

Technical Demonstration of EV Powertrain Evaluation Combining Simulation and Real Power Supply

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[Summary]

As a countermeasure to global warming, the automotive sector is pursuing decarbonization through an xEV shift. To accelerate widespread adoption of Battery Electric Vehicles (BEVs), which are expected to become the future mainstream powertrain, automakers are stepping up their transition from conventional powertrains to motor-based systems. To help achieve a BEV society, we conducted a technical demonstration of Power HIL — a novel approach that integrates Hardware-in-the-Loop Simulation (HILS), a methodology widely used in automotive development, with a bidirectional DC power supply. This enables powertrain performance evaluation equivalent to that of a real vehicle as part of system-level assessment, and is expected to contribute to improved development efficiency, reduced cost, and a decrease in rework during physical vehicle evaluation. Going forward, we will advance validation using actual vehicle components with the aim of enhancing BEV development efficiency, improving quality, and expanding application to other domains.

1 Introduction

Recent climate change driven by global warming has become increasingly pronounced with Japan experiencing more frequent sudden heavy rainfall causing floods and landslips, and heightening the urgency for countermeasures. To help achieve a sustainable society, reduction of greenhouse gas emissions, especially carbon dioxide (CO₂) emissions, represents a critical challenge.

To address this challenge and promote greater efficiency in EV development, we have undertaken a technical demonstration of EV powertrain evaluation that integrates simulation with a real power supply. This article describes the background and context of the challenge in relative detail through to section 3, while section 4 and beyond present the results and status of the technical demonstration.

2 Social Challenges Driving xEV Adoption

According to a 2023 survey by Japan's Ministry of Land, Infrastructure, Transport and Tourism, the automotive sector as a whole accounts for approximately 16.5% of total domestic CO₂ emissions, underscoring the need to advance decarbonization. In the automotive market, a shift toward xEVs (x Electric Vehicles), which use electricity as a power source, is progressing with the aim of reducing CO₂ emissions. Representative vehicle types include BEVs (Battery Electric Vehicles), HEVs (Hybrid Electric Vehicles), PHEVs (Plug-in Hybrid Electric Vehicles), and FCEVs (Fuel Cell

Electric Vehicles). The government has established targets to promote widespread adoption of xEVs, and individual automakers are actively engaged in technology development, establishment of production methodologies, and building of necessary organizational frameworks. While significant future growth in BEV adoption is anticipated, this trajectory is accompanied by a range of social and technical challenges, including development of charging infrastructure, reduction of battery charging time, and extension of driving range.

3 BEV Development Challenges

3.1 Model-Based Development and Simulation Technology

In automotive development, MBD (Model-Based Development) — a development methodology that leverages simulation technology for the purpose of improving efficiency and quality — has been widely adopted. Behavior can be verified at the design stage by modeling control specifications and the structural characteristics of automotive components and subjecting them to simulation.

As shown in Figure 1, the MBD process can be represented by a V-model spanning requirements definition to physical vehicle evaluation. The primary simulation methodologies at each respective stage are MILS (Model-in-the-Loop Simulation), SILS (Software-in-the-Loop Simulation), and HILS (Hardware-in-the-Loop Simulation).

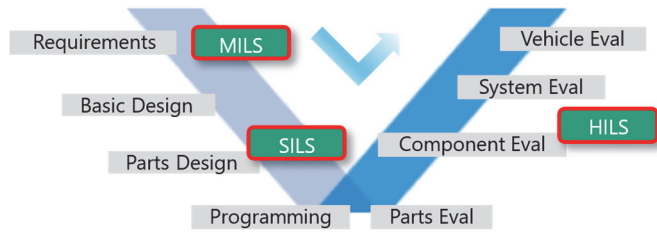


Figure 1 MBD V-type Model

Table 1 lists each method.

Table 1 Simulation Methods

Name	Outline
MILS Model-in-the-Loop Simulation	Verify control logic without physical hardware, using a model-based approach
SILS Software-in-the-Loop Simulation	Verify control algorithms using the implemented code in a PC virtual environment
HILS Hardware-in-the-Loop Simulation	Verify operation using hardware (ECU) and dedicated platform device

Among these methods, HILS plays a particularly critical role. A dedicated platform device serving as the simulation execution environment (HIL simulator hereafter) is connected via wiring harnesses to multiple ECUs (Electronic Control Units) mounted in the vehicle, enabling exchange of control signals, including I/O, CAN, and Ethernet, based on simulation results. This supports verification of complex cooperative behavior between ECUs, as well as repeated testing of abnormal conditions and failure modes that would be difficult to reproduce in a real-world environment.

However, verifying and evaluating the performance of a powertrain that handles electrical power requires continuous refinement of the simulation model.

3.2 Powertrain Evaluation

The powertrain of BEVs is transitioning from the engine and fuel (such as gasoline) used in conventional internal combustion engine vehicles to a motor system centered on motors, inverters, and batteries (Figure 2). This transition necessitates new initiatives, including revisions to performance evaluation criteria for newly introduced components.

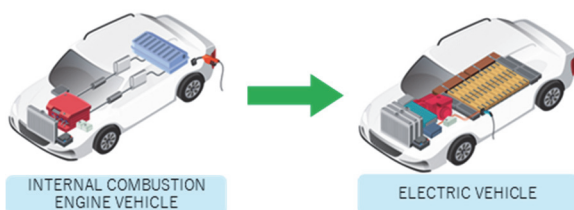


Figure 2 Transition to Motor System

Meanwhile, competition in the automotive market, both domestically and internationally, is intensifying, creating pressure to further streamline development processes and bring new vehicle models to market earlier. However, when issues arise during powertrain evaluation after completion of a physical vehicle, the resulting rework is substantial, leading to delays in the development schedule and increased costs. To mitigate and avoid such risks, it is more effective to conduct system-level evaluation equivalent to that of a physical vehicle using real electrical power prior to actual vehicle evaluation.

3.3 Integrating Simulation and Real Power Sources

To streamline BEV development, we are working to achieve Power HIL, a powertrain performance evaluation method that integrates HILS with a bidirectional DC power supply (power supply unit hereafter). This method features a HIL simulator combining environment, vehicle, component, and control models to simulate operations such as charging and driving (acceleration, deceleration, hill climbing, rough-road driving, etc.) to control the power supply unit, to evaluate performance with power transfer equivalent to an actual vehicle applied to the motor/inverter and battery. Figure 3 shows an example of a Power HIL system configuration using a real battery.

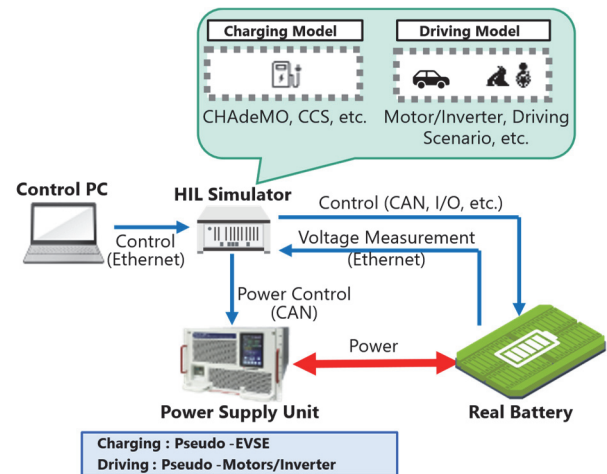


Figure 3 Power HIL System Configuration using Real Battery

Furthermore, as shown in Figure 4, the verification accuracy of MILS and SILS is improved to refine the model by feeding back evaluation data to the upstream process.

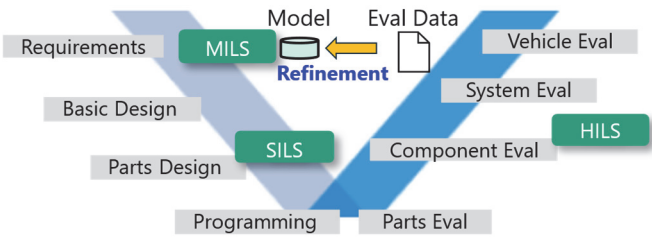


Figure 4 Refinement of the Model Using Evaluation Data

4 Technical Demonstration

In fiscal 2024, we collaborated with a domestic automobile manufacturer to demonstrate Power HIL utilizing existing equipment. The following describes this initiative.

4.1 System Outline

The system was constructed by combining a control PC (Table 4), a HIL simulator (Table 5), and a power supply unit (Table 6). Since using actual vehicle components during simulation model development carries safety risks, a power supply unit was adopted as a pseudo-battery.

Figure 5 shows the basic system configuration.

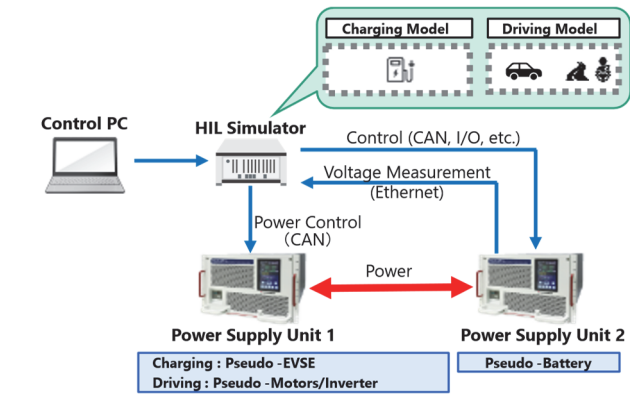


Figure 5 Basic System Configuration

The primary objectives of this demonstration were to validate the model executed on the HIL simulator and to confirm the feasibility of power supply control. With safety considerations in mind, power supply control was conducted at approximately 1/20 scale of the actual power level (i.e., the power handled in a real vehicle). Table 2 lists the components constituting the system and their respective roles.

Table 2 Equipment and Roles

Name	Function
Control PC	Controls operation of HIL simulator
HIL Simulator	Executes simulation models replicating charging and driving, and controls power supply unit
Power Supply Unit 1	Charging: Simulates charging by supplying power as EVSE Driving: Simulates motoring and regeneration through power supply and recovery
Power Supply Unit 2	Simulates battery by supplying and recovering power

The Takasago Seisakusho RZ-X2-10K was used as the power supply unit because it provides sufficient power capacity and charge/discharge functionality for the demonstration, offers high efficiency and low noise performance, excels in responsiveness and stability to rapid changes in voltage and current, and has an extensive track record among domestic automobile manufacturers.

A CAN (Controller Area Network) and Ethernet were used as the interface between the HIL simulator and the power supply unit. This demonstration conducted two evaluations: “charging simulation” (section 4.2), which evaluates battery charging performance by simulating EVSE (Electric Vehicle Supply Equipment: charging station) operation, and “driving simulation” (section 4.3), which evaluates powertrain performance by simulating motor/inverter operation during vehicle driving.

Additionally, prototype software (Power HIL Platform Software hereafter) was developed incorporating integrated control and data monitoring functions for each piece of equipment, including the HIL simulator and power supply unit. It creates simulation conditions, execution control, and status display via a GUI.

4.2 Charging Simulation

BEV charging methods include normal charging and fast charging, each with various charging standards. Table 3 lists the major fast-charging standards and regions.

Evaluating charging performance requires equipping a facility with EVSE units compatible with each standard at substantial capital investment and installation space. Therefore, charging simulation aims to reproduce each standard within a single evaluation system and assess charging performance including the battery control ECU. This demonstration selected CHAdeMO, which is widely adopted in Japan, as the target standard.

Table 3 Major Fast-Charging Standards and Regions

Charge Standard	CHAdEMO	CCS	NACS	GB/T
Region	Japan	Type 1: N. America Type 2: Europe	N. America	China

The charging was simulated by assigning one HIL simulator and one power supply unit to each of the pseudo-EVSE and pseudo-EV, following the sequence outlined in steps (1) through (4) below (Figure 6).

- (1) Start the charging sequence between the pseudo-EVSE and pseudo-EV.
- (2) Control the output of power supply unit 1 from the pseudo-EVSE in accordance with the current value commanded by the pseudo-EV in step (1).
- (3) Measure the voltage of power supply unit 2 within the pseudo-EV, and calculate the SoC (State of Charge: battery charge level) and next current command value, and notify the pseudo-EVSE via the communication in step (1).
- (4) Repeat step (3) until SoC reaches 100%.

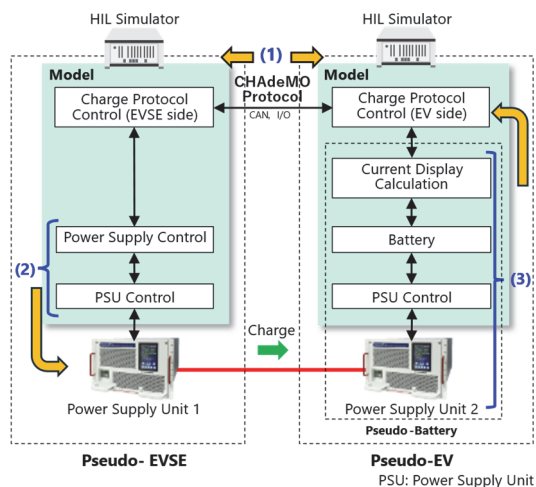


Figure 6 Demonstration System Configuration for Charging Simulation

Figure 7 shows the measurement results for the pseudo-battery SoC during the charging simulation.

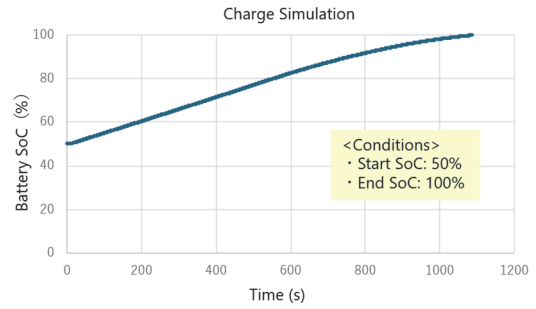


Figure 7 Measurement Results for Pseudo-Battery SoC During Charging Simulation

The results show that the pseudo-battery SoC increases as charging time elapses, demonstrating the model validity, including charging protocol control, and confirming that evaluation of battery charging performance is feasible. Furthermore, the charging monitor screen of the Power HIL Platform Software displays measurement data, such as energy and battery SoC during charging, enabling identification of normal and abnormal conditions on one screen and facilitating appropriate judgment and response (Figure 8).



Figure 8 Power HIL Platform Software Charging Monitor Screen

Although this demonstration targeted CHAdEMO, charging simulation for other charging standards can also be achieved simply by modifying the charging protocol control model and the I/O of the HIL simulator, without altering the fundamental system architecture.

4.3 Driving Simulation

During vehicle operation, a BEV transfers power between the traction motors and battery in accordance with motoring and regeneration, as governed by accelerator/brake inputs. Motoring refers to the state in which electrical energy is drawn from the battery to drive the motors during acceleration via accelerator input. Regeneration refers to the state in which the motors operate as a generator during deceleration via brake input, thereby charging the battery. Driving simulation reproduces this sequence of operations with the objective of evaluating powertrain performance under conditions closely approximating actual vehicle operation.

This demonstration adopted the WLTC (Worldwide-harmonized Light vehicles Test Cycle), an internationally recognized standard for fuel and energy consumption evaluation, as the driving pattern. The WLTC consists of four phases: low speed, medium speed, high speed, and extra-high speed, encompassing driving conditions representative of urban roads, suburban roads, and motorways.

The simulation vehicle model used was a standard model provided by the HILS vendor. Power consumption was calculated based on the motoring/regeneration of the motors/inverter model. During motoring operation, the power supply unit was controlled to output a negative value (–) to simulate discharge of the pseudo-battery.

Conversely, during regenerative operation, charging was simulated by controlling the power supply unit to output a positive value (+). The driving simulation was carried out using one HIL simulator and two power supply units, following the procedure outlined in steps (1) through (3) (Figure 9).

- (1) A standard vehicle model within the HIL simulator reproduces, via simulation, driving state under the WLTC pattern.
- (2) Calculates motoring/regeneration (–/+) of motors/inverter and controls power supply unit 1 accordingly.
- (3) Measures terminal voltage of power supply unit 2, serving as pseudo-battery, and computes SoC.

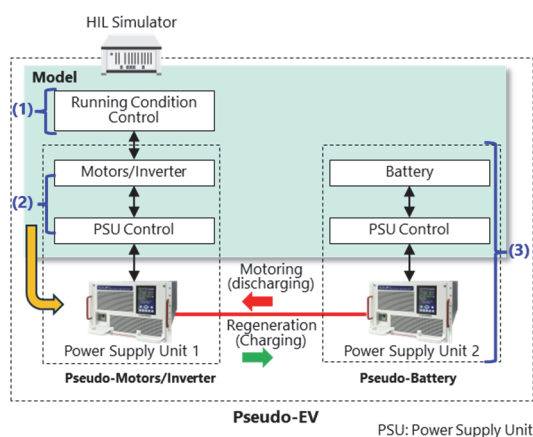


Figure 9 Driving Simulation Demonstration System Configuration

Figure 10 shows the measured vehicle speed, motoring/regeneration, and pseudo-battery SoC for each WLTC phase during driving simulation.

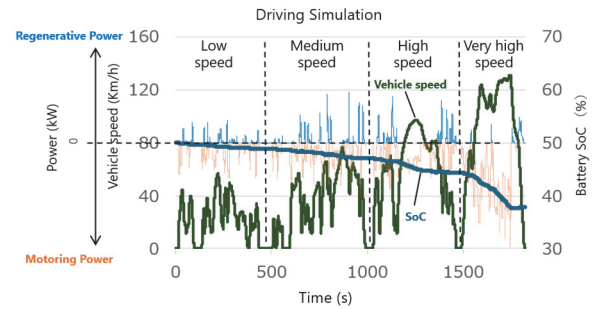


Figure 10 Measured Pseudo-Battery SoC During Driving Simulation

The results confirm that power fluctuations equivalent to those of an actual vehicle — corresponding to power consumption by motors driving in each phase and power generation by motors during deceleration — are successfully reproduced, demonstrating that powertrain performance under driving conditions can be evaluated without using a physical vehicle. This driving simulation also enables the calculation of energy consumption efficiency, a key evaluation metric. The driving monitor screen of the Power HIL Platform Software displays measured data including vehicle speed, accelerator/brake operation, power consumption associated with motoring/regeneration state of the motors/inverter, and SoC, helping the operator assess on one screen the normality or abnormality of charging and discharging during driving, and facilitating prompt and appropriate judgment and corrective action (Figure 11).

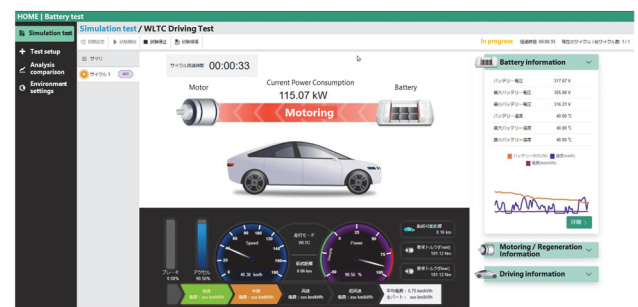


Figure 11 Power HIL Platform Software Driving Monitor Screen

This demonstration used a standard model provided by the HILS vendor as the vehicle for simulating driving. However, evaluation of powertrain performance under conditions more closely approximating actual vehicle operation is achievable by substituting a model customized to a vehicle from each automotive manufacturer.

4.4 Power System Switching

In this powertrain performance evaluation, charging simulation and driving simulation are switched alternately to

monitor the SoC transition and calculate energy consumption. However, the power transfer circuits are configured separately in each simulation, resulting in different connection points to the battery. To eliminate cable reconnection work, a junction box was prototyped (Table 7) and inserted between the power supply unit and the battery (Figure 12) to achieve seamless power-circuit switching.

Furthermore, since the power supply unit and battery are not connected directly, the junction box enables isolation even in the event of unintended current flow, thereby improving safety.

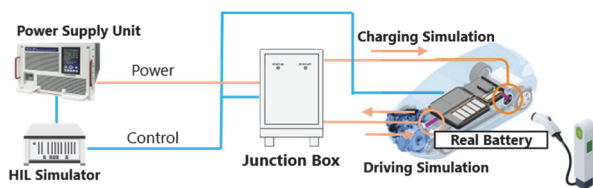


Figure 12 Power System Switching

The prototyped junction box was designed primarily to verify feasibility, including component selection and structural design needed for power circuit switching, and was about 1/20 scale of the actual power level, matching the demonstration system.

Figure 13 shows the internal structure of the junction box.

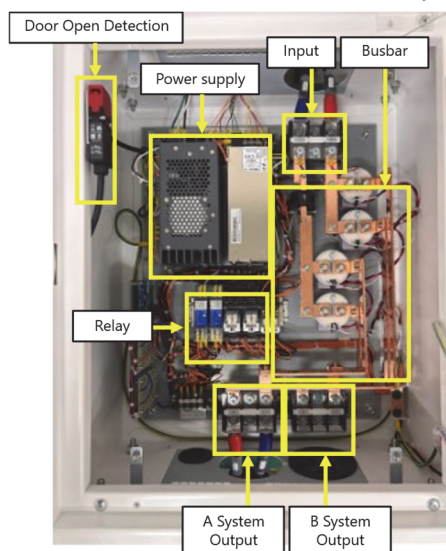


Figure 13 Internal Structure of Junction Box

Validation in the demonstration environment confirmed the adequacy of the components and circuits, as well as the system control sequence, considering safety. Adaptation to full-scale power applications is possible by replacing components with those meeting the specifications for the required applied voltage and current.

5 Future Challenges and Outlook

This demonstration confirmed the Power HIL feasibility using a motors/inverter model and pseudo-battery. The next step will be a similar demonstration using actual vehicle components to verify the validity of the models and methodology.

Going forward, the automotive market is expected to see further growth driven by widespread adoption of xEVs and fully autonomous driving. Furthermore, advances in technologies such as SDV (Software Defined Vehicle) and OTA (Over-The-Air) updates enable modification of vehicle ride quality and functionality through software, expanding efforts to sustain long-term user satisfaction even after market introduction.

At development, there is growing emphasis on improving the efficiency of design and evaluation processes, with an increasing tendency to expand use of simulation. Nevertheless, powertrain systems still require efficient performance evaluation using actual electrical power. Since this methodology is applicable both to the automotive market and to a broad range of industries, including agricultural machinery, construction machinery, marine vessels, aviation, and aerospace, we intend to expand its application scope.

6 Conclusions

EV powertrain technology was evaluated to improve the efficiency of BEV development by integrating simulation with real electrical power sources. The expected battery SoC transition was successfully confirmed by controlling the power supply unit from a HIL simulator to simulate EVSE power control, as well as power control via motor drive and regenerative power generation to simulate the powertrain during driving. These results demonstrate that evaluation equivalent to that of an actual vehicle is achievable.

Based on these demonstration results, we aim to help accelerate development of automobiles toward reaching a BEV-based society through the early market introduction of Power HIL.

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Table 4 Control PC Main Specifications

Item	Specification
OS	Windows 10 Pro for Workstations Plus (64 bit)
CPU	Intel® Xeon® Gold 5222 Processor × 2 (Dual-processor)
Graphics	NVIDIA® TITAN RTX (GDDR6 24 GB)
Main Memory/Storage	96 GB (DDR4-2933)/1 TB (SATA 6 Gb/s)
Network (LAN)	1 × RJ45 (10GBASE-T, 1000BASE-T, 100BASE-TX)
Power	1125 W/100 Vac (50/60 Hz)
Dimensions/Mass	Approx. 216 (W) × 556 (H) × 445 (D) mm/ approx. 23.7 kg (standard configuration)
Operating Environment	Temperature: 10° to 35°C; Humidity: 10% to 90% (no condensation)

Table 5 HIL Simulator Main Specifications

Item	Specification
OS	RTOS
CPU	Intel® Core™ i7 Processor
Main Memory/Storage	4 GB (DDR4)/8 GB flash memory
Interface	Gigabit Ethernet
	RS232 interface with standard UART
I/O Board	1 × RJ45 (10BASE-T, 100BASE-TX, 1000BASE-T)
	1 × Dsub-9P
	4 × RJ45 (10BASE-T, 100BASE-TX, 1000BASE-T)
I/O Board	Ethernet
	CAN
	8 (CAN, CAN-FD)
I/O Board	Multi-I/O
	Analog, Digital
Power	350 W/100 to 240 Vac (50/60 Hz)
Dimensions/Mass	Approx. 250 (W) × 400 (H) × 200 (D) mm/ approx. 7.5 kg (excluding board)
Operating Environment	Temperature: 0° to 50°C; Humidity: 5% to 95% (no condensation)

Table 6 Power Supply (RZ-X2-10K) Main Specifications

Item			Specification
Output	Rated output voltage/rated output current/ rated output power		+100 V/±300 A/±10 kW
Input	Operating power supply		180 to 250 Vac, 3-phase, 45 to 65 Hz
Constant Voltage (CV)	Set range	Hi/Lo	+0.00 to +102.00 V/+0.000 to +30.600 V
Constant Current (CC)	Set range	Hi/Lo	−306.00 to +306.00 A/−30.600 to +30.600 A
Constant Power (CP)	Set range	Voltage: Hi/Current: Hi	−10.200 to +10.200 kW
		Voltage: Hi/Current: Lo	−3.060 to +3.060 kW
		Voltage: Lo/Current: Hi	−9.180 to +9.180 kW
		Voltage: Lo/Current: Lo	−918.0 to +918.0 W
Series/Parallel Operation	Expandability	Max. connected units	Series: 5 units/Parallel: 10 units
	Max. rated output voltage/Max. rated output current		+500 V/±3000 A (10 units in parallel, without series)
	Max. rated output power		±200 kW
Other Functions	External communication interface		LAN/CAN CAN FD (option)
Operating Environment	Ambient temperature/humidity		0° to 40°C/20% to 85% (no condensation)
Dimensions/Mass			430 (W) × 355 (H) × 650 (D) mm/approx. 70.0 kg

Table 7 Junction Box (Power Line Switching Unit) Main Specifications

Item	Specification	
Inputs/Outputs	1/2 (A, B)	
Rated Voltage/Rated Current	Rated impressed voltage: 100 Vdc/Rated carrying current: ±100 Adc	
Voltage Monitor Output	Scale/Accuracy	+10 V/+100 V (Internal circuit insulation voltage: 500 Vdc)/within 100 V ±3%
Current Monitor Output	Scale/Accuracy	±10 V/±100 V (Internal circuit insulation voltage: 500 Vdc)/within 100 V ±3%
Output Switching	Signal specification	Voltage-free contact input, 24 Vdc, 20 mA min.
Input/Output Lines	1500 V, MLFC 60 mm ² , 2-conductor twisted, 10 m (crimp terminals M8, M12) × 3	
Input Operating Voltage	Single-phase 90 to 110 Vac, 50/60 Hz, approx. 10 A max.	
Dimensions/Mass	Approx. 600 (W) × 500 (H) × 300 (D) mm/approx. 40 kg	

Publicly available