“FRCM Series” of EV Quick Chargers

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ABSTRACT

Electric vehicles are being released one after another, and the quick-speed charging spots construction is accelerating in Japan to deal with global warming. Fuji Electric developed quick-speed charging units that use general-purpose inverters and released them on the market. This time, we developed the “FRCM Series”, a quick charger for electric vehicles based on front-end power supplies. The power unit, insulated from high-frequency waves, and has solved the problem caused by harmonics. The charger cabinet is lightweight at 210 kg and its depth is 480 mm, similarly thin as a general vending machine. The panel has a universal design seeking ease of use, and employs safety design using a hardware sequence that blocks both input and output to reliably cut the current in emergencies as well.

1. Introduction

Automobile emission regulations have been increasing in severity year after year as a means of dealing with global warming. For example, the “ZEV mandate” in California, the United States stipulates that 10% of all cars sold must be pollution-free or eco-friendly. In order to deal with this situation, each automobile manufacturer has been stepping up its development and market introduction of eco-friendly cars.

In the year 2010, car manufacturers were making announcements one after another of market launches or planned market launches of electric vehicles (EV), thereby making it quite apparent that there has been an increasing trend toward the development of eco-friendly electric vehicles. Japan has seen an increase in the building of quick charging spots, and efforts are being made to build an infrastructure environment that allows electric vehicles to be used without anxiety.

Fuji Electric has developed quick chargers that use general-purpose inverters, and successfully introduced the products to the market. Recently, we have launched a series of electric vehicle quick chargers called the “FRCM Series.” FRCM Series quick chargers are based on a new concept that incorporates a high-frequency isolated power supply unit, a panel with a thin-plate structure, etc.

2. Product Characteristics

(1) High frequency isolated power supply unit

Previous models have used a general purpose inverter for a power supply unit, and have suffered from problems such as issues involving power supply harmonics and their inability to extend output power. Therefore, we developed a power supply of 12.5 kW per unit based on front-end power supplies. By connecting the two power supply units in parallel, this charger enables the rated output of 25 kW. This charger is available to connect low-voltage switchgear, and it is free from the power supply harmonics problem.

(2) Thin structure enabling installation space-saving

As shown in Fig. 1, the FRCM Series makes use of the thin panel structure technology of vending machines. The charger cabinet is lightweight of 210 kg and its depth is 480 mm, the same thinness as a general vending machine. Our previous “FRCH Series” models had a weight of 700 kg and a depth of 700 mm. Most of quick chargers are placed in the corner of parking place since their thin structure enables effective use of space. Fuji Electric's vending machines

Fig.1 “FRCM Series”

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have an outstanding track record with over 5 million units shipped in total. Therefore, our company has the know-how of products used by the general public people, including technologies that ensure durability and anti-crime performance. The FRCM Series quick chargers are designed using this know-how.

(3) Universal and safety design features

The exterior side of charger door employs the same general universal design*1 of vending machines. In addition, Fuji Electric's safety design policy was adopted, making the quick chargers safe and easy to use.

3. Power Supply Unit

3.1 Outline functionality and characteristics

(1) External appearance and functions

Figure 2 shows the external appearance of the power supply unit. The output power of a single power supply unit is 12.5 kW. Since it is possible to connect and operate several power supply units in parallel, the output of the charger cabinet can be increased to 25 kW, 37.5 kW, or 50 kW etc.

A cooling fan is prepared at the top of the charger and constructed so as to evacuate cooling air from bottom to top. When connecting the power supply units in parallel, all terminal blocks and connectors are placed at the front of the charger so that they can be arranged and installed side by side.

If an uncontrollable abnormality or malfunction occurs inside the power supply unit, it can be disconnected safely from the power supply line of the charger cabinet using the circuit protector located at the top of the AC input terminal.

Furthermore, the configuration switches located at the bottom make fall back operation possible when using multiple units in parallel or if a failure occurs.

(2) Outline of operation

This power supply unit uses a constant current control system so as to be used for battery charging. It measures a variety of different information such as internal voltage, current, and temperature. If a malfunction occurred, the error log function of the unit records this information into its internal memory. The various kinds of information can be accessed by connecting the unit to a PC, and thereafter, be easily used in factor analysis to discover fault causes at the time of malfunction.

(3) Electrical specifications and characteristics

Table 1 shows the major specifications of the power supply unit. In stand alone power supply units, an efficiency of 92% is guaranteed. This level of efficiency falls sufficiently above the CHAdeMO*2 specification of 90% for charger cabinet as a whole. Since the AC-

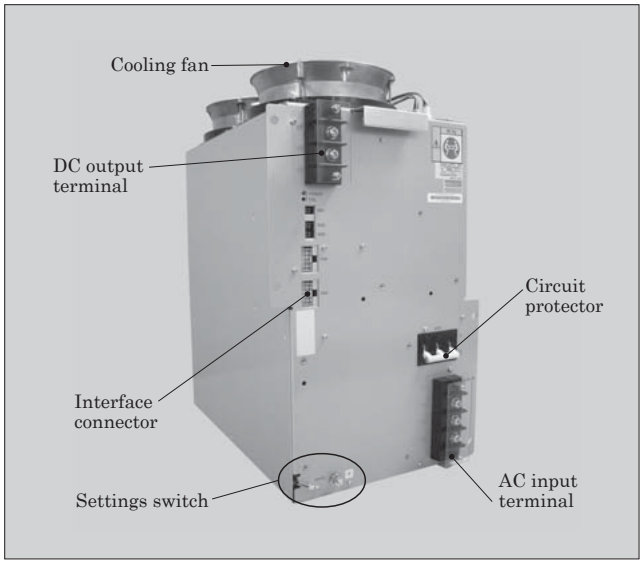


Fig.2 Power supply unit

Table 1 Major specifications of power supply unit

Item		Specification
Input characteristics	Input voltage	3-phase 170 to 264 V AC
	Frequency	50/60 Hz
	Inrush current	50 A or less
	Efficiency	92% or more
	Power factor Harmonic current regulation	95% or more IEC, EN61000-3-2 (Compliant)
Output characteristics	Output voltage	50 to 500 V DC
	Output current	0 to 31.25 A
	Ripple spike	Within ± 10 V
	Output ripple current	1.25 A p-p or less
	Overvoltage protection level	520 to 540 V
	Overcurrent protection level	102 to 130%
Environmental conditions	Operation temperature/ humidity	– 20 to 50 °C/5 to 95%RH
	Storage temperature/ humidity	– 40 to 70 °C/5 to 95%RH
	Vibration resistance	0.5 G, 3 to 60 Hz, 1 cycle/2 minutes×5
	Overheat protection	Yes
Regulation	Conformable standard	CHAdeMO Ver 0.9 compliant
	Overseas safety standard	UL2202
Others	Dimensions	W230×D465×H380 (mm) (Not including projecting parts)
	Weight	26 kg or less
	Cooling conditions	Forced air-cooling (bottom air intake, upper exhaust)

*1: Universal design: This refers to a design that optimizes its ability to be used by numerous different kinds of people regardless of age, disability, etc.

*2: CHAdeMO: Trademarks and/or registered trademarks of the CHAdeMO Association

DC converter in the input block of the power supply unit has a power-factor correction circuit in it, an input current wave takes a form similar to a sine wave, and thus, there is no need to install a capacitor for power-factor correction on the outside of the charger. In addition, this product conforms to the "Guideline of Harmonics Reduction for Consumers who have High-Voltage or Ultra-High-Voltage switchgear."

The output part of the DC/DC converter aims to reduce output ripple current and downsize the isolation transformer by using a high frequency swiching of 80 kHz.

Since a long-service life fan is used for the purpose of cooling, the unit is designed so as not to need parts replacement during the 8-year lifetime of the charger under ambient temperature conditions of 40 °C. Furthermore, since a variable speed fan is used, acoustic noise can be reduced by controlling the fan rotation to appropriate speed by measuring temperature in the power supply unit. This power supply unit can also be used in the United States as it conforms to UL2202, the safety standard for chargers.

3.2 Circuit configuration and power supply technology

Figure 3 shows a circuit block diagram of the power supply unit.

(1) Input part

The AC-DC converter of the input part makes use of 3-level power-factor correction circuits (patented). By treating 3-phase AC input correctively and carrying out control so that input current takes the form of sine wave, a stable direct intermediate current is obtained. Through digital control with a digital signal processor (DSP), control circuit realizes waveform shaping of input current as well as the stabilization of output voltage. Compared with conventional analog control systems, the number of control circuit parts has been reduced by 80%, thus cutting down the size of the board area significantly.

(2) DC intermediate part

Two electrolyte capacitors are connected in series in the DC intermediate part. The voltages at the top and bottom of the electrolyte capacitors are controlled to be the output voltage. Since the voltages at the top and bottom of the electrolyte capacitors are controlled, the circuit system becomes compatible with an AC input voltage of 400 V by changing only the voltage settings that output to DC intermediate voltage. There is no need to change circuit configuration or parts.

(3) Output part

A phase shift converter system is used in the DC/DC converter of the output part. By employing zero volt switching (ZVS), switching loss of the metal-oxide-semiconductor field-effect transistor (MOSFET), which is used as a switching element, is reduced and efficiency is improved. This DC/DC converter provides output of 3.125 kW per one circuit. By connecting four circuits in parallel, an output power of 12.5 kW is obtained as one power supply unit.

The power supply unit is also equipped with a current balance circuit so that even when several units are connected together, each unit can produce an identical output current divided equally. Reliability is increased by equalizing the load of each power supply unit. Since diodes are also installed for the prevention of backflow in the output, even in the rare case that the power supply unit is damaged, it is possible to prevent current backflow from the battery.

4. Cabinet

4.1 Outline of charger

(1) Thermal design

When the efficiency of a charger with an output of 25 kW is 90%, 2.5 kW of heat must be discharged during times of maximum output. Therefore, the biggest issue is the emission of heat. Since it is the greatest priority of the power supply unit, which is the hottest part, construction has been made so that unit's case is located as close as possible to the top. This design allows for generated heat to be immediately discharged to the outside of the cabinet from the top plate.

Figure 4 shows the arrangement of parts inside the cabinet. Two power supply units are connected

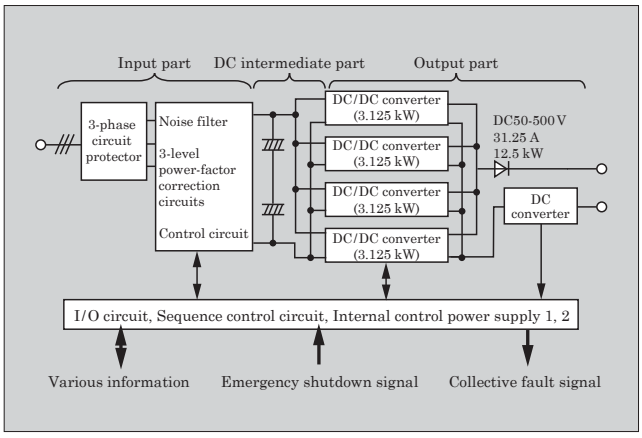


Fig.3 Circuit block diagram of power supply unit

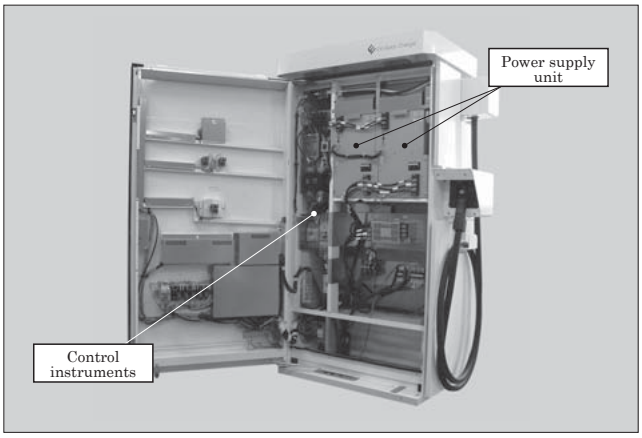


Fig.4 Arrangement of parts inside the cabinet

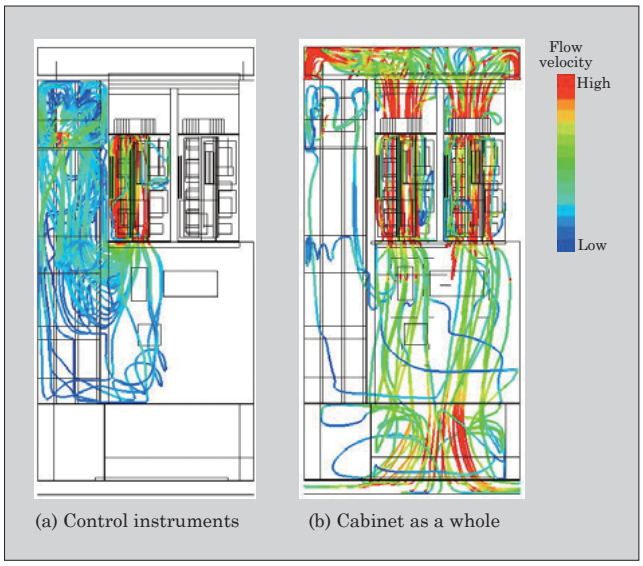


Fig.5 Air-flow simulation analysis inside of the cabinet

in parallel to the top part of the cabinet, and the least number of parts possible are arranged at the bottom of the power supply units considering air-flow. All of the main circuit-related parts such as earth leakage breaker, magnetic contactor and fuses are arranged on the left side. By separating them from the power supply units, air-flow is secured and heat issues are solved.

Figure 5 shows the results of the air-flow simulation inside of the cabinet. The air-flow and temperature distribution inside of the cabinet can be seen easily, and this makes it possible to carry out theoretical studies regarding parts arrangement. Validity was evaluated before a trial manufacture of the product, and we were able to confirm that everything conformed very well.

(2) Universal design and safety features

The exterior side of the door employs a universal design to perform layout of an LC display, manual operation buttons and the like.

For the main circuit interruption, a breaker with earth leakage breaking function and a magnetic contactor for interrupting main circuit are allocated in input part, and super rapid fuses and a DC contactor for interrupting DC output are allocated in output part. Emergency cutoff, which is carried out using the emergency stop switch, door switch etc., has been configured by a hardwired sequence using a safety relay. Dual cutoff of both the input and output circuit allow to ensure cutoff, which is designed with safety in mind. Furthermore, a protective function is also incorporated into the charger to halt the output of the power supply unit in the case of detecting an abnormality in the output, etc. of the control part.

The power supply unit is made of two units connected in parallel, which operate cooperatively during normal operation. If one unit were defected, the other unit can carry out operation in fall back.

4.2 Employing design know-how of vending machines

The thickness of a sheet steel of a switchgear cabinet, etc. is typically 2.3 mm. However, vending machines make use of a cabinet technology that combines reinforcement parts and materials on a thin board, thereby providing sufficient cabinet rigidity. We have incorporated this same design technology into the production of this charger, which possess sufficient cabinet rigidity with a board thickness of 0.7 mm in both the main body and door. As a result, we have enabled to reduce the weight of the charger to 210 kg from the conventional unit weight of 700 kg, thus achieving a considerable weight savings.

Figure 6 shows the structure of door part and Fig. 7 shows an example of a stress analysis. Since the door exhibits cantilever motion with the opening and closing of the door, strength is a particular issue. In addition, another issue is the support structure of the main body since the power supply unit is approximately 60 kg. Therefore, structural stress analysis was carried out using 3D CAD for the reinforcement parts and support structure, and numerous tests were implemented before carrying out the trial production. As a result, we were able to prepare an optimized design that ensures a sufficient strength for the product. None of the parts use commercially sold steel materials, but use parts of optimal shapes and sizes obtained by bending and curving thin plates of sheet metal used for vending machines. Reinforcement parts in the door are also structured so as to serve as gutters when water drips down from various devices attached to the door such as the display device and switches.

In addition, other functional parts such as a door lock mechanism, hinge mechanism and door stopper were prepared so as to be compatible, to the extent possible, with parts used in vending machines in order to achieve enhancements in reliability.

With the exception of the main circuit, the wiring work avoided the screw wiring that uses terminal block, and adopted a wire harness that uses connec-

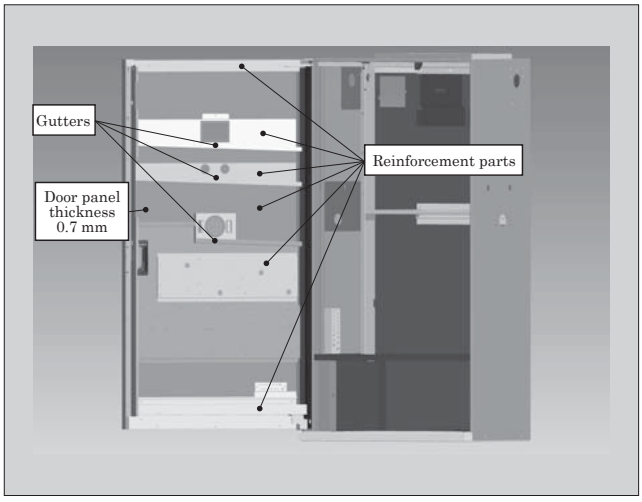
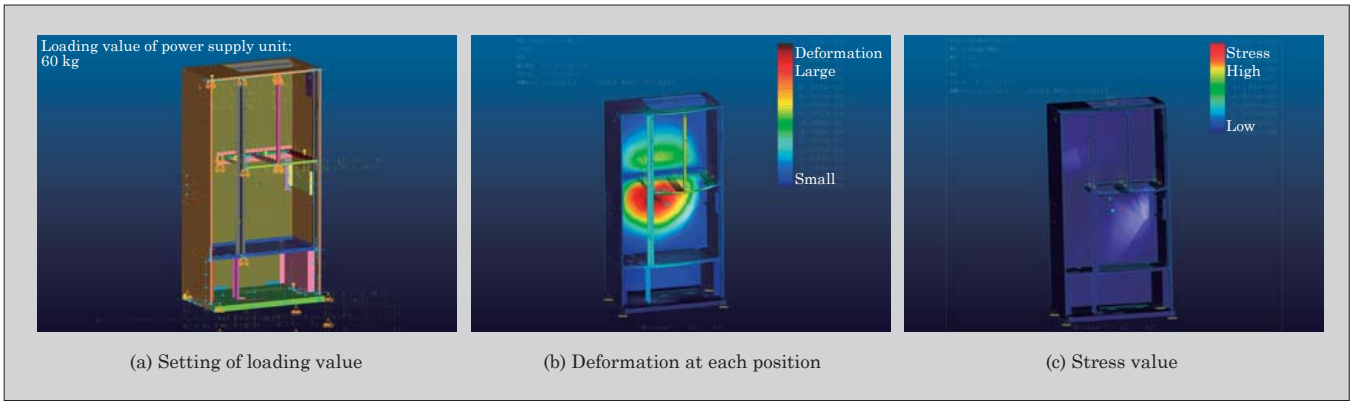


Fig.6 Structure of door panel



(a) Setting of loading value (b) Deformation at each position (c) Stress value

Fig.7 Example of stress analysis

tors, which is the same configuration used in vending machines. As a result, the wiring work by only using connectors was accomplished. Furthermore, by fixing the wiring with angle clamps, reliability as well as assembly easiness was realized.

In addition, each of the electric parts was integrated as a unit type so as to create a design that could contribute to the assembly line whereby electric parts and wiring are connected beforehand to attached metal fittings.

5. Postscript

In this paper, we have introduced “FRCM Series” of quick chargers for electric vehicles. The market for electric vehicles and quick chargers is expected to expand from now on as the market takes on a new form and creates new types of demand. In the midst of this changing market, many companies are trying out various possibilities in order to discover and meet customers' needs.

Fuji Electric will dedicate itself to the development of electric vehicles community using its power supply technology. Our power supply units will be globally certified with UL and CE markings as well as compatible to overseas voltage specifications (480 V AC). In addition, our charger units will be able to meet the various needs of customers, being fully equipped with applications compatible with billing networks, coin-operated fee collection equipment, etc.

As we work to develop products that meet the new market opportunities brought about by electric vehicles, we look forward to continuing to make contributions toward the construction of a low carbon society through our power electronics technology.