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Internal battery temperature estimation using series battery resistance measurements during cold temperatures

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Abstract

A technique has been developed to estimate the internal battery temperature (T_{bat}) of secondary batteries by measuring the series battery resistance (R_{B}) at cold ambient temperatures. Tests were performed on both lead-acid and nickel metal hydride batteries at different cold temperatures to obtain useful plots of R_{B} versus T_{bat}. R_{B} was measured by using a pulse discharge circuit to apply a short-duration current pulse (I_{B}) directly to the battery. The test results indicated that R_{B} not only varies with temperature but also varies with the amplitude of I_{B}. The R_{B} versus T_{bat} plots were later utilized to predict T_{bat} from R_{B} during alternating current (AC) battery heating at cold ambient temperatures.

Keywords: Battery temperature; Battery resistance; Alternating current; Battery heating; Cold temperatures; Lead-acid

1. Introduction

In order to improve the performance of series battery packs at cold temperatures, their electrolyte needs to be warmed up. Although several external heating strategies can be used, these methods add considerable weight and expense. Moreover, if the pack is allowed to reach a very low temperature, these methods require significant amount of time for warming the batteries since the external heat energy must penetrate the large mass of the pack. Internal heating strategies, such as circulating alternating currents (AC) at high frequencies to heat batteries via I^2R losses seem to be a viable alternative [1–4]. This strategy has produced very encouraging preliminary results and the effect of these currents on overall battery life is currently being studied.

No matter what technique is used for heating secondary batteries, it is imperative that their electrolyte temperature be monitored as they warm up [5]. This is necessary because overheating can damage a battery beyond repair. It is quite easy to measure the battery case temperature (T_{x}) but this does not provide a good estimate of the electrolyte temperature (T_{bat}). It is therefore, necessary to monitor T_{bat} rather than T_{x}. This is possible by inserting a thermocouple or a thermistor within the battery case during manufacture. However, at present, battery manufacturers have not been doing this, and therefore, an alternate technique is required to monitor T_{bat}. Fortunately, the series battery resistance, R_{B}, varies with the internal battery temperature and therefore, this parameter can be used to monitor T_{bat}.

2. Cold temperature battery performance

At cold temperatures, such as those below 0 °C, battery charge and discharge become increasingly difficult. Fig. 1 shows a simplified model that can be used to explain the problem for most types of batteries. V_{o} represents the open circuit voltage of the battery while R_{c} represents the resistance due to the ohmic voltage drop. The overvoltage resistance, R_{ov}, is used to represent the additional energy that must be supplied to get charge into or out of the battery [6,7]. As the temperature drops, R_{ov} increases because more energy is required to either charge or discharge the battery. R_{ov} is usually much larger than R_{c}, and therefore, at a sufficiently low temperature, it can be used to predict the internal temperature of the battery. However, it is also highly nonlinear with respect to the state-of-charge (SOC) and the magnitude and direction of the current, I_{B}. Therefore, SOC and I_{B} must be known while predicting R_{ov}. R_{B} represents the sum of R_{ov} and R_{c}.

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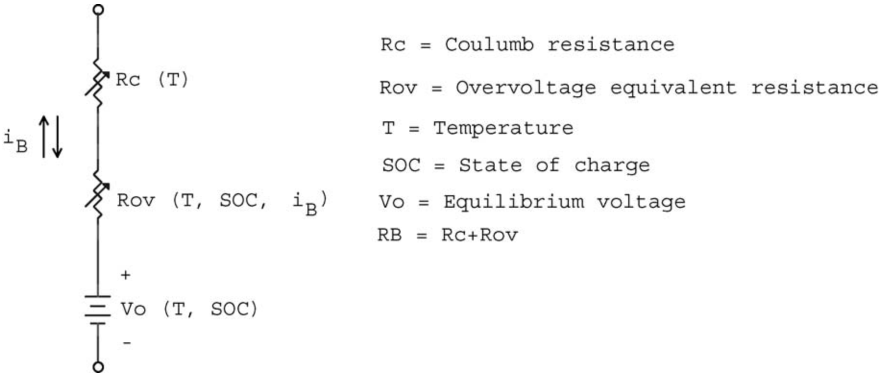

Fig. 1. Battery model.

3. Estimating internal battery temperature by measuring series battery resistance

3.1. Lead-acid batteries

In order to observe the behavior pattern of R_B with respect to internal battery temperature changes, tests were first performed on a Hawker Genesis G12V13AH VRLA battery with SOC = 67%. As the part number indicates, this is a 12 V_{DC} battery with a rated capacity of 13 ampere hours (Ah) at the 10 h discharge rate. This particular model was chosen because the same model also was available for comparative testing at Department of Energy's National Renewable Energy Laboratory (NREL). The following procedure was used to measure T_{bat} from R_B.

At 25 °C, an I_B equal to a fixed amplitude was applied for 2 s, and the battery voltage drop (ΔV_{bat}) was measured. Therefore, the series battery resistance (R_B) is given by

$$R_B = \frac{\Delta V_{bat}}{I_B}. \quad (1)$$

This process was repeated at 10, 0, −10, −20, −30 and −40 °C, after allowing the battery to soak for at least 4 h at each temperature. Therefore, after each temperature soak, T_{bat} can be assumed to be equal to the external ambient temperature. R_B was measured using I_B amplitudes of 50, 100, 200, 300, 400 and 500 A_{DC} at each temperature. R_B was found to vary with the amplitude of I_B and therefore, these different values of I_B were used for measuring R_B. The tests were performed using the AeroVironment ABC150 power processing system [8] to apply the 2 s I_B current pulse directly to the battery. The I_B pulse amplitude was accurately measured with a Hall effect sensor since the 2 s pulse was found to saturate all of the available current pulse transformers. Fig. 2 shows the experimental setup.

In order to obtain the ΔV_{bat} measurements, a second battery (V_s) was placed in series with the voltage probe to provide a 12 V_{DC} offset voltage. This was necessary to obtain a sufficiently high resolution for ΔV_{bat} on the scope. To provide a well-defined point on the decaying ΔV_{bat} pulse, the ΔV_{bat} and I_B values at the end of the pulse ($\Delta t = 2$ s) were used for all the R_B calculations.

ΔV_{bat} in all of the plots, such as Fig. 3, uses the 0 V_{DC} point as the reference. All the scope traces used a time scale

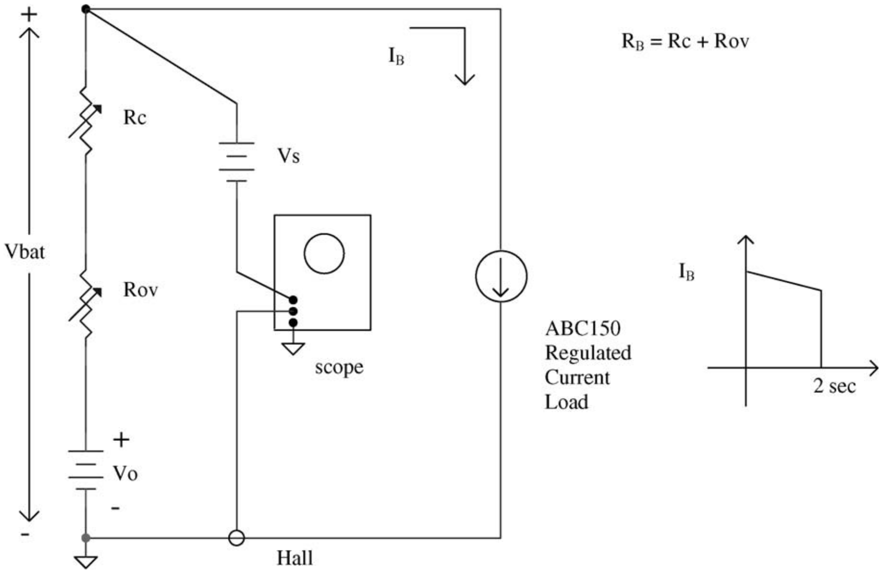

Fig. 2. Pulse discharge test circuit using the ABC150.