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First Results from Field Testing of Fast Charged Hybrid Buses in Umea, Sweden

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Abstract

Two existing hybrid diesel electric buses were recently converted to be the world's first ultra-fast chargeable "Plug-In" hybrid buses in Umeå, Sweden. By placing an automatic fast charger at one end of a bus route, these buses can run entirely in electric-only mode. They have the extra security of a backup biodiesel generator yet use much smaller batteries than an all-electric bus. The fast charger fills the batteries each time a driver reaches the end of a route. The first results from testing these buses are presented here. We demonstrate that 100% all-electric operation is achievable with this approach for the 14 km circular airport route in Umeå, Sweden.

Keywords: bus, fast charge, public transport, HEV (hybrid electric vehicle), demonstration

1 Introduction

The City of Umeå, working together with Hybricon, e-Traction, and Opbrid SL is currently testing 2 full-size 12 meter urban buses that have been converted to fast charged hybrids. The two Volvo 7700 city buses were previously converted to battery-dominant serial hybrids using e-Traction wheel motors. Starting in January 2011, the first bus was converted to fast charging and delivered to Umeå in early March for preliminary Winter testing. The second bus arrived in June, along with the fast charger. Testing commenced in July and is ongoing. This paper presents the first results from this testing.

1.1 Background

Electrification of public transport is a high priority in Umeå City, to reduce emissions of pollution and CO2, reduce noise, reduce costs, and improve public health. Umeå is a relatively small university city, with access to very clean electricity from hydro and wind. It currently uses diesel and ethanol buses for a popular public transport system. An electric tram was considered too expensive, and the city did not wish to install overhead wires for a trolleybus system for cost, aesthetic and maintenance reasons. Current hybrid buses appeared to be expensive for a relatively small gain of 20-30% fuel efficiency, and natural gas buses would still emit large amounts of CO2 and noise. All-electric battery buses were considered not to have the range required for 18 hours of operation. The team of Hybricon, e-Traction and Opbrid successfully presented a fast-charged hybrid solution that was very attractive to the city. It combines the all-electric running of a battery bus with the reliability of a diesel hybrid bus, all without any overhead wires or large infrastructure costs [1]. This was also achieved without any reduction in the interior space of the bus. The result is reliable, practical, electric bus transport that is quiet, and due to Hybricon's knowledge, adapted to the very cold climate in northern Sweden. The bus was named the “Arctic Whisper” because of its extremely quiet operation.

2 System Description

e-Traction Volvo 7700 Fast Charged Hybrid Bus

During an earlier project in Apeldoorn, Holland, several Volvo 7700 diesel buses were converted to serial hybrids to demonstrate the efficiency of the e-Traction electric wheel motors. The original diesel driveline was removed, and replaced with two e-Traction SM/500-3[2] wheel motors mounted on a rear axle construction, a 50kWh Valence LFE battery pack, and a 70kW diesel generator.
To convert to fast charging, the battery pack size was increased to 100kWh, and an Opbrid Busbaar[3] fast charging system was installed. This consists of two pneumatically operated Schunk pantographs on the bus, and a roadside charging station based on the “Moveable Conductor Rail” system by Furrer+Frey with a charger provided by Schaefer Power. The first bus was converted to fast charging in only 6 weeks.

Photo of Bus and Charging Station.

Without fast charging, the Arctic Whisper has an all-electric runtime of about 2-3 hours with the 100kW batteries before the diesel generator needs to turn on.

Charging Infrastructure
A single 100kW, 400V DC charger has been installed, along with the Opbrid Busbaar overhead charging station. The bus pulls up next to the station, and a 12 meter section of Furrer+Frey “Conductor Rail” swings over the bus. The overhead rail consists of two 6 meter sections of Conductor Rail separated by an insulator, one for positive and the other for negative isolated DC. The two pantographs on the bus raise up to contact the rail to start the charging. After several minutes of charging, the pantographs lower, and the bus continues.

Photo of Charging Station

3 Operation

Operation: The Umea project consists of two steps: The first uses the best available batteries that could be delivered during in the beginning of 2011, Valence LFE batteries[4]. The second, to be performed this coming winter, will use 45kWh of nLTO batteries from AltairNano[5] instead of the 100kWh Valence battery pack.

Operation with 100kWh Valence LFP Batteries:

The Valence 100kWh pack is slow-charged at night with a 25 kW charger to fill the packs and also to balance the batteries. The bus will be used for airport traffic on a 14 km route and therefore were tested for this on a similar route of 14.5 km. The bus runs for 30 minutes, with a 10 minute break to wait for passengers at the airport. With 10 minutes charging, it is possible to add 14 kWh of power. With this added power, the bus can run all day using electricity under typical conditions.

The State of Charge (SOC), drops gradually during the day, but there is sufficient extra battery capacity so that the diesel generator never turns on under normal loads, as shown in Fig 1:

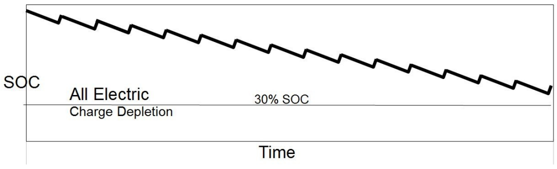

Fig 1: SOC, Normal Operation

If there are extra energy demands, for example heavy heating/air-conditioning needs or greater than average passenger loads, then the pack gradually discharges towards a lower limit of 30% SOC.

If the SOC ever drops below 30%, the on-board diesel generator automatically starts up to maintain the SOC at 30% until the next fast charge opportunity.

The result under these conditions would be a SOC charge pattern as shown in Fig 2.

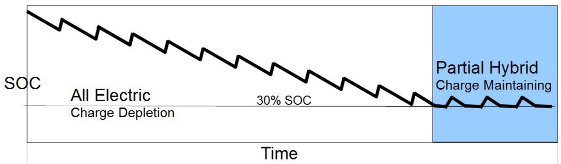

Figure 2: SOC Pattern under heavier than average loads

This illustrates how the backup hybrid diesel generator can assist under more difficult situations such as very cold or very hot days or heavy passenger loads. The backup diesel assures that the bus never stops due to a lack of electricity.

Testing Methodology:

During the test period, the buses were tested for use as airport transportation on a 14.5 km circular route that takes 30 minutes and allows a 10 minute stop/charging time. This test was intended to closely simulate the Umea airport route as shown in figure 3.

Fig 3: Umeå air port route

Testing was performed by driving the route four times, stopping at each bus stop for a typical stop time, and then stopping at the charging station for 10 minutes. While no passengers were carried during the tests, the effects of the added weight can be calculated. The test route was slightly longer than the actual airport route at 14.5 km in order to stop at the charger which is still in a test location.

Test Results

The route takes about 30 minutes, and the bus runs every 40 minutes. This allows 10 minutes of charging for every 30 minutes of running. The route is 14.5 km in distance.

Four cycles of the test route with fast charging were run. Figure 4 shows the SOC and the battery current. The SOC is the blue line. The SOC decreases about 2,5 kWh each cycle. Since there are 70kWh of reserve battery power, this gives enough reserve for 28 round trips before the diesel generator would have to turn on.

Since the airport bus runs every 40 minutes from 5 am to 10 pm, there are 25 runs a day. This shows that there is just enough reserve capacity to run the bus all day without the diesel generator turning on. This indicates that the battery is sized correctly for this route and fast charging regimen.

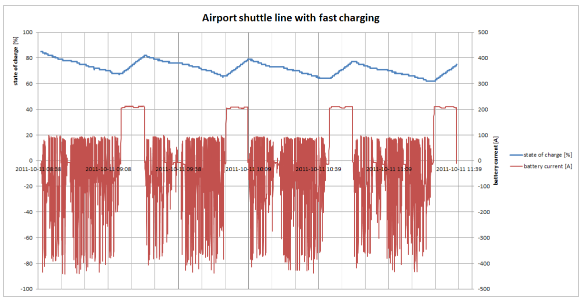

Figure 4: Collected data showing SOC and battery current for four 13 km round trips with fast charging.

Figure 4 also shows the battery current during the runs in red. The charging current of 208 Amps can be easily seen as the four square positive current spikes. The shorter spikes are both acceleration (negative spikes) and regenerative braking (positive spikes).

The charging rate of the 100kW battery pack is 1C (100kW), approximately the maximum for these Valence Lithium Iron Phosphate batteries. However, this charging rate is spread out over the day, in 10 minute pulses every 40 minutes, which is somewhat easier on the batteries than a single long fast charge at mid-day.

One concern was that the battery temperature would rise to unacceptable levels, as there is no battery active cooling in the Arctic Whisper. Fortunately, the ambient temperature is relatively low in Umeå and thus this has not been a problem. In other climates, this should be carefully examined.

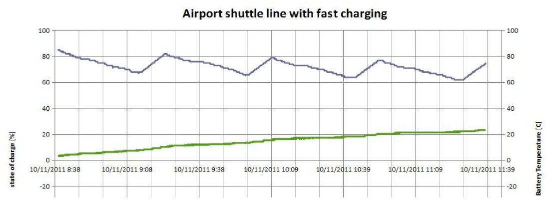

Figure 5: Battery temperature vs SOC

Conversely, very low battery temperatures are problematic for LFE batteries. This will be solved by parking the buses inside at night. During the day, the heat generated internally by the batteries during usage is expected to keep them warm enough. More testing during the coming winter will be done to verify this. Also, the planned switch to LTO batteries will help, as this chemistry tolerates temperatures down to -30C.

Figure 6 shows the distance traveled over the four runs vs the SOC. This shows that after 58 km, the SOC has only dropped by 10%. Without fast charging, the batteries would be exhausted, and the bus would run under diesel power as a normal hybrid. With fast charging, the bus can continue running electrically all day, without using any diesel.

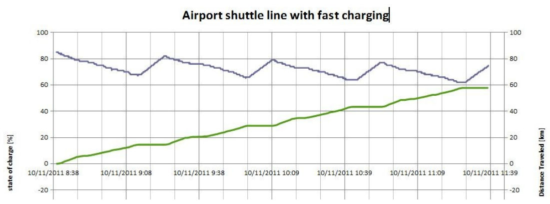

Fig 6. Distance traveled vs SOC

Finally, figure 7 shows the energy expended over the four 14.5 km runs.

As expected, the graph of energy used is very similar to the distance traveled. In this case, 64kWh were expended to travel the 59km, for an average energy use of 1.10 kWh/km. This very good energy use per km is a result of the very efficient E-Traction wheel motors and regenerative braking.

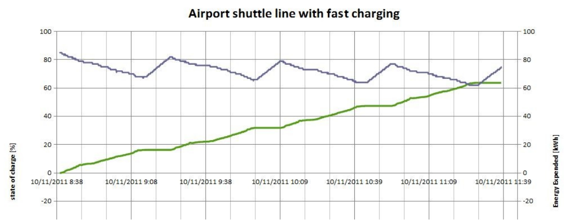

Fig 7. Energy expenditure, excluding charging.

Extrapolating this to a normal day of 25 runs per day gives the following daily numbers:

Distance travelled	362 km
Electricity consumption	400 kWh
Diesel consumption	0 l
Night time charge	70 kWh
Daytime charge	330 kWh

A 10 minute charge at 100kW adds about 14kWh, for an available daytime charge capacity of 350kWh for 25 runs.

These numbers are somewhat low, as these tests were carried out on a cool day with no passengers. With typical additional energy demands of heating/AC, passengers and luggage, we expect the electricity consumption to increase to meet the available charge capacity (daytime + nighttime) of 420kWh. On some days, a small amount of diesel may be burned by the backup generator as in Fig. 2. Also, during cold winter days, a diesel heater will be used for heating.

For comparison, To achieve these results without daytime fast charging, a battery of 450kWh would be required, weighing almost 5000 kg. The 100kWh Valance LFE battery pack on the Arctic Whisper weighs about 1200 kg which is a considerable weight savings.

The planned 45kWh LTO battery for the next phase will weigh even less, at about 600-700 kg. The AltairNano LTO batteries can be charged at over 240kW, with shorter charge times, longer life, and better cold weather performance.

Operational Observations

The initial tests went very smoothly. The driver encountered no problems with docking under the Busbaar charging station. No problems were encountered during driving.

The Arctic Whisper is very smooth and quiet, due to the E-Traction wheel motors. There is no gear or motor noise, and the bus is very easy to drive.

Conclusions:

Initial testing of 100kW fast charging of the hybrid bus 'Arctic Whisper' for use in a 14 km airport circular route that runs every 40 minutes showed that it is possible to run the route completely electrically under normal conditions. This assumes 30 minutes running and 10 minutes of charging. The backup hybrid diesel generator is available when more power is needed, such as in cold weather or higher than average passenger load, or when shorter charging times are desired. While a 10 minute charge time is adequate for this route, a shorter charging time may be desirable for other routes in Umea.

Future plans include using different battery chemistries capable of faster charging and higher charging rates of over 200kW as well as extending this architecture to 18 meter articulated buses.

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