ELSEVIER

Journal of Power Sources 53 (1995) 339–340

JOURNAL OF POWER SOURCES

A battery model for the monitoring of, and corrective action on, lead/acid electric-vehicle batteries

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Received 15 August 1994; accepted 2 September 1994

Abstract

This paper presents battery monitoring and control system design objectives, together with a discussion of the specific parameters that are most influential to system development. The resulting precision fuel-gauge, coupled with cell-balancing circuitry to equalize cell capacities, can make a significant contribution to vehicle performance.

Keywords: Electric-vehicle batteries; Lead/acid batteries; Battery model

With the oil crisis in the early 1970s, an intensive development of electric vehicles, i.e., passenger cars, delivery vans and buses was initiated. In the early stage of the demonstration phase, it became quite clear that the lead/acid battery (or more precisely the battery pack) requires more attention than can be provided by simple meters for current, voltage and ampere-hours. This led to the requirement for a sophisticated monitoring system, which, according to our understanding, should be extended to a supervisory system. The main objectives of such a supervisory system are:

- precision fuel gauge
- charge – or better – capacity balancing for modules/cells out of step
- provision of a standardized data set as a control parameter for both a rapid external and a standard onboard charger
- storage and evaluation of relevant data from vehicle commissioning until end of life for further processing in connection with a leasing contract or for the service engineer
- supervision and control of a thermal-management system

The implementation of the functions requires a self-consistent and self-adjusting battery model. Great attention must be paid to minimizing the number of product and design parameters selected for allocation of a specific battery to the supervisory system.

The algorithm for determination of the residual capacity and the 'miles-to-go' includes the following.

- Calculation of the actual capacity in relation to the nominal one. The Peukert function is replaced by ten representative points and linear interpolation is applied according to the average load i_{av} from beginning of the discharge to the present.
- Correction for the actual average battery temperature T against the standard one T_0 according to:

$$C(T) = C(T_0)(1 + a + b \ln(i_{av}/i_{nom})) \tag{1}$$

- Calculation of the state-of-charge (SOC) by first eliminating the losses that result from the inner resistance, R_i, from the battery voltage, U_b, to give a 'zero load' voltage, U_0, i.e.,

$$U_0 = U_b + iR_i \tag{2}$$

and a second comparison with the 'zero load' voltage versus SOC graph represented by 11 support points by interpolation.
- Correction for the actual battery capacity as a percentage of the nominal one.

The actual capacity is determined by comparison of the discharged ampere-hours and the current-related capacity with the SOC whenever: (i) the battery has been fully charged according to the supplier's specification; (ii) the actual discharge exceeds a specified value, e.g., 60% of the current-related capacity.

By application of a trend analysis, it is possible to exclude erratic fluctuations that can even be found in laboratory experiments, or at least keep them within acceptable limits.

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SSDI 0378-7753(94)01997-A

Weak cells or modules refer to those with a capacity that is significantly lower than the average or those with extremely high self-discharge, e.g., due to internal shorts. They may be supported by energy transfer, either from the full battery or from strong modules via d.c./d.c. converters. These two methods have certain advantages and disadvantages, as well as hardware cost and reliability implications. The actual power that can be transferred depends on the SOC, the actual load on the full battery and the capacity deficit of the modules to be assisted.

The basic design of the on-board charger consists of three steps:

- constant current (power) until gassing voltage is reached
- constant (gassing) voltage with tapering current
- constant current, e.g., limited by the recombination reaction.

The supervisory system should provide both correction of the gassing voltage for the actual battery temperature and a signal upon meeting the full-charge specification value. Other control parameters can be incorporated directly in the charger.

For rapid charge the situation is different. The charger can be allocated neither to a vehicle nor to a battery. Thus, the charger will be used by different vehicles and battery types, and all the necessary information must be transferred. This appears to be more difficult than is in fact the case. For a lead/acid battery only the power-limiting maximum voltage must be provided. This parameter should be continuously updated to account for changes in the internal resistance. A revision of the algorithm according to the results, from the US Advanced Battery Consortium (USABC) programme on rapid charging will be necessary.

The long-term memory must be structured according to the importance of the data. The system must be told which information can be eliminated, accumulated or concentrated into averages in order to provide space for a full life-span with a limited size. In the model discussed here, the record of the first year will have the same size as, for example, that of the previous month. It will cover detailed records of the deepest discharge, the greatest charge, the Ah turnover, the number of standard and deep discharges, as well as statistical data on the depth-of-discharge, minimum cell voltages, and relative duration of different temperature values. All this information may be down-loaded to a PC or equivalent laptop computer that is provided with a reading code and a graphic evaluation program.

The intention is to provide the end-users with only the data that they require, i.e.,

- a miles-to-go indicator = fuel gauge
- an economy symbol = kWh/km or kWh/mile
- a warning lamp or other symbol that shows the battery to be in a dangerous or faulty condition = maintenance required.

Only service stations should be able to do the down-loading. With the subsequent data and graphs, an engineer will have a powerful tool to locate the fault and initiate corrective action for:

- conditioning or repair of modules
- replacement of faulty components
- replacement of full battery.

Also, it will be possible to make a decision on whether a production fault, abuse or normal deterioration has caused the failure.

The situation is more difficult when it comes to thermal management. This will be necessary, but it is not clear which of the methods under discussion, namely:

- water jackets between the modules
- general fan cooling/heating
- cooling with water pipes inside the cells

will be realized by the battery industry. In any case, the control is different as will be the supervision. Developers of battery monitoring systems look forward to a decision on thermal management method and will allow for its incorporation.

All input parameters for the above model are available from the results of the test program as suggested by the USABC. Further work is required to implement the model into a microprocessor, and to verify its validity by mounting it on a real battery and making a comparison of the direct and long-term output with the reality.