Electric-Bus Fast Charging at the Santa Barbara MTD

Dale Lemon [a], Paul Griffith [a], Zail Coffman [a], Gary Gleason [b]

[a] *Santa Barbara Electric Transportation Institute, P.O. Box 957, Santa Barbara, CA 93102, info@sbeti.com*
[b] *Santa Barbara Metropolitan Transit District, 550 East Cota Street, Santa Barbara, CA 93103, Gleason@sbmtd.gov*

ABSTRACT

The objectives of the Fast-Charging project are to evaluate the practicality of charging battery strings at high rates, to configure an electric transit-bus with a battery system and battery-monitoring system suitable for use in a rapid-recharge environment, to install a high-rate charger (Norvik 300-kW) at a location appropriate for opportunity charging, and to operate the bus and charging system for a period of approximately one year in regular transit service. Issues under evaluation include the extent to which the utility of electric buses can be increased as a result of opportunity charging at rapid-recharge rates, and the influence that rapid charging has on battery health and longevity. The impacts that the on-peak, rapid charging of battery-electric buses has on the utility grid are also under investigation.

Demonstration of Utility of 300-kW Charger Applied to Battery Strings

The initial effort involved the selection of a battery product suitable for rapid-recharge application, and evaluation of the behavior and performance of a long battery string under rapid recharge conditions in a bench-test environment. Several Valve-Regulated Lead-Acid (VRLA) batteries were studied in terms of their potential integration (fit and function) into a 26-foot electric bus, and high-rate charging of short-string arrangements was performed. The variable power-draw and regenerative braking profile attendant to the operation of the subject bus on a typical transit route was applied to the cycling regimen of the candidate batteries.

Bench-top Testing – 12-V Configuration

Laboratory testing of several battery candidates in short-string (12-V) configurations was performed using Norvik's 24-kW (600-A) charger-discharger. All process parameters including voltage, current, charge, module temperature, and ambient temperature were recorded.

The batteries were subjected to a one-hour duty cycle typical of a 26-foot electric bus in transit service, followed by a brief recharge at high current. Among the products tested, Optima Deep-Cycle Yellow-Top (D750S) batteries demonstrated the best performance, and appeared to be the most suitable for this application in terms of charge acceptance and cycling characteristics. However, a 150-Ah product that could meet the fast-charge criteria (6 minutes at 300 kW) and be configured as a single-string 50-kWh, 324-V system was not available. In order to satisfy project objectives, a unique method of connecting three 52-Ah strings into a 156-Ah (50-kWh) set was employed.

More than 250 charge-discharge cycles were performed (60-minute discharge followed by a 6-minute recharge). These tests demonstrated that it is possible to use opportunity charging without suffering any permanent loss of capacity, provided that the battery set periodically receives a full charge.

During the testing, more than 60 consecutive partial recharge cycles were performed before delivering a full charge. In practical terms, this means that the bus could be operated "around-the-clock" without interruption, provided that it received a 6-minute recharge once an hour.

Bench-top Testing – 324-V String

The purpose of this testing was to examine the behavior of the selected battery product in a long-string arrangement under fast-charge conditions. The battery system was assembled in a configuration necessary for integration into the bus.

Five to six cycles consisting of a one-hour discharge followed by a six-minute recharge were performed over 8-hour periods. Even with a 10°C temperature difference between modules, the pack was safely recharged and ready for the next run.

More than 140 cycles were successfully performed on the 324-V string during this phase of the project without the need to replace any of the modules. No loss of capacity was observed at the conclusion of testing, and the modules in the pack remained fully balanced, exhibiting a voltage difference of only 0.1V during discharge.

Bus Modification

Substantial modification to the 26-foot electric bus was undertaken in order to enable recharging at 600 A. An important focus of the project is the identification of

0-7803-4967-9/99/$10.00

recharge schedules that may be optimal for battery longevity and that are also compliant with operational constraints imposed by transit applications. Recharge frequency and depth-of-discharge range are among those parameters that are expected to be influenced by route scheduling requirements.

The original 128-kWh Ni-Cd battery ($63,000) was replaced with the 50-kWh VRLA system ($7,290), whose significant reduction in range was considered tolerable in light of such cost savings and the nature of the fast-charge project. Additionally, while the power output of the VRLA system is nearly 40% lower than that of the original battery, the resultant 276-kW output (at 20% state of charge) substantially exceeds the 68-kW peak-power requirement of the drivetrain motor.

As previously stated, it is expected that the electric bus as configured for rapid charge will be able to perform virtually unlimited daily service provided that it periodically receives a brief recharge. The 20 kWh consumed during a nominal 15-mile circuit can be replenished during 5 minutes of recharge at a 250-kW average charge rate.

The relatively frequent cycling of the battery in an opportunity-charging scenario also leads to shallower depths of discharge, thereby extending cycle life and increasing total energy throughput for a given battery product over those levels experienced with more extreme discharge depths.

Bus Operations

Initial operations of the modified bus were curtailed when it was realized that the initially fitted battery was experiencing an abnormal rate of module failures. These failures were most likely due to the use of modules from different manufacturing lots and failure of maintenance personnel to adequately control the battery-conditioning process resulting in the mismatch of module capacities within the battery. The replacement battery was composed of modules from a single manufacturing lot, and battery-conditioning cycles were completed by the manufacturer. Significant delays in the program were occasioned by malfunctions in on-board systems not related to the fast-charging investigation.

Figure 1 depicts a high-rate charge episode in which 80 Ah (34 kWh) were transferred to the battery in twenty minutes, 50 Ah of which were transferred in the first six minutes.

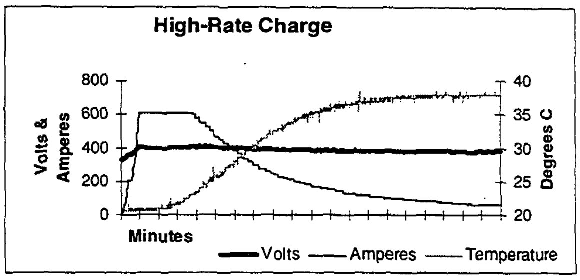

Figure 1. High-rate Charge Episode

Operations with the new battery were initiated with rapid-charging current limited to 300 A for the first five operational cycles. Charging current was then increased after every three or four operational cycles in 50-A steps. Two to four cycles per weekday have been accomplished, and equalization charging at 2-3 A is conducted on a nightly basis. As of early-December 1998, over 50 cycles have been accumulated in transit service. This service has been conducted at a deeper level of discharge than originally anticipated, but actual service conditions are often more rigorous than the best high-fidelity simulations. Energy-consumption variance due to factors such as weather, traffic congestion, passenger loads, and driver energy-management skills must be accommodated. All-day tests involving hourly cycles of approximately 35% of battery-capacity discharge (20 kWh, 54 Ah) followed by six-minute recharges at the highest current rate the battery will accept are being conducted in order to characterize the system under more realistic conditions.

Utility Impact Assessment

The impacts of high-power charging and its usage patterns on the power grid are also under investigation. Southern California Edison is monitoring harmonic and power quality effects at both the charger site and at the local substation. Preliminary indications are that fast-charge impact to the utility grid is negligible.

Acknowledgments

A number of organizations and agencies have contributed to these projects. Principal among them are the Advanced Lead-Acid Battery Consortium, the Federal Transit Administration, the Santa Barbara MTD, the Santa Barbara APCD, the Electric Power Research Institute, and Southern California Edison.