Basic Study to Improve Evaluation Tester Performance for Battery Electric Vehicle (BEV) and Hybrid Electric Vehicle (HEV)

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Abstract

Due to the rapid transformation of electrification in auto industry, the evaluation items in automotive R&D activities have been recently increased as is the cost for testing. Compared with conventional traction systems, new traction systems produced by various auto manufacturers are diverse. Traction motors are undergoing to have more compact design, higher rotation speed while car batteries are getting higher power density.

In order to reduce the evaluation cost for traction systems, testing of each part of the traction equipment is conducted using dynamometers, thus reducing evaluation time. More than ever, for dynamometer specifications, a compact design, larger capacities, higher response speeds, higher accuracies, and faster motor rotation speeds are required. Against this technical background, we have developed basic technologies in order to cope with the requirements of the times.

1 Preface

In the current automotive market, a Hybrid Electric Vehicle (HEV) (a gasoline engine + multiple traction motors) and a Plug-in Hybrid Electric Vehicle (PHEV) are becoming popular. Also gaining popularity, is a Battery Electric Vehicle (BEV), which is equipped with only multiple traction motors. Car electrification is an effective means of reducing the emission of CO_2, which is said to accelerate global warming. The traction motor is driven primarily by the power of lithium ion batteries. Such batteries are becoming higher in power density. As a result, the car travel distance has improved. For the purpose of a compact and light-weight design of the traction motor, efforts are being made to increase the motor rotation speed. The higher the functions and more complicated the automotive systems, the more it results in the rapid increase of development costs for reliable evaluation during development. For the development of traction mechanisms in efficiently devised combination of different power sources, a variety of testing devices are needed in compliance with their diversity. This paper introduces our R&D initiatives for the characteristic improvement of BEV and HEV evaluation testers.

2 Requirements of BEV and HEV Evaluation Testers

The first most important target required for the BEV and HEV evaluation tester is the compact design. Next, the requirements for the battery emulator are quicker response, higher accuracy, and larger capacity. Lastly, the requirements for motors and inverters for dynamometers are higher power density and higher rotation speed. Such requirements reflect the fact that the traction motor is moving towards higher power density and compact design, with the maximum frequency level of traction motors increasing.

Fig. 1 shows an example of the evaluation system for the HEV driving system. This example explains a simulation of a gasoline engine, batteries, and driving wheel load. This uses an evaluation tester. In the case of the evaluation tester including a battery emulator, it is necessary to insulate this battery emulator because the negative electrode of the battery must be grounded. This insulation mechanism can be established by inserting a transformer between the AC input circuit and the battery emulator. In this case, however, there is an issue that overall system configuration becomes larger because the transformer is large.

Fig. 2 shows a schematic drawing of system configuration for the recently developed evaluation tester. The battery emulator that simulates the battery behavior is composed of choppers. The dynamometer that simulates the gasoline engine or driving wheel load is composed of a Pulse Width Modulation (PWM) inverter and a motor. In the case of a system configuration applying the battery emulator with a unique insulation mechanism, an input AC transformer can be omitted thanks to the adopted insulation mechanism. The input power source for the choppers and PWM inverter can be made to the DC. Accordingly, only one PWM rectifier can be used in common for multiple choppers and PWM inverter. We realized the compact design of overall evaluation machines.

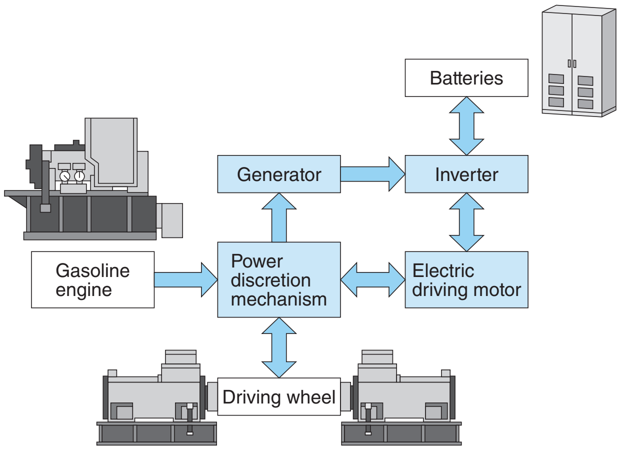

Fig. 1 Example of Evaluation System for HEV Driving System

An example is shown to simulate and evaluate the driving wheel load, gasoline engine, and batteries of the HEV.

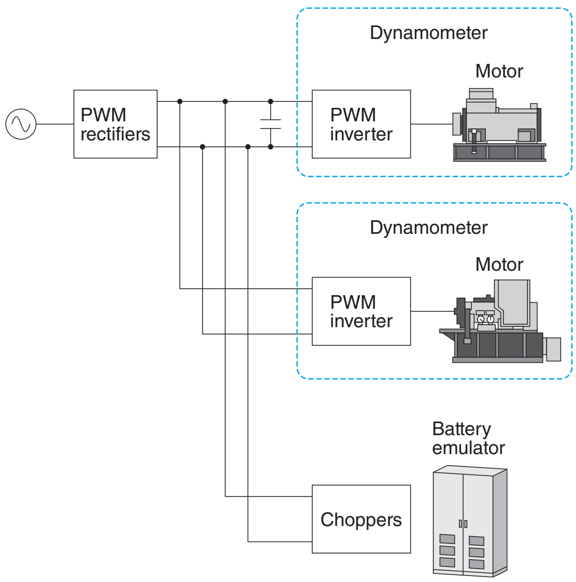

Fig. 2 Schematic Drawing of System Configuration for Recently Developed Evaluation Tester

An example of a common DC input source is shown using two respective sets of dynamometers and battery emulators. The DC source is established with PWM rectifiers.

3 Improvement of Battery Emulator Performance

Fig. 3 shows a schematic drawing of the main circuit for the battery emulator. **Table 1** shows specifications of the battery emulator which we examined in this paper. First, a DC/DC converter and chopper are combined. Next, this combination is defined as a single unit, and multiple units are gathered together for multiplexing. This multiplex configuration can realize large power capacity and high-speed response performance. If the load is applied to a sample under test by using a battery emulator without any insulation capability, the line-to-ground voltage of the testing sample may be greatly changed and this will adversely affect the testing sample. It is, therefore, necessary to provide insulation capability to the battery emulator. For the

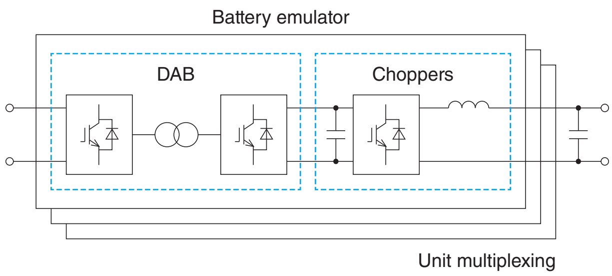

Fig. 3 Schematic Drawing of Main Circuit for the Battery Emulator

The battery emulator realizes the higher performance by the multiplexing of Dual Active Bridges (DABs) and choppers.

Table 1 Specifications of the Battery Emulator

Specifications of the battery emulator examined by simulation are shown.

Item	Specifications
Maximum capacity	330 kW
Maximum output voltage	1300 V
Maximum output current	1500 A

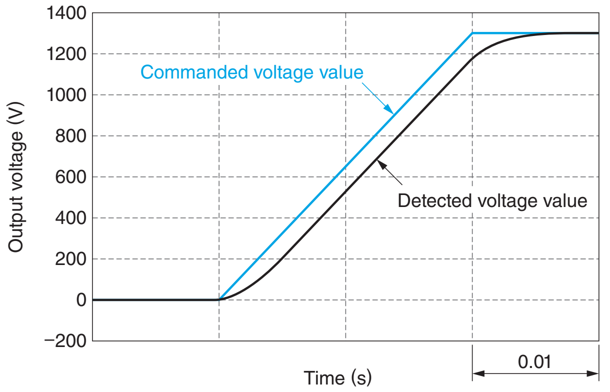

Fig. 4 **Simulation of Voltage Response by the Battery Emulator**

Within approximately 0.02 seconds, it reaches a maximum voltage of 1300 V.

DC/DC converter in this case, we adopted a Dual Active Bridge (DAB) that is capable of high power traction and regenerative action which has an input/output insulation capability. The DAB can make the system into more compact design. The DAB is composed of two full-bridge circuits and a high-frequency transformer.

By the individual control and cooperative control of each unit, the unit output of each unit is synchronized and a combination of these can realize high accuracy of output voltage. **Fig. 4** shows a simulation of voltage response by the battery emulator. Waveforms of simulation are shown when the voltage command is changed from 0V to 1300 V. A voltage of 1300 V is attained approximately in 0.02 seconds; thus we confirmed there was a high speed response and high accuracy follow-up against the command value.

4 Increase in Inverter Frequencies for Dynamometers

In order to realize a high rotation speed of the motor for the dynamometer, the inverter output frequency must be improved. **Table 2** shows motor specifications. The motor type is a Surface Permanent Magnet Synchronous Motor (SPMSM) and its maximum rotational speed value is 20,000 min^{-1}. When the number of poles is 4, the maximum frequency required for the PWM inverter is 666 Hz. Since the maximum output frequency of our dynamometer inverter, THYFREC VT350DY, is 533 Hz. – the inverter's maximum output frequency has to be further improved. To improve the output frequency, there are two issues. The first issue is that the current accuracy is low because the number of PWM pulses per period is decreased and current harmonics are increased. The second issue is that the inverter voltage saturation tends to occur in the vicinity of the maximum rotation speed because the motor induced voltage goes up in proportion to the number of revolutions.

To solve the first issue, correction was made for the reduction of wasteful time consumption to the current control mechanism in order to improve the current control response. As the solution to the second one, weakened flux control was improved to lower the output voltage required for the inverter. When a current command is generated, the torque command and revolving speed are made to avert the occurrence of voltage saturation in order not to exceed the rated inverter current. If voltage saturation occurs in the middle of operation or the rated inverter current should exceed, the developed algorism is used to compute the current command again in order to avoid the occurrence of saturation phenomena. **Fig. 5** shows waveforms from simulation of the maximum speed operation. We confirmed that normal operation is maintained even when maximum speed operation is performed.

Table 2 **Motor Specifications**

Motor specifications are shown.

Item	Specifications
Motor type	SPMSM
Rated capacity	300 kW
Maximum revolving speed	20,000 min^{-1}
Rated torque	500 N·m

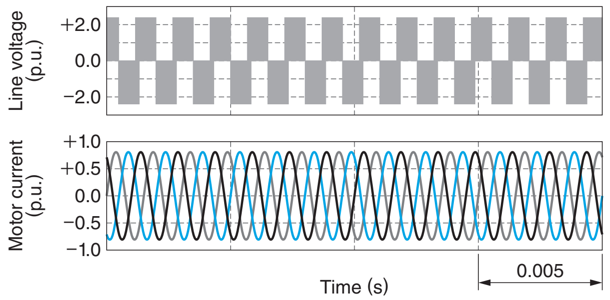

Fig. 5 **Waveforms from Simulation of Maximum Speed Operation**

The upper stage shows the motor line voltage and the lower stage shows 3-phase motor current. Normal operation can be confirmed even at the maximum revolution level of 20,000 min^{-1}. The unit is a motor rating of 1.0 p.u.

5 Postscript

This paper introduced our initiatives to improve performance characteristics of the BEV and HEV Evaluation Tester. Going forward, we will promote testing on actual machines in addition to the simulation in order to verify the adequacy of the tester.

To propose more highly functional testing equipment in the future, we will work on improving the equipment for further electrification of the auto market and wider adoption of BEVs and HEVs.