UDC 621.382.333:621.311.6:621.335

TRANSISTORIZED AUXILIARY POWER SUPPLY FOR ROLLING STOCK

Tomoaki Sugimoto
Ken'ichi Okamoto
Yoshitaka Fujiwara
Yoshihiro Konishi

I. FOREWORD

Recently, inverters, DC-DC converters, and other static equipment have come into use as auxiliary power supplies for rolling stock to supply power for interior lighting, control apparatus, air conditioning equipment, etc.

Since these equipments are made up of a self-exicted conversion circuit with DC1500V, DC750V, or other high voltage supplied directly from the trolley line, fast turn-off thyristors and reverse conducting thyristors suitable for high voltage power supplies are used in these circuits. However, these elements have various points which should be improved, such the lack of a self-quenching capability, the need for an auxiliary commutation circuit for self-excited conversion operation, equipment size, weight, electromagnetic noise, etc.

Under these conditions, with the recent progress made in high voltage, high current power transistors, Fuji Electric directed its attention to the superior switching characteristics with self-quenching capability of transistors and the structural benefits of equipment using them and has undertaken research to apply power transistors to auxiliary power supplies having a fairly low capacity and has proceeded with the development of equipment using them.

This report describes the application technology of power transistors to high voltage power supplies and the basic circuit construction of the equipment for transistorized auxiliary power supply for rolling stock and introduces specific equipment.

II. FEATURES OF TRANSISTORIZED AUXILIARY POWER SUPPLY

The power transistor features a self-quenching function, faster switching than a thyristor, low saturation voltage, low loss, etc. Therefore, inverters, DC-DC converters, and other auxiliary power supplies using them have the following features matched to the demand for their use in rolling stock.

1. Superior performance

High frequency pulse width modulation (PWM) and fast control are possible by using the fast switching characteristic of the power transistor. This makes it easy to obtain a sine wave output voltage with a filter and allows the realization of a high performance inverter with a low distortion output voltage and fast response.

2. High reliability

Because the power transistor has a self-quenching capability, an auxiliary commutation circuit is unnecessary. Therefore, with an inverter constructed with power transistors there is no commutation failure by power supply conditions, load conditions, etc., the circuit construction is simple, and higher reliability can be obtained.

3. Small size, light weight construction

By using a high transistor operating frequency and using the transformer, reactors, and filter capacitors connected to the transistor at a high frequency, the devices and parts can be made small and lightweight.

Moreover, because an auxiliary commutation circuit is unnecessary, its circuit parts and wiring are eliminated and the equipment construction becomes simple and equipment having a compact construction can be realized.

4. Low noise

Since a commutation reactor is unncessary, there are few sources of electromagnetic noise and the noise of the overall equipment can be made lower.

5. High efficiency

Because an auxiliary commutation circuit is unnecessary, there is no commutation loss and the transistor loss is small and the efficiency of the overall equipment is high.

III. EQUIPMENT CONSTRUCTION AND OPERATION

1. Main circuit construction

The basic circuit construction of this auxiliary power supply is shown in *Fig. 1*. In an auxiliary power supply, an input filter circuit consisting of a capacitor and a reactor or resistor is installed at the power supply side to limit the harmonic current component induced in the power supply

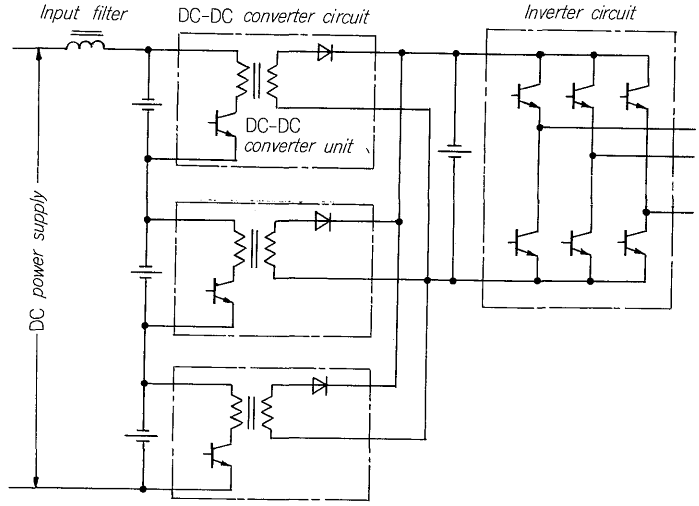

Fig. 1 Principal circuit diagram of transistorized auxiliary power supply

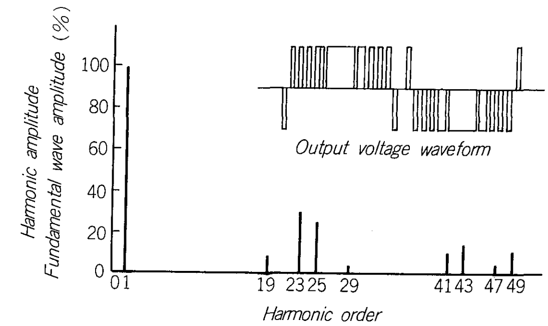

Fig. 2 Output voltage waveform of inverter and its harmonic spectrum

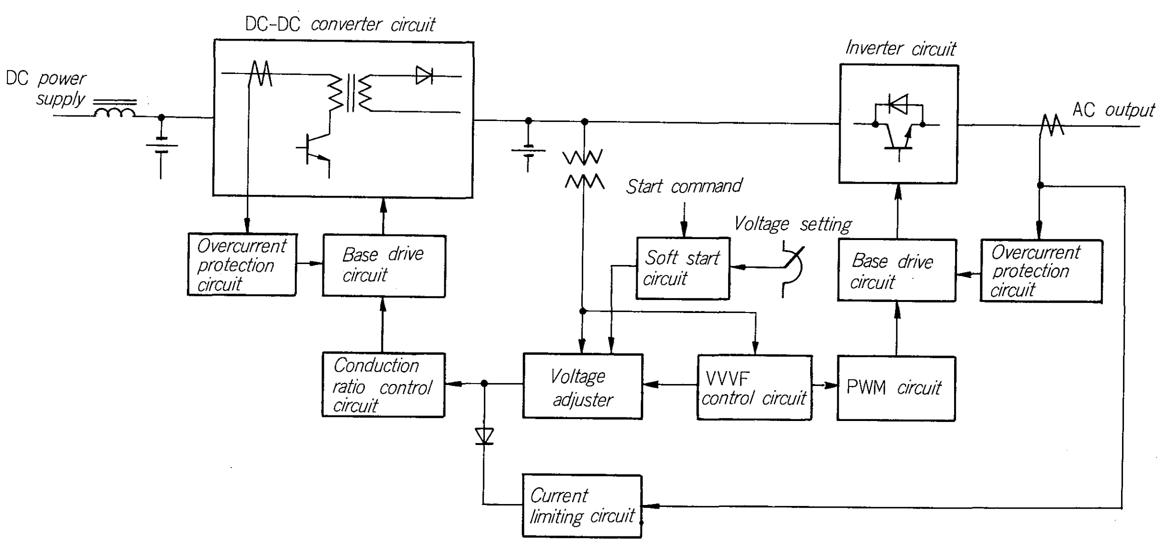

Fig. 3 Block diagram of control circuit

by this operation within the permissible range.

This equipment consists of an input filter circuit and the following DC-DC converter circuit as well as an inverter circuit.

The basic circuit construction and operation of each unit are described below.

1) DC-DC converter circuit

This circuit converts the high voltage DC power supply voltage to an isolated voltage suitable for the power supply voltage of the last stage transistor inverter.

Multiple transistorized DC-DC converter units are connected in series at the primary side, these converter units are connected to the high voltage DC power supply and the secondary side is connected in parallel, and a DC voltage is obtained by smoothing with a capacitor. The primary side voltage of each DC-DC converter unit is serially divided equally by input filter capacitors corresponding to the number of units and is equally shared by parallel connection at the input of each unit.

The transformer reset winding and output smoothing reactor have been eliminated and the circuit construction has been made very simple by using a ringing choke type transformer with the transformation and series inductance function as the isolation transformer of each DC-DC converter unit.

The transformer and smoothing capacitor have been made small and light by operating the transistor at a high frequency on the order of kHz.

2) Inverter circuit

This inverter circuit receives the output voltage of the preceeding stage DC-DC converter and produces a single-phase or three-phase sine wave output voltage.

Conversion to sine wave output uses a 5 pulses/half period PWM system and is refined so that the number of switchings of the transistor is small and the low harmonics are eliminated. The output voltage modulation waveform and the harmonic spectrum in it for three-phase for this modulation method are shown in *Fig. 2*. It can be seen that the harmonic components up to the 19th harmonic are eliminated.

2. Control system

The basic control block of this equipment is shown in *Fig. 3*. The output voltage is adjusted by giving an output voltage command to the output adjuster with a voltage setting, taking voltage feedback from the DC-DC converter output voltage, and controlling the DC-DC converter conduction ratio control. On the other hand, switching of the inverter circuit transistor is controlled by command from the PWM circuit through the base drive circuit.

At starting, the output voltage is raised gradually through a soft start circuit. Even if the power is momentarily interrupted such as when the pantograph is separated from the trolley line, the output voltage is raised gradually by refeedback through the start command input.

At induction motor load closing, etc., control such that the rotating speed of the motor raises gradually by limiting the starting current by lowering the voltage and frequency at the same time with a VVVF control circuit. (Patent pending)

3. Protection system

The following protection circuits are provided this auxiliary power supply to protect the transistors against overvoltages and overcurrents caused by changes in the outside conditions or internal trouble, etc.

1) Filter capacitor voltage unbalance protection

When multiple DC-DC converter units are connected in series, the voltage distribution balance among the units is maintained by an input filter capacitor provided at the input of each unit. For filter capacitor voltage unbalance protection, a circuit which detects the input filter capacitor voltage of each unit, compares the detected values, and disconnects the transistor base drive circuit when the voltage balance has been disturbed by more than a certain value by a internal trouble is provided.

2) Overload protection

For overloads, a current limiting circuit which reduces the output voltage according to the amplitude of the current is provided.

3) Short-circuit protection

For output short-circuits and other sudden current changes, a fast response speed protection circuit which turns off the transistor before the capacity of the transistor to withstand this current is provided.

IV. AUXILIARY POWER SUPPLY

A DC600V power supply, 2 kVA inverter and DC1500V power supply, 40 kVA inverter are introduced below as examples of actual auxiliary power supplies using power transistors.

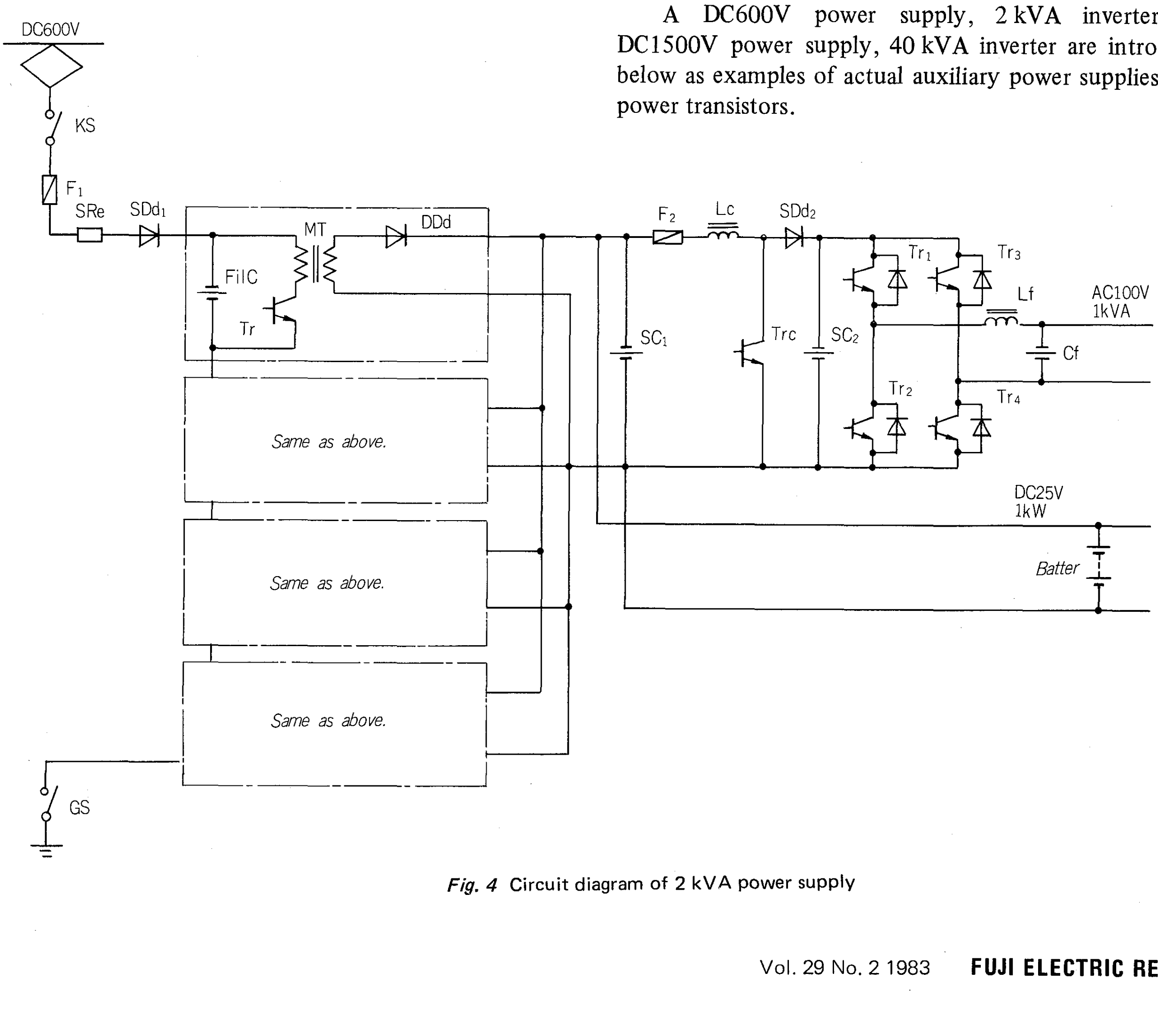

Fig. 4 Circuit diagram of 2 kVA power supply

1. 2 kVA inverter

This equipment supplies streetcar control power and power to the interior fluorescent lighting, and has the following specifications:

Input voltage: DC350-750V nominal DC600V

Output capacity: 2 kVA continuous

Output voltage: AC100V, single-phase 60Hz sine wave 1kVA. DC25V, 1 kW

Cooling system: Natural air-cooling

The main circuit construction is shown in *Fig. 4*. The transistors used are 500V, 50A (2SC1056) at the DC-DC converter circuit and 500V, 50A (EVK31-050 module) at the inverter circuit. Four DC-DC converter units are connected together.

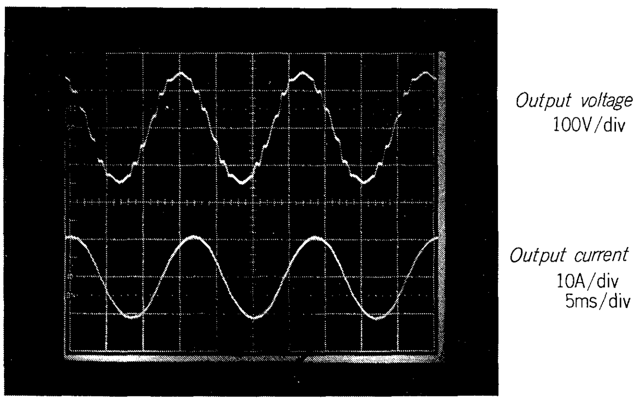

Fig. 5 Waveforms of output voltage and current

The features of this inverter are that the DC power supply battery in the car is connected to the DC-DC converter circuit output and the battery is charged at all times and that a battery is used as the inverter power supply so that the AC output is not interrupted when the power is momentarily interrupted when the pantograph is separated

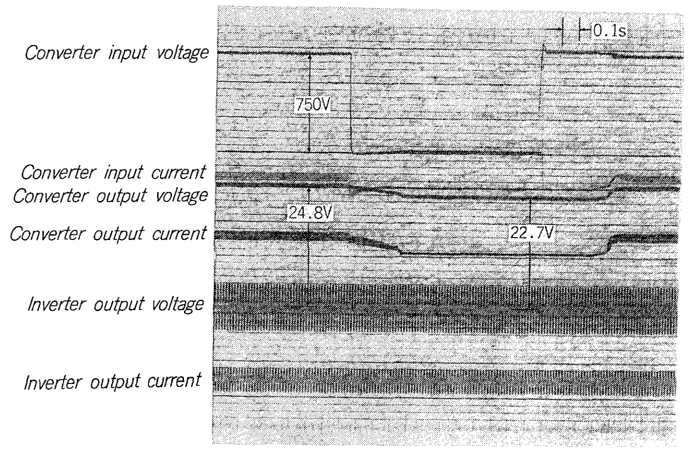

Fig. 6 Response of voltage and current at power failure

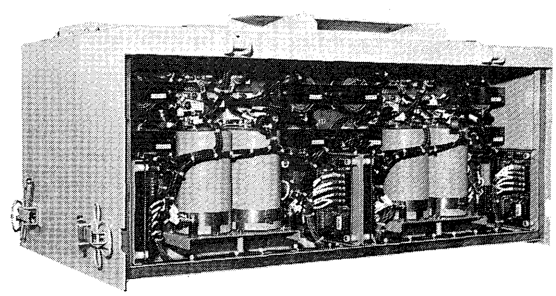

Fig. 7 2 kVA power supply

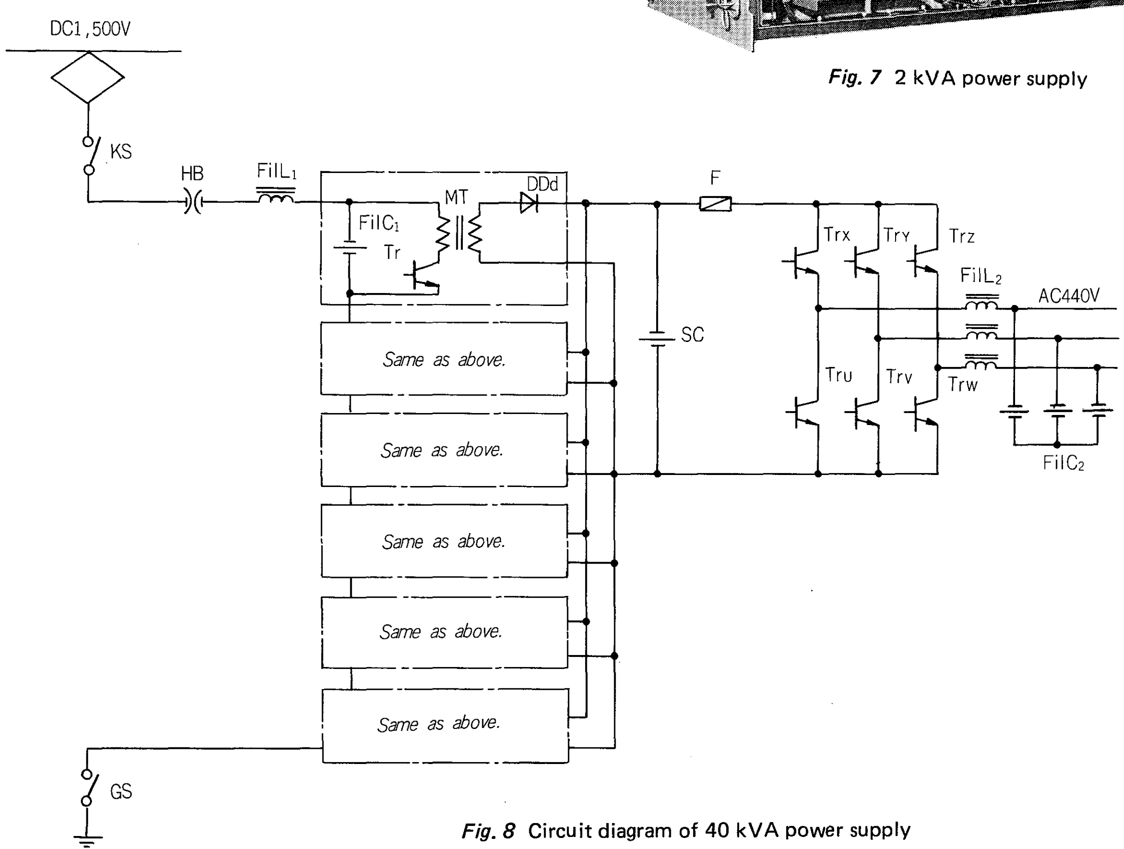

Fig. 8 Circuit diagram of 40 kVA power supply

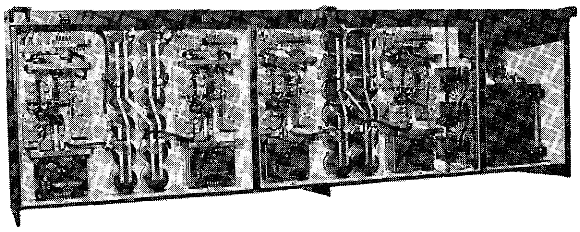

Fig. 9 40 kVA power supply

from the trolley line and when passing sections. (Patent pending)

Since the battery voltage is DC25V at this inverter, AC100V output voltage by providing a transistorized voltage boosting chopper circuit after it.

The AC output voltage and current waveforms of this inverter are as shown in *Fig. 5*. A power interruption test oscillogram is shown in *Fig. 6*. The noise is 58 dB (A range).

Fig. 7 is an exterior view of the equipment. The equipment is a small 870 mm wide, 410 mm high, and 490 mm deep.

2. 40 kVA inverter

This equipment supplies power to the air conditioning equipment for one car, and has the following specifications:

Input voltage: DC900-1850V, nominal DC1500V

Output capacity: 40 kVA continuous

Output voltage: AC440V, three-phase, 60Hz, sine wave

Cooling system: Natural air-cooling

The main circuit construction is shown in *Fig. 8*.

The transistors used are all 1000V, 100A (ET127). The DC-DC converter circuit consists of six converter units connected together.

The air conditioning equipment motor is started by VVVF control. An exterior view of the this equipment is shown in *Fig. 9*.

V. CONCLUSION

Fuji Electric established circuit technology for the application of power transistors to auxiliary power supplies which are supplied power from the high voltage power supply of railways and has proceeded to develop several equipment using this technology as described above. More than 10 single-phase inverters of several kVA or less have already been manufactured and their special features are expected to be recognized and their application is expected to spread in the medium and low capacity range of about 40 kVA. Moreover, element development for the purpose of making power transistors more higher capacity than today is proceeding, and we think that equipment will steadily advance in the future with the application of these elements.