STEEM: ALSTOM and RATP experience of supercapacitors in tramway operation

Jean-Paul Moskowitz
Alstom Transport
Transport Global Solutions
Saint-Ouen, France
jean-paul.moskowitz@transport.alstom.com

Jean-Luc Cohuau
RATP
Département du Matériel Roulant Ferroviaire
Paris, France
jean-luc.cohuau@ratp.fr

***Abstract*— The STEEM project is a research and experimentation project in public transport. Its goal is twofold: increase tramway systems energy efficiency and allow a vehicle to run without overhead contact lines. It associates a tram manufacturer (Alstom), a public transport operator (RATP) and a public research laboratory (INRETS) with the financial support of the French governmental agency ADEME under a PREDIT program. It is based on the use of onboard supercapacitors, and a demonstrator has been installed on an existing tramway of RATP T3 line. This vehicle is running in revenue service since late 2009 and delivers its first promising results.**

Keywords: Tramways, Energy efficiency, Energy Storage, Supercapacitors, Catenaryless

I. INTRODUCTION

STEEM is a French acronym for *Système Tramway à Efficacité Energétique Maximisée*, or *Maximised Energy Efficiency Tramway System*. This Research & Development project has been performed as a partnership associating Alstom Transport, RATP and INRETS and is supported by the French governmental agency ADEME under a PREDIT program (French Framework Program on Research, Experimentation and Innovation in land Transport). This project studied different technological solutions, from simulations to full-size prototypes, with a twofold objective:

- increase significantly the global energy efficiency of tramway systems, by reducing the energy consumption of the vehicles, and
- allow a vehicle to run without overhead contact line.

In this paper, we shall explain the origin of the project, remind the state of the art, describe the solutions adopted and present the first results.

II. NEW MARKET REQUIREMENTS

A. A continuously growing need for public guided transport

In order to cope with the growth of population and inherent congestion of their centres, many cities have opted for urban public transport during the last decades. Running at grade level and fed by an overhead contact line, tramways require a much smaller investment cost than metros. They use electrical traction and are emission-free vehicles whereas buses rely on petroleum. Therefore more and more cities in the world decide to create a light rail system.

B. New market requirements: visual impact and energy optimisation

New considerations emerged with the generalisation of this transport mode. The visual impact of the catenary becomes a concern for many cities, in particular those with a preserved historical centre. They require the absence of catenary on one or more interstations. On a smaller scale some request this ability to cross a crossroad.

Beyond these considerations for the visual impact of the light rail system, more and more transport authorities are concerned with energy optimisation, and the necessity to reduce energy consumption as a way to fight global warming.

III. STATE OF THE ART

As an alternative to the Overhead Contact Line (OCL) on some parts of the line, one can either supply continuously the energy through the ground or store the energy onboard the vehicle.

Catenaryless operation is already in revenue service in a couple of cities. The first system ever installed, APS (Alimentation Par le Sol, or Ground Power Supply), uses a conducting rail integrated into track platform. This conducting rail is split into segments separated by insulated joints. No more than one or two segments can be live simultaneously and the length of the segment is such that live segments will always be situated below the vehicle and between its end axles. APS has been put in revenue service in 2003 in Bordeaux where it allows 14 km of operation without catenary. APS is described in [1] and is now under installation in Reims, Orléans, Angers, Brasilia and Dubai.

Another solution has been chosen for the 20 Citadis tramways of the city of Nice. The requirement for catenaryless operation was limited to two squares in the city centre, each of about 450m. The technology of NiMH batteries was chosen and the line has been put in revenue service with success in 2007.

978-1-4244-8218-4/10/$26.00 ©2010 IEEE

The battery system offers limited performances, and the APS system implies ground infrastructure and is best suited for high performances, similar to catenary, with no limits on auxiliaries' consumption and duration of unscheduled stops.

To improve energy efficiency when no catenaryless section is required, one can also choose a reversible substation. Alstom has build and tested such a prototype in La Rochelle: HESOP (Harmonic and Energy Saving Optimizer), which allows to recover 99% of the tramway braking energy [2] for operation under OCL.

Past experiences have studied on-board energy system, to address the two requirements. A demonstration with a flywheel was conducted in Rotterdam [3], and some experiments with supercapacitors or hybrid storage have also been described [4], [5], [6] and [7].

IV. The STEEM vehicle

To use onboard Energy Storage, one has to know the amount of energy needed to fulfil the tramway's mission, both for traction and for auxiliaries' consumption. This energy depends on the line characteristics: track profile, distance between stations … and on the operational modes: commercial speed, comfort level, number of unscheduled stops between stations …

For a given tramway line, characterised by the positions of stations, gradients, curves, speed limits, we take into consideration the rolling stock performances and operational conditions and describe the objective performances in terms of speed profile and energy requirements station by station.

For the STEEM project, we chose to develop an on-board energy storage system made of supercapacitors. The system has been installed on a RATP Citadis tramway and is running on line T3 in Paris network.

Supercapacitors have a very high power density that enables quick recharge during a small period of time. The system, roof-mounted on the tramway, allows energy optimisation by permitting braking energy recovery even when the line is not receptive.

The energy storage system also enables tramways to run without catenary. Relying solely on its onboard energy, the vehicle can run from one station to the next one. To extend the catenary-less section of the line, a quick recharge device in station can be used. A GPS-based localization system and an energy management module define the best way to store and deliver the energy for both economy and autonomy modes.

Fig. 1 shows the profile of RATP tramway line T3 and indicates the energy content, for each interstation and each direction. The figures were calculated with a Citadis 402 vehicle, with a load AW3 (6 passengers/m²), as explained in table I.

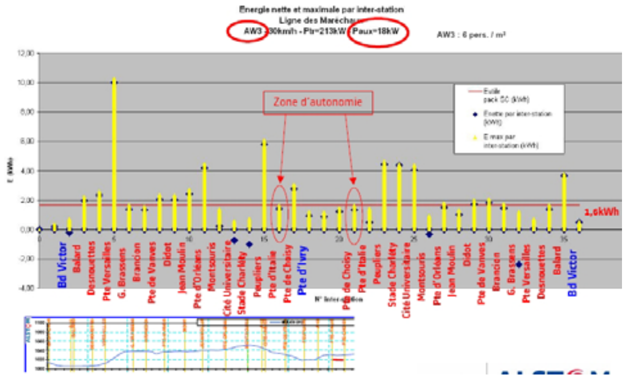

Figure 1. Example of energy content

We used 54V – 130F modules assembled in series-parallel, for a total of 48 such modules. The usable energy is 1.6 kWh. The complete box, with the modules and the associated power electronics and control-command, appears in Fig. 2.

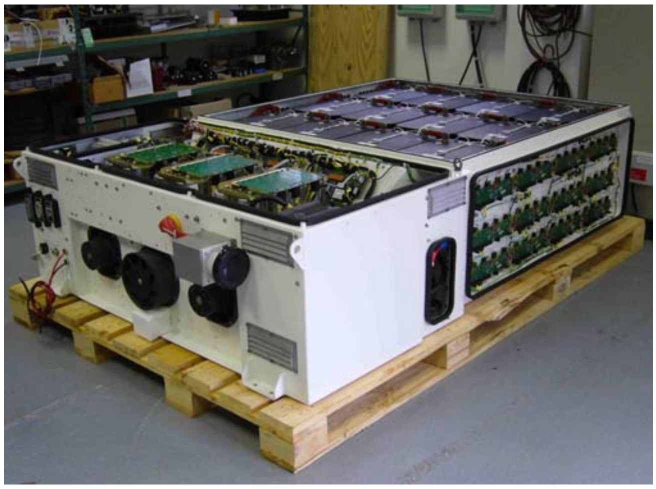

Figure 2. Supercaps box with its power electronics

The vehicle chosen for the project is one of the 21 Citadis 402 trams running on RATP line T3. It is important to notice that this is a very capacitive vehicle, whose main characteristics are given in table 1.

TABLE I. Characteristics of Citadis 402

Nominal voltage	750 V DC
Vehicle length	43.7 m
Vehicle width	2.65 m
AW0: Tare weight	57 tons
weight in AW2: with 4 passengers/m²	78 tons
weight in AW3: with 6 passengers/m²	86 tons
number of seats	78
capacity in AW2 (4 passengers/m²)	78 seated + 226 standees = 304 passengers
capacity in AW3 (6 passengers/m²)	78 seated + 339 standees = 417 passengers

The supercapacitors box was installed on the roof of the existing vehicle to keep passenger capacity unchanged. Fig. 3

show its integration, the supercapacitors box being represented as a green rectangle.

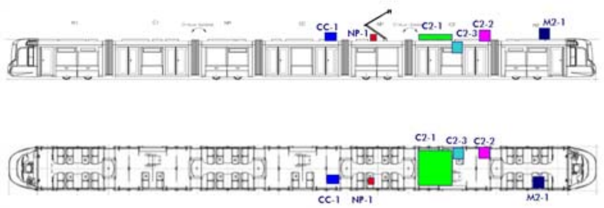

Figure 3. Installation of Supercapacitors on roof of RATP Citadis

V. SUMMARY OF TESTS

In order to validate the performances of the solution and to get the certification to be allowed to transport people in revenue service, tests were performed at different levels, from supercapacitors modules to train loaded in AW3 running on line.

The supercapacitors modules have been submitted to performance and abusive tests (fire, high temperature, crush test). With their associated chopper and a complete traction equipment, they were tested on Alstom Tarbes test bench. The RATP Citadis, once modified and equipped with the supercapacitor box, went through dynamic tests on La Rochelle test track before being sent back to Paris. The complete certification file was produced and submitted to the authorities and Certifer, the French notified body, delivered an authorisation to run in revenue service with passengers.

VI. MAIN RESULTS

The tram is running in revenue service with passengers since late 2009. Large posters installed inside and outside of the vehicle inform the public that they are riding an experimental train, in an operation supported by ADEME.

Figure 4. Annouce inside vehicle informing the public

A. *Notice for results meaning. T3 line receptivity*

In order to analyse a transport experimental result, one has to take into consideration the size of the rolling stock and the configuration of the line. RATP and Alstom have chosen the most capacitive vehicle, which is therefore the heaviest and needs the more energy to move and run without external power supply.

For energy savings, one has to consider line receptivity: regenerative braking depends on the possibility for other trains to reuse the energy sent back through the catenary. Receptivity depends on several factors, among which traffic density, train positions and line voltage. The heavier the traffic, the higher the line receptivity (during peak hours, there are more chances to find a train needing energy to accelerate close to a given train which is braking).

The added-value of using an Energy Storage System (ESS) will appear higher if it is used on a line with a smaller receptivity. In such a case, when a train is braking and no other vehicle on the line can reuse braking energy, this braking energy is dissipated in a braking rheostat. The presence of an ESS on board will lower the rheostatic losses.

On the other hand, in case of a high line receptivity, an onboard ESS will be less needed since braking energy can be reused by another train.

Similarly, during winter and summer when auxiliaries' consumption is higher due to heating or air-conditionning, the added-value of an onboard ESS is lower: braking energy will be first reused in the braking vehicle to supply its own auxiliaries.

T3 line has a very high receptivity, because it is a short line (7.9 km) which is operated with a large fleet of capacitive trams (40m-long) running with a short headway: 4 minutes. During peak hours, 16 trams are running , which makes a ratio greater than 2 trams/km. For comparison, most tramway lines in France have a ratio smaller than 1.5 trams/km, often with 30m-long vehicles.

B. *Catenaryless operation*

RATP and Alstom decided to run in catenaryless operation from Porte d'Italie to Porte de Choisy, a 300m long interstation. It makes STEEM the first tramway with supercapacitors in revenue service for catenaryless operation. Since the overhead contact line is installed all along the line, the STEEM vehicle lowers its pantograph while it is stopped at the passenger station, runs with its pantograph lowered all along the interstation, and rises its pantograph while it is stopped at the next passenger station.

Fig. 5 represents in a red rectangle the interstation run with the pantograph lowered.

Figure 5. Line T3 plan and catenaryless operation

This configuration was chosen taking into account the energy requirements listed in Fig. 1. Before going into revenue service, tests were performed in all load configurations (from AW0 to AW3: with 6 passengers/m²).

Today the vehicle runs in revenue service, as shown in Fig. 6, and the catenaryless interstation is operated automatically, thanks to a GPS-based localisation. The ability to meet one or two unscheduled stops during this run has been confirmed.

Figure 6. Train 301 running pantograph lowered

This ability to run without catenary is a key benefit for the customer. RATP is taking these results into consideration for the definition of future lines, for the crossing of some roads, or crossing of civil works (ability to go under a bridge with less civil works impact). Quick recharge tests through the pantograph and a rigid catenary have also been done in a complete quick recharge station installed in the RATP depot.

C. *Energy saving operation*

The other key customer benefit is the energy consumption reduction, with and without catenary. A new simulation tool was developed to take into consideration the mean consumption of a complete fleet, whereas traditional tools consider worst case for sizing the infrastructure.

When a modern tramway brakes, it regenerates electric energy that is sent through the overhead line only if it can be used by another vehicle requiring energy somewhere along the line. Losses by Joule effect occur along the catenary. Supercapacitors allows storing braking energy on board the vehicle. This energy will be later reused by the same vehicle when needed for traction or auxiliary consumption.

With the control strategy currently under test on the vehicle in real operational conditions, during regenerative braking, the available energy is first used by the auxiliaries of the tram. This avoids all losses either by Joule effect along the OCL or the efficiency of the supercaps and chopper. The complement of the braking energy is then used for recovery by other trains, and if the line is no longer receptive energy is stored in the onboard ESS for later reuse. In case the ESS is fully charged, the energy is dissipated in the braking rheostat.

Measures performed in winter time show effectively a smaller energy reduction. During some days when the weather was rather cold, the vehicle requires more energy for its auxiliaries than for traction.

Measures performed in spring time with a mild climate have shown an average daily energy reduction of about 13%, with values between 10 and 18%. This values are obtained on a line with a very high receptivity, with 16 40m-long trams running on a 8 km-long line at peak hours.

Others results were obtained by comparing the energy consumed by the STEEM tram and another witness tram, running at the same time during the same periods of time.

Fig. 7 shows the difference in energy during a given day. The energy consumption depends also on the driver’s way of driving, the load of the vehicles, the traffic conditions. A long term study is necessary to smoothen these variations and avoid any bias in the results.

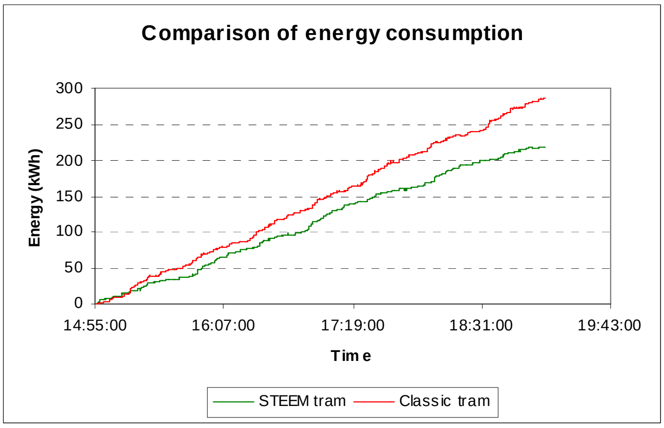

Figure 7. Comparison of energy consumption between the STEEM tram and another tram

VII. CONCLUSIONS

Supercapacitors have a very high power density that enables quick recharge during a small period of time. This technology allows both energy optimisation and autonomy from the overhead line.

The STEEM project consisted in the development of an on-board energy storage system made of supercapacitors. The ESS has been roof-mounted on a RATP Citadis, extensively tested, certified by an independent agency and is running in revenue service on Paris tramway line T3.

The energy consumption of the demonstration vehicle has been reduced. The energy storage system also enables the tramway to run without catenary. Relying solely on its onboard energy, the vehicle can run from one station to the next one. For this kind of operation, the operational environment appears to be of paramount importance, and shows the benefit of associating a manufacturer and a public operator for this kind of research project.

ACKNOWLEDGMENT

This project is being supported by the French governmental agency ADEME under a PREDIT program (French Framework Program on Research, Experimentation and Innovation in land Transport)

REFERENCES

[1] T. Ficat, J-P Caron, G. Baudienville, and B. Ciry, « APS : l’Alimentation Par le Sol, une solution rénovatrice pour les tramways », Revue Générale des Chemins de Fer, avril 2009, pp. 25-40.

[2] Daniel Cornic, “Pilot project for reversible DC substation”, UIC energy Efficiency Days 2009, Tours, september 2009.

[3] J-P Moskowitz , “Alstom puts a nail in the coffin of catenary“,European Rail Outlook, september 2005, pp. 27-28.

[4] F. Lacôte, “Innovative solutions for a perfect integration of the urban transport system in the city”, 56th UITP world congress, Roma, June 2005.

[5] M. Meinert, “New mobile energy storage system for rolling stock”, 13th European Conference on Power Electronics and Applications, 2009. EPE '09, 2009 , pp. 1-10 ;

[6] M. Fröhlich, M. Klohr, and S. Pagiela, “Energy storage system with ultracaps on board of railway vehicles“, WCRR 2008

[7] F. Lacôte, “Alstom – future trends in railway transportation”, Japan Railway & Transport Review 42, december 2005, pp. 4-9.