Taking charge

Flash-charging is just the ticket for clean transportation

If you thought that charging electric vehicles was all about fiddling with charger cables followed by long and unproductive waits, then think again. ABB has - together with partners - developed an electric bus that not only automatically charges in 15 to 20 s, but also provides high transportation capacity and energy efficiency. The bus connects to an overhead high-power charging contact when it pulls into a stop and tops up its batteries during the time its passengers are embarking and disembarking. Besides being an attractive means of transportation, the TOSA bus also has numerous environmental bonuses. It is silent, entirely emissions free, uses long-life and small batteries while the visual clutter of overhead lines and pylons that is often a barrier to trolleybus acceptance is made a thing of the past. The system is inherently safe because the overhead connectors are only energized when they are engaged, and the electromagnetic fields associated with inductive charging concepts are avoided. A demonstrator has been running in the Swiss city of Geneva since May 2013. Such has been the success of this demonstrator that the city of Geneva is now going to run a full line based on the TOSA concept. The Genevan Public Transport operator (TPG) has signed a contract with ABB and the Swiss bus manufacturer HESS to deliver the line in spring 2018. Let the future begin.

The TOSA demonstration bus in public service in Geneva.

The world is becoming increasingly urban. In 2008, for the first time in the history of humanity, more than half the planet's population lived in cities. Cities bring with them many challenges, not least of which is the efficient organization of transportation. To avert gridlock and reduce pollution, planners across the globe are encouraging the use of public transportation.

Public transportation in cities can take numerous forms, but what they all have in common is that they require energy to be transmitted from a fixed supply to a moving vehicle. Some particular solutions aside, this transmission takes one of two forms: Power is either stored on the vehicle (usually in the form of diesel fuel, as on a bus) or transmitted electrically (requiring a continuous contact system as on metros, trams and trolleybuses). The latter forms of transportation are typically seen on heavily used corridors where the significant infrastructural investment is easier to justify. The former solution is typical for more lightly patronized corridors

Footnote

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where lower startup costs permit routes to be created or modified more flexibly.

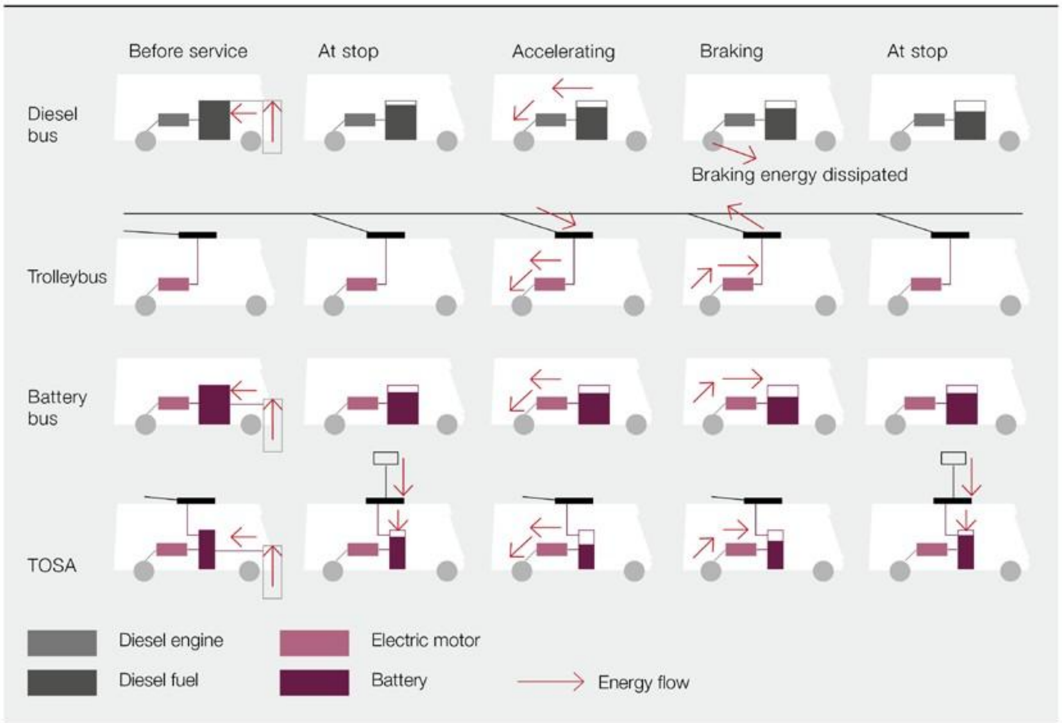
This status quo has held its own for many decades, but how much longer can it do so? Uncertain fuel prices and the reduced acceptability of noise and pollution have led manufacturers and operators to think about alternatives to diesel for powering buses ➔ 1.

1 Signs of change

- A McKinsey study predicts the price of Li-Ion batteries for cars will fall by almost 75 percent (from present level) by 2025.
- Carbon duties are being introduced across the world and will rise further.
- There is global pressure to reduce emissions from road transportation (e.g, EURO 6 emissions standards)
- Progress in power electronics (higher switching frequencies, lower losses, more compact converters) are increasing the viability of all-electric solutions.

Solutions, implemented to varying degrees, include less conventional fuels (such as natural gas) and adopting alternative propulsion concepts, for example hybrid buses, battery buses and trolleybuses. A feature shared by the latter three is that they use electric motors, permitting energy to be recovered when the bus brakes, creating an opportunity to reduce energy wastage. Recovering energy is not, however, strictly the same as re-using it. Hybrid and battery vehicles use batteries to bridge the mismatch between supply and demand, whereas in the case of trolleybuses this can be handled by the substations and grid ➔ 2.

2. Comparison of modes of operation



Battery buses have limitations. Despite considerable progress in battery technology, their energy density is orders of magnitude lower than that of diesel fuel [1]. The extra weight that batteries add to the bus reflects negatively on its energy footprint, and the space they require can reduce passenger-carrying capacity. This can be countered by using fewer batteries (and recharging them more often) but such additional visits to the charging station have a time and productivity penalty.

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The trolleybus trumps these disadvantages. The absence of a larger on-board energy storage system reduces vehicle weight and permits better acceleration using less energy. The disadvantage, however, lies (or rather hangs) in the overhead lines. These are costly to install and maintain and are not always welcome due to their visual impact ➔ 3.

3 Alternatives to overhead lines

The idea of seeking to transmit power to vehicles by means other than overhead lines is far from new. In the early part of the 20th century, some tram systems used a so-called "conduit", in which a conductor was embedded in a narrow groove in the road. However, the groove was vulnerable to blockage by debris, while the risk of electric shock to other road users could not be excluded. Several manufacturers have revisited the idea in recent years, with the conduit being replaced by a safer and more sophisticated contact – or induction-based transmission. These can be combined with batteries avoiding the need to embed the costly equipment along the full route. The induction-based version can also be used to recharge other road vehicles, including buses. However, the system retains several disadvantages, including energy losses during charging and the high cost of burying the charging infrastructure.

ABB's flash-charging system is inherently safe because the charging points are only energized when the bus is actually connected ➔5. Because it uses a direct electrical connection, concerns over electromagnetic fields can be mitigated. Furthermore, not requiring the installation of heavy equipment under the roadway simplifies the installation process and reduces the associated disruption.

Is there a way to keep a battery bus on the road without resorting to either large, heavy and space-consuming energy storage or to frequently having to take the bus out of service for a deep and full recharge?

Transport passengers not batteries

One fundamental difference between buses and automobiles is that buses follow fixed routes. The question of "range of operation" which is of significance to electric cars is reduced to the more manageable "distance to next recharging opportunity" for a bus. With buses predictably stopping at regular intervals, charging points can be located at the stops. With the bus being able to top up its charge at these points, the need for large and heavy batteries is avoided and the vehicle becomes lighter, more agile, more energy efficient as well as providing more space for passengers inside. Furthermore, if charging time can be limited to the time that the bus needs to stop anyway, negative effects on the schedule can be avoided. Together with partners ➔ 4, ABB has created the TOSA bus to present a solution based on this approach.

4 Partners in the TOSA project

The following four companies initiated the TOSA project:
– TPG, Geneva's public transportation operator
– OPI, Lake Geneva area office for the promotion of industry
– SIG, Geneva's utility
– ABB (ABB Sécheron)

(hence the name TOSA, which also stands for "trolleybus optimisation système alimentation" or optimized charging system for trolleybus)

Further partners of the project include:
– Palexpo (trade fair center) and Geneva airport
– Hepia (University of applied science), architecture design of the bus stops
– HESS, manufacturer of the bus
– Canton of Geneva, Federal Office for Energy, Federal Office for Highways
– EPFL and HeArc Universities

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Flash-charging and smart grid

The high-power (600 kW, 20 s) charging of the high-power density batteries on the bus can result in load peaks affecting the local grid. The flash charger station, however, flattens out the demand by charging batteries located on the wayside over a period of a few minutes while drawing a lower current from the grid. As this current is up to 10 times less than would be the case without storage, the connection can be made with a cheaper and more readily available low-power supply.

With limited time being available at stops (passengers typically embark and disembark in 15 to 25 s), as little time as possible should be lost in establishing the electrical connection – the Energy Transfer System does this in under a second. As the bus approaches a stop it is the driver's responsibility to oversee the safety of the passengers and pedestrians and keep an eye on surrounding traffic. To avoid placing additional demands on the driver, the connection system is automatic. A laser aligns the moving equipment on the bus roof with the static overhead receptacle ➔ 5. The connection is made as soon as the brakes are applied.

5 The bus recharges at stops using its roof-mounted contacts that engage using laser guidance.

By virtue of the receptacle's height above the road surface, and furthermore by being energized only when a bus is present, this is an inherently safe solution.

The timetable defines the service and the economics

Operating costs for a bus service are highly dependent on driver wages, schedule frequency and fleet size. Therefore, the change from diesel to electric supply should not reduce the commercial average speed nor require an increase of the fleet size to provide the same service.

It was this requirement that led to the creation of two types of feeding stations along the route: The flash station and the terminal station. As described, the flash stations provide a short high power boost of energy. However, drawing 600 kW for 15 to 20 s is not sufficient to fully recharge the batteries ➔ 6. More prolonged charges of four to five minutes at 400 kW are thus delivered at the terminus where buses are scheduled to stop for longer periods

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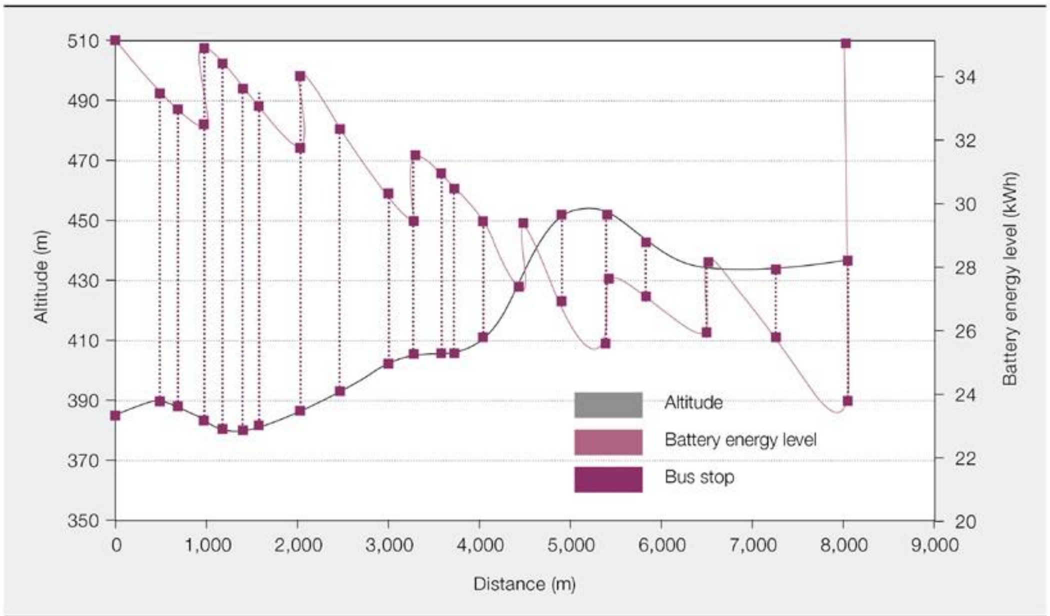
(in order permit the driver to take a break and to provide some recovery buffer in case the bus is running late). The time required for recharging at the terminus should thus not risk causing the bus to fall -behind its schedule or to be unable to catch up when it running late.

6 Short top-up charges help maintain the battery level.



The terminal charger consists of an IGBT based rectifier. This converts the incoming AC supply to DC in a similar way as is done for DC railways, trams or trolleybuses. However, the IGBTs provide the advantage of being able to maintain the output voltage at a desired level independent of fluctuations in the voltage on the AC network. This is important for two reasons. The first is that the on-board battery chargers need to step up the voltage to charge the batteries and so the voltage provided on the wayside cannot be higher than the on-board battery voltage. Secondly the voltage cannot be too low because then the current drawn would be too high for the required power.

The flash charger uses the same type of IGBT charger as the terminal but it has a lower power capacity. Its function is to regulate the amount of charging current flowing into the wayside batteries. When the bus connects, the flash-stations' controller closes a contact on the output side of the batteries to discharge them into the bus.

During operation, the batteries receive further top-up charges as the bus brakes. Rather than using a friction-based system that converts all the kinetic energy to heat, the bus's motors can switch to generator mode and return much of this energy to the batteries ➔ 2.

The battery charge for a typical trip is mapped in ➔ 6. The graph shows how the batteries are topped up at stops but a far larger charge is received at the terminus stop.

There is a third type of charger, for the depot, where a longer charge is applied to compensate the energy required between the operating line and depot location. As there is more time for charging at the depot a flash-charging station is not required. A total of four buses can be connected to a depot charger, which charges them sequentially. The bus connects using its automatic connection system as it does along the route. This together with the logic programmed into the depot feeding station "wakes up" each bus in tern for charging and then

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puts them back into "sleep mode" once the charge is complete. This saves energy without requiring depot staff to monitor the charging procedure. The electrical configuration is a simple but reliable 12-pulse diode rectifier as commonly used for railways; however, the power rating of the depot is a mere 45 kW avoiding the need for costly electrical infrastructure in the depot.

Renewable energy

The TOSA bus is inherently suitable for using renewable energy. In contrast to classical electric vehicles, which typically recharge when they arrive home in the evening, the bus recharges during the day and can thus make direct use of solar energy as it is produced. The ability of flash-charging stations to store energy for short periods and flatten out charging peaks can also protect the system against short-term fluctuations in solar generation.

A competitive solution

ABB’s flash-charging system for buses is already competitive today, as demonstrated by the pilot operation. In a scenario with diminishing costs of batteries, it may become even more competitive in the future.

With diesel buses becoming increasingly less attractive, from an emissions and cost point of view, and operators seeking an attractive modern form of transportation without having to hang wires in the street, flash-charging is well situated to replace both existing trolleybus routes and urban diesel routes.

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