Improving storage efficiency in electric buses

by Mike Rycroft, features editor

The development of battery powered electric vehicles has been focused mainly on private passenger vehicles, while public transport seems to have been neglected. A reassessment of the journeys public transport vehicles make has led to the development of battery powered buses and bus rapid transit (BRT) systems. Several trial systems are in successful operation at various locations around the world, and there is a growing interest in this sector of the electric vehicle (EV) market.

Electric powered public mass transport has been in use for many years in the form of trams, trolley buses, subway trains and other forms of transport, and the components and controls for such vehicles are well developed. Tram-type vehicles are confined to routes which allow permanent connection to the supply of electricity, mainly by overhead wires, which have all the associated problems of safety, breakage, and power failures, as well as adverse affects of weather, besides being unsightly. Trams, which generally run on rails, are confined to fixed routes on main roads, while liquid fuel buses are commonly used in all cities for mass transportation in addition to fixed route vehicles, over relatively short distances on defined routes with defined stops, and can be used on routes that cannot be served by trams. There is a move to increase the use of public transport, especially BRT systems which run in specially allocated lanes, and electric vehicle technology is finding an increasing application in the battery driven electric bus (BDEB) public transport sector.

The electric passenger car was developed to have the same freedom of travel as the liquid fuel version, i.e. it can be driven anywhere as long as there was fuel in the tank, and the EVs storage battery was developed to allow this. Developers of batteries for EVs have focused on extending the range that a car can travel between battery charges and distances in excess of 200 km have been achieved. The development of batteries for private vehicles has made it possible to consider battery powered public transport as well. Other developments such as super-capacitors and ultra-capacitors have increased the viability of electric public vehicles. The much larger dimensions of public transport vehicles (PTV) allow far more flexibility in the placement of batteries and super- and ultra-capacitors than would be possible in a private vehicle. If the electric car has been successfully developed to replace the liquid fuel vehicle, should the same not be applied to buses to give an all-electric public transport system?

Battery powered public transport

At first sight this would appear a very daunting challenge requiring huge batteries to run the bus for a full day’s operation, and although this has been done, and there are several examples of battery powered electric transit buses that can run for more than 200 km on a single charge, there are other options to consider which make the concept far more viable.

Trip requirements

Designers of electric cars focus on getting the maximum trip distance between charges. This involves maximising the storage capacity of the battery which is limited in size by the size and shape of the car. For public transport the design criteria is different. The critical issue here is not how far the vehicle can travel but how far it must travel between charges, and how much recharge time is available at recharge stations. One must also consider what the minimum amount of energy is to be stored between charges. Considering the possibility of recharging at the terminus of a route, or at every stop even, reduces the storage requirements drastically. If the bus can be recharged at several points along its route and at the terminus, the question becomes one of how far must the bus travel before it can be recharged. The answer can vary from the low-end – the distance between stops, to the high-end for a full route returning to the start. So the storage device must be capable of storing enough charge to travel from less than a km, if it is assumed that the vehicle can be recharged in the short period during stops, to several tens of km between departure and re-arrival at the terminus. The trip requirements for various public transport systems is shown in Fig. 1 [1].

This means that the storage battery is much smaller than that which would be...
required to run the vehicle all day or for several hundred km, and this radically changes the design and cost of the vehicle. It is also possible to include a reserve of 15 to 30 min of operation in a separate battery which can be recharged overnight at the terminus.

There are three options for energy storage on electric buses:
- Battery only
- Battery and super-capacitor combination
- Ultra-capacitor only

Operational requirements

Electricity consumption

Liquid fuelled vehicles consumption is measured in l/km, but EV consumption is measured in kWh/km. Figures obtained from operators of battery powered buses range from 1.5 to 3.5 kWh/km [2]. Ultra-capacitor buses operate in the range of 1.0 to 1.5 kWh/km [3].

Recharge requirements

Recharging of batteries is limited to about five times its capacity (5 C), i.e. 100 kWh battery could be recharged at 500 kW. This places restrictions on the recharge arrangements. Super- and ultra-capacitors can be charged at much higher rates which creates opportunities for rapid charging at short stops. The amount of charge stored will be determined by the trip distance, while the charging rate will be determined by the layover or stop time, which is estimated to be between 15 and 30 s.

Example [2]

Based on the assumption that a typical 12 m electric bus consumes 2.5 kWh/km at an average speed of 18 km/h, the bus will consume 45 kWh per hour from its battery. If the battery capacity is 70 kWh, the bus can be expected to operate for about 90 min between charges. However, if the battery can be recharged en-route at bus stops, its range will increase dramatically. Assuming an accumulated non-driving time of 20 min/h (e.g. 40 stops at 30 s per stop), the charging power would need to be 135 kW/h (three times the hourly discharge rate).

Recharge options

Idle time or overnight charging

The battery is charged when the bus is not in service, either overnight in the depot or during off peak traffic hours when the bus is idle. The charging rate is set to optimise the efficiency and life of the battery.

Opportunity charging

The battery is charged whenever the bus stops, either at a designated passenger stop, or at the terminus at the end of the run. In one specific version the battery will be charged whenever the bus runs over a charging strip, i.e. while it is in motion. Opportunity charging requires rapid charge capability, with charge rates running as high as 500 kW for short periods.

Recharge stations

Existing electric vehicle infrastructure makes use of existing trolley or tram overhead wires for opportunity charging at points of intersection along the routes. A retractable pantograph is used to connect the charger to the overhead supply wires. This method is not suitable for rapid charging and is generally used at the terminus.
a capacity of 200 kW are being tested [5], which allow rapid charging of the battery/energy storage system. Induction chargers are buried under the surface of the road, and the pickup coil on the bus is normally retracted when not charging.

An innovative approach developed by the Korea Advanced Institute of Science and Technology uses strips buried in the road to transfer energy to a bus on the move [6]. The Online Electric Vehicle system, or OLEV, features electric power strips which have been buried 30 cm under the surface. These provide power to the bus through electromagnetic coupling, charging an onboard battery and powering the vehicle’s electric motor. The power strips need to be embedded in only 20% of the length of a road to keep the vehicle running. The system’s creators say that the technology alleviates the problems usually associated with hybrid vehicles such as heavy batteries, lengthy charging and limited range.

Long range electric buses: Hong Kong eBus [7]

Introduced by KMB, eBus, Hong Kong’s first ever franchised battery-powered electric bus, was put into service on 9 September 2013. The start of its passenger service between Tsim Sha Tsui Star ferry bus terminus and So Uk, a distance of 6.6 km, marks a zero-emission milestone for KMB and takes the Hong Kong public bus industry to new heights in environmental protection. Jointly developed by KMB and the manufacturer, the single-deck eBus, 12 m long, has a maximum capacity of 66 passengers and is capable of a speed of around 70 km/h. eBus is powered by lithium-iron-phosphate (LiFePO4) batteries, also known as lithium ferrophosphate batteries, which take only about three hours to be fully charged by means of a cable in the charging station of the bus depot. When fully charged, the eBus can travel distances of more than 180 km. The battery, which can also capture energy from regenerative braking, makes the bus more efficient in terms of electricity consumption per km.

BYD electric bus [8]

The BYD bus is being tested by a number of transport operators worldwide. This bus is powered by iron-phosphor batteries which the company developed in-house. BYD claims that no emissions and no pollution emanate from its electric buses, and the chemical materials contained in the battery can be recycled without any toxins. As for the power system of this pure electric bus, BYD’s in-wheel motor drive system functions as both an in-wheel motor drive and hub reductor. The maximum power output is 90 kW and the maximum torque is 550 Nm. Solar panels fixed to the prototype vehicle were reported to provide more power to supplement the on-board batteries. Although they were included on BYD’s demo units,
they are not fitted to those which have been running on the road commercially. The battery has a capacity of 324 kWh (600 Ah) and bi-directional AC charging allows full charging within 5 h at 60 kW or 1.6 h at 200 kW. The bus has a range in excess of 250 km.

Opportunity charging buses

The Siemens e-bus [9]

Vienna, the first city to operate these vehicles, has been using them on two bus service routes in the city centre since October 2012. It is the first fully electric bus fleet in scheduled service in Europe whose complete power requirement is supplied from the onboard battery system. The major advantage compared to a diesel or gas-driven bus is the 25% lower power requirement.

Using advanced battery technology it is possible to accumulate electricity so efficiently that it can be used on vehicles for public transport. On this basis and in combination with the latest technology, the company developed an e-bus concept, whose operating power is supplied solely from on-board batteries. The heating and air-conditioning equipment is also battery-powered. This all-electric concept has been implemented for the first time on a series production scale in cooperation with the bus manufacturer Rampini. Twelve 8 m long electric midi-buses have served Vienna’s city centre from the autumn of 2012. The operational concept is designed for a quick-charging process at the end station, which increases the battery’s lifespan by following a constant charging cycle.

The e-bus is equipped with nine lithium-ferrite batteries, three of which are located on the roof, five in the rear and one under the bus in place of the fuel tank. The battery capacity installed on board is 96 kWh and the drive uses ELFA 85/150 kW motors. An efficient battery-management system is provided to control the batteries and to monitor battery temperature and voltage. Batteries are charged at the respective terminal stop of the bus route. Electrical power is drawn from the overhead lines of the Vienna Light Rail/Tram system by means of current collectors and fed to the on-board battery-charging unit. The buses operate on 7 km routes in the inner city of Vienna with 10 to 15 min charging per route. The buses have a maximum speed of 62 km/h and a capacity 40 passengers. The range without charging is said to be 120 to 150 km (in city traffic).

Sinautec's ultra-cap bus [3]

Sinautec’s ultra-capacitor bus is powered by the ultra-capacitor bank on the lower deck of the bus. While the vehicle loads and unloads passengers at bus stops, the vehicle is recharged by the overhead charger in less than 30 s. Sinautec’s ultra-capacitor buses have been serving the greater Shanghai area since 2006, with energy efficiency figures of 1.0 kWh/km. The 41-passenger bus has a maximum speed of 50 km/h. Energy is stored in 5.9 kWh ultra-capacitors, which are charged for 30 s at bus stops at a rate of 120 kW, as well as for 5 min at terminal stops. The maximum range is 5.5 km with full air conditioning in summer and 9.5 km without air conditioning in winter. The bus charges once every two stops during summer and once every five stops during winter. The charger operates at 600 to 720 V/200 A. The air conditioning unit consumes 15 kW.

Siemens e-BRT [10]

The Siemens electric bus rapid transit system (e-BRT) uses vehicles which run on electricity without overhead contact lines and without rails. These vehicles are equipped with electrical storage units which combine super-capacitors, batteries and converters, carrying enough power to reach the next stop. At each stop, the e-BRT vehicle is recharged for about 20 s, i.e. less time than passengers usually need to get on and off the bus. Electricity which is generated when the vehicles brake or slow down is also stored in the super-capacitor in the storage unit. The super-capacitor provides high discharge current for acceleration and because of its high charge rate capabilities, absorbs energy generated when braking. The bus is independent of local power failures as a reserve battery can hold sufficient charge to run back to the terminus. The super-capacitor also allows rapid recharge at short stops. While light rail, trams and trolley buses require specific infrastructure with restricted routes, e-BRT vehicles can travel on standard roads, sharing them with other users. The only special infrastructure needed is a 200 V overhead contact system.
needed is bus-stops doubling as charging stations. In Siemens’ e-BRT system, such stations contain intelligence to help steer the electric buses into position as they approach the stops. This ensures more precise contact with the charging system and easy access for the passengers at a low-floor level.

Recycled buses [11]

An American company, Complete Coach Conversion specialises in upgrading end-of-life liquid fuel buses to electric ones, typically producing a 100 km range, 215 kWh battery-operated bus which has been fitted with a new drive train for about 25% of the price of a new electric bus. Recharging at 480 V/100 A takes about 4 h.

Potential for the South African mass transport sector

Battery powered Gautrain?

Although battery powered light rail systems have been successfully introduced in some major cities, the size of the Gautrain and distance between stops makes this idea impractical. There is, however, no reason why this technology could not be applied to the Gautrain buses.

Conclusion

By far the majority of South Africa’s commuting public use public transport in the form of mini-bus taxis regularly [12]. As these contribute to the CO₂ levels in the country’s cities they should be replaced by a system which is less detrimental to the environment. The DoE’s plan for energy efficiency includes a modal shift to mass transit from private transport and this favours the application the BPEB.

Several options are possible:
- New electric buses on existing BRT routes
- Recycling and rebuilding of older diesel or petrol driven buses to electric drive, which may be an overlooked business opportunity

If the millions of Rand spent on developing up-market high-performance electric passenger vehicles had rather been spent on developing electric buses or taxis, or on a system for the conversion of older buses and minibuses to electric drive, the outcome could have been far more successful.

References


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