STATUS AND RESULTS OF ANL LIFE EVALUATION OF VALVE-REGULATED LEAD-ACID LOAD-LEVELING BATTERIES

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Argonne National Laboratory has developed and initiated a three-year life evaluation of both gelled-electrolyte and absorbed-electrolyte valve-regulated lead-acid (VRLA) battery technologies for deep-discharge applications. The objectives are (1) to use accelerated testing techniques to obtain data within 6 months on VRLA battery life expectancy, and (2) to determine VRLA battery life within a 2-3 year time period under temperature and depth-of-discharge (DOD) conditions that simulate those encountered in a utility load-leveling environment. The accelerated life test uses a matrix of operating conditions designed to increase the stress of known failure modes, thereby accelerating the mechanisms that cause battery end-of-life. The primary failure mode is expected to be active material changes caused by charge-discharge cycling (i.e., microstructural and morphological changes, sulfation, mass isolation, loss of surface area, loss of porosity, etc.). The test matrix consists of four sets of operating conditions (80% and 100% DOD and 30°C and 50°C temperature), which include the stress factors to accelerate failure.

There are two types of VRLA batteries being tested: (1) 12-V modules manufactured by Johnson Controls, Inc. (JCI), with a gelled electrolyte; and (2) 6-V modules manufactured by GNB, Inc., with an absorbed electrolyte. Each module undergoes acceptance, baseline performance, and life testing. After failure, a teardown examination/analysis is conducted to identify the failure mode. End-of-life is defined as the inability to furnish 80% and 64% of rated capacity for the 100% and 80% DOD tests, respectively.

The GNB modules were received at ANL in November 1988, and four were installed in the test system for evaluation. Those modules have successfully completed their acceptance and baseline performance tests. Two of the modules were placed on life test at 30°C, and a third is undergoing 100% DOD accelerated life testing at 50°C. The fourth module is on float charge and awaiting 80% DOD life testing at 50°C while the high-temperature charge data are being examined.

The JCI modules were received in February 1989, and testing was initiated on four of the modules. Acceptance and baseline performance tests were completed in April. The four JCI modules were placed on the same test regime as the GNB modules.

Constant-current/constant-voltage (CI/CV) charging was initially recommended by both manufacturers (CV = 2.35 V/cell with -5 mV/°C temperature compensation at >25°C). The time needed to achieve the desired 105% charge return from 100% DOD was excessive for both the GNB (~18 h) and JCI (~26 h) modules. These results were discussed with each manufacturer, and GNB requested that their charge procedure be changed to a CI/CV/CI method to ensure an 8-h daily charge return of 105%. JCI was satisfied with an 8-h charge return of ~103% and recommended the continued use of CI/CV charges with a CV of 2.35 V/cell.

Results of the acceptance and baseline tests (Table 1) show that the percentage weight variation among the GNB modules was a factor of four greater than that for the JCI modules. However, the capacities of the GNB modules matched to within 2% and

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were about 17% higher than their specified ratings at both the 8-h and 3-h discharge rate. A 23% decline in module capacity resulted with increased discharge rate (130 ⇉ 272 A); this decline is in close agreement with that specified by GNB.

The average capacity of the JCI modules was within 1% of the manufacturer ratings at both the 8-h and 3-h discharge rates. Their capacity decreased by only 12% as the discharge rate was increased from 135 to 318 A. However, individual module capacities at the 8-h rate varied (minimum to maximum) by ~7%. At the 3-h rate, the variation increased to ~12%. The module-to-module capacity variations were discussed with the manufacturer, who recommended that the weakest module be given a special 24-h charge with a CV level of 2.45 V. Following the special charge, the capacity of the weakest module increased by ~9%, and the variation between modules decreased to 7.4%. The manufacturer did not deem a 7% variation in module capacities to be excessive.

Life cycles were performed with discharges at a 3-h rate to a voltage limit and daily charges limited to 8 h or 105% return. A 3-h discharge and 8-h charge were selected to maximize the total Ah per day of life testing. Battery resistance ($R_B = \Delta V/\Delta I$) and IR-free voltage vs. DOD will be periodically derived from pulse discharge test data. Variations in these parameters with life will be studied for possible early identification of battery failure.

Two GNB modules (EG03LL03 and EG03LL04) and two JCI modules (EJ90LL01 and EJ90LL02) were placed on life test at 30°C in May 1989. An 80% DOD discharge cut-off voltage (DCOV) of 5.64 V and 11.54 V is being used for the GNB and JCI modules, respectively. The capacity history of these modules is given in Fig. 1. The GNB module has retained ~100% of its initial 770-Ah (4583-Wh) capacity after accumulating a total of 158 test cycles. The JCI module retains ~101% of its initial 802 Ah (9705 Wh) after accruing 138 cycles. The GNB and JCI modules being cycled to 100% DOD at 30°C use a DCOV of 5.25 V and 10.5 V, respectively. The GNB module has retained ~95% of its initial 1009-Ah (5885-Wh) capacity after accruing 125 cycles, and the JCI module has increased its capacity by ~2% to 960 Ah (11.34 kWh) after 115 cycles. Equalization charges (24 h or 110% return) are being performed about every 25 cycles. The GNB modules show a slight drop in capacity on the first discharge after an equalization charge. This is the result of a decline in their operating temperature caused by the long charge period. Subsequent discharges show that their capacity has improved with equalization charging. In comparison, the equalization charges have had no noticeable effect on the capacity of the JCI modules to this point in their life.

Accelerated life testing at 50°C and 100% DOD was initiated on a third GNB and JCI module. The capacity history of these modules is given in Fig. 2. Both modules had an initial 30°C capacity of ~1000 Ah prior to high temperature operation. With the start of 50°C operation, the capacity of the GNB module increased by ~13% and the JCI module by only ~3%. These increases in capacity are less than those of flooded-electrolyte types of lead-acid batteries (>20%) for the same temperature rise (20°C). However, the capacity of both VRLA modules started to rapidly decline with cycling at a rate of >1%/cycle. The initial CI charge rate was reduced from 300 to 150 A, but this had no effect on the rate of capacity loss. The charge return was then increased from 105% to 110%, which stopped the rapid decline in capacity on both modules. Continued cycling with 110% charge return at 50°C recovered some of the lost capacity, but not all.

Returning to an operating temperature of 30°C and cycling with a charge return of 110% has increased the capacity of both modules to almost its initial level. The initial results indicate that both battery types need a higher charge return (≥110%) at 50°C to maintain reproducible performance. Hence, the 8-h daily charge time limit will be removed, and the needed overcharge at 40 and 50°C will be identified for both 80% and 100% DOD operation. The results will be reviewed with each manufacturer, and a charge regime will be defined for 50°C cycling.

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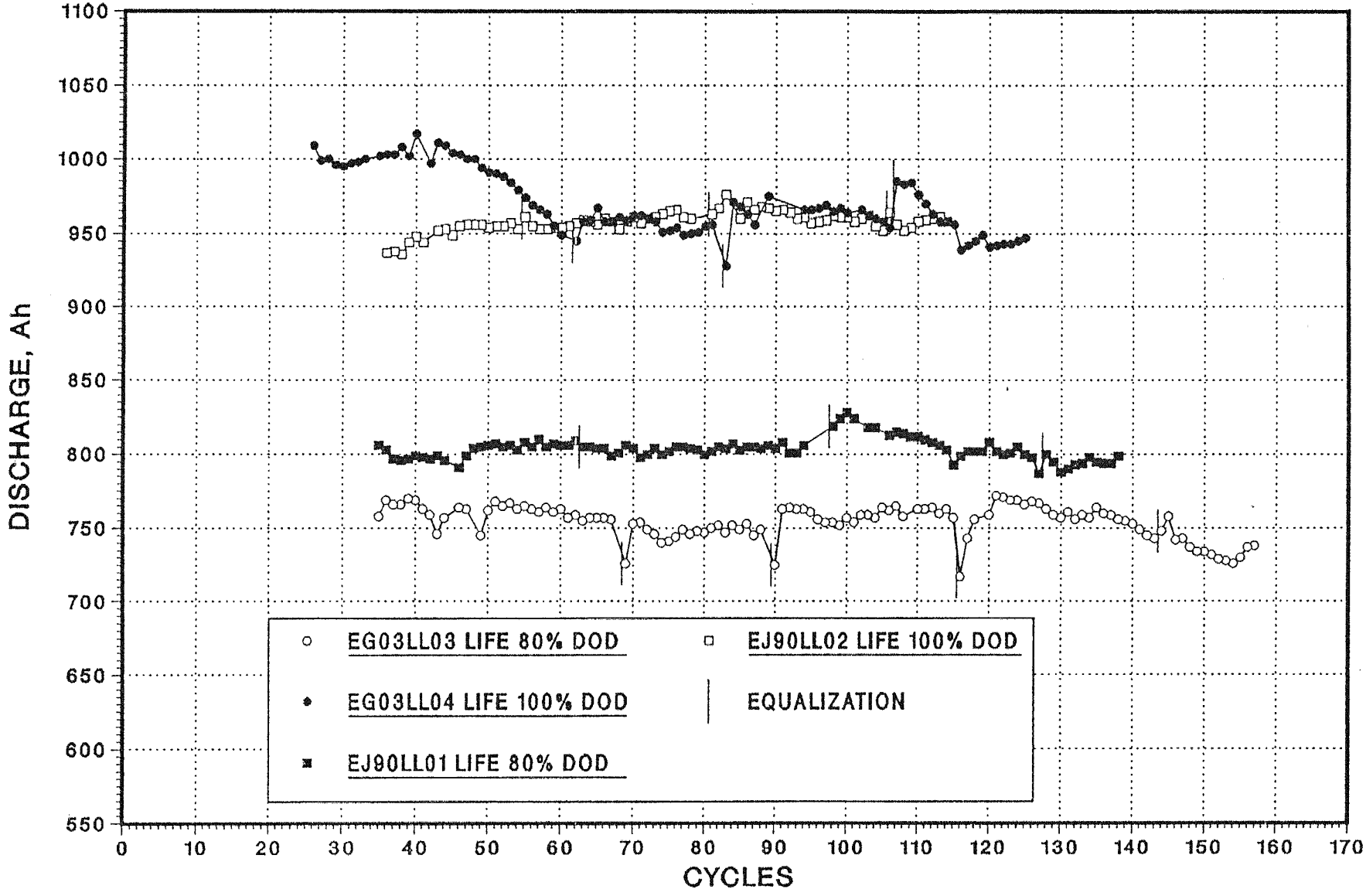
PRELIMINARY RESULTS OF VRLA BATTERY ACCEPTANCE AND BASELINE PERFORMANCE TESTS

Manufacturer	GNB	JCI
Model Number	85A25	15-LL12-70
Average Weight, kg	248.4	517.5
Variation	1.6%	0.4%
Capacity To 1.75 V/cell @ 25°C		
Mfr. 8-h Rating (Ah)	1040	1080
Average (Ah/Wh)	1234/7297	1077/12863
@ CI Rate (A)	130	135
Variation	1.9%	7.0%
Mfr. 3-h Rating (Ah)	816	954
Average (Ah/Wh)	947/5510	964/11450
@ CI Rate (A)	272	318
Variation	1.0%	7.4%
Volts @ 80% DOD (V)	5.644	11.451
Variation	0.3%	0.4%

CAPACITY HISTORY OF VRLA MODULES AT 30°C



CAPACITY HISTORY OF VRLA MODULES AT 50C