KNOWLEDGE BRIEF

IN MOTION CHARGING
INNOVATIVE TROLLEYBUS

MAY | 2019

INTRODUCTION

Urban sprawl and the significant environmental degradation are among the main factors that have led to a renewed interest in urban development and sustainable urban mobility. The latest technologies answered the public call for better environmental and post-fossil alternatives. The electric transition is not inexpensive but by using high efficiency systems, like light or heavy rail, the electrical drive can be cost-effective, sustainable and, in the end, a given no-brainer solution.

IN MOTION FEEDING

Electric transport solutions are based on the permanent supply of electric energy to the vehicle in motion, what is called **In Motion Feeding.** The development of electric batteries led engineers to propose new environmentally friendly solutions and make electric vehicles more flexible and maneuverable for operators.

A VERY EFFICIENT AND INTERESTING SOLUTION

There are several ways of charging electric systems such as **Flash charging,** charging at the bus stops for about 10 - 15 seconds during the boarding of passengers, **Opportunity charging**, charging at the terminus stops between the shifts, **Overnight charging**, charging during the night at the bus depots or **In Motion Charging**.

In Motion Charging provides a very efficient and interesting solution for the electrification of city transport. All other means of charging on the spot have their potential limits, as electrical energy is approximately 100 times longer than chemical energy transfer, pumping diesel into the bus.

In Motion Charging can be also combined with opportunity charging.

This Knowledge Brief presents the benefits of introducing trolleybuses with In Motion Charging into a city. It also describes the benefits of upgrading an already existing trolleybus system with In Motion Charging technology, combining passing under the overhead wires network with battery charge while operating in autonomous battery mode (with lowered current collectors).

Charging with In Motion Charging current collectors - Cagliari, Italy

WHAT IS IN MOTION CHARGING?

The development of battery technology enabled the trolleybus to become one viable solution in the electrification strategy of cities. While driving, the trolleybus charges its on-board batteries, which enables in average, for each kilometer under the catenary to drive one, two or even three kilometers without catenary in commercial conditions. The range depends on the energy consumption of the operation (vehicle length, gradients, etc) and the power limits of the equipment (e.g. IMC500 charging model for 500 kW energy transfer enables maximum recharging).

CHARGING ROAD INSTEAD OF CHARGING STATIONS

This is not taking any investments in new charging infrastructure and **does not take additional time in to charging batteries during the operation**, if there already exists a trolleybus infrastructure, which can then be used. Traditional trolleybuses that used to feed braking energy back to the grid were only efficient when another trolleybus was in the same section. By storing this energy in the onboard battery, the energy, as well as the flexibility of the operation can be increased without harming the timetable.

So In Motion Charging has a traction battery for full electrical operation including comfort devices such as electrical heating. To connect and disconnect the current collector system for In Motion Charging works reliable around the world at all weather conditions and is done simply by pressing a button.

When installing new overhead wires, it should preferably be installed at the least expensive places (e.g. using straight lines) or most meaningful places (e.g. at stops with waiting times or at gradients with a higher energy demand). Most relevant is the time under the overhead wire.

Generally, when the bus drives with low speed under the wire, it increases the charging is time, compared to when it is higher speed. Therefore, it is more cost effective to install In Motion Charging roads on route sections in which lower speeds are used than on higher speed motorways.

Ideally, several routes served by electric buses can be bundled to one In Motion Charging road. This would improve the synergy for several routes sharing the same infrastructure and result in an even more costs effective investment.

COMPARISON WITH OPPORTUNITY CHARGING

Stationary contact charging involves the necessity to stop the vehicle while it is being charged, which means that

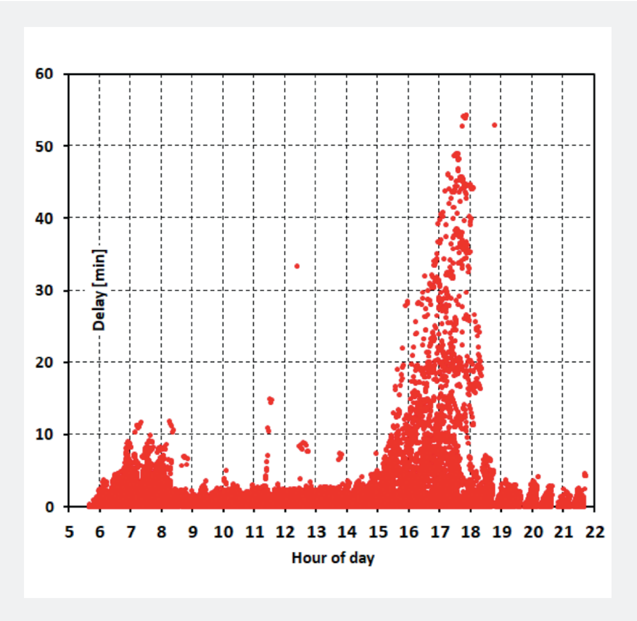
Heating of the vehicles / overnight battery charging & conditioning possible - Solingen, Germany

the operator is losing time, thus money during forced operational break. Moreover, it may result in the need to increase the number of vehicles necessary to operate the line. The table presents an example of 4 different charging times for different vehicle sizes when operating a route of 15 km and charging stations are localised at both terminuses.

VEHICLE'S LENGTH	CHARGING TIME
12 meters	9 min.
15 meters	10 min.
18 meters	12 min.
24 meters	16 min.

Energy consumption: 2,2 - 2,6 - 3,2 - 4 kW/h

The necessity of stopping the vehicle during the time of charging is of critical importance in the event of traffic congestion. They cause a delay in the arrival time to the final stop, which consequently shortens the time left to recharge the vehicle. In the case of stationary contact charging, this may lead to situations where the remaining stop time is too short to charge the vehicle **and may trigger the necessity to use a reserve vehicle**.



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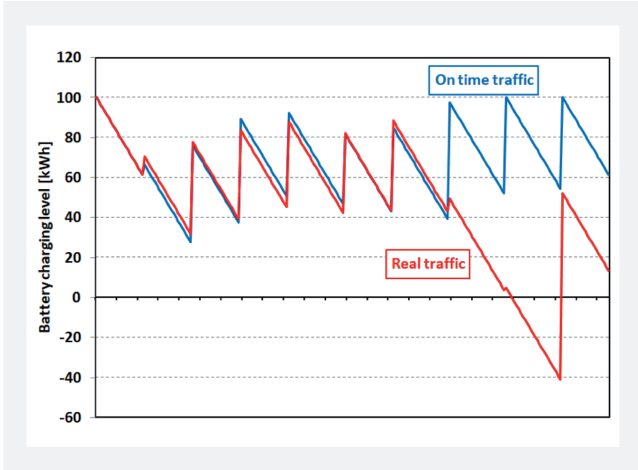
An example of delays of arrival to final stop on a bus route

The type of charging mode (stationary or dynamic, thus In Motion Charging) has a fundamental impact on the battery cycle. In the case of stationary charging, it is necessary to charge the battery with the energy needed to cover the entire distance of the route. Dynamic charging allows to limit the amount of energy level accumulated, because the length of the autonomous fragment is shorter.

The traction battery can constitute between 20% and 50% of the acquisition price of an electric bus, therefore reducing its capacity impacts to the initial investment and also reduces the cost of replacement in the future.



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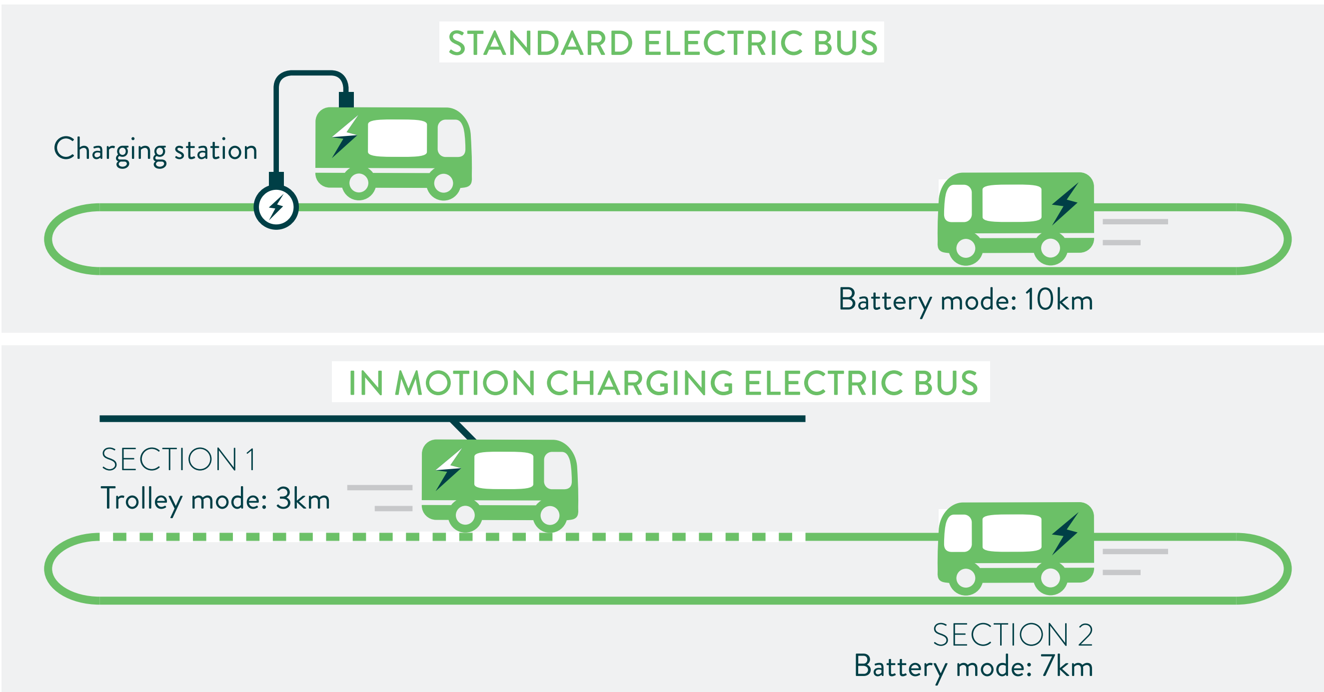
Influence of traffic delays on trolleybuses operation - during peak hours delays can lead to reduction of stopping time, which can be too short to fully charge the vehicle as planned

Planning for electric bus systems depends on multiple contextual criteria. However, the most widespread charging approaches until now are overnight charging and opportunity charging. As the overnight charging seems most suitable for small fleets of short buses with a moderate daily kilometric performance, the principle of opportunity charging (often in combination with overnight charging) seems more adequate to overcome the limits of range by recharging during line operation. This also reduces redundent the required infrastructure peak power for charging a bigger fleet during the night.

The less known innovative In Motion Charging concept is quite comparable to opportunity charging: The higher the charging power is, the lower the charging time is. This also applies to overhead wires or charging units along the line.



Covering part of the route by overhead wires allow to reduce the capacity of the batteries

ADVANTAGES OF IN MOTION CHARGING

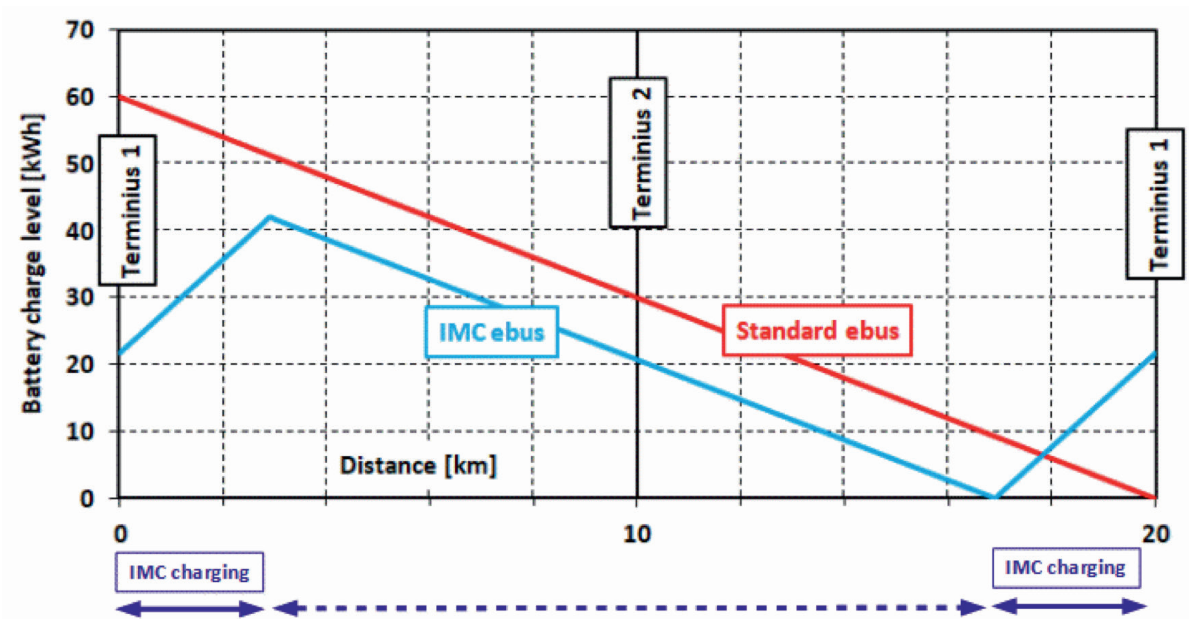
COVERING 20 - 40% OF THE ROUTE BY OVERHEAD WIRES

- Up to 80% is autonomous driving
- Trolleybus functionality In Motion Charging
- No need to stop for charging
- Efficiency and flexibility
- No extra vehicles and drivers required for operating In Motion Charging
- Smaller battery capacity and more passengers
- The infrastructure is not just less expensive per km, but also by 60% - 80% shorter
- Infrastructure investment less expensive than in case of standard trolleybus and much less in comparison to tram
- Overhead wires infrastructure simpler and cheaper than in standard trolleybus route since expensive and maintenance intensive switches, crossings and even some curves can get avoided
- Balanced energy demand of the vehicles with batteries leads to higher utilisation of infrastructure

SUCCESSFUL IMPLEMENTATION EXAMPLES ACROSS THE WORLD

For the past 130 years, trolleybuses have been running in approximatively 300 cities all over the world. The fast development of battery technologies (e.g. Lithium Ion, LFP and LTO) became an important driver of the trend of the introduction of battery busses in urban environments. It also led trolleybuses to become interesting again in the market to answer this call for sustainable mobility. Trolleybuses equipped with a battery pack offers a lot of new advantages for this mode.

In recent years a range of cities have introduced In Motion Charging systems – Eberswalde, Esslingen, Solingen (thus all systems in Germany), Cagliari, Zurich, Geneva, Berne, Biel, Gdynia, Lublin, Budapest, Arnhem, Szeged, Tula, Nalchik, St. Petersburg, Landskrona, Rosario, Castellion, Marrakech, Dayton, Seattle, San Francisco and others.



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Covering part of the route by overhead wires allow to reduce the capacity of the batteries

SUCCESSFUL IMPLEMENTATION OF IN MOTION CHARGING SYSTEM IN SEVERAL CITIES

PRAGUE

After 45 years off the roads, Electric trolleybuses are back on streets of Prague. Electrification of public transport is an essential part of the strategy of Prague for decreasing negative environmental impacts of transport.

There was a different initial situation in Prague, without trolleybus infrastructure after the closure of the last trolleybus line in 1972. **Trolleybus cities are looking to extend the range of trolleybuses to increase efficiency in their operations to** allow independent operations in case of disturbances and decrease cost for network development. Operations in such cases are organized 70-90% under In Motion Charging mode and only 10-30% in battery mode.

Prague's vision of this In Motion Charging project is different, it is a combination of: In Motion Charging section / opportunity charging at terminus overnight charging and balancing batteries at the depot.

Charging power only up to 70 A / 50 kW in compare to ideal charging power (mentioned in study) up to 150 A / 120 kW (with possibility up to 200 A / 150 kW in winter).

Full length of test line is 10 km, so trolley section is only 10% (used only uphill section) or 16% (if used both direction) of line length.

Next step of the In Motion Charging development in Prague is the preparation of regular operation for full electrification of line 140 (pilot section is part of this line). The line is 23 km long, peak headway is 6-7 minutes and there shall be served by 15 articulated vehicles.

The preparation of line 140 has already started, with expected operations to beginning in 2020 or 2021.

ST. PETERSBURG

St. Petersburg is completing the first stage on the establishment of the first large integrated project in Russia (after pioneer routes in Tula and Nalchik) for trolleybuses using In Motion Charging system. The new mode of transport is planned to launch in the city historical center where the route No. 17 is passing the famous Kazansky Cathedral.

It is the first city in Russia to apply a systemic approach to transition to an In Motion Charging system with the purchase of 115 innovative trolleybuses in 2017 and 2018. It was the largest contract for such vehicles in the country.

Six months of regular operations of In Motion Charging trolleybuses made possible to use all the advantages of the innovation:

- The extension of trolleybus lines to new residential areas without the construction of new infrastructure;
- Prompt change of trolleybus routes passing through the areas of road construction works;
- Route duplication during the long-term repair of tram tracks;
- Removing overhead wires in-front of monuments in the historical center (Kazansky Cathedral)

GDYNIA

Since 2009 PKT Gdynia started operating trolleybuses with an In Motion Charging system. Originally the vehicles were equipped with nickel-cadmium batteries with a capacity of 16 kWh. Since 2015, vehicles with high-capacity lithium-ion batteries with capacities of respectively 40 kWh and 69 kWh have been introduced in operations.

Due to the very good characteristics, the possibility of autonomous trolleybuses drive is used not only in emergency situations, but also when there is insufficient stock on bus routes.

© SUE Gorelectrotrans, Saint Petersburg

Trolleybus/ Tram operator of Saint Petersburg

In the latter case, battery trolleybuses often function on bus routes using, for charging purposes, the overhead wire line which covers the common sections of the routes.

This was done on a large scale from the 29 June to the 1 July 2016, in collaboration with the organisation of the Open'er Festival. Using their auxiliary drive, the vehicles were able to cover long sections of the routes, reaching as much as 29 km.

This project allowed the creation of a measurement database concerning the operation of battery trolleybuses with considerable use of auxiliary drive. It also allowed the use of these data as guidelines when dimensioning the public transport routes based on the In Motion Charging. This task was realised, within the framework of the Eliptic "Electrification of public transport in cities" H2020 project.

ESSLINGEN & SOLINGEN

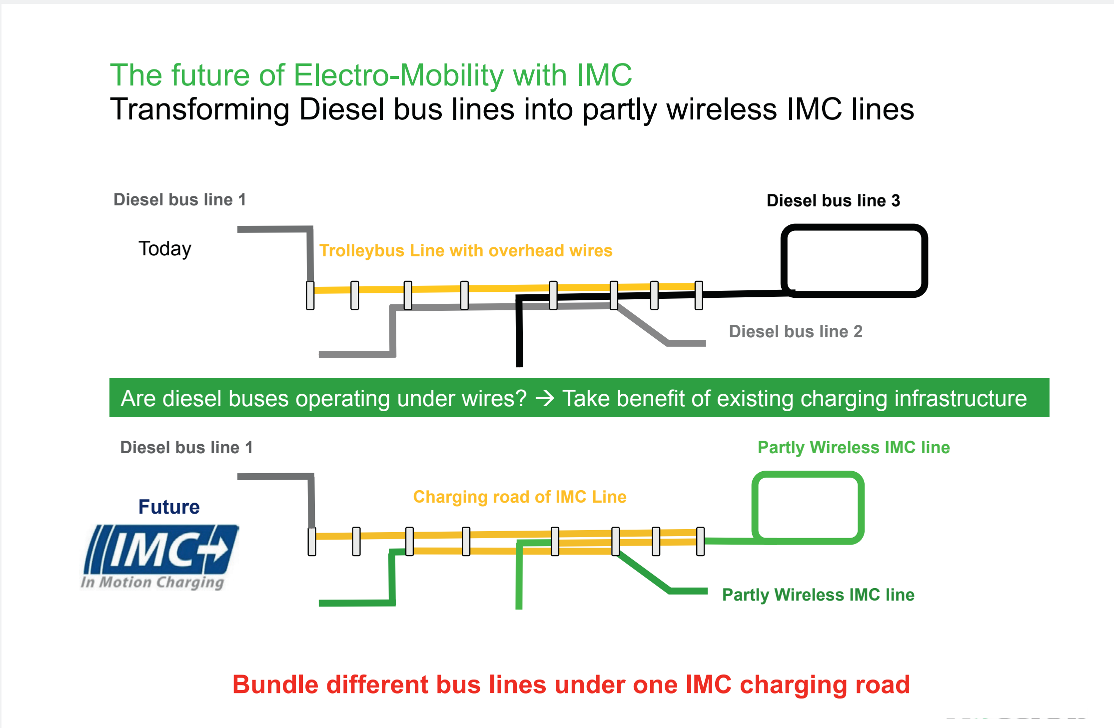
In Solingen, the diesel buses of line 695 were transformed into IMC500-electric buses. This bus line was operating the diesel buses and a 2 km long bi-directional section of overhead wires.

This was enough for charging the IMC500 buses back and forth on an 18 km long round trip reaching almost 80% wireless operation. This is possible due to a very powerful equipment allowing the power draw of 500 kW from the overhead wire, suppling the 2 x 160 kW traction motors, the 40 kW for auxiliaries such as heating or air-conditioning and at the same time the battery gets recharged with up to 240 kW. Thanks to that powerful charging concept IMC500, the required amount of overhead wires is minimal, opening the perspective for many other diesel bus lines to get converted into emission free In Motion Charging lines. The objective of the IMC500 bus for Esslingen was wireless line extension of 2/3 of the line, thus 1/3 under the wires.

UPCOMING IMC IMPLEMENTATIONS

Many cities, using a trolleybus infrastructure are now implementing In Motion Charging vehicles for wireless line operation, such as Montreux and Geneva.

In addition, new overhead wire lines are being installed in Italy for the Rapid Coastal Transport, between Rimini and Riccione, as an electrical Bus Rapid Transit (BRT) in 2019 or the new system of Verona in Italy.



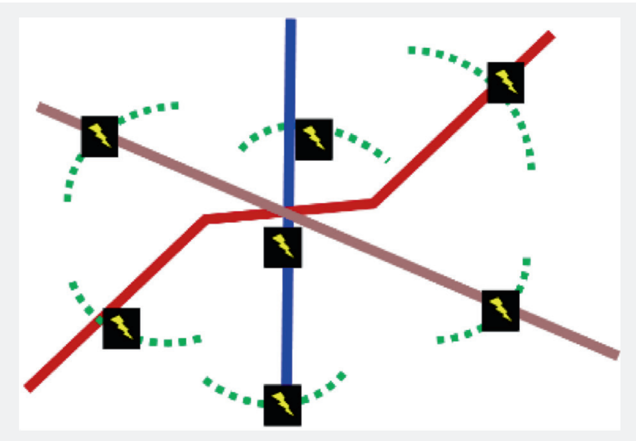
Solingen can serve as a show-case example of transforming diesel-bus lines into In Motion Charging lines

SYNERGIES WITH OTHER PT MODES (ELIPTIC)

In many cities, trams and trolleybuses transport systems operate in complementarity (Milan, Zurich, etc), which raises opportunities about the possibility of their joint supply of electricity.

In Milan, the e-bus serves the ring line around the city center.

Usually, rail systems cover the straight main transport axes of a city, like the spokes of a wheel. An In Motion Charging system can use the existing substations along these straight axes to create radial In Motion Charging lines around these straight axes.



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Combining In Motion Chargin trolleybuses with a rail system

Existing infrastructure is being reused to extend the e-mobility network by combining In Motion Charging trolleybuses with a rail system. The substations (black) of the existing tramway and/or metro system (blue, brown, red) can be used by In Motion Charging roads (green) for radial In Motion Charging lines.

If high gradients are the reason why a rail line has not been extended, the In Motion Charging trolleybus can do that. As rubber wheels have a better adhesive grip on the road (coefficient of friction) than steel wheels on the rails, a trolleybus was and is the perfect choice for a route with gradients.

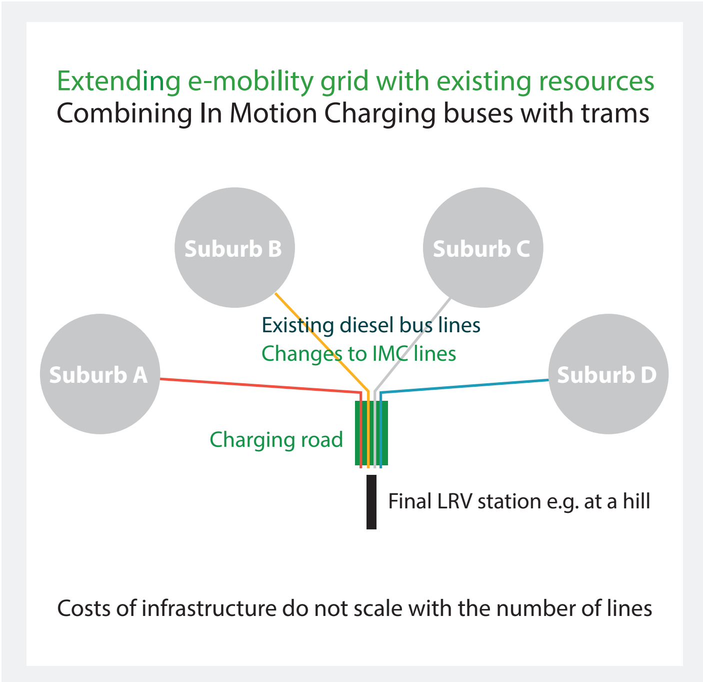
If several bus lines, currently served by diesel-powered buses, are bundled on such a steep gradient to connect several suburbs or towns with the city, an In Motion Charging road along this gradient makes it possible to change over to In Motion Charging trolleybuses and extend the existing e-mobility grid of the rail.

Reusing the existing rail infrastructure and maintenance employees (both for the vehicles and infrastructure) can reduce the costs and mental hurdles for the introduction of In Motion Charging.

COMMON INFRASTRUCTURE

The rail substations from e.g. tram or subway can be used also for In Motion Charging trolleybuses. This can be realised with common or separated busbar. The existing infrastructure poles might be used for the additional overhead wires, if these poles can cope with the additional weight.

Generally speaking the overhead wire of a tram cannot be used, since the U-shaped profile of the current collector head might collide with the fixations of the wires, the crossings or the separators. Besides, tram wires often don't have one continuous wire through intersections, where the wires get pulled and straightened in order to compensate the expansion of the wires due to the temperature.



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CONCLUSION

For introducing a new reliable trolleybus system in a city, the installation of some few overhead wires can be the least expensive and sustainable solution. This is particularly cost effective for big fleets or for high energy demanding operation due to high average commercial speed (Bus Rapid Transit), high pace, long articulated trolleybuses or for environments requiring heating or air conditioning systems. In Motion Charging supplies these vehicles with the energy that they need and allows a 24h/7 operation without pausing. Since IMC500 charging concept requires just around 20% - 40% wires *on the track (depending on several parameters), it is easy to find suitable and acceptable sections to install overhead wires.*

The better and the more efficient the batteries develops in the future, the more important the recharging technology becomes, thus the efficient transfer of energy from the infrastructure into the vehicle. At the moment, overhead wires with the In Motion Charging concept with 500kW power transfer is by far the most powerful concept. Therefore, trolleybuses with In Motion Charging system often generate the lowest operating cost.

The laws of physics (energy transfer for charging = charging power x charging time) confirm the benefits of In Motion Charging since it allows sufficient charging time as well as high power.

The design of the poles needed for the In Motion Charging road infrastructure can be modern, historical or nearly invisible with plants around the poles. The poles can also be combined with stylish illumination. An architecture competition for a city-specific design can reveal attractive ideas and makes the installation acceptable in many areas. Installing an In Motion Charging system in a city can result in a higher level of the quality of life.

Articulated or even double-articulated In Motion Charging trolleybuses should be the first step to an introduction of e-buses for heavy frequented lines. *This approach could lead to have an optimum business case, as the bus driver is by far the main cost driver, thus maximum passengers per driver is crucial. Besides replacing heavy diesel-powered traffic by silent emission free In Motion Charging trolleybuses, the quality of the air will quickly improve. Cities that intend to introduce a tramway system (overhead wires) should consider whether their requirements for the passenger capacity can be achieved by double-articulated trolleybuses.*

New In Motion Charging systems cost less than new rail systems under certain conditions, they can be realised faster, and trollybuses are not stopped by roadworks, accidents or illegally parked cars. Avoiding grooved rails in the street, would also avoid the costs of cleaning and maintaining rails, while reducing the number of bicycle accidents. Each benchmark analysis for introducing an e-bus system should include the In Motion Charging concept, and they should reflect the specificities of each individual case to find a truly objective and economic solution.

Illustration of an In Motion Charging trolleybus running on a wireless section in the city center

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