figure 7 shows the state of wheel grounding when the unit is stationary and when the handle is lifted up. This approach eliminates the need to immobilize the wheels, and enables easy mobility by one person using the wheels of the unit, while helping assure stability when the unit is stationary.

Operability when loading and unloading the unit from a vehicle was also taken into consideration, and grips were placed on the front and rear of the unit and on either side. Figure 8 shows the PE9000 being raised up. Holding the front and rear grips together with the side grips makes it possible to tilt the unit in a stable manner and allows greater ease loading the unit in a car trunk than with front and rear grips alone.

Such considerations made the unit easier to carry and reduced user load while loading into and unloading from the trunk.

3.1.5. Structure to absorb impact force when in a vehicle

The CLARITY FUEL CELL frame structure comprises impact-absorbing sections to help absorb the impact during a collision and a high-strength cabin zone that helps protect occupants and fuel system components.

When the PE9000 is being transported on-board the CLARITY FUEL CELL, it is loaded in the trunk, which is an impact-absorbing section. The PE9000 unit itself has an impact-absorbing structure like that of the trunk, in consideration of the CLARITY FUEL CELL's safety in the event of a rear-end collision. The high-strength main frame is divided into right and left parts that are joined by brackets and pipe. External forces that are applied during normal use are received by the high-strength frame shown in Fig. 5. Strong impacts that occur from the side during a collision are mitigated by the structure shown in Fig. 9, with brackets and pipe comprising a force-mitigating section. In this way, this unit helps ensure the strength to withstand ordinary

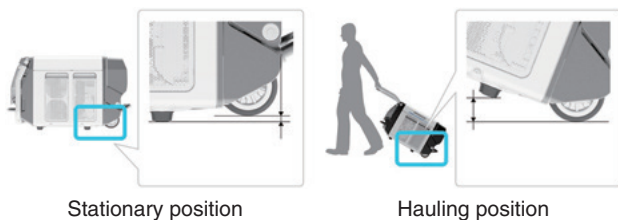


Fig. 7 Configuration of wheels and contact with ground



Fig. 8 Raised up position

handling while also allowing the PE9000 to deform under force at or below the high-strength cabin zone.

3.2. Cooling Technology to Achieve High Power Output and High Quality Power Source

The inverter and converter installed in the PE9000 generate heat during operation due to internal loss, and therefore require cooling. The PE9000 was designed to be a power output system with high power output, but consideration was also given to minimizing the cooling fan capacity in order to make the cooling structure efficient and achieve greater compactness and lighter weight.

The converter's two substrate layering composition and hollow structure shown in Fig. 6 also contribute to heat dissipation performance. This arrangement enabled passive electrical elements that are the main heat sources to be concentrated on the bottom circuit board where they could be closer to the cooling fan, providing for efficient heat dissipation. The hollow structure provides a layer of air inside the converter, promoting priority heat dissipation to the diecast case. In addition, urethane with a superior rate of thermal conduction was adopted as the mold material applied to elements on the bottom-layer circuit board, further enhancing the amount of heat dissipated. As a result, sufficient release of heat was made possible even in the compact form factor with high power output.

Air cooling by electric axial-flow fans was adopted as the cooling method. The use of axial-flow fans has two methods: intake attachment, in which the fan is positioned to draw air into the case interior; and exhaust attachment, in which the fan is positioned to blow air out from inside the case. Intake attachment is effective when heat-generating sections are concentrated within the case. Exhaust attachment is effective when heat-generating sections are dispersed within the case⁽¹¹⁾. Figure 10 shows the composition of inverter, converter, and cooling fans. For this development, a structure combining intake and exhaust attachment was adopted in order to optimally position the fans to match the inverter and converter heat values and heat-generating locations.

Figure 11 shows the results from analysis of heat-generating locations and air-circulation zones. This shows how the inverter, where more heat is generated due to internal loss and the heat-generating locations are

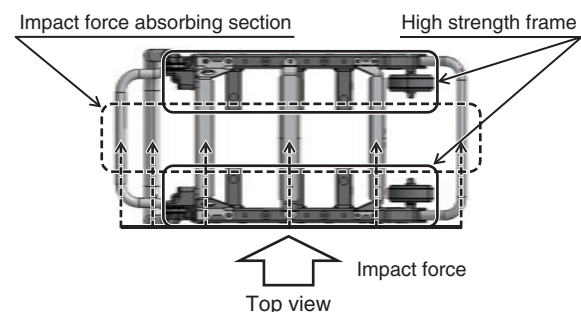


Fig. 9 Frame composition of Power Exporter 9000

concentrated, is cooled using an intake attachment fan. The converter, where less heat is generated and the heat-generating locations are dispersed, is cooled using an exhaust attachment fan. This layout makes it possible to cool the unit with fans that are compact, lightweight, and use less power, than if the fans were concentrated on one side or the other.

By the above technologies, the PE9000 achieved a sound power level of L_{WA} 57 dB while realizing a high power output of 9 kVA.

3.3. Technology for Mutual Compatibility with Vehicles

3.3.1. Conformity with V2L Guidelines

The PE9000 was the first in the world to satisfy the V2L certification standards⁽¹²⁾ for testing and compliance with V2L Guidelines. This makes it possible to connect with next-generation vehicles that have external power feeding function not only of CLARITY FUEL CELL but also of other manufacturers, achieving high general versatility.

On the other hand, avoiding limitations of the connected vehicle means that it is necessary to support a wide range

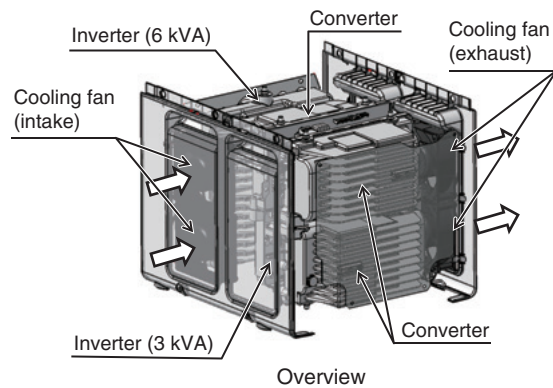


Fig. 10 Composition of inverter, converter and cooling fans

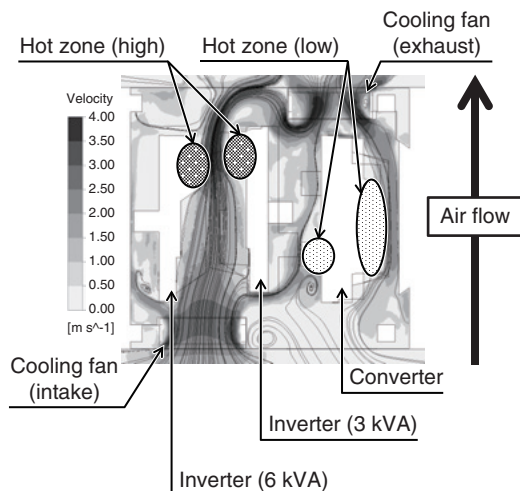


Fig. 11 Air flow analysis results

of input voltages, so the LLC current resonant method was adopted for the converter. The LLC resonance drive method performs soft switching (zero voltage switching) by resonance between the coils (L) and condenser (C) shown in Fig. 6. A wide range of voltage gain can be obtained by changing the switching frequency. By use of this method, the PE9000 can successfully convert a wide range of input voltage from 150 V to 450 V into a constant output voltage with a high degree of efficiency and low level of electrical noise. As a result, the PE9000 achieves a conversion efficiency of 90% or more at rated output when connecting with the CLARITY FUEL CELL.

The CLARITY FUEL CELL was also designed to comply with the V2L Guidelines in order to assure mutual compatibility with external power output systems other than the PE9000. The unit has thus achieved high usability. The power supply technology used in the CLARITY FUEL CELL is described in the following.

3.3.2. CLARITY FUEL CELL power supply components

The CLARITY FUEL CELL generates electricity by means of its fuel cell and provides DC electricity to the PE9000. Figure 12 shows the CLARITY FUEL CELL main components. The hydrogen fuel that is required for the fuel cell to generate electricity is in a high-pressure hydrogen tank. The tank stores approximately 5.0 kg of hydrogen under 70 MPa of filling pressure. This can provide about seven days of electric power for a typical household. Figure 13 shows the components for the section that supplies power. The electric power is generated by the

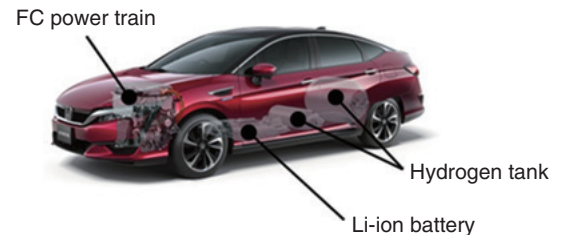


Fig. 12 Main components of CLARITY FUEL CELL

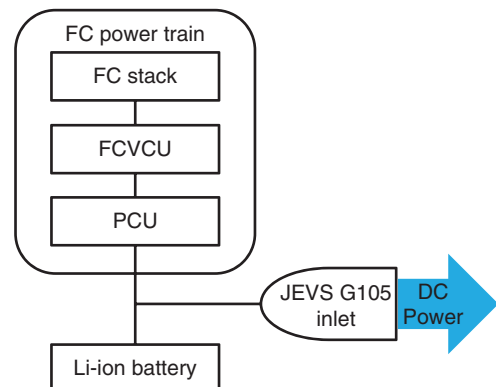


Fig. 13 Components for power export

fuel cell stack and then the output voltage is controlled by the FC voltage control unit (FCVCU) and the power control unit (PCU)⁽¹³⁾. It is connected in parallel with the lithium-ion battery and the power is supplied through a Japan Electric Vehicle Standard (JEVS) G105 inlet. Transient fluctuations in the electric power supply are covered by charging or discharging the lithium-ion battery, thus making it possible to provide a stable supply of electric power.

3.3.3. CLARITY FUEL CELL energy management while supplying electric power

The electric power supplied from the vehicle is generated by the fuel cell stack according to the load capacity of electrical equipment connected to the electric power source. The method of supplying electric power from a high-voltage battery after charging it can cause charge/discharge loss. The aforementioned method was thus adopted to assure high efficiency. Out of consideration for the next time the vehicle is going to be driven, control is implemented to keep the state of charge (SOC) of the high-voltage battery from dropping while power is being supplied.

Envisioning cases when the user is not present in the vehicle cabin while power is being supplied, the system is equipped with a function that automatically halts electricity feeding and uses telematics to notify the user by smartphone or other such means when the remaining hydrogen level becomes low. The system then automatically stops supplying power.

It is envisioned that there will be fewer occasions to supply power than there are to drive. It is necessary, therefore, to make the operation to initiate power supply easy for users to understand. To that end, after the power supply connector has been engaged, power can be supplied by simply following the same operation as for driving (turning the POWER switch ON while pressing down on the brake pedal).

3.3.4. Coordinated display of estimated possible duration of power supply

V2L devices are envisioned as being used across a wide range, from no load to rated output. It is also envisioned that, in the event of emergency, electrical equipment will be used, and a high degree of usability in such cases was aimed for by making it possible to check for a general indication of how long electric power can continue being supplied at the present rate. This system provides a display on the PE9000, the CLARITY FUEL CELL, and a smartphone. Figure 14 shows the indicator LED on the PE9000 and the MID in the CLARITY FUEL CELL. The PE9000 calculates the present supply of electric power from the size of the attached load, and transmits this by telecommunication to the CLARITY FUEL CELL. The CLARITY FUEL CELL calculates the number of hours it can continue supplying power from the remaining hydrogen according to the electric power supply figure it received and its own consumption. That number

is displayed on both screens. As shown in Fig. 3, this information is also transmitted to smartphones by means of the system server. Figure 15 shows the smartphone display. The system specifications provide the means to check the power supply status even from a location that is removed from the vehicle.

These three displays provide a simple, sensory means for judging the status of the PE9000 in a manner resembling the displays on the electrical equipment being used. The time can be checked in detail on the vehicle MID, and it can also be checked remotely by smartphone. The system thus achieves high usability.

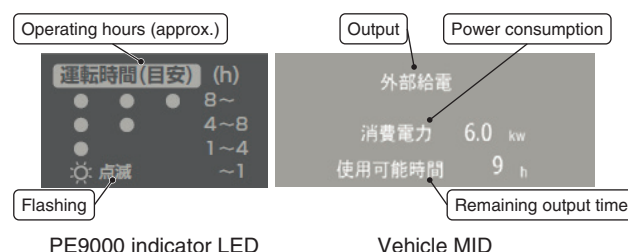


Fig. 14 Design example of indicator LED and vehicle MID on external power output system



Fig. 15 Design example of internavi application on smartphone

4. Conclusion

The PE9000 was developed as an external power output system that provides next-generation vehicles with new value as moving electric power sources. The main technologies achieved yielded the following conclusions.

- (1) Achieving compactness and lighter weight made it possible to load the unit in a CLARITY FUEL CELL trunk. The unit was also constructed to make it easily portable after unloading from the trunk.

- (2) An efficient cooling structure was provided, thereby realizing a cooling function at high power output of 9 kVA. The application of inverter technology of engine generators further achieved high-quality power output.
- (3) The PE9000 is in conformity with V2L certification standards, and ensuring the CLARITY FUEL CELL design's compliance with V2L Guidelines enhanced the widely compatible functionality of the connection.

5. In Closing

In order to verify where to apply the PE9000, the following field tests and demonstrations were performed.

- (1) System matching with medical equipment was confirmed in a joint research project with the Tottori University Faculty of Medicine. The system was also used in participation with a Disaster Medical Assistance Team, which is a medical team trained to provide mobile emergency assistance during disasters (Emergency use).
- (2) The system was used in disaster management training for people unable to readily return to their homes, and was confirmed for usability of next-generation vehicles equipped with external power feeding function and for driving the electrical equipment needed during disasters (Emergency use).
- (3) The system was used to supply power to vehicles involved in the Tokyo Michiterasu illumination and in the event car, verifying use of the external power feeding device in public spaces (use during normal times).

The above results provided confirmation of the PE9000's prospects as a method for building a national resilient society against natural disasters and realizing the hydrogen society that Honda is heading toward.

The PE9000 was developed on the assumption that it would serve a useful purpose at evacuation locations and where medical care is being provided during disasters. Going forward, the system will be expanded with variations for expanded dissemination that can be carried more easily and meet needs for personal use, with the aim of developing this not just for the Japan market, but as a product for the whole world.

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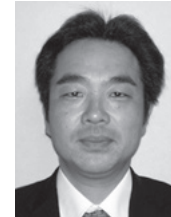
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