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Change it – The intelligent Battery Change System
An ideal solution for the public traffic

Stefan Wallner[1], Marlene Solis[2],

[1] *Wallner Energietechnik GmbH, Ottobrunner Straße 37, 82008 Unterhaching, Germany*
E-mail: stefan-wallner@t-online.de
[2] *Wallner Energietechnik GmbH, Ottobrunner Straße 37, 82008 Unterhaching, Germany*
E-mail: marlene.solis@web.de

Abstract -- For big cities, public transport is of great importance. Moreover, it is common wisdom that fossil fuels are scarce and expensive. It is, therefore, indispensable for the commercial traffic branch, in general, and especially the intensively used bus fleets, in particular, to examine their suitability for an electric drive system. The battery change system "change it" takes up the challenge and enables a symbiosis of e-mobility and economy. The electric bus will be provided at each of the terminals with a freshly charged battery to renew its drive back to the other terminal. The remaining high cycle battery is left for charging in the station. This change allows a continuous driving, despite the use of relatively small and inexpensive batteries. The additional installation of a peak power capacitor (ultra-caps) in the vehicle extends the lifetime of the battery. The initial investment in the changing stations pays off in a short time.

According to a long run planning of 10 years, the zero-emission driving with "change it" is both quiet and ecologically desirable and, in addition, cheaper than the current technology. Furthermore, this technology has a door opening function in the e-mobility. The development of battery technology will be pushed forward as with "change it" a more attractive bus operation is possible. The proof of the economic electrical bus drive can apparently be demonstrated. This approach has the potential to rise to a top seller.

Keywords -- "city bus", "public transport", "electric bus", "simulation", "efficiency"

1. Introduction

As we all know, our society has to become more independent from oil and should use more renewable energy in the future. Many research projects are working on alternative driving concepts and are trying to find out what would be the best way to drive on electricity. Especially the commercial transport is very promising to show effective results. In this case, the savings of CO_2 are remarkable and a fast decrease of particular matter can be watched. It will significantly reduce the consumption of resources. To realize this idea in the intensively-used vehicles sector we developed the concept of a smart battery exchange system named "Change it". This allows that the public bus service will be economically attractive and can be used in urban centers.

2) System Description „Change it"

A pure electric driving is possible because „Change it" is working with high cycle batteries. By changing the batteries at the termini, the use of small, lightweight and inexpensive batteries is feasible. This leads to an economically attractive way of electric mobility in urban centers: at the terminal stop, the old batteries are replaced in each bus by new ones which are automatically inserted through the roof. The change over roof allows the maintenance of low-technology, there is no room lost in the passenger compartment and the safety is increased. Due to the battery exchange, the range problem is solved and the electric bus can start the route again.

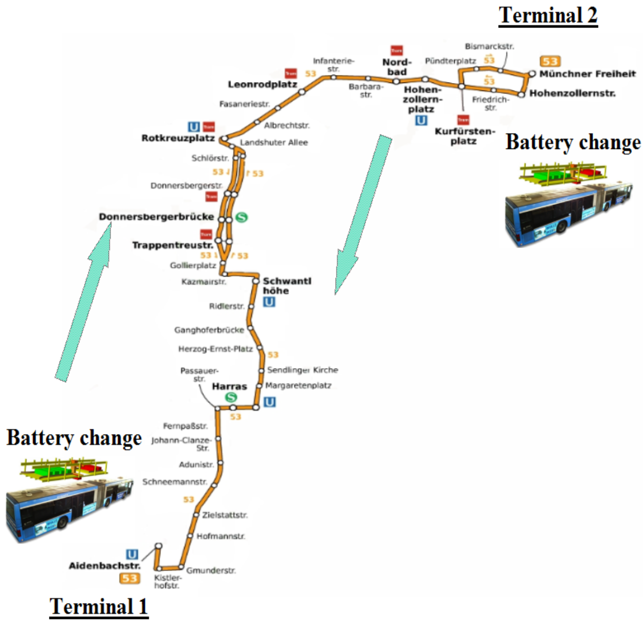

Figure 1: Line 53 in Munich with battery change on each terminal.

3) Facts and Figures

For example, let us have a look on the line 53 in Munich (Germany) which is typical for urban transportation. Round about 5:00 o'clock in the morning the busses start their business and run till 23:00 in the evening. One Bus is doing 19 movements form terminal 1 (Aidenbachstr.) to terminal 2 (Münchner Freiheit).
The working shift for the vehicle takes 17 to 18 hours and, due to the length of one route of 12,7km, there is a total distance of 241km per day.
The line 53 is on 365 days a year on service, so 11 busses keep the 10-minute cycle running.
In sum, all vehicles ride close to 1 million km a year. Based on the fact that a conventional bus has a fuel consumption of 0,65 l/km and the average cost of diesel are 1,00 € per liter, than the operating company has to spend 6,5 million € in 10 years for diesel fuel.

4) Power curve

With our measurement devises we get a very accurate speed profile from a real vehicle in operation. With our simulation and calculation tools we get the power demand on the dc-link-voltage for each second.
This curve shows the power requirement of the line 53 (Aidenbachplatz → Münchner Freiheit) in Munich (Germany).

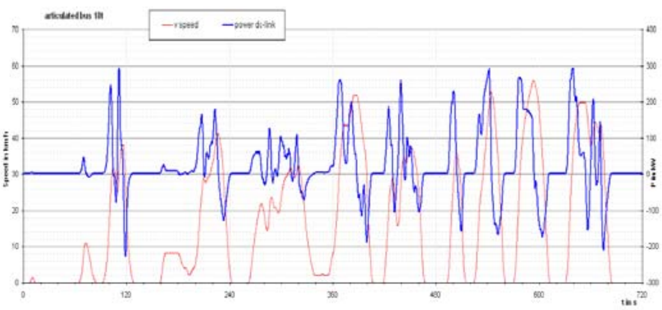

Figure 2: Line 53 power demand from GPS measuring during the first 12 minutes

Thus, the expected energy demand can be accurately determined. Auxiliary equipment such as steering, compressor, and air conditioning are included. Also rush hours when the bus carries many passengers can be simulated.

5) Simulations

Special situations, special requirements, aging of components, all be played out and predetermine the optimal sizing. With extensive analysis and simulation, the technical risk is reduced for the construction of the first sample vehicle and it significantly reduces the costs. Due to the intensive power during acceleration and braking we propose to use ultra capacitors to support the battery. A close to reality simulation with a power management could be done. The result in the next graphs show the differences in battery load during the first 12 minutes

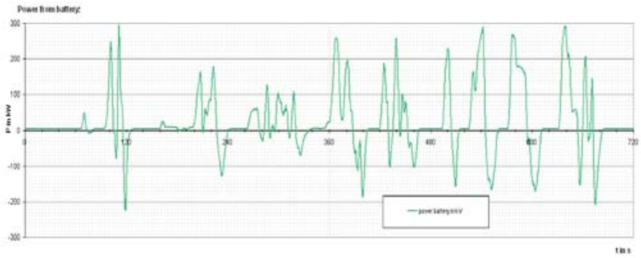

Figure 3: line 53 power from battery **without** ultra capacitors during the first 12 minutes

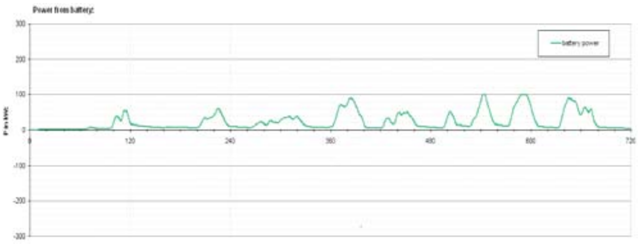

Figure 4: line 53 power from battery **with** support of ultra capacitors during the first 12 minutes

Figure 3 und 4 show the difference of power duty for the battery when we use an ultra capacitor for an instantaneously power supply. The overall efficiency is getting better from 1,8 kWh/km to 1,55 kWh/km
Power losses in the battery will be reduced from 3,2 kW down to 0,45 kW. The amount of energy which has to pass the battery is 42kWh to drive the bus on line 53. Due to the support of the ultra capacitors we reduce this amount to 19kWh.

Additional to the load profiles of the components, we get detailed information of energy consumption. There are several possibilities which could be checked in advance before the vehicle is built up. On tables 1 we show the expected power consumption with different numbers of passengers and with additional heating needed in cold winter time.

Tables 1: expected power consumption

	line 53		
	30 passengers	100 passengers	100 passengers 6kW heating
Consumption KWh / km	1,49	1,83	2,26
expected range in km	32,2	26,2	21,2

Different scenarios simulations will help to get a precisely prediction. This is the best data base to get the future costs for components and energy consumption under control. After finding the best concept the requirements are given to be competitive to existing technologies.

6) Battery requirements

By reason of battery change on top roof, we think that the weight should be less than 600 kg. With today lithium ion technologies there are cells available to get a sufficient storage size to run from one terminal to the other.

In our suggested concept, there will be 3.000 battery charges per year with 40...60% DOD (Depth Of Discharge); In ambition, to extend its operation time up to 10 years then the battery has to do 30.000 cycles of round 50% discharge. To keep the battery always in the best temperature range, is under this circumstances, a matter of course. The charging time of approximately one hour seems to be slow enough for a long life time of the battery.

As the lifetime of the battery is concerned, capacity, load profile, chemistry, power management and cooling are essential. The costs can be itemized down to any kWh over the complete use.

c [€/kWh] = B[€] / (Q [kWh] * C [1])

c: storage cost per kWh
B: Battery costs
Q: Energy passing thru battery per cycle
C: Cycles depending of load profile

7) The solution

As the simulation shows, the power boost by ultra capacitors from an economic point of view, is advisable. To keep Lithium-Ion und ultra-caps in a low temperature is for the lifetime of both components very helpful.
Heating and air-condition have to be optimized to an acceptable minimum energy losses, so the effect to the battery is small enough. The battery change is carried through fully automatically and needs no more than 180 sec.

8) Battery technology

Because of the expected high cycle rate, special high technology batteries are necessary. Depending on the material for the anode and cathode different lifetime and safety levels are estimated. An accurate simulation of the bus line allows determining the load situation for the battery.

Sample: li-Tech:
40 Ah High Energy Cell

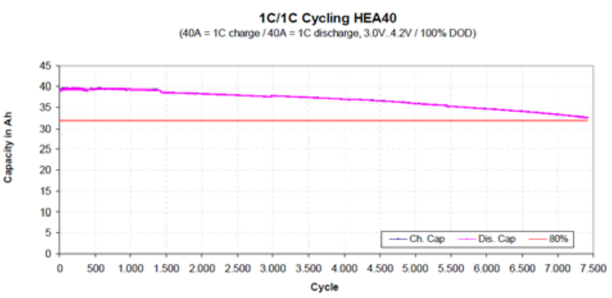

Figure 5: [1]Source: li-Tech, VDV Berlin, 23-24.02.2010

In figure 5 the test was done in 100% discharge cycling. Due to the situation we expect 50% cycling in our application, so we believe to get 15.000 cycles as well. The graph shows the end by 80% capacity, the battery is not damaged yet. Because of the big reserve of capacity we can run the battery longer.

Sample: Leclanché:

Lithium metal oxide/Titanate cycles by 1C-rate and 37 °C between 2,8 V and 1,8 V 100 % DOD after 8000 cycles 80 % NC

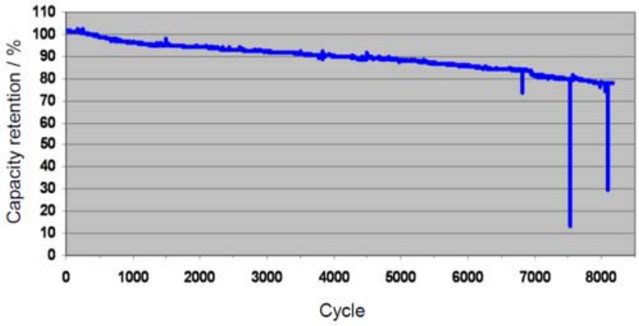

Figure 6: [2]Source: Leclanché Design & Elektronik 23.02.2010

Energy consumption of line 52 from simulation. All values are transferred to liters diesel equivalent. For diesel we calculate in this sample with a price of 1.10 € per liters, for electrical power 0.14 € per kWh and for hydrogen 6.80 € per kg.

9) Energie consumption by comparison

If you want to compare different technologies with regard to energy costs, than the simulation helps to get figures for the same selected line. We did this calculation for seven different power train concepts. All energy results are transferred to the equivalent "liter diesel / 100km". Otherwise, it has to be taken into account that the energy cost differ with the source and the marked situation.

On the line 53 in Munich we get simulated values of fuel / energy consumption and the "best case condition", that means: no extra heating, no air-condition, bus with 30% passengers.

Diesel bus	66,6	ltr diesel per 100km
Hybrid with Ultra Caps	45,5	ltr diesel per 100km
Hybrid with Battery	48,8	ltr diesel per 100km
Hybrid with Ultra Caps+Battery	41,8	ltr diesel per 100km
Fuel Cell with Ultra Cap+Battery	33,2	ltr diesel equivalent per 100km
Battery	16,4	ltr diesel equivalent per 100km
Battery with Ultra Caps **"Change it"**	15,5	ltr diesel equivalent per 100km

Figure 7: energy consumption form different power trains on line 53 by simulation

In a second step we took for energy costs as following values:

Diesel: 1,10 € per liter
Hydrogen: 5,00 € per kg
Electricity: 0,12 € per kWh

In any case these values are samples, because the prices change very fast over the time and region.

To get a complete imagination for the total cost we can add the expected serial cost for the technical concept and the energy costs over ten years.

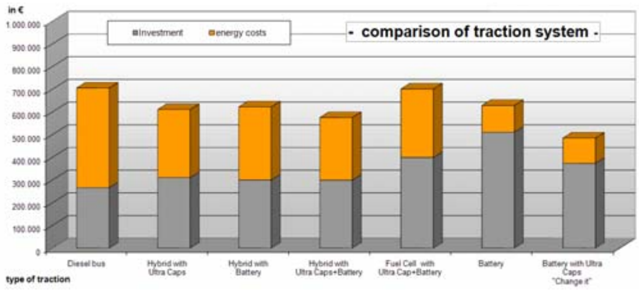

Figure 8: Investment and energy costs added

In general, this comparison is not very accurate because it is principally impossible to know what the prices for energy are and components in the future will be. But it demonstrates the importance that we use very efficient techniques for traction and storage elements. Thanks to the highest efficiency of the pure electric bus the orange part is small and, due to battery change, the investment in the technical structure is also manageable. One sixth of the costs for the battery swap station is to add to the grey block of investment.

10) Mechanical outlook

In the battery change system there is all electric equipment for charging included. It is save from vandalisms because all is in a height over 3,50m. The bus driver has to stop the bus in an area +-15cm as we know from car wash machines and the right place is indicated by a traffic light. The complete change is done fully automatically shorter than 3 minutes. The partly empty battery left behind will be charged during the bus is doing its usual route to the other terminal. Every 10 minutes, after the next bus has arrived, a fresh battery is available.

Figure 9:) Picture of Battery change system integrated in bus terminal "Aidenbachstr."

Here are some more samples showing how the Battery change system terminal station could look like.

Figure 10: change it for blue bus

Figure 11: change it for colorful bus

11) Safety

We can perform an optimal charge by virtue of a load slower than 1C this causes less stress for the battery.
The cooling system (air or water) can be designed and build easily and the necessary energy is provided by the charging station. If a battery shows an "abnormal" behavior during the loading process, the technical management will detect it and stop the charging. By informing the service team of the public transport agency, the maintenance can be triggered, while the bus will run on another reserve battery .

Due to the fact, that the charge equipment is more than three meters above the ground, there is no accessibility for persons in the high voltage area, it is safe from "vandalism" too.

In case of fire, flue gases can evade from the upper level directly into the air. Comfortable access for firemen is given.

Direct safety precautions:

A fire alarm system (smoke sensor / temperature sensor) will automatically warn the fire department if something should go wrong.

Theoretically, the station can also be equipped with CO_2 fire extinguishing system.

The load on the battery in the bus is moderate thanks to the support of the ultra capacitors. If the battery on the bus is in dysfunction, all the problems will concentrate on the roof and the passengers will have time enough to leave the bus for safety reasons. In case of a crash on the road, this will be an additional safety advantage. In rear-end collisions, the battery is relatively far away from the crash area (excluding rollover).

12) Benefits of "Change it"

zero emission	pure electrical drive, no exhaust
no fossil fuel	thanks to high efficiency proper for green electrical power
no higher costs	in case of high diesel prices the total costs are not higher
economical attractive	for a complete fleet over a period of 10 years you can save money
environment friendly	because of low energy consumption use of CO_2 free e-power possible
quiet	noise less traction system no vibrations

13) Marketing Aspects / Conclusion

Worldwide, 2-3 million buses in public transport are on the road. Accordingly profitable is the market for innovative technical alternatives. The concept of "Change it" is an economically attractive option for bus operators, electricity suppliers, cities and communities as an alternative to the existing diesel-fuelled public transportation. It can be used independently of the existing infrastructure in line operation. After a test phase and some optimizations, the battery system allows a bus operation completely independent of fossil fuels. A country's expenditures usually spent for purchasing oil from abroad, can be saved and re-directed into social and economical investments.

The first test operator is able to demonstrate its innovation power on the market. This is a great opportunity to present the most technological advancement of a company or city administration.

Because of the high efficiency of the system, the economic reasons for the use of renewable electricity are given. The reduction of CO_2 emissions contributes to achieve the agreed climate change targets. The zero emission and quiet driving will be in the interest of the inhabitants and bring a more appealing and eco-friendly image to this area.

References

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Dipl.-Ing.(FH) Stefan Wallner is CEO of a start up company which has the goal to improve efficiency. For EV´s he is specialist in simulation and analysis for best power train solutions.

Marketing-Betriebswirtin (VWA) Marlene Solis Weilbach
is responsible for Marketing and Sales at Wallner Energietechnik GmbH. She is a media expert and has large experience in international business.