

Development of Power Exporter e: 6000, External Power Output Device, with Three-phase 200 V AC Output Function

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ABSTRACT

The less-expensive and more versatile Power Exporter e: 6000 was developed based on the Power Exporter 9000 external power output device. A lower price was achieved while maintaining high quality by optimizing power output in response to market needs, reducing the number of parts in line with the reduced power output, and addressing change points with minimal cost. In addition, the first known function to provide three-phase 200 V AC output with three linked units has been added to realize Vehicle to Load and Vehicle to Home as an electrical facility for general use, thereby expanding use applications to large electrical equipment such as industrial equipment. The power supply cable length was extended and the control was modified to conform to the “Electric Vehicle V2L DC Charge/Discharge System Guidelines” to enhance connectivity with even more EVs, including those of other automakers.

1. Introduction

Honda aims to achieve carbon neutrality for all products and corporate activities by 2050. To help achieve this, the company has set a target of a sales ratio of 100% for EV/FCV in the automobile market by 2040⁽¹⁾. The EV market is in an expansion trend worldwide, and the need to utilize electricity stored in vehicles is also expected to expand accordingly.

Since 2016, Honda has sold the Power Exporter 9000⁽³⁾ (PE9000) portable external power output device, the first such device known to conform to the Guidelines of Charge/Discharge System for Electric Vehicle V2L DC version⁽²⁾ (hereinafter, V2L Guidelines). Figure 1 shows the configuration of the external power output system. The voltage supplied from the EV is DC voltage, and this voltage fluctuates depending on the condition of the vehicle and the battery. This fluctuating DC voltage is converted to the prescribed DC voltage by a converter, and then converted into AC voltage by an inverter to supply electricity to electrical equipment. The PE9000 uses Honda’s inverter technology developed for engine generators^{(4), (5)}, and features the ability to simultaneously output high-quality

AC voltages of 100 V and 200 V. It can also supply large power output of 9 kVA quietly and odorlessly, enabling phase-free use as a power source for events and kitchen cars in normal times, and as a power source for evacuation centers and disaster response headquarters that have lost power in the event of a disaster, etc.

However, products with lower output and lower price than the PE9000 are currently the mainstream in Japan’s external power output device market. Furthermore, the market for Business Continuity Planning (BCP) support for

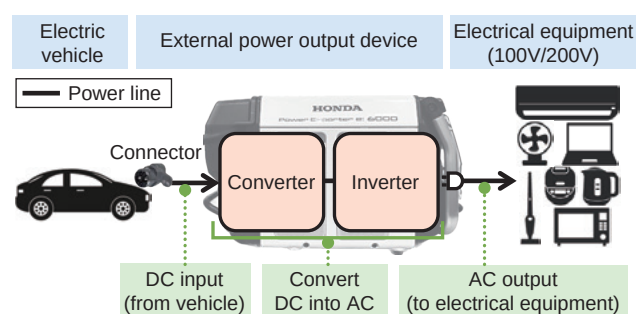


Fig. 1 Configuration of external power output system

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Table 1 Comparison of specifications

		PE6000	PE9000	A	B
Destination		Japan	Japan	Japan	Japan
Rated power (kVA)		6	9	3	4.5
Rated alternating current voltage (V)	Single-phase	100 / 200	100 / 200	100	100
	Three-phase	200	-	-	-
Receptacle		200 V × 1 100 V × 4	200 V × 1 100 V × 6	100 V × 2	100 V × 3
Mass (kg)		41	51	21	38
Volume (m ³)		0.128	0.128	0.073	0.093
Cable length (m)		2.1	1.2	2.0	2.0
Applicable standard	Charge/discharge system guidelines for electric vehicles V2L DC version	2.1	2.1	2.1	2.1
	CHAdeMO version	2.0	1.0	2.0	2.0

small and medium-sized business establishments is expected to expand in the future. As this BCP support anticipates the use of equipment such as shown in Fig. 2 (as of October 2023, according to Honda's research), it was thought that a 6 kVA class external power output device would be needed. In addition, with the expansion of the external power output device market, there are demands to enable use in a wider variety of devices, and the addition of three-phase 200 V AC (hereinafter, three-phase AC) output function that can operate large electrical equipment is expected. Meanwhile, the increase in EVs that conform to the V2L Guidelines is providing greater opportunity for use in combination with various vehicles, and there are also market demands to enhance the ease of connection with vehicles and increase versatility.



Examples of power consumption

2 air conditioners	1,600 W
20 ceiling lights	1,600 W
10 desktop PCs	1,000 W
2 laptops	60 W
1 electric kettle	1,000 W
1 TV	150 W
Total	5,410 W

Fig. 2 Example of instantaneous power consumption in BCP of small and medium-sized office

2. Development Goals

The Power Exporter e: 6000 (PE6000) external power output device was developed based on the PE9000 as a low-priced product with a rated output of 6 kVA, and further evolved to meet market demands. Figure 3 shows an external view of the PE6000 connected with an electric vehicle. While maintaining the functions and high power supply quality of the PE9000, development and manufacturing costs were minimized and a low price was achieved by using 7% fewer parts than the PE9000 and

reusing 88% of the PE9000's parts. In addition, the main development items were set as follows to meet market demands and make the PE6000 a more competitive product.

- (1) Addition of the first known three-phase 200 V AC output function
- (2) Increased versatility in vehicle connectivity

Table 1 lists the main specifications of the PE6000, PE9000, and competitors' products.



Fig. 3 External view of PE6000 with electric vehicle

3. Introduction of Developed Technologies

3.1. Three-phase 200 V AC Output Function

A three-phase AC output function was added to the PE6000. Three-phase AC is a type of commercial power supply stipulated by Japan's Electricity Business Act, and is a three-phase power supply with a line voltage of 182 V to 222 V and a phase difference between lines of 120 degrees. As three-phase power supply can operate large electrical equipment such as elevators and industrial equipment, implementation of this function in external power output devices is expected as a response to power outages. However, when operating large electrical equipment that exceeds 10 kW with conventional three-phase AC generators, Japanese law stipulates that notification of the safety regulations be provided to a national body and a chief engineer be appointed, and there were issues with operation in the event of an emergency. Therefore, this development

constructed technology enabling the combination of PE6000 units to enable proper and easy handling of large-output three-phase power sources.

3.1.1. Principle of generation of three-phase AC

Three-phase AC can be generated by synthesizing three sine waves called U-phase, V-phase, and W-phase. Figure 4 shows the system diagram, and Fig. 5 shows an external view of the three-phase AC output function. In this system, three EVs and three PE6000 units that conform to the V2L Guidelines⁽²⁾ are combined, and the two inverters mounted in each PE6000 are used to generate three-phase AC. The three PE6000s are designated Units A, B, and C, and the two inverters mounted in each unit are designated Inverter 1 and Inverter 2. When started in three-phase output mode, the phase difference between Inverter 1 and Inverter 2 is set to 120 degrees. If the start-up order of the three PE6000s is set to Unit A, B, and then C, Inverter 1 of Unit A outputs the U-phase, and Inverter 2 outputs the V-phase. Inverter 1 of Unit B that starts next outputs the V-phase by synchronizing with Inverter 2 of the previously started Unit A, and Inverter 2 outputs the W-phase. Likewise, Inverter 1 of Unit C outputs the W-phase, and Inverter 2 outputs the U-phase. The AC waveforms output from each PE6000 are then connected with a current collecting box to obtain three-phase AC power rated at 16.4 kVA (line current 52 A). This technology is an application of real-time communication synchronous control⁽⁴⁾ and parallel synchronous control⁽⁵⁾ cultivated through engine generators. Each technology is described in detail below.

Real-time communication synchronous control is a technology that sets the phase difference between the output waveforms of two inverters in the same device to an arbitrary angle, and outputs and maintains it with high

accuracy. In a previous dual-voltage inverter generator⁽⁴⁾, the phase difference of the 100 V AC waveforms output by Inverters 1 and 2 is set to 180 degrees. As a result, the phases of the positive and negative peaks of the output waveforms of the two inverters match, and thus 200 V AC output can be obtained by taking this difference. The PE6000 also performs similar control in single-phase mode.

Parallel synchronous control is a technology that enables synchronous operation of parallel-connected inverter generators without signal communication lines. Two inverters that output the same phase detect the phase difference between the voltage and the current, and slightly increase or decrease the output frequency based on the detected phase difference to approach each other, thereby maintaining waveform synchronization without signal communication lines. In a previous inverter generator that supports parallel operation⁽⁵⁾, this technology is used to automatically synchronize generators connected with a dedicated cable to synthesize power equivalent to two units.

As the developed system combines three vehicles and

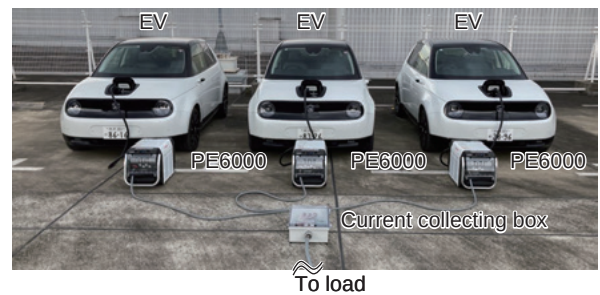


Fig. 5 External view of parallel three-phase 200 V AC output system

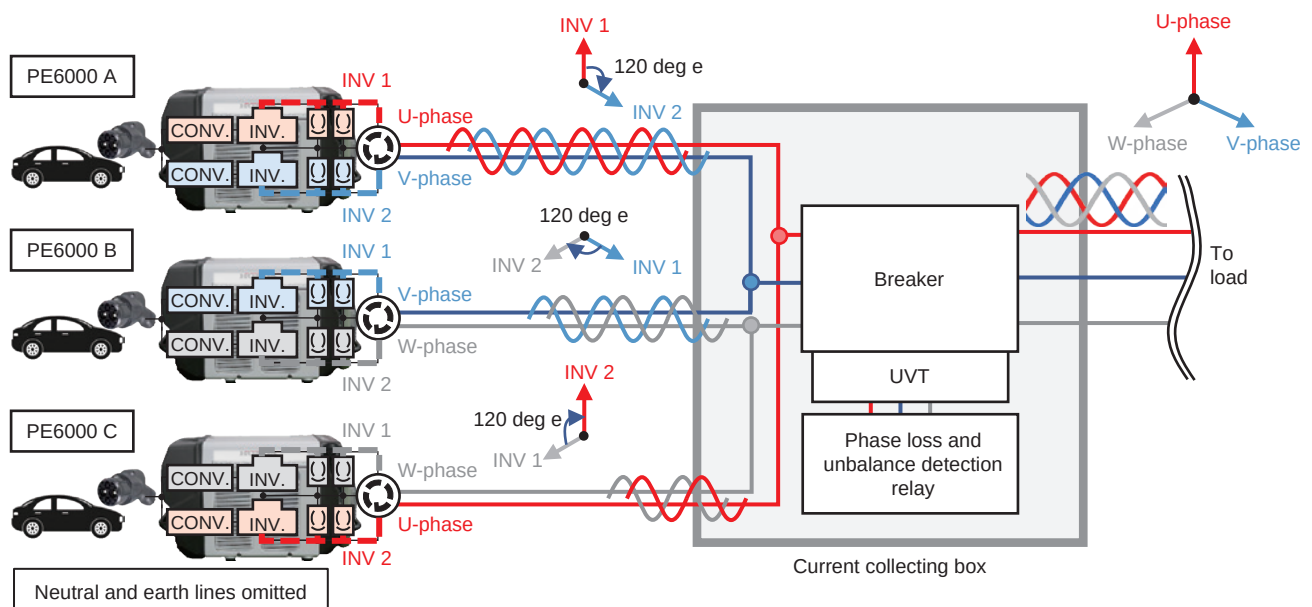


Fig. 4 System configuration of parallel three-phase 200 V AC output

Table 2 Conditions of single output test

Vehicle	Honda e (Honda)
Output power	No load
Power factor	—
Frequency (Hz)	50

three PE6000 units, there is the possibility that the output of one or two of the three PE6000 units may stop due to a vehicle power shortage or the overheating protection function of the PE6000, etc. In this case, the U-, V-, and W-phases would be lost or unbalanced, possibly resulting in damage to the connected electrical equipment. Therefore, the current collecting box is equipped with a phase loss and unbalance detection relay and an Under Voltage Trip device (UVT), and functions have been added to activate a breaker to stop power output in the event of phase loss or unbalance. In addition, functions have been added to notify the user with the indicator lamps of the PE6000 that power output has stopped.

3.1.2. Actual verification of three-phase AC output

It was confirmed that the PE6000 can output sine waves with the newly set phase difference of 120 degrees under the conditions shown in Table 2. Figure 6 shows the respective AC voltage waveforms output in single-

Table 3 Results of single output test

Output mode setting	Single-phase	Three-phase
One cycle of sine wave T (msec)	20.00	20.00
Time difference of zero-cross timing T_{diff} (msec)	10.00	6.67
Difference of electric angles θ_{diff} (calculated value) (deg e)	180.0	120.0

Table 4 Conditions of three-phase output test

Vehicles	3 cars, 3 Honda e cars
Output power (kVA)	16.4
Line current (A)	52
Power factor	Inductive load 0.8
Frequency (Hz)	50

phase mode and three-phase mode, and Table 3 shows the measurement results. The difference θ_{diff} between the electrical angles of the inverters can be obtained by Eq. (1) below.

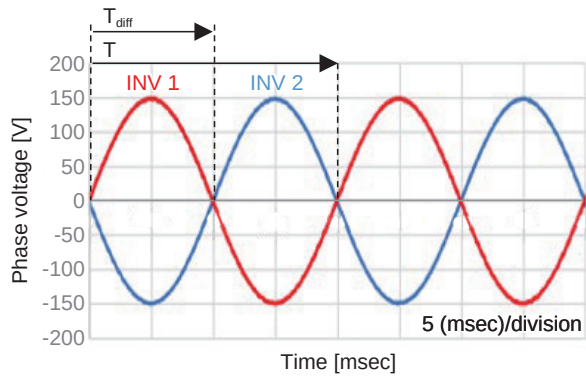
$$\theta_{diff} = \frac{T_{diff}}{T} \times 360 \text{ (deg e)} \quad (1)$$

T : Cycle (msec)

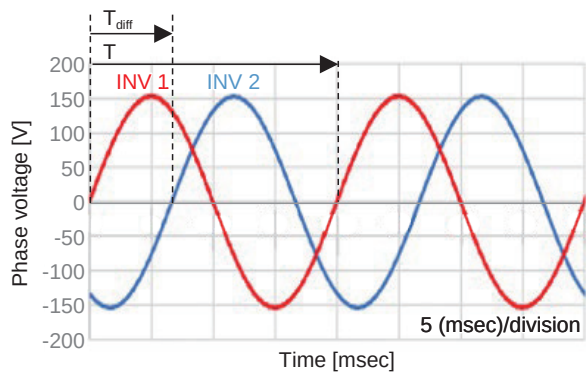
T_{diff} : Time difference of zero-cross timing (msec)

The phase difference of the output waveforms of two inverters started in single-phase mode was 180 degrees, the phase difference of the waveforms started in three-phase mode was 120 degrees, and the phase difference could be accurately controlled to the setting by real-time communication synchronous control.

Next, three vehicles and three PE6000 units were combined, and the three-phase AC output waveform was checked under the test conditions shown in Table 4 that assume an inductive load such as a motor. Figure 7 shows the line voltage waveform at a rated output of 16.4 kVA, and Table 5 shows the measurement results. The three-phase sine waves were synchronized by parallel



(a) Single-phase output mode



(b) Three-phase output mode

Fig. 6 Comparison of phase differences in single output waveforms for each mode

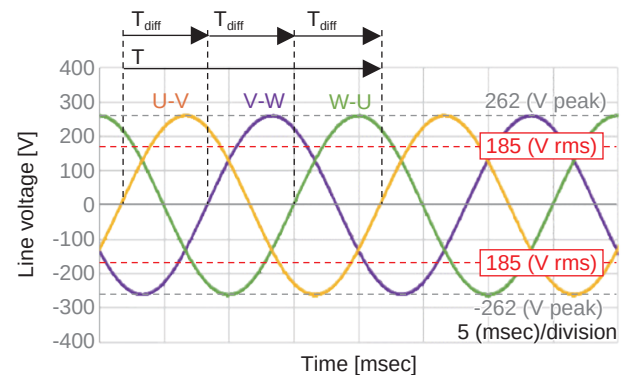


Fig. 7 Three-phase output waveform

Table 5 Results of three-phase output test

	U-V	V-W	W-U
Line voltage (V rms)	185	185	185
One cycle of sine wave T (msec)	20.00		
Time difference of zero-cross timing T_{diff} (msec)	6.67	6.67	6.67
Difference of electric angles θ_{diff} (calculated value) (deg e)	120.0	120.0	120.0

synchronous control, and an AC waveform with a line voltage of 185 V and a phase difference of 120 degrees, which is within the provisions of the Electricity Business Act, could be output.

The above technologies realize a three-phase AC output function and enable use in large electrical equipment such as industrial equipment. In addition, the power output per unit is 10 kW or less, the total power output is less than 50 kW, and the system conforms to the interpretation of technical standard for electrical facilities (Article 199-2)⁽⁶⁾. This realizes Vehicle to Load and Vehicle to Home (V2L2H) as an electrical facility for general use, which does not require notification to a national body or appointment a chief engineer, even though the power output exceeds 10 kW. Furthermore, the same unit can be switched between single-phase and three-phase for use, enabling use in a wider variety of situations than a dedicated three-phase power source unit.

3.2. Versatility of Vehicle Connectivity

The PE6000 and PE9000 are portable external power output devices that comply with the V2L Guidelines⁽²⁾, and have the configuration shown in Fig. 8 where the power supply connector is plugged into the power supply port of the vehicle, and the vehicle and the Power Exporter main unit are connected by the power supply connector cable. As the PE9000 was developed exclusively for the CLARITY FUEL CELL, the cable length was set to 1.2 m, which is suitable for the former. However, with the spread of EVs, the number of vehicles that conform to the V2L Guidelines is increasing, and opportunities to use the PE9000 in

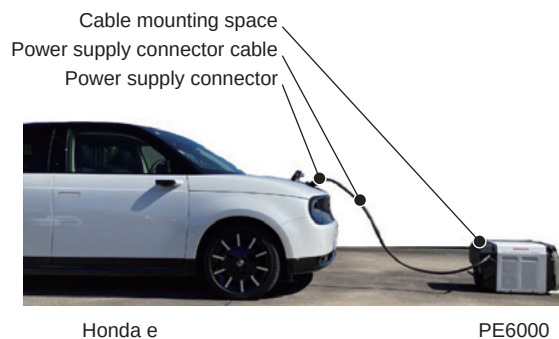


Fig. 8 External view of power supply connector and cable

Table 6 Comparison of specifications of power supply connectors

	PE6000	PE9000
Required maximum current (A)	36	54
Rated current (A)	37	100
Rated voltage (VDC)	Below 500	DC450
Mass (kg)	2.2	3.2
Cable	Length (m)	2.1
	Diameter (mm)	$\phi 23.4$ (typical)
	HV+/- conductor size (mm ²)	5.5 (10 AWG)
	Mass (kg/m)	0.5

combination with vehicles other than the CLARITY FUEL CELL are also increasing. As a result, issues with usability have become apparent, with the shortness of the cable making it a challenge to connect depending on the position of the power supply port of the vehicle. In order to expand versatility, the cable was lengthened, the electromagnetic lock system was changed accordingly, and the resulting issues were addressed. These three points are introduced below.

3.2.1. Longer power supply connector cable

The cable was lengthened without increasing the storage space by reducing the cable diameter and increasing the number of loops when storing the cable. Table 6 shows the specifications of the power supply connector. As the PE9000 has large power output of 9 kVA, a thick cable diameter of $\phi 26.3$ mm is needed. The cable diameter of the PE6000 was reduced to $\phi 23.4$ mm in accordance with the reduced power output. Furthermore, the cable storage specification winds the cable in three loops while gradually reducing the winding radius, as shown in Fig. 9. The space created by the smaller cable diameter was utilized by changing the winding specification, and achieved storage of the lengthened cable.

However, the reduced winding radius of the third loop in order to store the lengthened cable resulted in interference between the cable and surrounding parts, and reduced workability when storing the cable. This issue was addressed by verification using a 3D model to clarify the connector storage angle at which there is no interference between the cable and surrounding parts, and by designing a new holder.

The above measures enabled the installation of a 2.1 m power supply connector cable, the longest known for a portable external power output device compatible with the V2L Guidelines, while reusing the PE9000 frame parts other than the holder to reduce costs. This achieved a package that is easy to connect with a wider variety of vehicles.

3.2.2. Change of electromagnetic lock system

For safety performance reasons, the power supply connector is equipped with an electromagnetic lock using

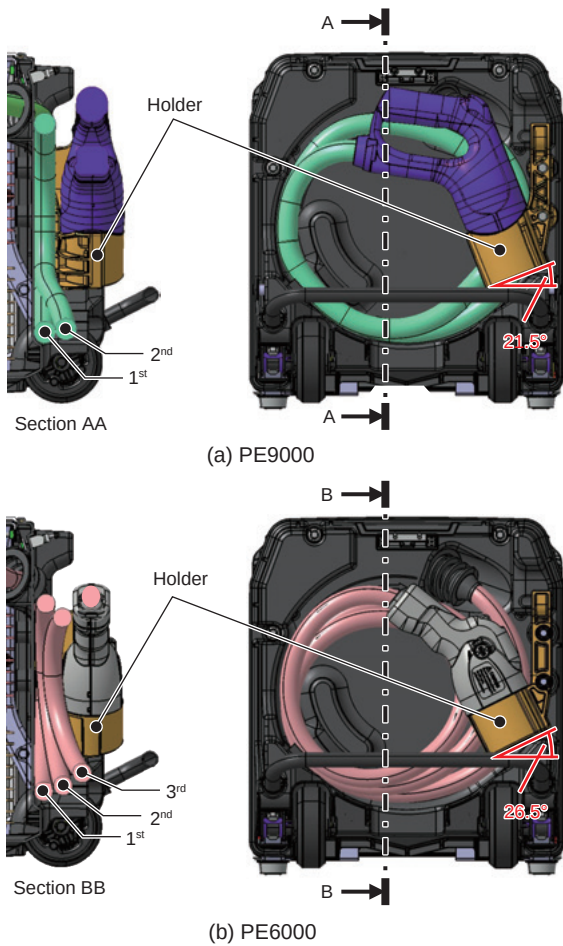


Fig. 9 Power supply connector cable storage status

a solenoid so that the mating between the vehicle and the power supply connector is not released during power supply. Due to the reduction in the power supply connector cable diameter, the electromagnetic lock system of the power supply connector was changed.

The V2L Guidelines stipulate that the electromagnetic lock specification should be a constantly energized type if the cross-sectional area of the conductor of the high-voltage cable of the power supply connector is 22 mm² or more, or a self-holding type⁽⁷⁾ if it is less than 22 mm². Therefore, as shown in Table 6, the large power output PE9000 that has a large cable diameter is a constantly energized type, whereas the PE6000 adopts a self-holding type because of the smaller cable diameter. Figure 10 shows the state transition diagram of the electromagnetic lock using a solenoid. In contrast to the constantly energized type that constantly consumes electric power while locked, the self-holding type consumes electric power only when switching between locked and unlocked, which has the advantage of being able to reduce the amount of electric power consumed by the electromagnetic lock. Compared with the PE9000, the electromagnetic lock of the PE6000 can reduce electric power consumption by 98.4% (0.31 Wh) when power is continuously supplied for 5 minutes, and by 99.7% (1.89 Wh) when power is continuously supplied for 30 minutes.

On the other hand, the addition of circuits was an issue in adoption of the self-holding type. The constantly energized type can control switching and detection of the lock state with a single circuit, but this calls for three circuits for the self-holding type. This development added a control circuit to the Electrical Control Unit (ECU) to

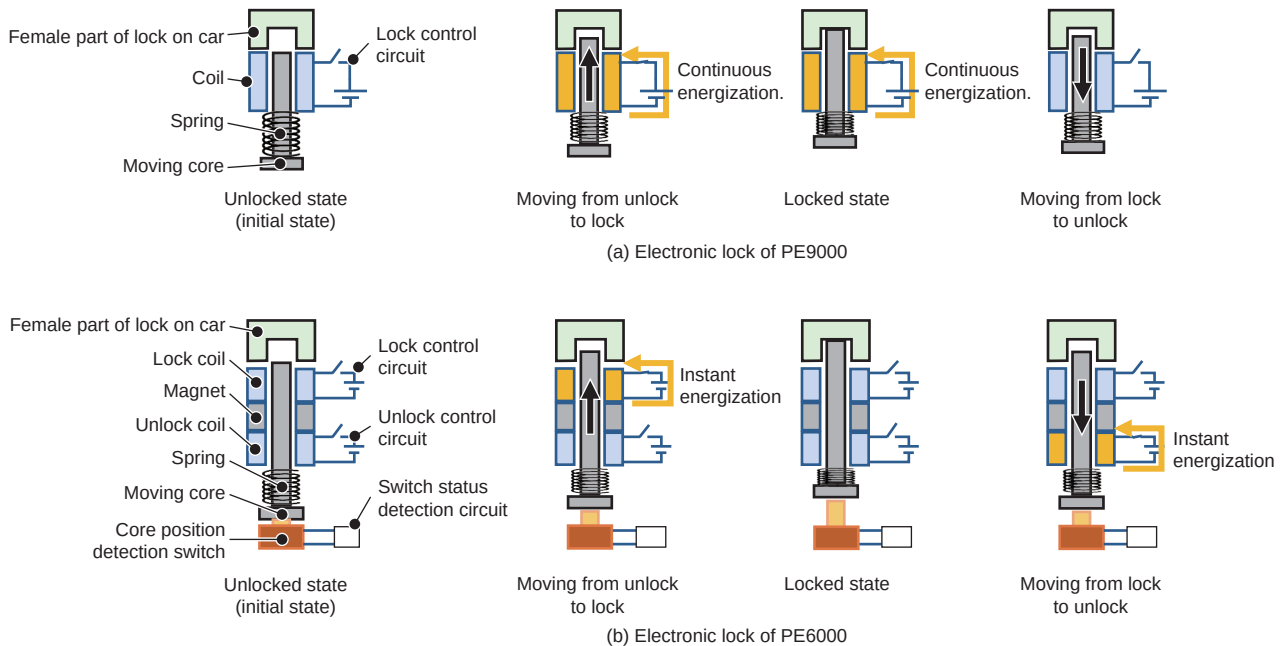


Fig. 10 State transition diagram of electromagnetic lock using solenoid

support the change in the electromagnetic lock. At this time, the board pattern was revised to maintain the board size, which enabled reuse of the ECU case and contributed to cost reduction without impacting the ECU layout and mounted components.

3.2.3. Response to issues due to change in lock system

The PE6000 and PE9000 are battery-less external power output devices without internal 12 V power supply. Therefore, the ECU is started and the electromagnetic lock is operated by receiving 12 V power supply from the vehicle. This 12 V power is supplied via the power supply connector or a 12 V accessory socket according to the specifications of the connected vehicle. Figure 11 shows an outline of connection when 12 V power is supplied from a 12 V accessory socket.

The constantly energized type PE9000 does not need 12 V power supply when switching from locked to unlocked, while the self-holding type PE6000 requires 12 V power supply as described above. Thus, the situation where the power supply connector cannot be disconnected may occur when the cable connected to the 12 V accessory socket is disconnected during power supply, when the power supply of the 12 V accessory socket is stopped by vehicle control, in case of irregular high-voltage battery start-up, or when the high-voltage cable has a broken wire.

This development addressed events where the power supply connector cannot be disconnected with the following two items.

First, a function was added to notify the loss of 12 V power during power supply by the lamp action of the indicator lamps. The notification enables the user to notice that the cable has been disconnected or the vehicle 12 V power supply has stopped, and to restore the 12 V power supply needed to unlock before performing the stop operation. This helps reduce events where the power supply connector cannot be disconnected.

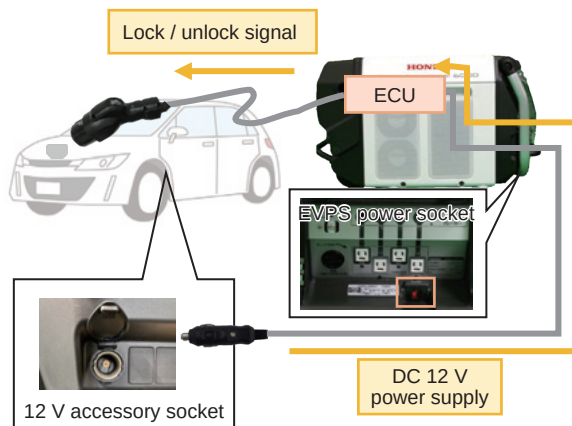


Fig. 11 System configuration of control power supply from 12 V accessory socket

Second, electromagnetic lock control was developed that enables removal of the power supply connector even if it could not be disconnected because the stop operation was performed in the condition with the 12 V power supply lost without noticing the above notification. When the power supply connector cannot be disconnected, the user restarts the PE6000 after restoring the 12 V power supply. Regardless of the state of the electromagnetic lock, the PE6000 performs self-diagnosis at start-up to determine whether the high-voltage battery has started up irregularly or the high-voltage cable has a broken wire. Based on the self-diagnosis results, if the power supply connector could not be removed due to a loss of 12 V power supply, the unlock operation is performed and normal operation is restored. However, if the power supply connector could not be removed due to an irregularity in the high-voltage system, the locked state is continued. Thus, normal operation is restored only when proper circumstances are confirmed, and the power supply connector can be disconnected as usual after power supply is completed.

The above technology enabled changing to a self-holding type without installing a 12 V battery.

4. Conclusion

The PE6000 was developed based on the PE9000 external power output device, and realized a low price by optimizing the power output while maintaining high quality and adding new functions. Sales commenced from September 2023. Despite the low price, the PE6000 achieved the development items set in response to market needs to provide expanded versatility and become a highly competitive product.

- (1) The PE6000 is considered the first such device to add a three-phase AC output function. Combination of three units enables the provision of a large power output of 16.4 kVA, expanding use applications to power supply for industrial equipment, etc.
- (2) The versatility of vehicle connectivity has been expanded by extending the length of the power supply connector cable to 2.1 m, considered the longest for a portable external power output device compatible with the V2L Guidelines. In addition, technical issues due to this change were addressed with minimal cost, which helped to realize the low price.

It is thought that the above technology will expand the range of use in V2L2H and enable the proposal of an even greater range of phase-free use. Honda is confident that the PE6000 will help support people's lives and lead to the expansion of customer joy.

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