High-Response Battery Emulator BS350 Improving Efficiency of Testing In-Vehicle Inverter with High Voltage and Large Current

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Abstract

In recent years, the electrification of automobiles has progressed rapidly, and each automobile manufacturer has an urgent need to develop in-vehicle systems to support electrification. When evaluating in-vehicle inverters and motors, battery charging and discharging work is required in preparation for testing when using actual batteries. This increases the cost of testing. To address this issue, battery emulators that emulate actual battery operation are being used.

The battery emulator THYFREC BS350 has dramatically improved performance over its previous model, THYFREC BS330. Specifically, in response to the recent trend towards higher voltage batteries and higher performance in-vehicle inverters, the voltage and current range has been expanded from the previous model to an output voltage of 1300 V and an output current of 1500 A. Furthermore, stable voltage output (constant voltage control/internal resistance control) has been achieved even in driving patterns with large load fluctuations such as sudden acceleration and deceleration of the in-vehicle motor.

1 Preface

In recent years, due to the rapid progress of electrification in the automobile industry, the number of test items in automobile research and development has increased. In actual evaluation tests of in-vehicle inverters combined with batteries, it is necessary to have multiple batteries on hand and to charge and discharge them in advance, depending on the usage environment of the test target. This increases the cost of testing. Therefore, there is a growing demand for battery emulators that can emulate actual battery behavior under various test conditions.

The newly developed battery emulator THYFREC BS350 (hereinafter referred to as "BS350") not only covers a wide range with an output voltage range of 10 to 1300 V and an output current range of ±1500 A, but also stabilizes the output voltage even when the load suddenly changes. It has high responsiveness that can be controlled (constant voltage control/internal resistance control). A new circuit method has been adopted to expand the output voltage and current range compared to previous model. This paper introduces the features and control performance evaluation of BS350.

2 Features of BS350

2.1 Main Circuit Configuration

Fig. 1 shows the circuit configuration of BS350. The BS350 consists of a Dual Active Bridge (DAB) connected to the DC input section and a chopper connected to the DAB, and provides a stable power supply to the in-vehicle inverter connected to the chopper output. A DAB is a power converter that isolates the DC primary side and DC secondary side. By connecting eight DABs in parallel to the DC input, eight isolated DC voltage sources are generated, each of which is connected to a chopper. The chopper has the same configuration as a single-phase inverter. By using a multilevel method and an interleaving method, the chopper outputs are arranged in 2 series and 4 parallel formats.

(1) Series connection of choppers

Two chopper outputs are connected in series to achieve a high output voltage. As a result, this topology can output up to twice as much as the

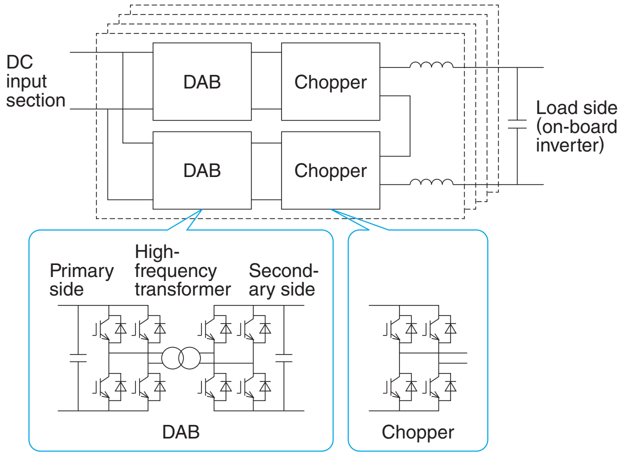

Fig. 1 **Circuit Configuration of BS350**

By using the DAB, the BS350 is composed of two chopper units connected in series and four units in parallel. As the result, we could realize high voltage, high current, and high responsiveness.

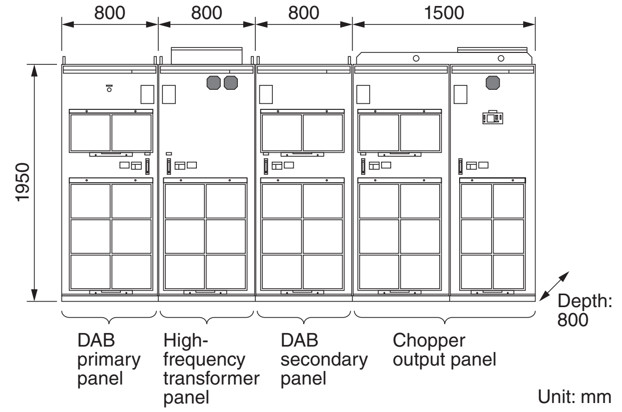

Fig. 2 **External Dimensions**

The BS350 is composed of a 4-panel array.

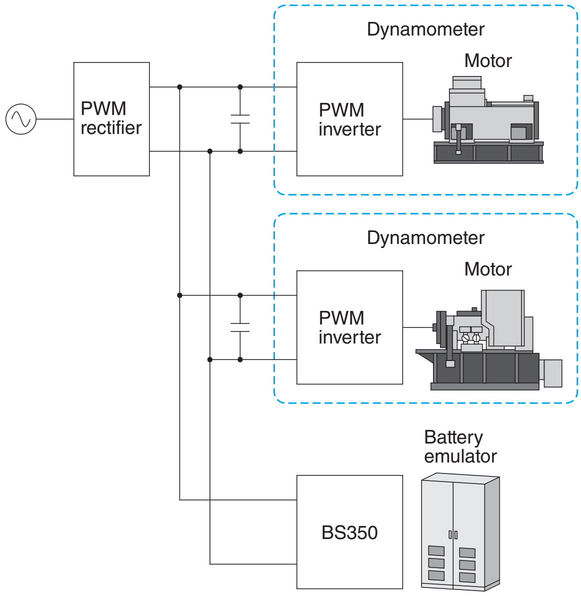

Fig. 3 **Schematic Diagram of Equipment Configuration of Drive System Evaluation System for Electric Vehicles**

At the two-axis drive train bench, two dynamometer units are used and the battery emulator is added for the electric vehicle.

isolated DC voltage source generated by DAB, achieving a high voltage output of 1300 V maximum for a DC input of 750 V. Additionally, by creating a circuit configuration that is symmetrical between positive and negative when connecting in series, the range of the lowest controllable voltage has been expanded compared to previous models and has been reduced to around 0 V.

(2) Parallel connection of choppers

By connecting four choppers connected in series in parallel, we achieved a large output current. By making four parallels, it is now possible to output four times as much current as before parallel connection, achieving a large output current of up to ±1500 A.

(3) High performance through multilevel and interleaving control

With two choppers connected in series, multilevel technology can be applied by appropriately shifting the switching timing between the choppers. Similarly, interleaving technology can be applied to a four-parallel chopper. By combining these technologies, we have expanded the control band eight times compared to a single chopper and achieved a higher control response. At the same time, the effect of reducing output voltage and current ripple was achieved, contributing to the compact design of passive components.

2.2 Panel Structure

The BS350 has a total of four panel configurations: a DAB primary panel, a high-frequency transformer panel, a DAB secondary panel, and a chopper output panel. Each panel corresponds to each related circuit or product: a primary circuit in the DAB circuit, a high-frequency transformer in the DAB circuit, a secondary circuit in the DAB circuit, and a chopper circuit in DAB circuit. Fig. 2 shows the external dimensions of BS350.

Fig. 3 shows a schematic diagram of the equipment configuration of the drive system evaluation system for electric vehicles. For the 2-axis drivetrain bench, we will construct a test system that combines two THYFREC VT350DY-H4700 dynamometer control systems and a BS350. Since the BS350 has the same height as the above devices,

Table 1 Product Specifications

Specifications of the BS350 are shown.

Items		Specifications
Circuit system		Multilevel and interleaving methods (Single-phase inverter two series and four parallel connection)
Rated capacity		330 kW
Maximum DC output voltage		1300 V
Maximum DC output current		1500 A
Minimum controllable voltage		10 V
Rated DC input voltage		750 V
Rated AC input voltage (Dedicated converter panel is used)		440 V ± 10% (60 Hz ± 5%)
		400 V ± 10% (50 Hz ± 5%)
Rated output		A0 model (100% continuous)
Setup system for command values		Analog input, CAN communications
Control system		Constant voltage control
		Constant current control
		Battery internal resistance emulation mode
Control accuracy※1	Constant voltage control	0.4% (of Maximum DC output voltage)
	Constant current control	0.5% (of Maximum DC output current)
Setup resolutions	Constant voltage control	0.1 V (for CAN communications)
	Constant current control	0.1 A (for CAN communications)
	Battery internal resistance emulation mode	1 mΩ (for CAN communications)
Settable range	Constant voltage control	0~1300 V
	Constant current control	−1500~1500 A
	Battery internal resistance emulation mode	0~2 Ω
Control responsiveness※1	Constant voltage control	20 ms (Time to reach 63% of command value)
Environment	Ambient temperature	0~40℃, annual average below 25℃
	Relative humidity	85% or below (Freedom from dew condensation)
	Altitude	1000 m or below
	Installations	Panel array configuration, front-side maintenance
	Cooling system	Forced air cooling
	Miscellany	Freedom from corrodible gases and dust

Note: ※1. Performance under our test conditions

these panels can be arranged side by side (see Fig. 2).

2.3 Product Specifications

Table 1 shows the product specifications of BS350, and Fig. 4 shows the voltage and current output ranges. It supports three types of control modes: (1) constant voltage control, (2) constant current control, and (3) internal resistance control. Internal resistance control is a control that adds battery internal resistance simulation operation to constant voltage control.

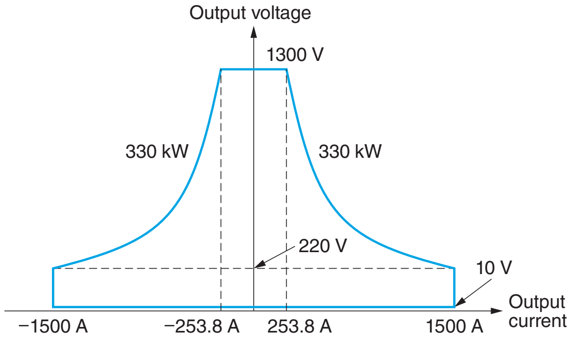

Fig. 4 Voltage and Current Output Ranges of BS350

The rated capacity of the BS350 is 330 kW. It can be operated within the voltage range of 10 V to 1300 V and within the current range of ±1500 A.

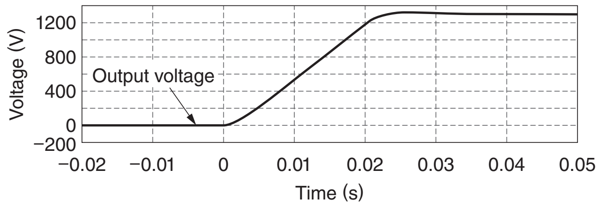

Fig. 5 Voltage Responsiveness

Waveforms of response in the step state are shown within the output voltage range of zero volt to 1300 V. While overshooting is restricted, the output voltage is converged to the goal voltage in a short time.

3 Performance Confirmation Results

3.1 Evaluation System

In evaluating the BS350, we measured the voltage and current characteristics by placing two BS350s facing each other and operating one under constant voltage control and the other under constant current control. Note that when evaluating voltage responsiveness, only the constant voltage control side was operated, and a no-load condition was assumed.

3.2 Voltage Responsiveness

Fig. 5 shows the voltage responsiveness when the voltage command value is changed in steps from 0 V to 1300 V under no-load conditions. The overshoot is 1.6% (relative to the maximum DC output voltage) and converges to the product specifica-

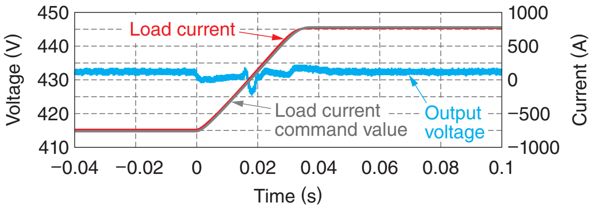

Fig. 6 **Output Voltage and Load Current Waveform when Load Suddenly Changes**

Under the condition that the load within ±330 kW is suddenly changed at the speed of 21.7 kW/ms at the output voltage of 433 V, it was confirmed that output voltage variations could be suppressed within 9 V.

tion's voltage control accuracy of 0.4% (relative to the maximum DC output voltage) in 30 ms from a step change in the command value.

3.3 Constant Voltage Control Characteristics

Fig. 6 shows the output voltage and the load current waveform when the load suddenly changes from −330 kW (−770 A) to +330 kW (+770 A) at a rate of change of 21.7 kW/ms (50 A/ms) with an output voltage command of 433 V. Even with steep load fluctuations, output voltage fluctuations can be suppressed to less than 0.7% (vs. maximum DC output voltage). Furthermore, constant current control also follows command value changes without overshoot.

3.4 Battery Internal Resistance Control Characteristics

Fig. 7 shows the output voltage and load current waveforms when the load current suddenly changes from 0 A to +500 A at a rate of change of 50 A/ms under the condition of an output voltage command of 433 V. When the internal resistance setting is 0 Ω, the output voltage can be controlled at a constant 433 V even when the load suddenly changes. On the other hand, when the battery internal resistance setting value is 0.3 Ω, the voltage drop value is 151.0 V under the output current condition of 503.2 A, and the calculated resistance

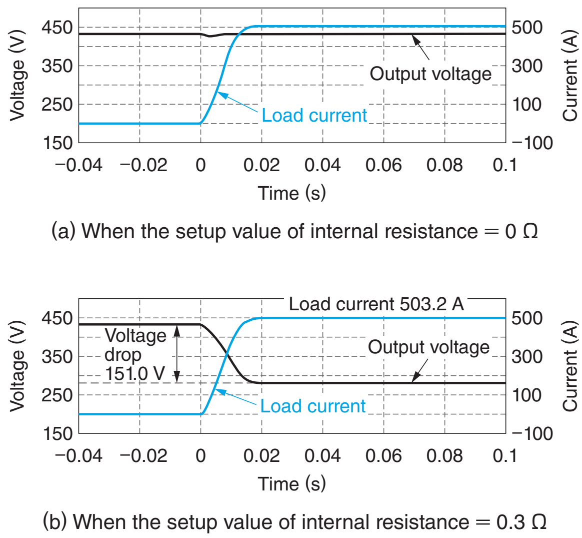

Fig. 7 **Output Voltage and Load Current Waveforms with Internal Resistance Control**

For the battery internal resistance emulation mode, it was confirmed that a voltage drop by the effect of battery internal resistance can be reproduced because the output voltage is reduced in compliance with load current variations.

value of 0.300 Ω matches the setting value. Even during sudden load changes, the voltage drop value is controlled without delay in response to changes in load current.

4 Postscript

We introduced the battery emulator THYFREC BS350. Compared to the previous model, the operating range has been expanded: output voltage from 750 V to 1300 V and output current from 500 A to 1500 A, while voltage fluctuations during sudden load changes have been reduced.

Going forward, we will continue to work on improving functions and developing new functions in order to contribute the EV development of automobile manufacturers.