A CHARGER/DISCHARGER FOR MODELING OF SERIAL/PARALLEL CONNECTED Ni-MH BATTERY

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ABSTRACT—Equalizing the state of charge of cell that affects the charge/discharge quality and efficiency of the battery through the charge/discharge characteristic experiments of battery source, we develope the high efficiency charge/discharge system which would be used in serial HEV with the constant engine-generator output. For this, establishes the electrical model of Ni-MH battery appropriate to the high efficiency charge/discharge conditions. There is no model of Ni-MH cell, so we used Ni-Cd model and obtain the Ni-MH model through the experiment. A reason that each cell has the same charge/discharge property for applying the cell model to serial/parallel connected battery source extensively is needed. Therefore, in this paper, propose the Ni-MH charger/discharger has the equalization charging function and selectable cut-off function.

1. INTRODUCTION

The battery with much more capacity and high efficiency, low EMI charger/discharger are needed in the portable apparatus in great demand and the EV which could be expected to be popular soon or later. The researches trying to increase the cell capacity of the next-generation cell such as Ni-MH, Ni-Cd and Li-ion are in process, but the remarkable results are not presented yet. Therefore, serial/parallel connected type battery source is being used when the large capacitive power source is needed in the pure EV or HEV.

However, the cell forming the battery source tends to decrease in the property as charging/discharging is repeated because of it's life cycle, current quality and temperature rise and the tiny difference of property in the manufacturing step, etc.. Consequently, it results in diminishing the overall property and life of the battery source. It also affect on the operational property and control of EV or HEV. Hence, the function to perform the equalization charging by each cell with equipped in EV or HEV, and the function to control charge current selectively are required.

Furthermore, model of battery should be noted in order to simulate the operational property of EV or HEV, and to determine the most suitable capacity of engine, generator, motor, etc.. Though the models of Lead-Acid, Ni-Cd cell was already presented, there is no model of Ni-MH cell. Therefore, the Ni-MH cell model will be proposed, and through this, the model about the battery source property connected serially/parallely should be achieved.

This paper is about the Ni-MH battery source modeling in serial HEV using several Ni-MH cells connected serially/parallely as the power source, and is about the charger/discharger for modeling. To seek for the Ni-MH cell model, Ni-Cd model which has the similar charge/discharge property as a basis, and the data which is obtained through the Ni-MH cell charge/discharge experiment are used for adjusting the parameters of Ni-Cd model proper to Ni-MH. However, the cell property of degradation by repeated charging/discharging of Ni-Cd model cannot be described. In addition, a prerequisite that each cell has the same charge/discharge property for applying the cell model to serial/parallel connected battery source extensively should be satisfying. For this, we embodied an idea that Ni-MH charge/discharge system has the equalization charging function and selectable cut-off function by each cell.

2. Ni-MH BATTERY SOURCE IN SERIAL HEV

HEV is to be classified into two types; parallel- type in which battery source and motor are linked mechanically to the established ICE(Internal Combusti- on Engine); serial-type in

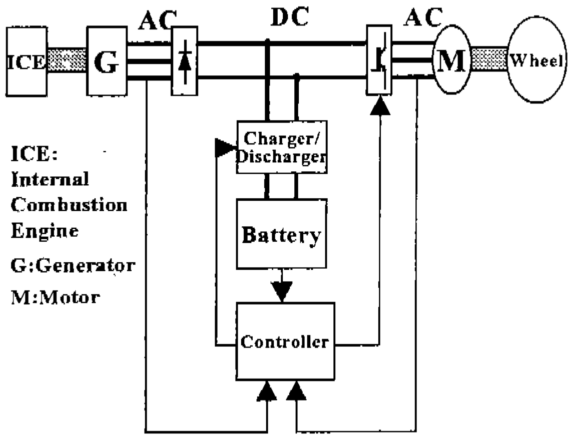


Fig. 1 Configuration of serial HEV

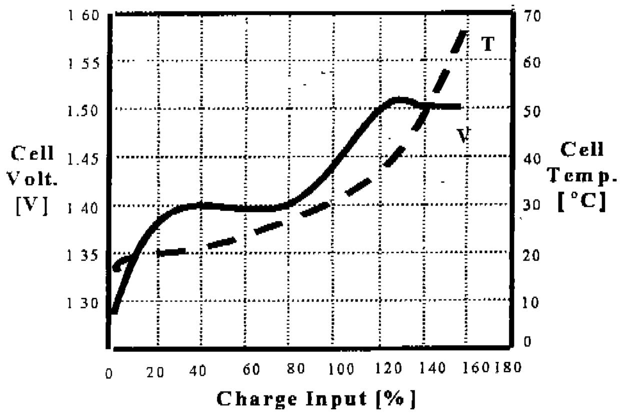


Fig. 2 Charging characteristics of Ni-MH battery

which the engine-generation system is linked to battery source system serially.

Parallel HEV has a structure in which the motor is linked to engine and motor, and linked to drive shaft again by the clutch. Engine and motor can downsized than serial-type, for it can obtains the driving force from both the internal combustion engine and battery source motor. This kind of structure has the battery and motor in addition to the usual ICE vehicle system and has a similar structure of driving force transfer to the usual ICE vehicle. However, the operational control is difficult because the engine and motor made in the special structure should be on and off as needed. This structure also has the disadvantage that the operational convenience and zero emission is hard to achieve.

Meanwhile, serial HEV has a structure having the engine-generator-battery-motor-wheel connection. Serial HEV can control the motor speed and torque easily, so it has the advantage of convenient driving and low emission. In addition to that, it is much close structure to the pure EV than parallel structure, so it can improve the efficiency of energy transfer by the optimal control of engine-generator/battery-motor. However, these operational properties of serial HEV have the current irregularity according to be changed load, and as the case may be, over current in the cell can damage the cell. Serial HEV can have a power supply from battery source and engine-generator unlike a pure EV. In accordance with the load condition, battery source can be discharged to motor and charged from engine-generator system. This operational property of serial HEV can result in the irregularity of charge/discharge current in battery, and according to circumstance, can result in over-current in battery, hence demage the battery[1][2]. Therefore, the battery charge/discharge methode proper to the operational property of serial HEV has to be developed in order to protect the unstable power into battery and to increase the charge/discharge efficiency. Hence, the property of battery source is the important factor in choosing each component of serial HEV. This paper developes the harge/discharge system of battery source in serial HEV construction as described in Fig. 1.

In case that the battery source system and engine-generator system are operated in connection, we can regulate the engine-generator output by assigning the load base to engine-generator output and excess or deficient load to the battery. In case that the engine is started or accelerated or deaccelerated, energy transfer efficiency of engine will worsen and the pollutions will increase. Therefore, we have to regulate the output power of engine-generator.

Ni-MH battery uses metal hydride as the cathode for avoiding the environmental problem caused by cadmium of Ni-Cd battery, but it has the same anode and electrolyte as Ni-Cd. Ni-MH has the high energy density, 30~40% high durability, greater capacity than Ni-Cd, so more attentions are concentrated as battery source of EV. But, Ni-MH is very sensitive to overvoltage when in charging, so we have to be careful about full charge, overvoltage, hot temperature and extreme temperature change for the efficient battery charging.

Fig. 2 shows the changes of voltage and current of Ni-MH in charging. In charging, battery voltage rises and the temperature does so gradually. At the point of 75~80% charge, the oxygen production at anode results in the sudden rise of voltage, so the temperature of two batteries rise suddenly by the reaction of re-fusion of oxygen. This sudden rise results in over charging the battery, so drop the rated full charge voltage. Consequently, the voltage of Ni-MH in charging varies according to charge current and the temperature[3].

The different variated method of Ni-MH charging method based on constant current charge have been used[4]. Among these, three-step charging and multi-step charging are being used in fast charging of Ni-MH battery. The representative switching method already established that is used in step charging has two types. ΔT type switch next charging step for avoiding the extreme temperature rise. ΔV type stops the charging and performs next charging step at the point of reaching the specific voltage. ΔV method varies to three different method, one is $\Delta V=0$ method

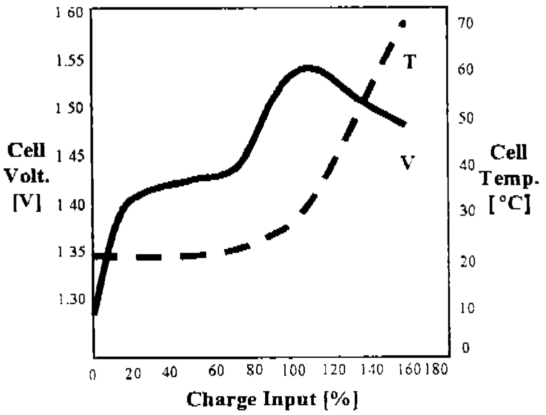


Fig. 3 Charging characteristics of Ni-Cd battery

switching at the point of voltage difference is zero to time variation. The others are $+\Delta V$ and $-\Delta V$ method switching at the point that voltage difference increase over or decrease below the specific value. As stated above, two charging method cut-off serial/parallel connected battery source collectively, enlarges the SOC difference between cells, brings about the overcharge or undercharge of the cell, and results in the rapid degradation.

Charge/discharge repetition in serial connected battery source can cause the disuniformity between the cells, and demage the durability of each cell and hinder the safety in battery operation. Therefore, we can extend the life cycle of cell and improve the stability by performing the equalization charge to solve the disuniformity between the cells.

3. Ni-MH BATTERY MODEL

The battery model for simulation are mathematical, electrochemical, electrical model, etc. Mathematical model analyses the ideal battery in comparatively simple formula, but the formula get complex when it considers several properties of the actual batteries, so the calculation program could be needed. Electrochemical model has the good model about already-established experimental results, but it also has very complex structure about the battery model needed in this paper. Hence, we used Zimmerman and Peterson's Ni-Cd model in this paper.

Fig. 3 shows the charging characteristics of Ni-Cd battery, and the similarity to Fig. 2 can be noted easily. Therefore, Ni-MH model can be constructed on the ground of Ni-Cd model through the experiments and adjusting the parameters. This is shown in Fig. 4. In this model R_1 represents the plate internal resistance. The back-to-front connected diodes D_1, D_2 represent the hysteresis and nonlinear internal resistance effects in the electrochemical cell. They are a function of the

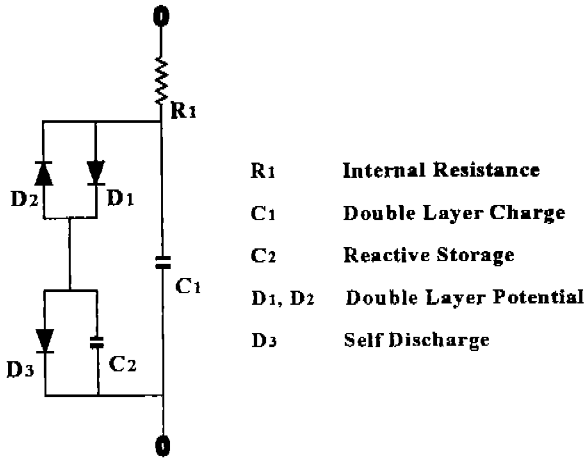


Fig. 4 Model of Ni-Cd battery

current direction (charge/discharge) and the depth of discharge (DOD). The diode D_3 represents the charge leakage and overcharge conductive leakage. C_1 represents the effect of linear capacitive elements storage across the double layer, and C_2 represents the effect of the chemical reaction storage[5].

The equations that describe the components of the model have been derived in Zimmerman's and Peterson's paper[6], and are presented briefly here. The equations for the diodes D_1, D_2 D_3, are

$$I_1 = 2\, k_1 \sinh (k_3 V_1) \tag{1}$$

$$k_1 = \frac{I_0\, e^{40.27 k_2 \left(1 - \frac{519}{T+459}\right)}}{e^{40.27 \frac{V_0}{L}} - 1} \tag{2}$$

$$k_3 = \frac{20900}{L(T+459)} \tag{3}$$

where,

I_0 = reference diode current[A] at 60°F and V_0
V_0 = reference diode voltage[V] at 60°F and I_0
T = actual diode temperature[F]
I_1 = actual diode current[A] at T and V_1
V_1 = actual diode voltage[V]
k_2, L = constants which may be determined by analysis of the experimental data.

The equations for the capacitors C_1 and C_2 are

$$C = A\, e^{-B(V-V_M)^2} + D \tag{4}$$

where,

C = capacitance value[F] at V
V = actual voltage level[V] of capacitance
V_M = median voltage level[V]
A = capacitance in [F] at $V=V_M$
B = distribution constant
D = minimum capacitance [F]

The Ni-MH battery model is taken to be the same with slightly different parameter values.

4. CHARGER/DISCHARGER CONFIGURATION

We constructed the overall charge/discharge system of Ni-MH battery source in the serial/parallel connection as shown in Fig. 5. Ni-MH cylindrical battery which has 1.2V, 1200mAh capacity, sold commercially, is used, and charge/discharge circuit is a switching component, is constructed. as a chopper circuit for step-down when charging and step-up when discharging. The terminal voltage of cell is put to 12 bit-A/D differentially by synchronizing converting cycle of A/D and choosing time of MUX. After measuring the terminal voltage of each cell, cell which has ΔV=0 is switched through digital output.

Produce the reference voltage which keeps constant current at the point of charging the reference voltage which keeps the value over or equal to DC bus voltage at the point of discharging. Selectively cut-off is constructed by using transistor for switching and photo-coupler. Three transistors are used in cut-off switch for charging, switching, and discharging of each cell. Each transistors are controlled by insulating the digital output by photo-coupler.

Fig. 6(a) and (b) describes chopper circuit in which charge/discharge occurs through buck and boost. First, at the point of charging, input voltage is put down, as T1 is switching. It flows is again through D2 when T1 is off. At the point of discharging, discharge switch S has to be closed, T2 be switching, and output voltage has to be raised over DC bus, because only when battery source voltage is over or equal to DC bus voltage, the discharge can occur. Once T2 is on, the energy is stored in coil L, and if T2 changes to be off, the discharge occurs through D2.

In this paper, deals with time-sharing equalization charging. This method time-shares the charging time inversely proportional to SOC of each cell, and uses control switch to connect one charging system to several cells in turn. Fig. 7(a) and (b) shows each cell's SOC before and after equalization charge respectively[7]. SOC is determined on check the terminal voltage of cell. This method has the advantage that we can increase the transplantation according to charging control method and alternation of target cell by just software modification.

This paper is going to deal with -ΔV=0 method which is superior in property of charging efficiency and can avoid overcharge. Fig. 8 shows -ΔV=0 charging method. Control switch is used for selectable cut-off as well. In this method, first serial/parallel connected battery source is charged by

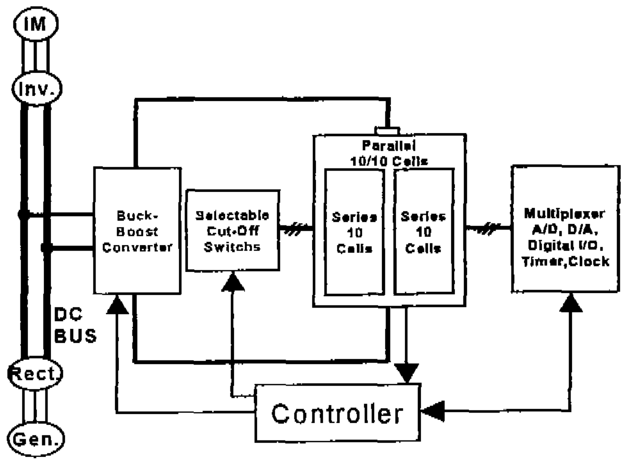
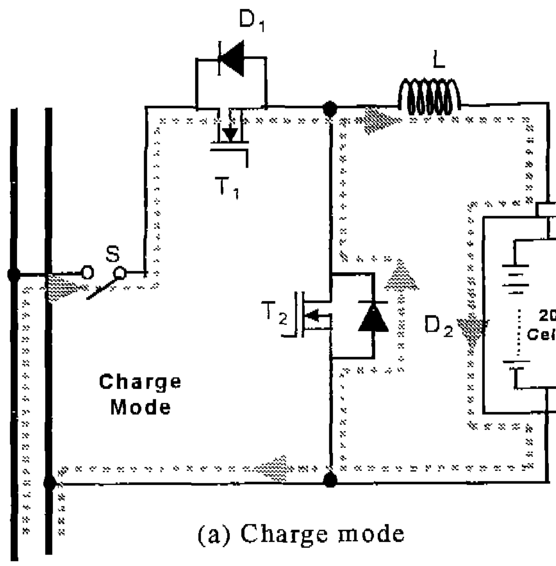
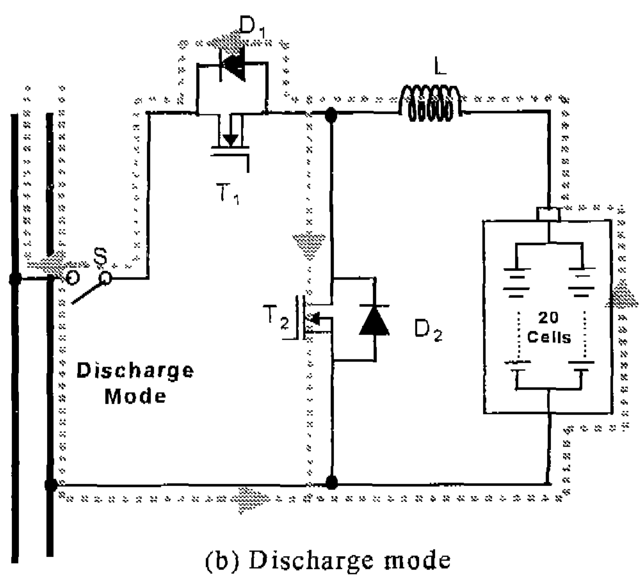


Fig. 5 Configuration of proposed circuit



(a) Charge mode



(b) Discharge mode

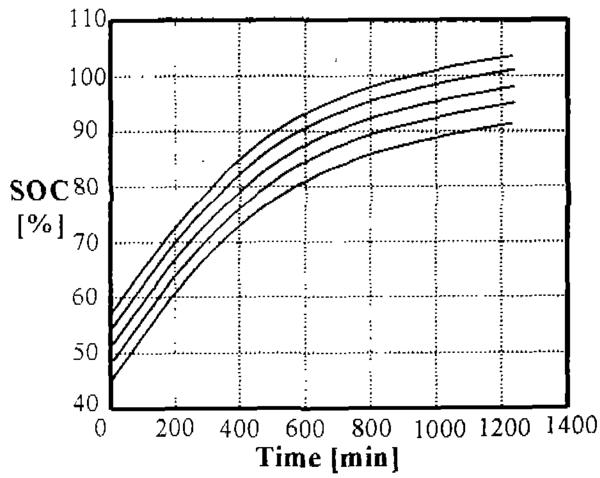
Fig. 6 Operations of charge/discharge in proposed system step one charge current, at the point of detecting the cell of ⊿V=0. switch it and then switch the other cells in order as soon as they have ⊿V=0. Once all the cells are switched, charge as step two charge current by equalization charging to avoid capacity disuniformity. In the step two and three, cell switching processes are same as step one. Fig. 9 shows control flow chart in which selectable cut-off is adopted, charging current is switched, and equalization charging is performed. We can avoid the degradation caused by the overcharge and undercharge of each cell connected serially by controlling that the voltage of each cell would be detected and the cell with ⊿V=0 would be switched selectively.

5. CONCLUSIONS

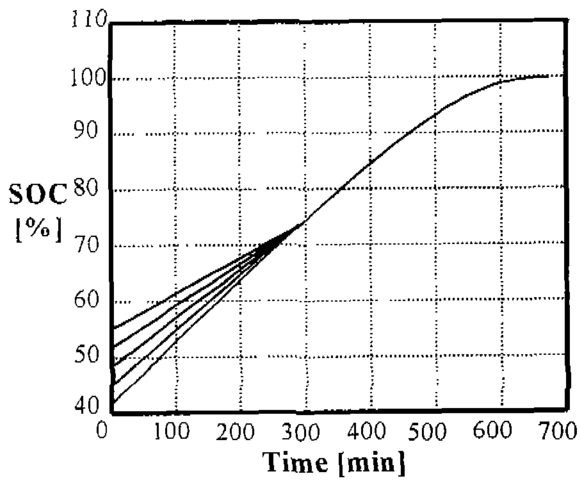
Fig. 10 shows the *properties of step charging* by selectable cut-off and the time-sharing equalization charging of three Ni-MH batteries serially connected. The capacitive imbalance between batteries can be overcome by including time-sharing equalization charging mode. consequently, efficiency of the battery can be raised and charging characteristics can be improved. Because of achieving the SOC difference of batteries is decreased, and charging characteristics of batteries serially connected can be remained. The charging time is longer than the case that equalization charging is not performed.

By using the selectable cut-off according to cell battery, the sudden cell battery degradation caused by overcharge can be avoided, and the efficiency of the battery can be increased. Further more, charging characteristics of the battery increases by performing equalization charging at the same time. Define temperature, voltage alteration according to the time as the basic parameters by the data obtained from the charge/discharge experiments of serial/parallel connected Ni-MH battery source. Construct the battery source model of serial HEV according to the load variation. The input of charge/discharge system is the regular output of HEV engine-generator system, and it can improve unstable power of charge/discharge system, so the battery can be protected from the discharge current and charge/discharge efficiency can be increased. In addition, by the selectable cut-off, the sudden degradation which results from the overcharge of each cell can be blocked, and expand the life of battery source.

For this, the construction in which two set of serial connected Ni-MH battery would be connected in parallel over again, and this construction will be used as a serial HEV battery source which has the constant engine-generator output.



(a) Without equalization



(b) With equalization

Fig. 7 SOC of Ni-MH battery

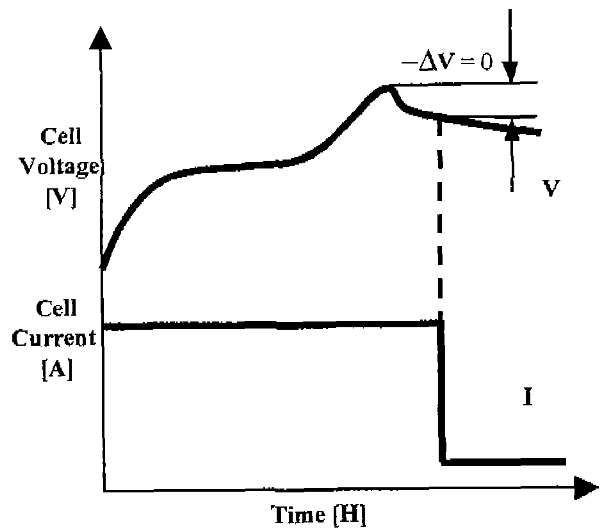


Fig. 8 Cut-off method

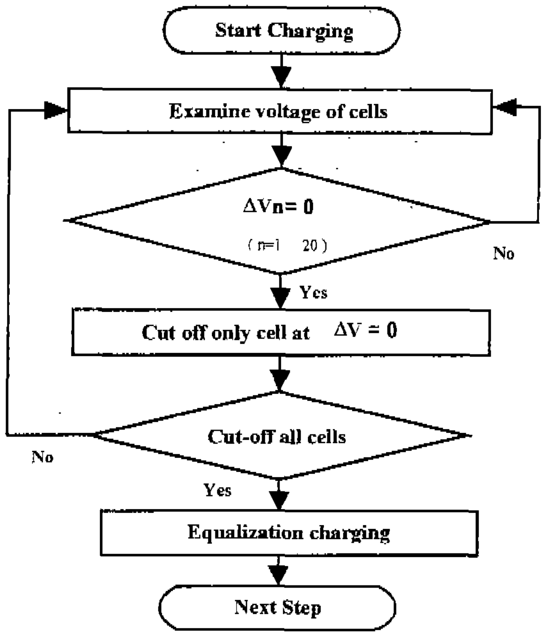


Fig. 9 Flow chart for selectable cut-off control

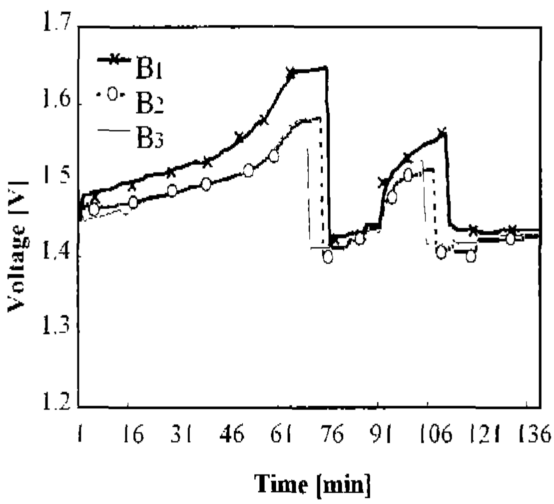


Fig. 10 Characteristic of step-charging with selective cut-off and equalization method for three cell connected serially

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