Autobus with four minutes recharges at the ends of the line

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The Power Point Presentation will be available after the conference.

Abstract

Standard electric buses use battery energy storage for all the day long and night charges. The high energy imposes high weight, volume and cost with impact on bus performances and a long return of investment. Another solution is buses with ultracapacitors with a fast charge station at each bus stop, but with a huge infrastructure cost. The ElLiSup project is based on a small battery, to be light and to have a limited cost, and a fast charge but only at the ends of the buses lines, or at nodal points. The goal of the presentation is to detail the concept, the prototypes of buses (an plug-in hybrid one with fast charge and the electric one with four minutes recharges at the ends of the line) and the charge station.

1. ElLiSup project presentation

1.1. Electric buses technologies

A standard electric bus uses night charges and a high volume and weight of battery to provide a 100km range for all the day long. For example, the battery weight is around 2 Tons. Because the number of cycle per day is only one, the investment return of the battery is in the range of seven years. There is a difficulty for the bus supplier to prove the reliability of the battery for such a long time.

A second solution for electric buses is to use a small electric storage with ultracapacitors and a high power charge station at each bus stop. The advantage of this solution is the cost and high life time of ultracapacitors. For example, the electric storage is designed for twice the distance between two bus stops to be tolerant at one charge station failure. Ultracapacitors life time and number of cycle are well known, which is an advantage to calculate investment return. The disadvantage of the solution is the huge investment infrastructure for charge. For example, a 200 kW fast charge station with a 20kV connection is necessary at each bus stop. The great number of stations with the material cost and the one of square meters in town implies a huge investment. This point limits the development of this interesting technical solution.

The third solution is to use a small battery storage designed for the bus line distance and to charge at the ends of the line. We will detail this solution.

1.2. Battery buses with ends of the line charges

Lithium batteries are in constant progress. Now, some commercial power lithium batteries are adapted for fast charge. For example, for electric tools, small iron phosphate Lithium ion batteries are specified for a total fast charge in ten minutes. The impact on battery lifetime of such a fast recharge is limited.

In France, correlated to the size of the towns, around 30% of bus lines are less than eight kilometers long, and 65% of bus lines are longer but have nodal connection points and the segments are less than 8 kilometers long.

For the concept, fast charge stations are located at the ends of the line and at nodal points. Classically, the driver has a five minutes stops at this nodal and ends points. To provide the energy transfer in four to five minutes, a 200 kW station is necessary.

Because of the small number of stations, the infrastructure cost is low. At the ends of lines the square meter cost may be less expensive than in the town center.

The challenge of this solution is to have a battery with a competitive cost of use compared to diesel solutions. Because of electric vehicle markets the battery performances are in constant progress, and costs decrease.

In this application the number of cycles for the battery is around ten to fifteen per day. So the life time of the battery to be competitive is only about two or three years depending of the battery size. There is an optimization to do about battery technology and size with impacts on battery costs, losses, cooling requirements and number of cycles in real use.

1.3. ElLiSup project

ElLiSup is one of the projects of “Grenelle de l’environnement” in France to promote electric vehicle development. Two prototype buses are in development and a 350 kW charge station is build..

The first bus is the transformation of hybrid bus in a fast charge plug-in one.

The second bus is a full electric one with ends of the lines fast recharge.

The two buses and the high power charge station will be presented in this paper.

The partners of the project are:

- IRISBUS for buses development,
- Michelin for specific tires and active wheels,
- ERCTEEL for power electronics,
- EDF for performance and safety battery tests, electric buses experimentation and electric distribution network impact,
- IFSTTAR for battery tests, vehicle energy consumption modeling and environment tests,
- IFP for battery tests and modeling,
- CEA for battery test, BMS algorithms, and battery pack design and realization,
- RATP for bus demonstration in Paris,
- RECUPYL for recycling.

2. Bus prototypes

2.1. Fast charge plug-in hybrid bus

IRISBUS commercialize a CITELIS bus with a diesel electric series hybridization. The diesel engine is downsized. It’s a six liter Tector with 300 horse power. BAE provides the hybridization chain [1]. The electric generator is a magnet synchronous one with a 140 kW power. The motor is an asynchronous one, with a nominal electric power of 120 kW. Its maximum power is 175 kW. The battery is an iron phosphate one (LiFePO4) with 2,3Ah A123Systems cells. The design of the battery is optimized for efficient air cooling and crash acceleration tolerance. The battery is an 11 kWh one.

In real use, diesel consumption is 29 to 39 % lower due to stop-start and energy recovery at each bus stop.

Figure 1: plug-in hybrid bus

In the ElLiSup project one of the objectives is the evolution of one hybrid bus to be charged with the high power charge station. Because of the small size of the existing battery the charge is limited to 50 kW in the first step.

A pantograph is designed and installed on the bus roof.

The objective of the plug-in modification is to provide a part of full electric range in the applications, for example for historic centers or pedestrian zones or to cross a tunnel without pollution. The full electric range is 3-4 kilometers. There is a compromise between battery lifetime and full electric range to adjust for the application.

Higher electric range may be provided by high energy storage in the battery. The 11 kWh existing battery is a very small one.

2.2. Electric bus with fast charges at the ends of the line

This electric bus uses batteries and ultracapacitors.

Ultracapacitors store the recovery energy at each bus stop and this energy is used for the bus restart.

The mean energy is stored in the battery to provide the height to ten kilometers range. At the ends of the line or at nodal points the energy is supplied in four or five minutes by the charge station.

For height to ten kilometers the energy to store is ten times less important than a standard electric bus with a 100 km range. To provide lifetime, the size of the battery is only tree time less important than a standard one. So the charge is a partial one with around 30% of deep of discharge.

Ultracapacitors are well adapted for millions of cycles but for low energy storage, for example some hundreds of watt.hour.

In the ElLISup electric bus concept ultracapacitors and batteries are associated. Ultracapacitors are used for braking energy recovery because there is one or two millions of braking cycles in a bus life and ultracapacitors are adapted for this number of cycles. Batteries are used for the main storage.

In the project, the impact of braking energy recovery on the lifetime of the battery is studied, to know if ultracapacitors use has a real impact on batteries lifetime, or if the fast charge batteries may bear the braking recovery cycles.

There are four 18 kWh battery packs and an ultracapacitors one. A bidirectional 80 kW converter is used in series with each battery pack and ultracapacitors one.

So a total energy management is possible with or without ultracapacitors, with full battery or a partial one.

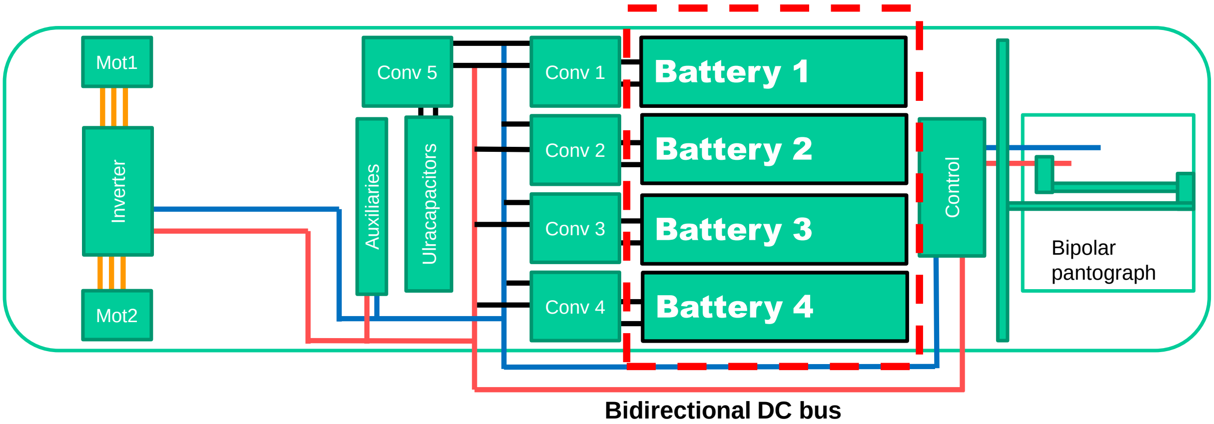


Figure 2: bus electrical architecture

2.3. Michelin Active wheel

The bus uses Michelin active wheels.

Figure 3: Michelin active wheel

Michelin Active Wheel is known a standard wheel that houses a pair of electric motors. One of the motors spins the wheel and transmits power to the ground, while the other acts as an active suspension system to improve comfort, handling and stability. The technology is such that a vehicle equipped with it will no longer need any gearbox, clutch, transmission shaft, universal joint or anti-roll bar. Active Wheel's compact drive motor and integrated suspension system has also enabled designers to fit a standard brake disc between the motors, which means the braking, drive and suspension components are all fitted within the single wheel.

For ElLiSup bus a specific active wheel is designed with adapted power for heavy vehicle traction motor and a mechanical brake but without active suspension. The system also allows torque from the motors to be electronically controlled for each individual wheel independently. The results are similar to the effects of an active differential.

Due to Michelin electric wheel and specific tires the design of the bus is optimized to provide more space.

Figure 4: space improvement

2.4. Lithium ion batteries

On the bus, four lithium ion battery packs are used. The nominal energy storage of each pack is 18 kWh. The packs are on the roof in parallel with an air cooling system. Each pack is associated with a bidirectional converter to manage energy transfer in charge and discharge.

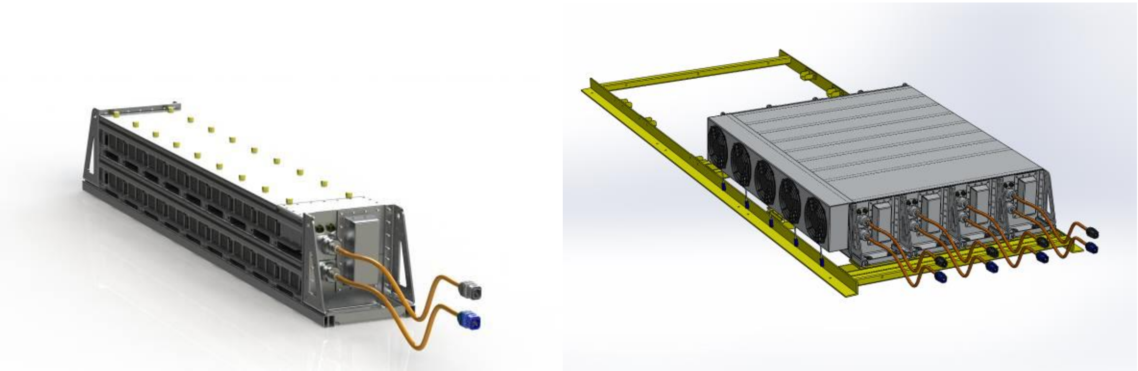


Figure 5: Battery packs

Lithium ion batteries need voltage monitoring to limit maximum and minimum voltage of each accumulator and balancing circuits.

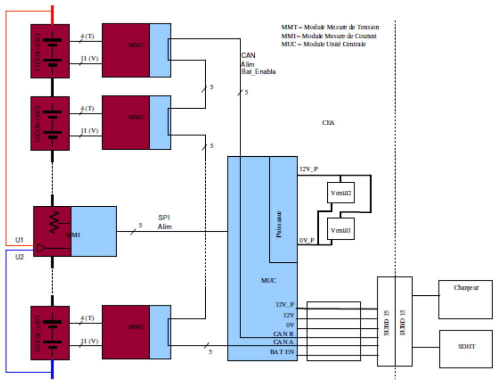


Figure 6: Battery Management System

Each battery pack has a Battery Management System. In each module an electronic card monitors each cell voltage and module temperature. The data are transmitted with CAN network. The current is measured by shunt to provide high precision from some Amps to 200 Amps. In central microcontroller the algorithms calculate the battery states: state of charge, state of energy, state of health, state of security.

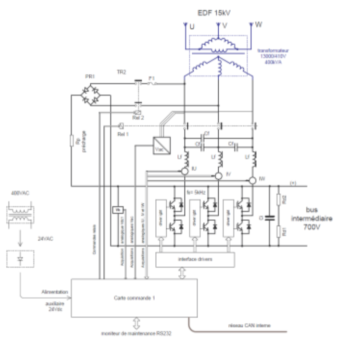
Figure 7: BMS central microcontroller

3. Recharge station

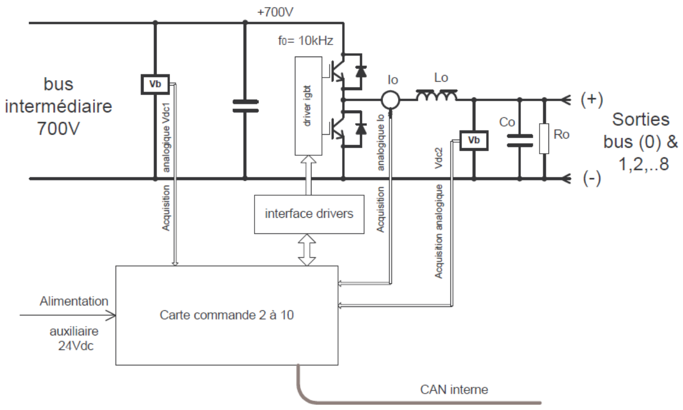
The recharge station in CEA is designed for 350 kW to supply the two buses in parallel.

Figure 8: CEA 350kW charge station

The recharge station is supplied with 15kV (or 20 kV) voltage to have a negligible impact on the electrical network. A standard transformer provides an isolated 400 V main.



An inverter absorbs sinusoidal current on the three phases to generate a 700 V intermediary bus.



Bidirectional buck converters are used to provide a constant voltage output to supply the bus.

To charge only one bus simultaneously the station may be a current source.

To charge buses in parallel, the station is a voltage source and each bus has converters to absorb the level of current on the station. This choice has been done for the project.

Because of the 350 kW power, nine 40 kW buck converters are used in parallel.

In the station in CEA, converters are connected in parallel for the four minutes buses charges and a used independently for battery cycling tests when no bus are present. So the station has to be bidirectional. High voltage vacuum relays are used for the connections and disconnections to the batteries in test or to the bus charge connexion.

The charge station is designed to minimize the pollution impacts: power factor, EMC, flicker and noise.

4. Conclusion

Now the plug-in hybrid bus is in test with CEA with the 350 kW charge station to optimize the different modes.

The electric bus with four minutes recharges at the ends of the line is totally defined and is in construction. Michelin electric motor was tested. Lithium-ion battery modules are qualified.

Four battery packs for the bus and two additional ones for lifetime test on the station are now in construction.

5. Literature

[1] BAE/Orion Hybrid Electric Buses at New York City Transit, A Generational Comparison, R. Barnitt, Technical Report NREL/TP-540-42217, National Renewable Energy Laboratory