Development of Charging System of Lithium Ion Battery Stack Using Bicycle Dynamo

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***Abstract*—Lithium ion battery charging system is developed using the dynamos mounted to a bicycle is conducted using a fabricated battery charger. Prototype of lithium ion battery stack is designed with four lithium ion batteries manufactured in our research laboratory, and these batteries are applied to the dynamo charging system.**

Keywords—lithium ion battery; battery stack; bicycle; dynamo; battery charger: DC-AC inverter

I. INTRODUCTION

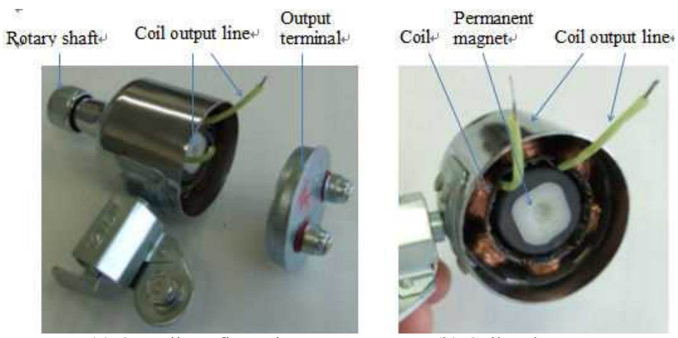
A rectifier circuit when two dynamos are simultaneously rotated is designed, and a charger with this rectifier circuit and a constant current and constant voltage circuit incorporated is fabricated. The lithium ion battery to be charged is configured as a battery stack in which four lithium ion batteries, each one of which provides 800 mAh battery capacity and is fabricated at the laboratory, are used and connected in series on a printed circuit board. Measurements are made on the charge and discharge characteristics as a battery stack using a charge and discharge evaluation device as well as the charge characteristics when charged by dynamos. Finally, measurements are made on the discharge characteristics of a battery stack when a DC-AC inverter is connected to the battery stack and an inverter drive experiment is conducted.

II. GENERAL DESCRIPTION ON BICYCLE DYNAMOS

In general, a dynamo means a bicycle power generator. The dynamo is available in two types: a rim dynamo (or roller dynamo) and a hub dynamo. A rim dynamo is a system for generating power by applying the rotary shaft of the main body to the rim of a bicycle front wheel and rotating the rotary shaft of the main body by rim rotations at the time of travel, which is an old method of power generation. A hub dynamo is a power generator integrally built into the rotary shaft (hub) portion of a bicycle front wheel. Both generators have a system for rotating a permanent magnet directly connected to the rotary shaft and producing AC voltage in the fixed coil around the permanent magnet (Fig. 1).

The rating of dynamo is prescribed in the Japanese Industrial Standard (JIS). It is prescribed that the dynamo output voltage should be 6 V when a bicycle speed is 15 km/h, and the output power should be 2.4 W, 3.0 W, and 6.0 W.

The type of dynamos used for the experiment is a rim dynamo. Based on the lithium ion battery specifications used for charging, dynamos of customized specifications of 12 V for output voltage and 6 W for output power when the bicycle speed is 15 km/h are used.



(a) Overall configuration (b) Coil and magnet

Fig. 1. Construction of rim dynamo

A. *Experiment on dynamo output characteristics*

The bicycle is fixed by a special-purpose stand and two dynamos are mounted to the rear wheel (tentatively called Dynamo 1 and Dynamo 2). The output characteristics of two dynamos when the bicycle is rotated are measured, respectively (Fig. 2).

(a) Dynamo 1 (b) Dynamo 2

Fig. 2. Dynamos mounted to the bicycle rear wheel

The bicycle speed is monitored by a commercially available speedometer. Fig. 3 shows the measurement result of Dynamo 1. For the output voltage (effective value) at the speed of 15 km/h, 15 V is obtained (nearly same result is obtained for Dynamo 2, too). In addition, the sine wave alternating current waveform with little distortion is obtained for the output voltage. The frequency of alternating current waveform obtained when the speed is 15 km/h is about 170 Hz to 180 Hz.

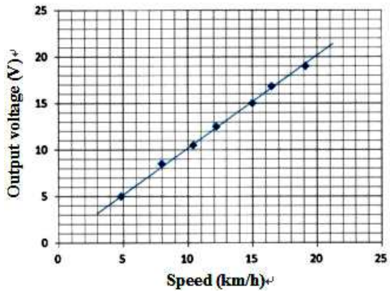


Fig. 3. Output characteristics when one dynamo is rotated

B. Rectifier circuit when two dynamos are used

The rectifier circuit is configured to simultaneously take output from two dynamos mounted to the bicycle rear wheel, and the relationship between the bicycle speed and the rectified voltage is measured. Fig. 4 shows the measurement circuit. The output voltage of Dynamo 1 and Dynamo 2 is full-wave rectified via diode bridges and electrolytic capacitors. The rectified output is connected via diodes for reverse-current prevention, and one direct current output is obtained after full-wave rectification of alternating current output of two dynamos. Fig. 5 shows the relationship between the bicycle speed and direct output voltage measured at no load (conditions in which any load such as batteries is not connected to the output side of the rectifier circuit). The experimental results mostly indicate the following, where V_{AC} denotes the alternating current output voltage of one dynamo and V_{DC} denotes the direct current voltage after rectification when two dynamos are used:

$$V_{DC} \approx 2 \times 1.42 \times V_{AC}$$

(nearly doubles the maximum value of V_{AC})

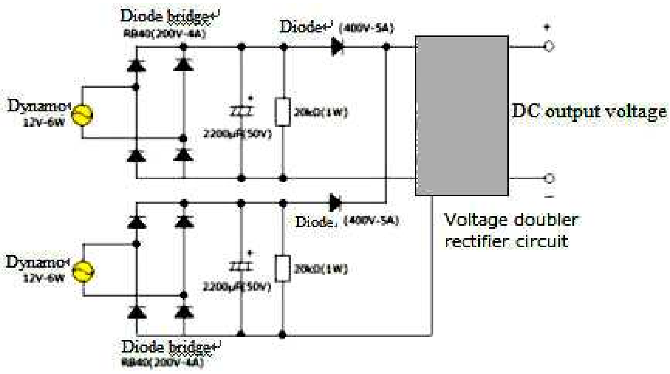


Fig. 4. Rectifier circuit using two dynamos

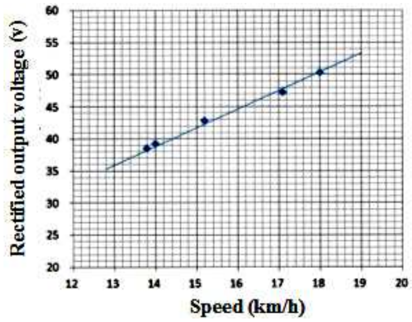


Fig. 5. Output characteristics when two dynamos are rotated

III. FABRICATION OF LITHIUM ION BATTERY CHARGING CIRCUIT

The lithium ion battery charger is fabricated by incorporating a rectifier circuit using two dynamos. Fig. 6 shows the overall circuit configuration of the designed charger. Because as shown in Fig. 4, the output voltage of the rectifier circuit varies in a comparatively wide range (35 V to 55 V) when the bicycle speed ranges from 13 km/h to 19 km/h, it is set to a predetermined voltage using the DC input type switching power supply (input voltage: 38 V DC to 63 V DC; output: 24 V DC; variation range: ±10%). After setting the output voltage of the rectifier circuit is brought to a predetermined voltage, the output voltage is used as the input power supply for the constant current and constant voltage circuit board, which is a charging circuit of lithium ion battery. Fig. 7 shows the circuit configuration of the fabricated constant current and constant voltage circuit board, and Fig. 8 shows a fabrication example. For design to fabrication and experimental examples of the constant current and constant voltage circuit board, see Reference [1].

In the following experiment, the output voltage and the output current of the constant current and constant voltage circuit board are set to 16.6 V DC and 1.0 A, respectively. Two ammeters (100 mA full range and 1.5 A full range) are mounted to the charger to monitor the charging current. The relevant ammeters are used by switching over to each other in accordance with the magnitude of charging current of lithium ion battery.

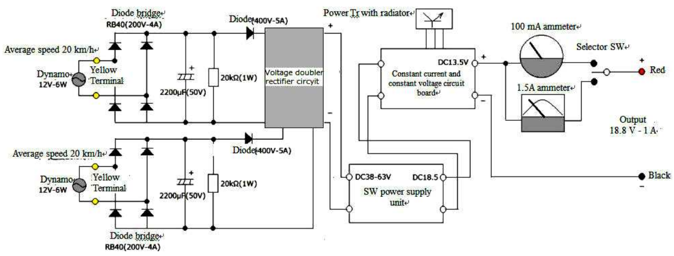


Fig. 6. Circuit configuration of lithium ion battery charger using two dynamos

Fig. 9 and Fig. 10 show a battery charger finished by incorporating connecting terminals of lead wires from two dynamos, rectifier circuit unit, switching power supply, constant current and constant voltage circuit board, output terminal for lithium ion battery connection, ammeters, and others in a commercially available case. The DC-DC converter (input: 35 V to 63 V; output: 5 V-250 mA) connected in parallel to the switching power supply outputs 5 V DC from the USB port simultaneously with charging the Li-Ion battery. This enables the charging of Smartphone and the use of USB devices.

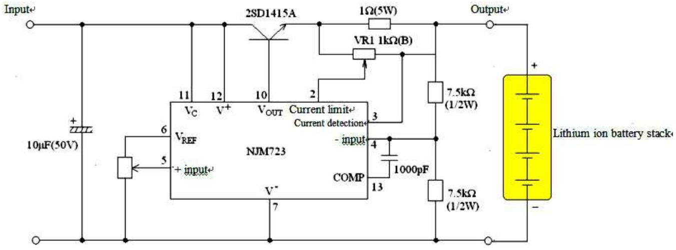


Fig. 7. Configuration of constant current and constant voltage circuit board

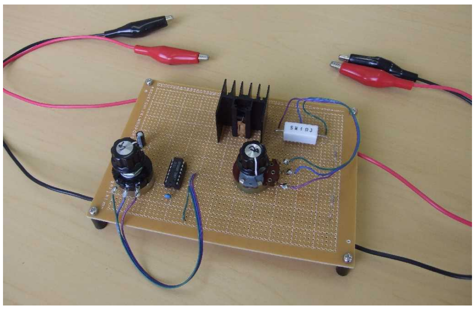


Fig. 8. Fabrication example of constant current and constant voltage circuit board

Fig. 9. Lithium ion battery charger using two dynamos

IV. LITHIUM ION BATTERY STACK CONFIGURATION

The lithium ion batteries charged from bicycle dynamos (hereinafter called the battery cell) are laminate type lithium ion batteries (800 mAh, 4.2 V) fabricated at the laboratory of the authors using jigs of the winding method. Four of them are mounted on the printed circuit board to configure a battery unit (hereinafter called the battery stack).

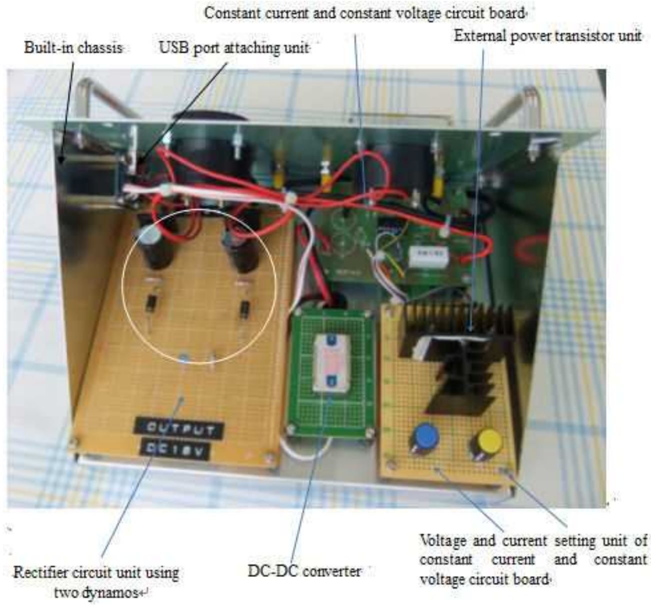


Fig. 10. Internal configuration of fabricated charger (switching power supply is fixed to the chassis bottom)

Fig. 11 shows the battery stack circuit configuration and Fig. 12 the fabricated battery stack. The four battery cells mounted on the printed circuit board are connected in series and configure a battery stack. The solder pads of the printed circuit board and electrode terminals of battery cells are spot-welded at several places using a spot welder.

Table 1 shows the battery specifications of the fabricated battery stack. Before performing dynamo-charging, charging and discharging characteristics of battery cell are measured (Fig.13). Fig. 14 and Fig. 15 show charging and discharging characteristics at 0.1C of battery stack measured by the special-purpose charging and discharging evaluation device (see Reference (1) at the end for the charging and discharging evaluation device)[1].

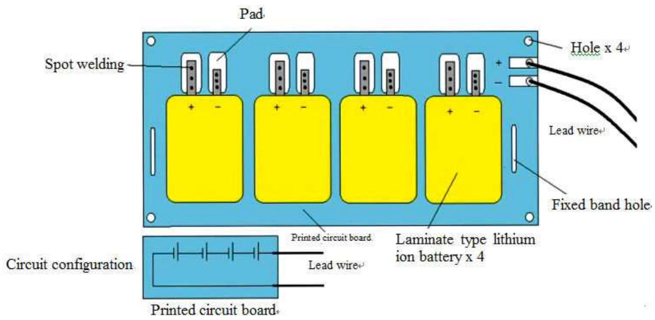


Fig. 11. Configuration of lithium ion battery stack

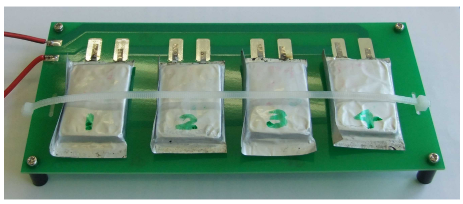


Fig. 12. Fabricated lithium ion battery stack

TABLE I. BASIC SPECIFICATIONS OF LITHIUM ION BATTERY STACK

Battery capacity	800 mAh
Charge end voltage	16.8 V
Discharge end voltage	12.0 V
Rated charging current	0.2C
Max. charging current	0.5C
Rated discharging current	0.2C
Max. charging current	0.5C
Size	94x220 mm
Weight	145 g

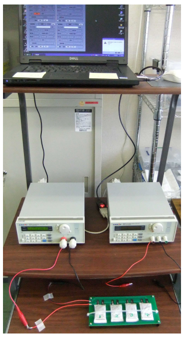
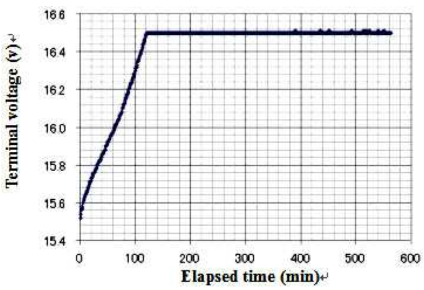
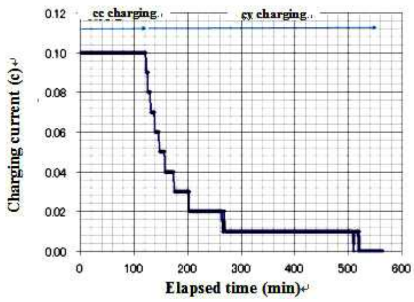


Fig. 13. Charging and discharging evaluation device for lithium ion battery



(a) Characteristics of terminal voltage with time



(b) Characteristics of charging current with time

Fig. 14. Charging characteristics of lithium ion battery stack

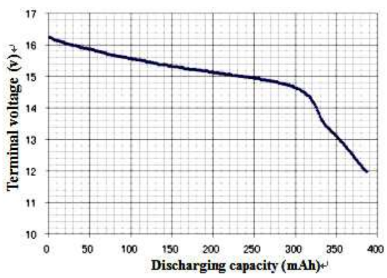
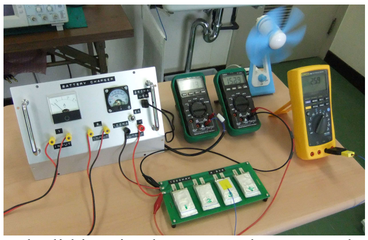


Fig. 15. Discharging characteristics of lithium ion battery stack

V. CHARGING EXPERIMENT OF LITHIUM ION BATTERY STACK BY BICYCLE DYNAMO POWER GENERATOR

Using a charger fabricated as above, a lithium ion battery stack charging experiment is conducted by a bicycle with two dynamos mounted. Changes with time of terminal voltage and charging current of the lithium battery when charging is continued are measured. Two persons take turns at pedaling the bicycle for 5 minutes each continuously for 90 minutes.

(a)Pedaling a bicycle with two dynamos mounted



(b)Charging the lithium ion battery stack connected to a charger

Fig. 16. Charging experiment of lithium ion battery stack by bicycle dynamos

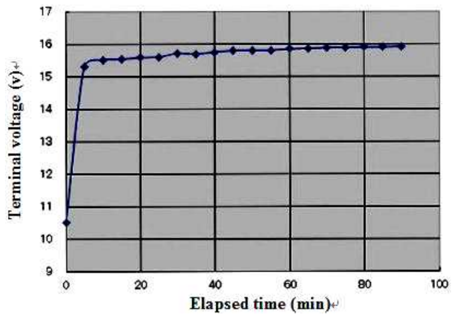


Fig. 17. Terminal voltage of lithium ion battery stack

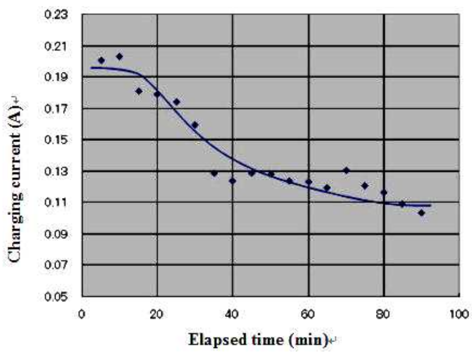


Fig. 18. Charging current of lithium ion battery stack

In such event, the bicycle is pedaled in such a manner that a constant velocity as possible could be obtained with the rear bicycle wheel (23 km/h). Prior to the experiment, the lithium ion battery stack is discharged at a constant current with the charging and discharging evaluation device, and is used under the conditions where the battery capacity and the terminal voltage are sufficiently lowered. To the charger USB port, a commercially available USB fan (5 V, 1 W) is connected so that the dynamo charging could be felt[3]. Fig. 16 shows the scene of the experiment.

Fig. 17 and Fig. 18 show the measurement results. The terminal voltage of the lithium ion battery stack rises as charging starts and after 90 minutes, the terminal voltage is charged to about 16 V. The charging current is 0.2 A (0.25 C) when charging starts and after 90 minutes, it lowers to about 0.1 A (about 0.1 C).

VI. DC-AC INVERTER DRIVE EXPERIMENT BY LITHIUM ION BATTERY STACK

Using the lithium ion battery stack charged by the bicycle dynamos, DC-AC inverter drive experiment is conducted. Fig. 19 and Fig. 20 show the circuit configuration and fabrication example of DC-AC inverter of astable multivibrator system, which was fabricated using a commercially available power transformer (center tap: 12 V; output voltage: 100/110 V; output capacity: 60 VA; frequency: 50/60 Hz) as an inverter transformer[2]. Fig. 21 shows voltage-current characteristics of inverter using light bulb load. See Reference (2) for design, fabrication and experimental examples of DC-AC inverter.

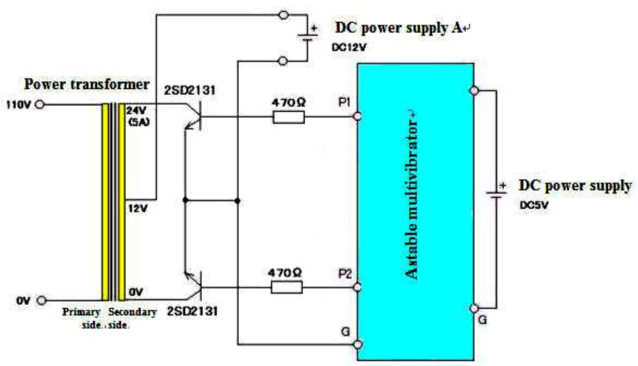


Fig. 19. Circuit configuration of dc-ac inverter

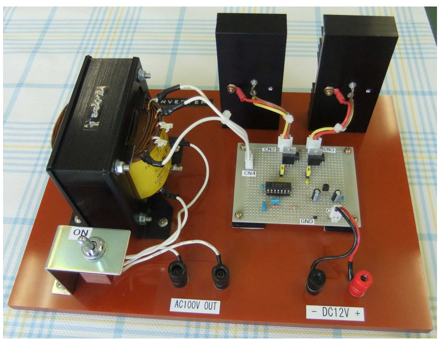


Fig. 20. Prototype of dc-ac inverter

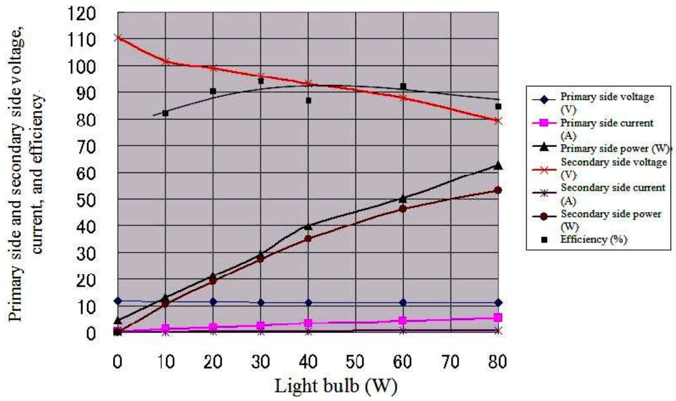


Fig. 21. Voltage and current characteristics of dc-ac inverter

The inverter drive experiment is performed when the lithium ion battery stack is connected to the DC-AC inverter input side and LED bulb is connected to the output side (Fig. 22). The terminal voltage and discharge current (inverter input current) of the lithium ion battery stack connected to the input side of DC-AC inverter are measured with time.

Measurement is continued until the discharge end voltage (12 V) of the battery stack is reached. Fig. 23 shows the measurement result. The power from the battery stack was enough to drive the DC-AC inverter for about 20 minutes.

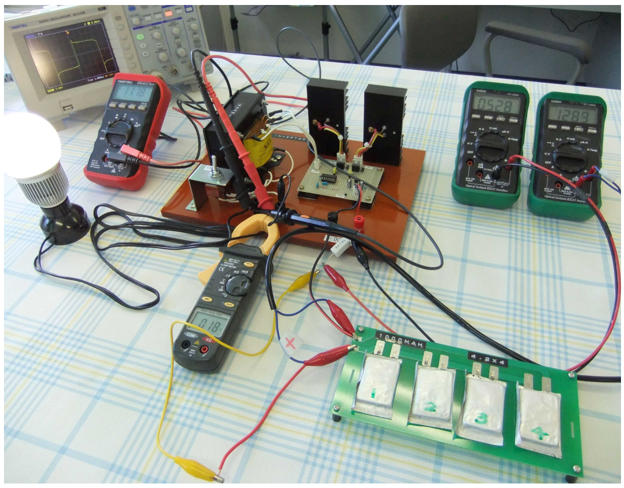
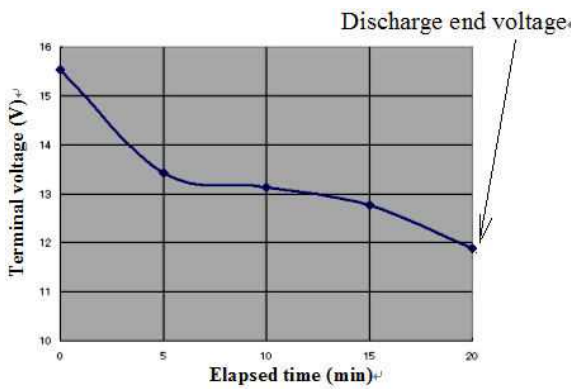
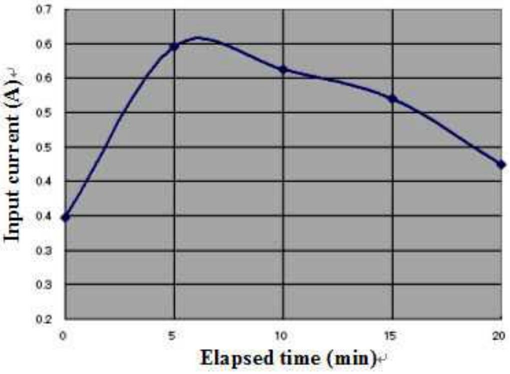


Fig. 22. Dc-ac inverter is driven by the lithium ion battery stack



(a) Change of terminal voltage with time



(b) Change of discharge current with time

Fig. 23. Change with time of terminal voltage and discharge current of iithium ion battery stack

VII. CONCLUSION

Lithium ion batteries have been reduced in size and weight as represented by mobile phones and Smartphone, and the battery capacity has been greatly increased in space and weight ratio compared to other secondary cells. Rapid charge and top-up charge/discharge of the lithium ion battery is enabled by constant current and constant voltage charging. As part of studies on the charging system using familiar bicycle dynamos, a special-purpose charger was designed and fabricated, a cell stack with printed circuit board mounted was fabricated by combining the lithium ion battery cells under fabrication at the laboratory, and charging experiments using the charger and the cell stack were conducted.

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