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AUXILIARY POWER SUPPLY FOR RAILWAY VEHICLE

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1. FOREWORD

An auxiliary power supply (APS) is equipment necessary to operate a railway vehicle. The APS is a supply source of the electric energy needed to control traction equipments, charge batteries, and to operate comfort facilities such as lighting, air conditioning and heating for service to passengers.

APS are classified into those which generate electric energy and those which convert the electric power supplied from the catenary as shown in *Fig. 1.*

Axle and engine-driven alternators are used with railway vehicles which run on non-electrified lines, for example, diesel rail cars and passenger cars which are pulled by a diesel locomotive. Motor-alternator and all static machines are used with railway vehicles which run on electrified lines, for exapmle, electric locomotive and electric car. Fuji Electric can manufacture all these types of APS.

Fuji Electric has an abundant APS manufacturing record and experience of 60 years, and has delivered numerous APS to national railways, public railways, and private railways around the world.

In particular, Fuji Electric continues to hold a 100% share of the ÁPS for passengers coaches and diesel rail cars of all the Japanese domestic railways.

The output capacity and main destination of the various APS delivered by Fuji Electric up to now are shown in *Table 1.*

Fuji Electric has accumulated advanced power semiconductor production technology and power electronics application technology over many years.

Recently, we developed and practicalized à high withstand voltage, large current GTO thyristor and power transistor with self turn off.

The performance and functions of Fuji APS are being advanced remarkably by the application of these high performance semiconductors and control technology applying IC and microcomputer. The technologically revolutionary static APS is mainly introduced here in after.

2. STANDARD SYSTEM AND DESIGN CONCEPT OF FUJI STATIC APS

Standard system of Fuji static APS is shown in *Fig. 2.*

Fig. 1 Classification of auxiliary power supply for railway vehicle

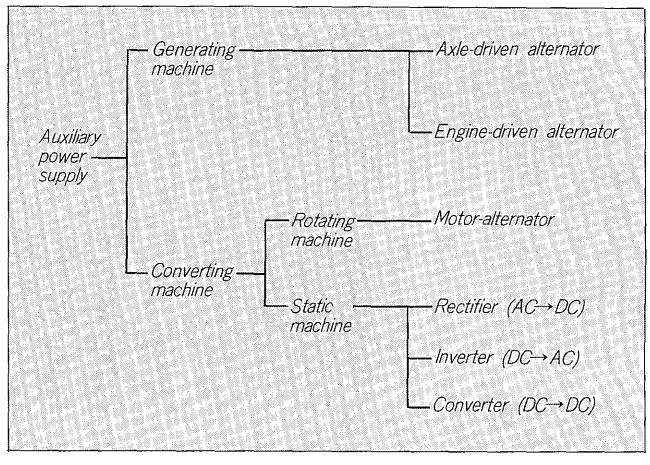


Table 1 Auxiliary power supply delivery record

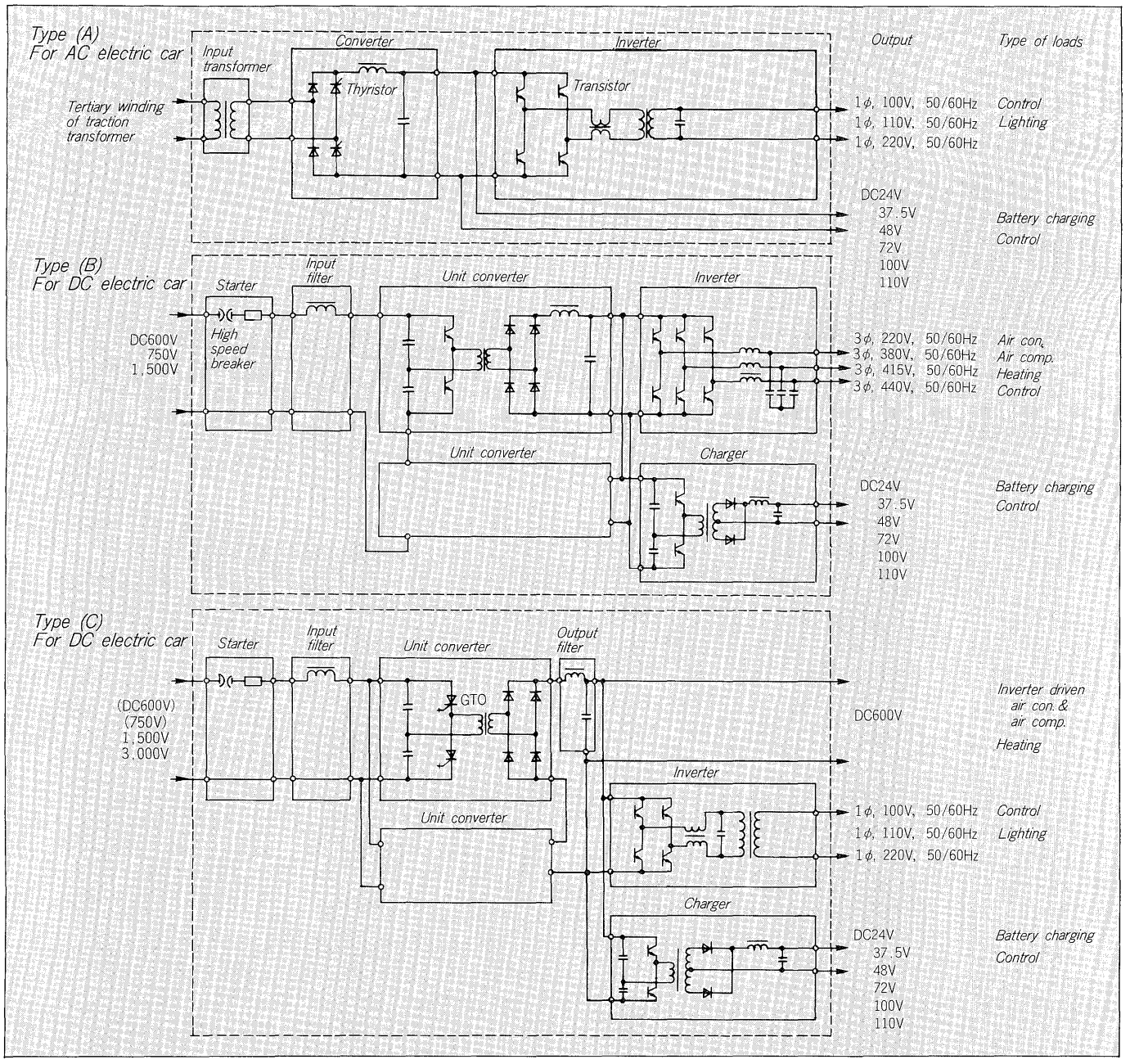
Item	Output capacity	delivery country
Axle-driven alternator	0.8~22kW	13 Asian countries 4 African countries 3 Central American countries 2 Oceanian countries
Engine-driven alternator	10~350kVA	7 Asian countries Mexico
Motor-alternator	90~210kVA	Japan
Rectifier	2~20kW	Japan
Inverter	0.4~320kVA	6 Asian countries
Converter	1~90kW	Japan

The Fuji static APS can be used with various catenary currents and can output the multiple voltages needed by the loads provided with railway vehicles.

The standard system consists of a converter portion and inverter portion and charger portion.

The converter portion absorbs the catenary voltage fluctuations and produces a stabilized and low DC voltage. The inverter portion converts the output of the converter to a sine wave current, and the charger portion converts the output of the converter to battery charging voltage. Fuji's design concept is that "if the voltage is kept constant by a voltage stabilizer at a preceding stage, the inverter and charger at the later stage can avoid the heavy duty to cope with an input voltage with large fluctuations."

Fig. 2 Standard system of static APS



2.1 APS for AC electric car-Type (A)

This APS is generally supplied from the tertiary winding of the traction transformer. Since large capacity air conditioner, air compressor, and heater are also supplied power directly from the tertiary winding, the capacity of the APS is generally smaller than that of the APS for DC electric car mentioned later.

A transformer to isolate the APS from other tertiary loads is provided at the APS input. Since the converter also serves as a battery charger, its output voltage coincides with the battery charging voltage.

Since the loads of inverter are limited to traction and auxiliary equipments control and lighting, it can be a single-phase type.

A transformer is provided to match the inverter output voltage to the voltage needed by the load and to isolate the battery from AC loads. When the air conditioner and air compressor require a stable voltage, the inverter portion is replaced by a 3-phase inverter and charger like Type (B) shown in *Fig. 2*.

2.2 APS for DC electric car-Type (B)

At the converter portion, multiple unit converters are connected in series according to the magnitude of the input voltage and multiple unit converters are connected in parallel according to the output capacity.

At present, Fuji Electric uses the GTO thyristor as the switching element for the unit converter when the catenary voltage is DC 1,500V or greater, or the total output capacity is approximately 150kVA or greater and a power transistor

module as the switching element when the catenary voltage is DC 1,500V or less, or the total output capacity is approximately 150kVA or less, as standard.

The case when two unit converters using transistors are connected in series is shown in *Fig. 2.*

Since the inverter feeds the air conditioner and air compressor, it is the 3-phase type. The pulse width modulation (PWM) control method which has a lower output voltage waveform distortion and a smaller output side AC filter capacity than the one pulse control method is used. The battery charger for feeding to DC loads is provided separately. The charger is operated at approximately 2kHz, so the transformer for charger and filter components are smaller than those in the method of rectifying output of 50/60Hz inverter.

2.3 APS for DC electric car-Type (C)

This APS was developed to supply power to an inverter driven air conditioner which can improve passenger comfort further.

The conventional air conditioner is ON/OFF controlled by comparing the thermostat set temperature with the temperature in the passenger room. Therefore, the passengers should feel that the environment inside the car is repeatedly too hot and too cold. The approach of new air conditioner is that "if the air conditioner compressor is driven by a VVVF (Variable Voltage and Variable Frequency) inverter and the compressor speed is varied linearly according to the air conditioning load, that is, if the cooling capacity is made variable, the environment inside the car will be maintained in the optimum state for the passengers".

In addition, if the air compressor is also changed to the VVVF inverter control system and both VVVF inverters are soft-started, the inrush current is eliminated and, therefore, APS transient over capacity is unnecessary and of the APS component parts, semi-conductor elements with a smaller current capacity are sufficient.

This APS supplies power to both these VVVF inverters. *Figure 2* shows the case when two unit converters using the GTO thyristor are connected in parallel. Both VVVF inverters are accompanied with the air conditioner and air compressor.

This APS has another merit. This merit is that since the converter output voltage is DC, the output of the multiple converters provided with the cars making up the train can be connected by train lines and all the converters can be run in parallel. Therefore, the necessary facility for extended supply by the other converters is omitted even if one converter should fail. For a 3-phase supply, this necessary facility indicates the additional devices for synchronous running.

Of course, this APS also includes an inverter for control and lighting and charger, the same as the Type (B).

3. FEATURES OF FUJI APS

The Fuji APS has the following features:

(1) Supply to load can be continued even during a short input power interruption.

With the Type (A) APS, the output of the converter is connected directly to the battery. When the pantograph is de-wired and when the car passes through a dead section, the input power is interrupted for a short time. At this time, power can be supplied to the AC load uninterruptedly from the battery through the inverter. This function corresponds exactly to the inertia of a motor-alternator. This system developed by Fuji Electric allows transition of the APS for AC electric car from rotating machine to static machine. Railway vehicles have numerous emergency loads. The emergency loads are modified to the DC supply type so that all these loads can be supplied from the battery. By using this system, the use of a DC supply type is unnecessary. For example, numerous passenger room lightings do not have to use the expensive DC supply type of fluorescent lamp with built-in inverter, but can use the ordinary AC supply type instead.

(2) Safety can be secured even when the high tension side is abnormal

With all the types of APS in *Fig. 2*, the converter portion includes a transformer. This transformer isolates the low tension output from high tension input.

Even if an abnormality should occur at the primary side of this transformer, high tension is not transmitted to the secondary side and the loads and inverter portion compornent parts can be protected.

(3) Small size, light weight, low noise

Fuji Electric uses a high converter driving frequency. When a GTO thyristor is used at the converter, the driving frequency is approximately 300Hz and when a transistor is used, the driving frequency is approximately 2kHz. Therefore, the converter transformer and the reactor, capacitor, etc. at its secondary side can be made small and lightweight and the noise generated by the transformer and reactor is low.

(4) Simple maintenance work

Fuji APS disperses the heat from the APS components by natural convection, provided there are no special restrictions on the space for installing the APS under the frame of the car. Therefore, since there are no cooling fan and convection air filter, maintenance work is simplified to blowing off of dust.

(5) Troubleshooting and recovery are fast

When the APS was stopped by some abnormality, nine analogue and digital data, including the voltage, current, and signal level of several points of the APS main circuits and control circuits for 300 milliseconds immediately before and directly after stopping are stored in monitoring equipment with internal microcomputer installed in the APS.

The memory element (RAM) continues to operate and the stored data is preserved by power supplied from a lithium battery with a life of approximately six years installed on the monitoring card even all the power sources on the car are shutdown.

These data can be read at the screen of a portable monitoring data reader with built-in personal computer.

They can also be printed out by printer. Since the trouble symptoms are clearly analyzed and diagnosed by this self monitoring and diagnostic function and the trouble cause and faulty part can be quickly located, quick recovery to service running can be expected.

4. TYPICAL EXAMPLE OF DELIVERED APS

4.1 APS for AC electric car——An example of Type (A) in *Fig. 2*

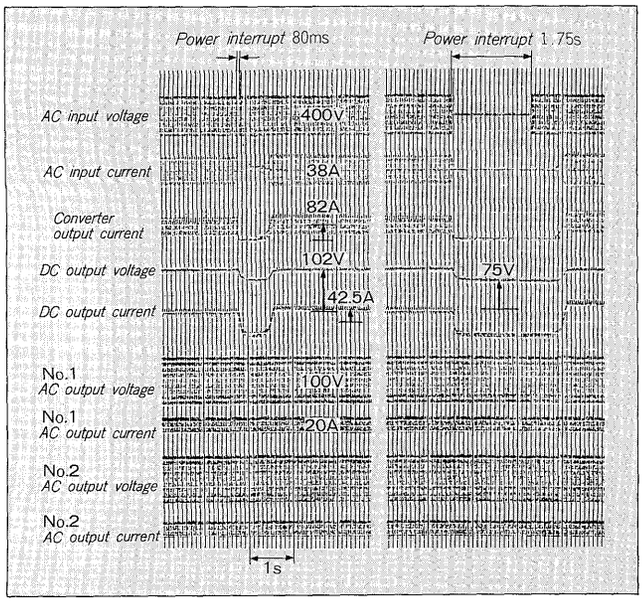
This APS supplies power to a three car EMU. Its main specifications are shown in *Table 2*. This APS can supply all DC and AC power from a battery while the train is passing an 8 meters long AC-AC dead section. The oscillogram when the input power was interrupted is shown in *Fig. 3*. In supplying power to three cars, the battery capacity is 40AH and a 2 minutes interruption can be covered.

The train mounting this APS operates in a region where there is a lot of snow. During the winter, the APS box is entirely covered by snow. Fuji Electric takes special countermeasures against the invasion of snow in the construction of this APS and countermeasures to protect the electric parts against deterioration of insulation from the dew formed inside the APS box. After delivery, this APS has been trouble-free even after three winters and Fuji excellent pre-care against these harmful natural phenomena was guaranteed.

Table 2 Specification of APS (clause 4.1)

Item		Specification	
Input	Rated voltage	AC 1φ, 400 V, 50 Hz	
Output	Type of current	AC 1φ, 50 Hz	DC
	Rated capacity	2 x 4 kVA	8 kW
	Rated voltage	100 V	100 V
	Voltage accuracy	±5%	±1%
	Ripple factor	–	5% (Peak to peak)
	Waveform distortion	10%	–
	Power factor	0.85 (lag)	–
	Tolerance	120%, 1 min.	120%, 1 min.
Ambient temperature		–35°C~+40°C	
Cooling method		Natural convection	

Fig. 3 Oscillogram when input power interrupted



4.2 APS for DC electric car——An example of Type (B) in *Fig. 2*

This APS supplies power to a three car EMU. The converter portion of this APS consists of four half-bridge connected unit converters connected in series.

Its main specifications are shown in *Table 3*. An outer view of the APS installed under the car body is shown in *Fig. 4*. In the world this is the first APS which applies transistors for all power switching devices and is supplied power from DC 1,500V catenary.

For these power switching, 1,200V/300A-bipolar transistor modules are used.

Since these are switched at 2KHz, the level of the noise generated by the APS is low.

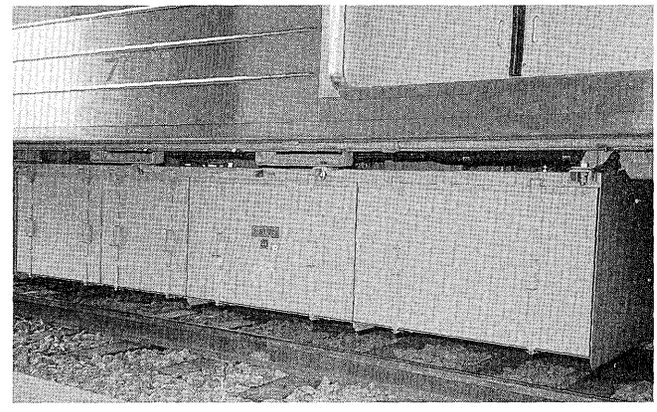
4.3 APS for DC electric car——An examplé of Type (C) in *Fig. 2*

This APS first stabilizes the DC 1,500V catenary voltage to DC 600V by means of a converter and supplies it to the DC traction motor field current controller and

Table 3 Specification of APS (clause 4.2)

Item		Specification	
Input	Rated voltage	DC 1,500 V	
Output	Type of current	AC 3φ, 60 Hz	DC
	Rated capacity	80 kVA	6 kW
	Rated voltage	440 V	100 V
	Voltage accuracy	±5%	±5%
	Ripple factor	–	5% (Peak to peak)
	Waveform distortion	10%	–
	Power factor	0.85 (lag)	–
	Tolerance	190% (Pf=0.58), 5 secs	110%, 1 min.
Ambient temperature		–10°C~+40°C	
Cooling method		Natural convection	

Fig. 4 Installation view of APS



inverter driven air conditioner and inverter driven air compressor. A power supply for control and lighting is housed in another box. The main specifications of the converter are shown *Table 4* and the specifications of the other power supply are shown in *Table 5*.

The converter consists of two paralleled unit converters using 4,500V/800A GTO thyristors. The two unit converters are phase difference controlled.

This control method suppresses the ripple current which flows in the filter reactor at the input side and makes the filter components small and lightweight. Electromagnetic interference and radio frequency interference can also be suppressed. The layout of the converter components is shown in *Fig. 5*. GTO stacks and diode stacks are located at the center of the converter box. At the right side of these stacks transformers and reactors are arranged. For the heat sinks of both stacks, aluminum nitride sheet is sandwiched between GTO/diode and the sink and is electrically insulated and both sinks are exposed to the outside of the converter box. This method has two merits: it prevents electric shock and improves the cooling effect. Because both stacks can be brought down forward, maintenance and inspection are easy. The transformer and reactor and power resistors are waterproofed and because they are installed at the open part of the converter box, heat radiation is more effective.

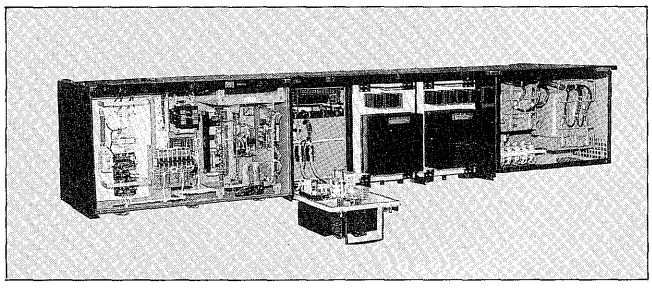
Table 4 Specification of converter (clause 4.3)

Item		Specification
Input	Rated voltage	DC 1,500 V
Output	Type of current	DC
	Rated capacity	90 kW
	Rated voltage	DC 600 V
	Voltage accuracy	−15% ~ +10%
	Ripple factor	5% (Peak to peak)
	Tolerance	150 kW, 1 sec
Ambient temperature		−10°C ~ +40°C
Cooling method		Natural convection

Table 5 Specification of another power supply (caluse 4.3)

Item		Specification	
Input	Rated voltage	DC 600 V	
Ouput	Type of current	AC 1φ, 60 Hz	DC
	Rated capacity	10 kVA	2 kW
	Rated voltage	100 V	100 V
	Voltage accuracy	−10%~+5%	−10%~+5%
	Ripple factor	−	5% (Peak to peak)
	Waveform distortion	10%	−
	Power factor	0.9 (lag)	−
	Tolerance	150%, 1 min.	150%, 1 min.
Ambient temperature		−10°C~+40°C	
Cooling method		Natural convection	

Fig. 5 Layout of converter components



4.4 APS for train coaches

The APS for coaches (without a motive power source) which operate on electrified lines does necessarily have to use an engine-driven alternator. Coaches pulled by an electric locomotive are generally supplied power from an electric power source installed at the locomotive or power van. However, the static APS introduced here is installed inside the separated room on the lounge car. Two APS with the same specification are installed on the one lounge car. The APS are supplied power from the catenary through two pantographs installed on the roof of the lounge car and supplies power to all the loads of the train coaches.

User evaluation after the old engine-driven alternator was replaced with the static APS was:

(1) Passenger comfort was improved by a substantial noise reduction and the elimination of the source of vibration and exhause gas odor.
(2) Maintenance and inspection work were simplified considerably.
(3) The total weight of the two power supplies was reduced from 19.4 tons to 6.4 tons and the total occupied space was reduced from 34.7m^2 to 8.0m^2.
(4) The danger of fire due to engine overheating was eliminated.

The main specifications of this APS are shown in *Table 6*, the layout of the inverter components is shown in *Fig. 6*, and the supply system to the train is shown in *Fig. 7*.

The feeding bus is two independent systems. These systems are wired through all the coaches which make up the train. The load is divided equally between the two systems. Even if one APS should fail, the failed APS is disconnected by switching the contactor (L1, K1, L2, K2) inside the cubicle and the air conditioner or heating load drops to half capacity and the supply of power to the two buses can be continued from the normal APS.

Figure 8 is an oscillogram which shows the APS switching action. It shows that when the No.1 APS failed, power

Table 6 Specification of APS (clause 4.4)

Item		Specification
Input	Rated voltage	DC 1,500 V
Output	Type of current	AC 3φ, 60 Hz
	Rated capacity	230 kVA
	Rated voltage	440 V
	Voltage accuracy	±5%
	Waveform distortion	2.5%
	Power factor	0.9 (lag)
	Tolerance	150%, 5 secs
Ambient temperature		−10°C~+40°C
Cooling method		Forced air convection

feeding to the No.1 bus from the No.2 APS was performed immediately. *Figure 9* is the main circuits of this APS. The main circuits of the No.1 APS and No.2 APS are identical.

To reduce the GTO thyristor switching loss and lower the noise, the fifth and seventh harmonics can be removed by operating this APS by two pulse PWM control and multi-connecting two transformers at the output side.

Especially, to lighten the duty of *the power factor improvement capacitor* installed at the fluorescent lamp in the coach, the voltage waveform distortion is suppressed to 2.5% by making the capacity of the APS output filter large.

4.5 APS for diesel railway car

In Japan, most first class diesel railway cars were equipped with two kinds of engines: traction engine and alternating engine. Therefore, since the alternating engine operates at the rated speed even when the train is standing still at a station, the passengers and the people on the station platform should be discomforted by noise from the engine.

Fuji Electric developed a generating system which can alleviate this discomfort. This new system eliminates the alternating engine, which is one source of noise, and drives the alternator by belt transmission from the auxiliary driving shaft of the traction engine instead.

The air conditioner compressor and air compressor are also driven by this auxiliary driving shaft.

The installation view of the alternator is shown in *Fig. 10*, the system composition is shown in *Fig. 11*, and the main specifications are shown in *Table 7*. Two engines and APS are installed on one car.

Since the three-phase output voltage and frequency of alternator change in proportion with the train speed, that is, the speed of the traction engine, the output voltage is maintained constant by adjusting the generator field current by means of an automatic voltage regulator (AVR). After the generator output is converted to DC by diode rectifier, it charges the battery and is supplied to the DC load. The AC load is supplied from the battery through an inverter.

Because the batteries of the multiple cars making up the train are connected by train line, the alternators are operated in parallel and the power supply is compensated by the normal alternator even if one alternator should fail.

This alternator can provide the rated power even when the train is standing still at a station, that is, when the traction engine is running at idling speed.

To prevent excessive discharge from the battery to the load when the engine is stopped, the alternator output volt-

Fig. 6 Layout of inverter components

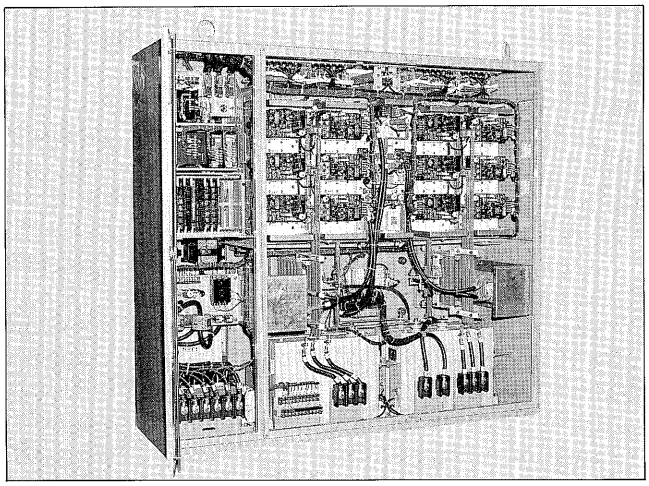


Fig. 7 Supply system composed of 2 sets of APSs

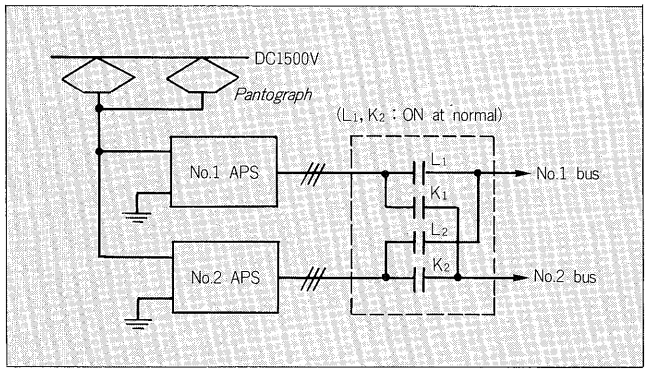


Fig. 8 Changing motion at break down of No.1 APS

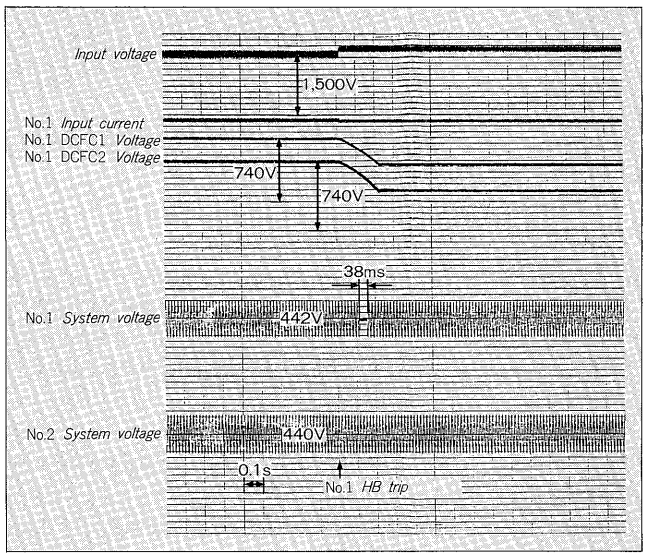


Fig. 9 Main circuits of APS multiple-connected with GTO inverters

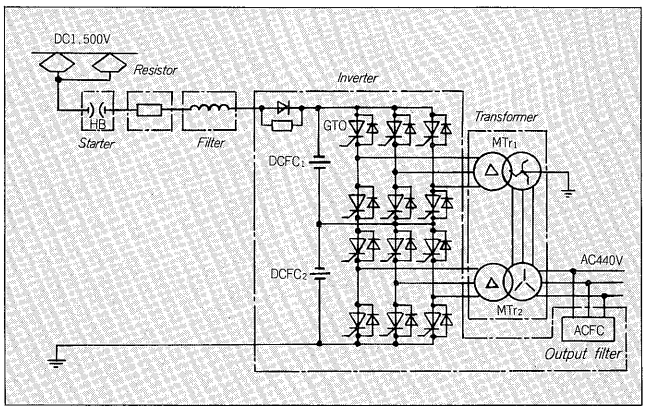
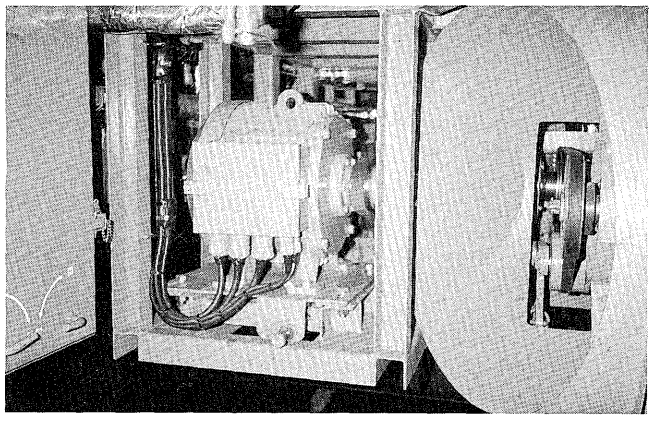


Table 7 Specification of APS (clause 4.5)

	Item	Specification
Alternator	Rated rotation at engine idling	1,880 rpm
	Engine/Alternator speed ratio	650/1,880=1/2.9
	Avairable rotation range	1,880~5,800 rpm
	Rated driving torque	60 N·m at 1,880 rpm
	Number of driving belt	3
	Insulation class	F (IEC 349)
	Cooling method	Totally enclosed fan cooling
AVR	Rated capacity	7 kW
	Rated output voltage	DC 28V
	Adjustable voltage range	DC 26 V~DC 30 V
	Cooling method	Totally enclosed natural cooling
Ambient temperature		−15°C~+40°C

Fig. 10 Installation view of alternator



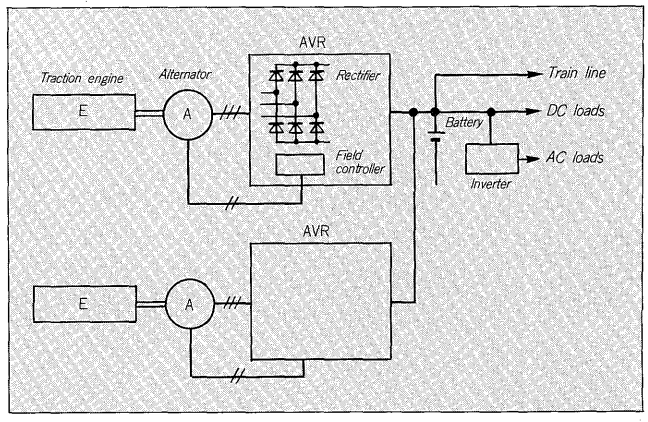
age is monitored and the interlock is provided so that all the loads are cut when the output voltage drops below 90% of the rated voltage. In other words, when the output voltage is 90% or more of the rated voltage, all the loads start automatically.

Because the AVR voltage setting is variable, the generated voltage can be properly adjusted according to the battery charging voltage.

This alternator has a claw pole construction. It does not have any slip rings and brushes and only the bearings should be maintained.

Moreover, Fuji Electric raised the alternator output

Fig. 11 APS system in parallel running



capacity to 20kW/DC 600V and has also delivered an APS which supplies power from this alternator to two 18,000 kcal/h (71,500BTU/h) inverter-driven air conditioners.

5. CONCLUSION

The features and typical examples of the system composition of the Fuji Electric auxiliary power supply for railway vehicle were introduced above.

Fuji Electric has also delivered auxiliary power supplies which meet user needs and backed by our superior power electronics technology and microelectronics technology for domestic and foreign coaches, electric cars, streetcars, and inter city and suburban electric cars.

To upgrade customer comfort and service, automatic vending machine, audio and video sets, telephone set, photoelectronic bulletin board, etc. are installed in the train.

The role of the APS as power source for these new facilities is becoming increasingly important.

As the next step, Fuji Electric intends to apply the IGBT (Insulated Gate Bipolar Transistor) which combines MOS-gate voltage drive, high speed switching, low on-state voltage and other excellent functions and performances to the next generation of APS and is striving to develop APS which are smaller, lighter, more efficient, easy to maintain, and highly reliable.