Selection of New VRLA Batteries and Adaptations to Battery Management for Series Hybrid Busses of Luxembourg City

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Abstract – The city of Luxemburg operated three Series Hybrid buses in the European Thermie demonstration project TR153/94. After several years of operation the battery packs needed replacement. Vito offered the city of Luxemburg technical support. New VRLA batteries had to be introduced in the battery packs applied in the series hybrid busses of Luxembourg city. Besides the search for the possible supplier, methodology of testing and criteria applied to perform an optimum selection of the batteries out of a bulk of delivered batteries had to be obtained. Besides improvements on thermal (cooling and heating) and electrical aspects, fine-tuning was required on the battery management system. Calibration was not only oriented towards the new batteries but also towards durability and lifetime. Measurements that captured the behavior of the new battery pack were performed during the different operating modes of the vehicle.

Index Terms – Valve Regulated Lead Acid Battery, Battery Management System, State Of Charge.

I. INTRODUCTION

Three hybrid buses have been developed and demonstrated in the city of Luxembourg. With these so-called Series-Hybrid busses - the propulsion is always electrical - an alternative was given to solve and overcome traffic and pollution problems. Pure electric traction mode enables emission-free operation in city centers, while hybrid traction mode extends the range by overcoming the capacity limitations of batteries. Additional benefits besides improved fuel economy were the obtained comfort for the driver and the passengers (acceleration, hill climbing, noise reduction, operating the bus,…).

These busses were the result of co-operation between the vehicle manufacturer Scania - DAB–Silkeborg, integrator of hybrid subsystems Delphi Automotive Systems Luxembourg, end-user Autobus de la Ville de Luxembourg (AVL), Agence de L’énergie, and CITELEC.

The vehicle is based on a standard so-called MidiCityBus, a full low-floor design, obtained through a special body structure, and the integration of all hybrid related subsystems (propulsion system, battery packs, APU, pumps, DC/DC converters,…) in a cradle at the rear of the bus. The body is made of aluminum filled with wood to obtain low weight. To kneel the bus for even easier access (wheel chair ramps are provided) or to pass a low ground clearance, the suspension can be varied in height.

General specifications of the vehicle:

- length: 9.50 m
- width: 2.50 m
- height: 3.01 m
- wheelbase: 6.35 m
- max. vehicle weight: 14000 kg
- capacity: 15 seated + 22 standees
- maximum speed: 55 km/h (*)
- peak power: 160 kW (*)
- acceleration (0…30 km/h): 6s at 1,2m/s² (*)
- acceleration (0…50 km/h): 14s at 1,2m/s²(*)
- gradability (hill start): 15 %
- gradability (at 20 km/h): 12 %
- pure electrical range: 35 km
- hybrid electrical range 300 km

(*) electronically limited by calibration

The vehicle is driven by two AC induction motors (105 kW peak) with a common combining gear system. Each motor has its vector-controller IGBT inverter (120 kW peak), which allows regenerative braking. The overall propulsion peak power is 200 kW. The average power demand of the vehicle is 35 kW. While the Auxiliary Power Unit (APU) delivers the average power, batteries can deliver up to peak power demand in electric mode.

Originally, all vehicles were fitted with APU’s consisting of an "Onan" generator driven by a 2 liter gasoline engine with catalytic converter instead of 6 liter diesel engine. One vehicle however has been converted for the use of diesel fuel, with a new APU consisting of a "Panda" generator driven by a 1.9 liter TD Volkswagen diesel engine. The...
APU engine runs at constant speed, at optimized operating point.

A central vehicle control unit (Propulsion System Controller – PSC) performs overall control functions of the vehicle, communicating with controllers from the other subsystems and ensuring proper vehicle operation.

Each bus consists of two battery packs, each of a string of 26 VRLA batteries, which are switched in parallel. Each battery pack has its own Battery Pack Management (BPM) with integrated safety control (Automatic Disconnect Circuit – ADC). The nominal system voltage is 312 V with battery energy of 33 kWh.

Recharging of the battery packs can be accomplished in the following ways:

- Internal charging through regenerative braking and/or activation of the APU
- External charging through the usage of a conventional 15 kW overnight charger at the bus depot or the fast charge station located at the Luxembourg railway station. This station consists of a large buffer of batteries, recharged from the grid at low power (10 kW), and allowing a fast charge in 12 minutes eliminating heavy and expensive electric supply connection and peak power consumption.

The relative simple request to replace the current batteries from AVL towards Vito resulted in an intensive work. Not only was there the search for the best possible and available batteries, also engineering work was executed for optimal construction of the battery packs. Aspects related to the selection of the batteries for the battery strings (introduction of so-called Q-factors), design and engineering of the battery packs (mechanical, thermal, electrical), operational factors (charge, discharge, equalization, temperature), the way the vehicle is used (acceleration, regenerative braking, operation of APU), and external factors (overnight charger, fast charger) were taken into consideration.

The results are shown in fig. 3.

II. SELECTION AND INTEGRATION

To limit complexity and cost of the project, no deviation from the current battery technology was introduced. This means that the new batteries had to belong to the VRLA technology. This battery technology was also one of the cornerstone for the definition and approach of hybrid concept for these busses. Measurements and reports from the original project confirmed the correctness of this approach. Important conditions were that the new batteries had to be suited for this application and available.

The following steps were taken:

- Selection of the VRLA battery and supplier
- Disassembly of the previous battery packs
- Integration of the new batteries
- SW adaptations of the Battery Pack Management System

The specifications of the original VRLA battery from Delphi Automotive Systems were:

- Voltage: 12V
- Specific Power: 253W/kg@20%SOC/30sec
- Specific Energy: 35.3Wh/kg@C/3disch. rate
- Weight: 18.8 kg
- Dimensions: L388mm/W116mm/H175mm

VRLA battery suppliers were contacted (UBC Batteries, CSB Batteries, Sunrisco Sunpower Batteries, Yuasa, Panasonic, Hawker, …) and several criteria were used to determine the preferred battery and supplier (types of batteries, availability, references, technical specifications, offered technical advice, support and guidelines, terms of delivery, guarantee period, prices…).

Hawker Invensys was selected as preferred supplier after fulfilling the above criteria. The selected battery was the Genesis G70EP 70 Ah. Samples were immediately available.

A bulk of 62 batteries, all manufactured during the same period, were delivered. Important was the introduction of the so-called Q-factors to allow elimination of the batteries which deviates the most.

Each battery was submitted towards a particular test cycle, based on real-time measurements during the "Cessange Test" consisting of climbing a 14% slope and descent with regenerative braking in the suburb of Cessange. This test drive is 15 times simulated with Digatron BTS600 in one test cycle. This hill in Luxembourg City has become notorious among hybrid bus manufacturers.

The results are shown in fig. 3.

Observe that initially the batteries were fully charged, and at high SOC (first 3 cycles) regenerative braking is not optimal. At the end of the test cycle the batteries were charged again.
Based on the test results, it was possible to deduce a number of Q-factors. These relative factors provide an indication of deviation from the 'average' battery. A value of 100 is associated with the highest deviation.

Combining the different Q-factors, it was possible to redraw the batteries which were deviating the most. Remarkable was the presence of a high deviation in weight (up to 3%), not only with the new but also with the previous set of batteries. This is likely due to the control of amount of lead during manufacturing.

III. OPTIMALIZATION IN USAGE OF BATTERY PACKS

With the introduction of new batteries, along with the increase of capacity (10%), an significant increase of weight was introduced (20%). Given the location of the battery packs and type of application, this was an acceptable trade-off. The volume of the battery packs did not change significantly (same frame).

Improvements on the thermal management was accomplished by moving the individual electrical heating strips from the side towards the bottom of each battery, introduction of isolation between battery and frame, and the more refined airflow for the cooling system.

An additional benefit was the increase of the pure electrical range from 35 to 40 km (modification of original general specifications of the vehicle as described in section I).

Initial approach of “endless floating” after equalisation of the batteries was introduced and tested but later, to ensure correct initialisation of SOC during each daily overnight charging phase, taken out.

IV. OBTAINED RESULTS

Measurements of individual battery voltages (26) in battery packs were taken with the vehicle at 'idle' at different SOC's. At SOC of 30%, all voltages are still above 12.2 V.

Measurements of individual battery voltages in battery pack driving the vehicle in the suburb of Cessange with the APU activated, shows all voltages above 11V. This confirms the appliance of the targeted strategy.
V. CONCLUSIONS

The results of this project shows:

- significant differences within one delivered bulk of batteries
- improvements towards mechanical, thermal, and electrical aspects
- increased expectations towards durability and lifetime for the battery packs
- extended range in pure electrical drive mode
- robustness of the current vehicle design and architecture
- solid Luxbus concept

REFERENCES


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