

Charging and Discharging Method of Lead Acid Batteries Based on Internal Voltage Control

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Abstract

A new method of charging and discharging has developed to improve the performance of charging and discharging of lead-acid batteries. The battery itself has an internal resistance that makes it difficult to control the charging and discharging process because the capacity of the battery is estimated by the potential difference between the two electrodes of the battery, named external voltage. When the effective internal resistance of the battery is increased due to the deterioration, the external voltage is too high to stop charging even though the battery has not stored a sufficient amount of energy. This paper introduces a new method of charging and discharging and the resulted effectiveness of this method to the lead acid battery life prolongation is shown.

Keywords

internal voltage, lead-acid battery, charging and discharging system

1. INTRODUCTION

To prolong the life of automotive batteries is a crucial issues for the sustainable development and improve the environment. We have studied on the prolongation of lead-acid batteries [Kozawa, 2003, 2004; Minami et al. 2003, 2004]. The state of the art in lead acid batteries is evaluated by the repetition of charging-discharging cycles. Japanese Industrial Standards (JIS) specify 14.5 V as the final charge voltage of 6-cells lead acid battery. Any charging in excess of this voltage generates hydrogen gas. Therefore, in compliance with this standard, charging usually stops and the battery switches over to discharging when this voltage is attained. The final discharge voltage is set, again by JIS, at 10.5 V so that performance can be evaluated in terms of time and capacity by discharging from the fully charged state at a constant current until reaching 10.5 V. However, these two voltages are in reality the voltages at the terminals of the battery. An actual battery has an effective internal resistance, R . Therefore, the voltage drop $V = I \times r$ that occurs because of the charge and discharge currents, I , is evaluated differently in battery charging and discharging. A new method for obtaining the battery's internal voltage, V , and using this to control battery charge-

discharge current is proposed. It involves stopping the current for a short period of time during battery charging and discharging, and measuring the battery voltage in that instant.

2. CONTROL SYSTEM OF THE CHARGE-DISCHARGE

An automatic charger-discharger is fabricated to evaluate battery deterioration. Figure 1 is an example of such experimental result. It can be seen that, when charging starts, voltage increases, whereas when discharging starts, voltage decreases. Moreover, as the number of cycles increases, discharge time becomes shorter with

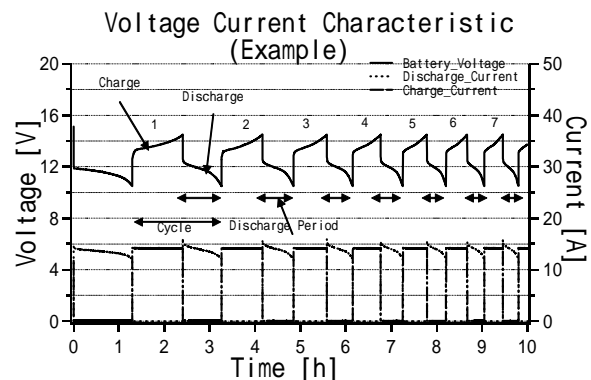


Fig. 1 Voltage and current characteristics in charging and discharging without based on the external (terminal) voltage measurement

each cycle. This is caused by the increase in internal resistance as the battery deteriorates and it occurs despite the constant discharge current. For this reason, battery voltage rapidly depletes in proportion to the magnitude of the internal resistance, hence discharging to 10.5 V becomes faster. In other words, by watching the change in discharge time per cycle, it is possible to identify the change in internal resistance of the battery, that is to say, the state of battery deterioration.

The previous test system consists of a charger-discharger that controls external (terminal) voltage. It switches back and forth between charging and discharging according to the terminal voltage. A charger-discharger that runs by controlling internal voltage controls charging and discharging based on the internal voltage of the battery. This internal voltage is the battery voltage (Electromotive force) when current is not flowing to or through it. The external voltage includes the $I \times r$ drop caused by the discharge current, I .

The new system consists of charger-discharger which controls the voltage using its internal voltage as follows. The objective is to fully charge a battery by flowing sufficient current to it. As the battery repeatedly charges and discharges, it gradually deteriorates. Its internal resistance increases until current eventually stops flowing through it. As an equivalent circuit, the battery would look like Figure 2.

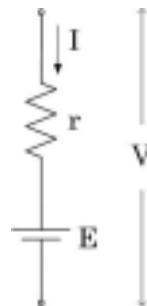


Fig. 2 Equivalent circuit of the battery

$$E = V - r I \quad (1)$$

E is the battery's internal voltage (electromotive force), V is the external (terminal) voltage and r is the effective internal resistance. From Eq. 1, it is understood that, when a constant current flows to the battery, the terminal voltage, V , changes because of the internal resistance, r . As the battery deteriorates and the internal resistance, r , increases, the terminal voltage, V , increases to 14.5 V in a short period of time and charging ends. In this state, charging ends with little or nothing to do with the electromotive force of the battery. A sufficient amount of current does not flow to the battery and resultantly the

battery does not fully charge. The charger-discharger that works by internal voltage control eliminates the effects of this internal resistance so as to store sufficient energy in the battery.

The basic circuit for repeatedly charging and discharging the battery is shown in Figure 3. It consists of relay circuits for controlling battery charging and discharging, and a measurement circuit. In charging, the charge relay is ON, while the discharge relay is OFF, hence charge current flows from the charger to the battery. In discharging, the charge relay is OFF, while the discharge relay is ON, hence discharge current flows from the battery to the load.

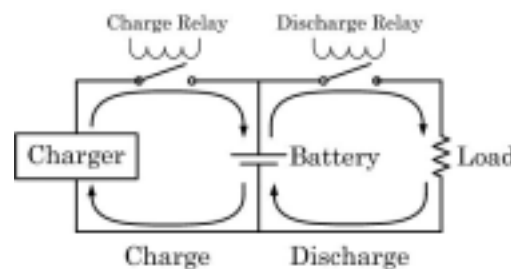


Fig. 3 Conceptual view of charger-discharger

The relay circuit for previous controlling battery charging and discharging is shown in Figure 4. The charge relay and discharge relay of Figure 3 control current flow so that, when battery voltage reaches 14.5 V, the device switches over to discharging and, when voltage drops to 10.5 V, it switches back to charging. The charge relay and discharge relay switch positions according to voltage. That timing and circuit are as follows. Figure 4 shows how the charge relay and discharge relay switch positions.

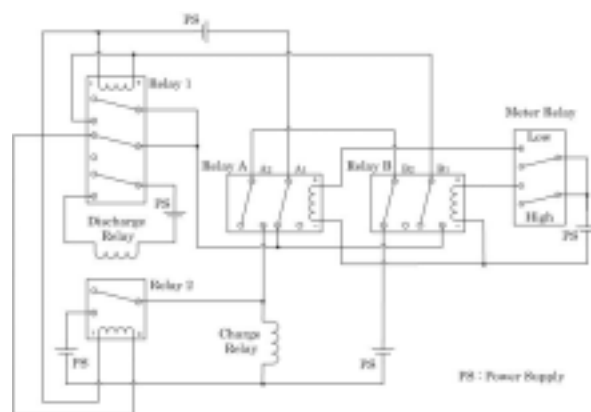


Fig. 4 Relay circuit for controlling battery charging and discharging

The meter relay in Figure 4 is a meter with switches for controlling circuit positions according to voltage level. When the maximum is set to 14.5 V and the minimum to

10.5 V, and battery voltage reaches those levels, the switches activate. Also, relays A, B, 1 and 2 control the charge and discharge relays that controls direct current flow to the battery. Figure 5 shows the relationship of switches A1, A2, B1 and B2 of relays A and B, and battery voltage.

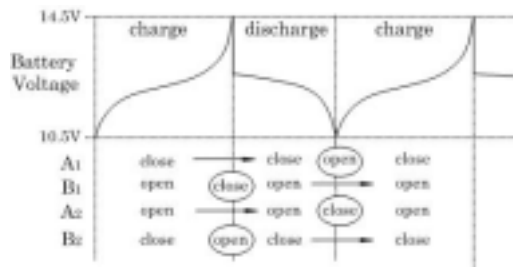


Fig. 5 Relationship of relays A and B, and battery voltage

In charging, switch A1 is ON, therefore 12 V are applied to the relay 2 and resultantly the relay 2 turns ON. Accordingly, the charge relay turns ON and hence current flows to the battery and charging starts. Also, relay 1 is OFF, therefore the discharge relay stays OFF. When the battery is fully charged and voltage exceeds 14.5V, the high end of the meter relay turns ON. In that instant, B₁ turns ON and relay 1 turns ON. Accordingly, because the discharge relay turns ON, current flows from the battery to the load and discharging starts. At this time, relay 2 is OFF, therefore the charge relay is OFF. Here, when voltage drops, both the high and low ends of the meter relay turn OFF as in charging, but the circuit is self-holding so that discharging continues. Using an AD converter (ADC-11), all of the voltages and currents are recorded into a PC and measured (Figure 6). Current is measured with a current converter.

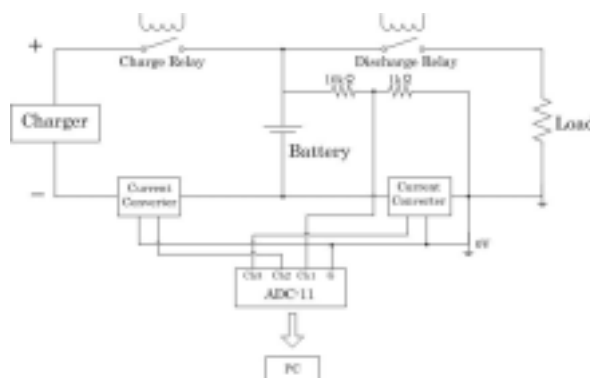


Fig. 6 System of data logging and PC

3. NEW CHARGER-DISCHARGER OPERATED BY INTERNAL VOLTAGE CONTROL

Even with deteriorated batteries of high internal resistance, this charger-discharger that works by internal voltage control can eliminate the effects of this internal

resistance and store energy in batteries. It controls charging and discharging using the internal voltage rather than the terminal voltage of the battery. A view of the device is shown in Figure 7.



Fig. 7 A photograph of internal voltage controlled charger-discharger

To know the internal voltage of a battery, Eq. 1 tells us to stop current flow to and from the battery and read the terminal voltage of the open circuit. The internal voltage of a battery can be known without any effects from internal resistance both in charging and discharging. For that reason, this device opens the circuit for a short period of time during charging and discharging, and reads the voltage. A circuit diagram of this device is shown in Figure 8.

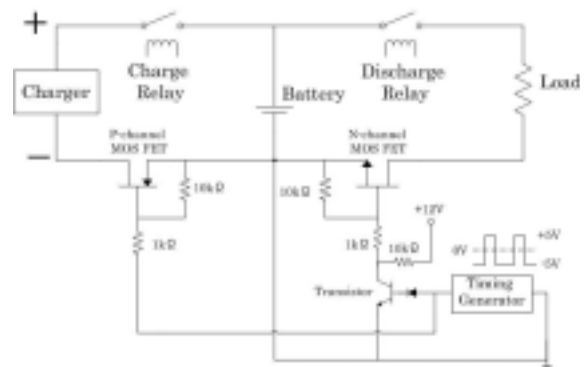


Fig. 8 Internal voltage controlled charge-discharge circuits

To turn off the charging in Figure 8, a P-channel FET is used. To turn off the discharging, an N-channel FET is used. A timing generator controls the operation of these FET. This timing generator generates pulse voltages of +5 V and -5 V. At +5 V, a transistor is turned to prevent +12 V from being turned on the N-channel FET, hence the N-channel FET is not turned on. The P-channel FET is OFF with positive voltage. At -5 V, the transistor is not turned on, therefore voltage split from the +12 V power supply is supplied to the N-channel FET causing

it to be turned on. This -5 V is applied to the P-channel FET, causing it to be turned on. Therefore, this circuit is open while +5 V are being output from the timing generator. The duty cycle of the pulse to monitor the internal voltage of the battery is set to be 60 ms which corresponds to 2% duty-cycle to the normal charging-discharging period. During the off-time of charging-discharging current, the internal voltage is successfully sampled and holded to control the timing of charging and discharging.

4. EXPERIMENT RESULTS

Using this system, the effects of additives on batteries are measured. The ITE additive by Kozawa *et al.*, [2003, 2004] is a useful liquid solution with particles of several μm in size that is injected into the electrolyte of the battery. These particles affect the electrolyte during charging and discharging. This ITE additive has shown to prolong the service-life of batteries. The purpose of fabricating this device is to further improve this effect. The internal voltage V_i , external voltage, V_o , can be sampled and recorded simultaneously by the data logger that samples every 5 sec. The charging is changed to be discharging at the internal voltage of 14.5V, while the discharging is changed to be charging at the internal voltage of 10.5 V. A test battery which is 12 volt 28 Ah lead-acid battery for automobile starter (40B19L) is charged and discharged repeatedly as 0.5C (14A). The charging current and discharging current are kept almost constant. Figure 9 shows an example of the time variation of external voltage, V_o , and the internal voltage, V_i , at the beginning of the experiment phase (5-10h since the experiment is started).

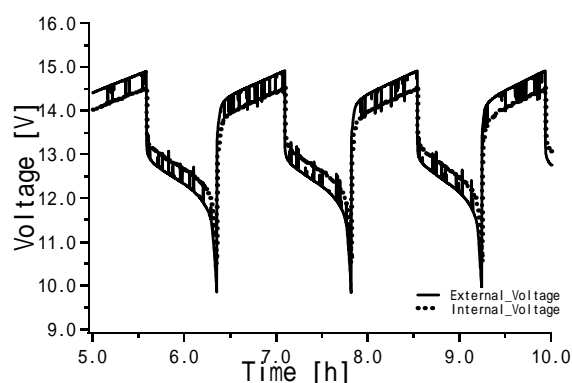


Fig. 9 An example of the time variation of the internal voltage and external voltage of test battery

Figure 10 shows an example of the time variation of external voltage, V_o , and the internal voltage, V_i , at the time of 20-23h since the experiment is started.

The experimental result to compare two methods is shown in Figure 11. The time variation of the battery

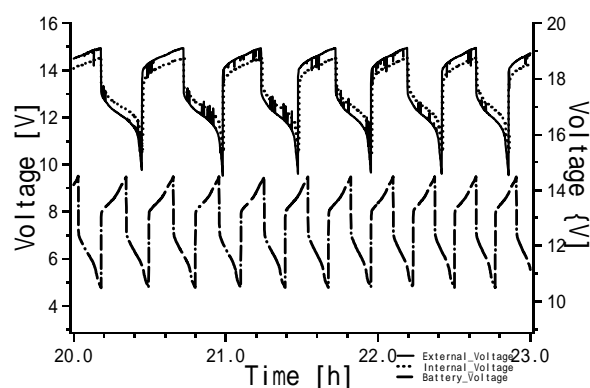


Fig. 10 An experimental result of comparing two methods of charging and discharging controls

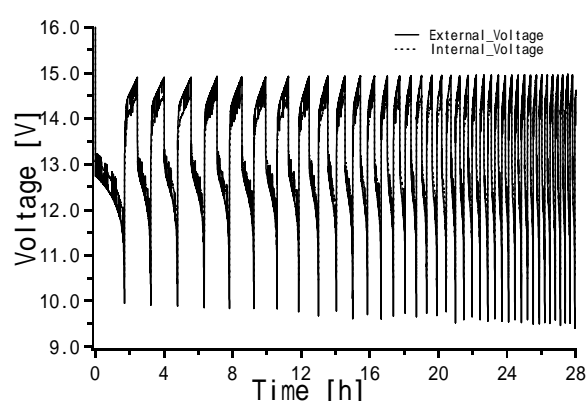


Fig. 11 The time variation of the battery voltage characteristics during the whole experiment

voltage characteristics during the whole experiment by the internal resistance control is shown.

Figure 12 shows that a result of two methods based on the period of charging and discharging. The maximum charging voltage and the minimum charging voltage are set to be 14.5 V and 10.5 V respectively. The period is defined as the duration of one cycle of charging and discharging. The result shows clearly that the period by the internal control is kept longer than that by the external control.

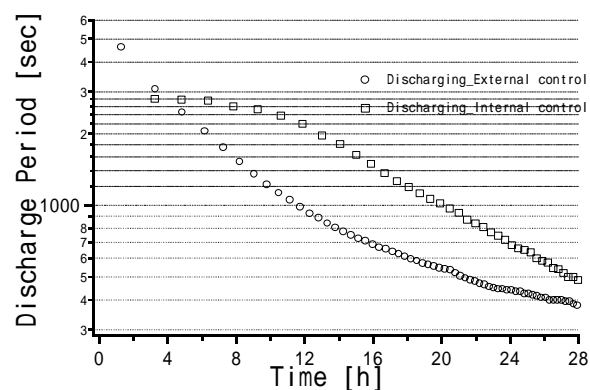


Fig. 12 An experimental result of two methods; the internal voltage control and the external voltage control

5. DISCUSSIONS AND CONCLUSIONS

Let's discuss about the pulse duration to stop the current which is set to be 60ms. Is it sufficient for the battery to be settled. During the switched-off time, the internal voltage, V_i , is sampled and holded is used as the battery voltage to control the charging and discharging. The internal resistor is created by the following three components: (1) Surface resistance by discharge reaction called activation bipolarization), (2) Electron diffusing resistance or called pure resistance of $PbSO_4$ and metal Pb, (3) Ion conduction resistance due to the diffusion of H_2SO_4 ion. Among them, terms of (1) and (2) decrease shortly (order of μs) after the current stops. The time constant of ion diffusion is several seconds. In this experiment, 60ms is effective to reduce the effect of term of (1) and (2). The duty ratio of current stopping time is 2% during the charging and discharging. The experimental result confirmed that the control of internal voltage by such system is useful to prolong battery life. The use of additive increases internal voltage and is believed to produce the prolongation more effectively.

This experiment confirmed that the internal voltage control works well for the process of charging-discharging. The life of batteries is significantly extended for repeating the deep cycle use compared with the method by the conventional external voltage control. This means that the capacity of batteries can sufficiently utilized when the internal voltage control is used. By the deep charging of batteries the effect of sulfation can be avoided. This method can be suitably applicable when additives is used for prolongation of life because the upper limit of charging batteries increases.

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