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Innovative Technologies for Light Rail and Tram: A European reference resource

Briefing Paper 5
Hybrid Battery/Supercapacitor - Hybrid Electric and Rapid Accumulator Systems
September 2015


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Sustainable transport for North-West Europe's periphery

Sintropher is a five-year €23m transnational cooperation project with the aim of enhancing local and regional transport provision to, from and withing five peripheral regions in North-West Europe.

INTERREG IVB

Investing in Opportunities

This project has received European Regional Development Funding through INTERREG IV B.

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INTERREG IVB North-West Europe is a financial instrument of the European Union's Cohesion Policy. It funds projects which support transnational cooperation.

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INTERREG IVB

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Report produced by University College London

Lead Partner of Sintropher project

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Background

This briefing paper is one of a series that together comprise a European reference resource for innovative technologies rail-based based systems, with particular reference to light rail and tram-based schemes in cities and regions. The approaches are also relevant, in many cases, to heavy rail and even other forms of public transport for example bus.

The resource is one of the Investments undertaken for the Sintropher project funded under the INTERREG IVB North West Europe Programme for transnational co-operation. The overall aim of Sintropher project is to develop sustainable, cost-effective solutions to improve connectivity to, from and within poorly connected regions in North-West Europe - to use innovative transport links to connect peripheral regions of NWE with the core European transport network of high-speed trains, via effective interchange hubs.

There has been a particular focus on tram-train systems which allow local trams to run on to national rail networks, pioneered in Germany, firstly in Karlsruhe and developed in Kassel, which allow urban tram systems to extend over national rail tracks to serve extensive city regions. The project has also looked at other innovative forms of tram systems such as single-track tramways, as well as high-quality transport interchanges that link such systems to major national or transnational rail or air hubs.

The project began in late 2009, with fourteen partner agencies in five EU Member States, and lead partner University College London (UCL): Valenciennes (France); the Fylde Coast (UK); West Flanders (Belgium); North Hesse (Germany); and Arnhem-Nijmegen (Netherlands).Participants included public transport operators, local authorities, regional transport agencies, and universities.

They have worked together on a series of feasibility evaluations, pilot investments and demonstration projects, as well as comparative analyses of EU best practice. The total budget is more than €23m, with funding part-financed by the EU's INTERREG IVB Programme.

A €1.5m project extension in 2014, covers follow-on work to capitalise on results from the initial project, and added a fifth objective: to test technologies for low cost transport links in different territorial contexts, plus integrated territorial corridor plans that help these links unlock wider economic and regeneration benefits; and better recognise these in business cases. This included two new partners (total now 16) and two extra demonstration regions (total now 7) in West Flanders Brugge-Zeebrugge (Belgium) and Saar-Moselle (a cross-border region France-Germany).

Innovative technologies for light rail and tram – developing opportunities

Previous results from Sintropher show that low-cost systems, such as tram-train, tram-rail, and single-track tram systems, have clear potential but there is no single "best" solution and these opportunities must be assessed and adapted to city/regional circumstances. (Sintropher Report *Connecting European regions using Innovative Transport. Investing in light rail and tram systems: technological and organisational dimensions.* See references at end.)

Additionally over the 5 years of Sintropher, there have been dramatic developments in relevant transport technologies. The most important are (a) very long-life batteries that allow electric trams and trains to operate over substantial distances "off the wire"; (b) charging devices that boost battery life by recharging at stops en route – e.g. the supercapacitator technology demonstrated at the 2010 Shanghai Expo, or the induction system employed by Bombardier in their Remove trams and buses; (c) discontinuous electrification that allows electric trains and trams to "coast" under bridges and through short tunnels where it would be impossible or prohibitively expensive to install overhead catenary.

Also, a recent Report by UK Network Rail *"Network RUS: Alternative Solutions"* (July 2013) - an input to its Route Utilisation Strategy for long-term planning of the national rail network - has reviewed these developments. This work followed a remit to think imaginatively about cost effective solutions for accommodating growth in UK passenger demand, and operating services more efficiently. The solutions which are considered in the UK context are generally over and above the conventional solutions such as types of rolling stock and 25kV AC overhead line electrification. It looked at tram-train, tram systems, battery-powered vehicles, hybrid light rail, personal rapid transit, bus rapid transit and guided bus, and electrification solutions for lightly-used routes. Its main focus is existing rail lines in the UK network, but it can also be used to consider options for new transport corridors in urban areas.

The Report's overall comment is "Whilst some of the solutions are close to an appropriate stage of development (or adaption) for introduction onto the UK rail network, others will require more attention, for example on battery technology. It is important to be aware that, by definition, a process of innovation is a process of change and that some technologies that are not listed as appropriate at present may become appropriate after further development work. It is possible that over the next 30 years there may be some significant technological developments that could reshape the market for public transport and how it is powered."

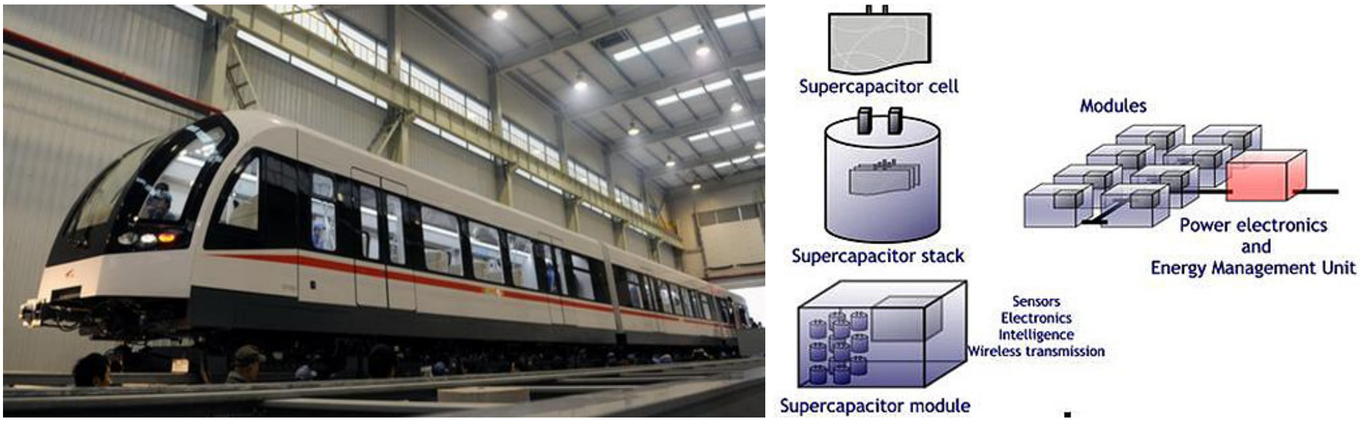
So within the project's partner regions, there has been further feasibility work to test these kinds of innovative low-cost solutions in different city/regional contexts, including new developments in technical solutions.

The European reference resource informs project partners' work, and is also intended to be of relevance to much wider audiences especially. Particular target audiences are governmental authorities and transport agencies at city, regional, national and EU levels; and transport professionals and practitioners who may be involved in the initiation and implementation of new transport links

The reference resource is a snapshot in time (September 2015) and obviously the field of technologies is developing on an ongoing basis - it is hoped to update the briefing papers periodically as necessary.

Super-capacitor/Hybrid Trams

Super-capacitors and super-capacitor/battery hybrid trams are a relatively new addition to catenary-free tram technologies. These trams have evolved from battery-powered or -assisted trams as an alternative method of energy storage and capture. Generally, super-capacitor trams have short operational ranges and charge quickly at stations or points of rest. Most super-capacitor systems are paired with traction batteries to provide both high outputs during acceleration and to extend ranges during regular operation and cruising. Bombardier, Siemens, and CAF are all currently developing and offering super-capacitor/battery hybrid trams with varying systems. Chinese light rail manufacturer CSR has also developed a solely super-capacitor tram at its facilities in Guangzhou with plans to enter operation before 2020.



Left: The Guangzhou super-capacitor tram developed in tandem with CSR. Right: Schematics of a super-capacitor module.

Technology

Super-capacitors have much lower energy capacities compared to batteries but offer greater charge densities. These densities can be 10 to 100 times greater than those of batteries and offer significant output during acceleration or climbing gradients and are achieved through the 'physical rather than chemical' storage of the energy. The structure of super-capacitors, namely the method by which they store their charge, allows them to be charged and discharged over 100,000 times - far exceeding the number of cycles capable by traditional batteries which average 2,000 to 40,000 cycles. Super-capacitors are also able to capture power from braking sections of track through regenerative breaking, providing further charging and power generation capacities.

With the exception of the Guangzhou super-capacitor-only tram, all trams using the technology to date are super-capacitor/battery hybrids. The batteries help to provide power through maintaining speeds on level segments of track while the super-capacitors help to provide additional high-current power during acceleration and climbing gradients. These trams average top operational speeds of anywhere between 45 to 70 km/h and average catenary-free operational distances of between 800m and 2.5 km before recharging. There are a number of super-capacitor-enabled systems available on market with CAF's 'Rapid Charge Accumulator' (ACR), Bombardier's 'Mitrac Energy Saver' (MES), and Siemens' 'Hybrid Energy Storage' (HES) the most popular.

Attractiveness

- Offer greater energy densities and outputs than traction batteries.
- Significantly greater number of life cycles than traction batteries.
- Extremely short recharge times of 10-30 seconds, allowing for near-full recharges at stations.
- Do not use fossil fuels and improve air quality along lines.
- Do not require expensive third rail technologies such as electrified ground rails.
- Can be installed on tradition tram carriages and integrated into propulsion systems.
- Technology supported and in development by many high-end engineering companies, promising significant improvements and upgrades in next decade.

Risks

- Currently one of the most expensive tram technologies.
- Very low energy capacities, generally requiring auxiliary or assistant systems to fully operate catenary-free.
- High maintenance and replacement costs, although greater life expectancy than traction batteries.

Track Record

While initial development and uptake was slow, super-capacitor trams are now in use (mostly as super-capacitor/battery hybrids) on a number of networks globally. Spain, Portugal, and China in particular have been early adopters and innovators with Taiwan, France, Germany, and the UK also either currently operating or planning super-capacitor-equipped tram networks. Super-capacitor trams are currently being engineered and installed in Qatar and Taiwan.

Hybrid Electric Storage Case Study Example: Almada-Seixal, Portugal

Rapid Charge Accumulation Case Study Example: Seville, Spain

Hybrid Electric Storage Case Study: Almada-Seixal Tram

System Specifications:

Lines:
Line 1 (Cacilhas – Corroios), Line 2 (Corroios – Pragal), Line 3 (Cacilhad – Universidade). Total length 13 km.

Rolling Stock: 24 Combino Plus four-section, 100% low-floor, bi-directional cars. Capacity: 338 passengers.

Equipped with a Mobile Energy Storage unit comprised of double-layered super-capacitors and a NiMH battery.

Status: In service April 2007, first vehicle delivered 2005.

Cost: Unknown.

Ridership: Unknown, increasing year-over-year.

Why was the technology chosen in Almada-Seixal?

Stakeholder relationships: In order to deliver the new network the Portuguese Government establish the Metro Transportes do Sul (MTS) to oversee development and operations. Siemens is a stakeholder of this organisation.

Benefits

- With a 20km extension planned, the super-capacitor/hybrid trams allow for greater flexibility in network design.
- HES trams reduce power consumption and emissions by up to 30% making the corridor a “green” investment.

Drawbacks

- Initial procurement and engineering costs were significantly higher than other catenary-free options available on the market.

Assessment

See below.

Future Prospects and Transnational Relevance

See below.

Rapid Charge Accumulator Case Study: Seville Tram

System Specifications:

Lines: MetroCentro (T1) tramline, 2.7 km in length.

Rolling Stock: CAF Urbos 3

Status: Full service 2012.

Cost: Unknown.

Ridership: Unknown.

Why was the technology chosen in Seville?

Inner-city Festivals: Each year the City of Seville administration would take down overhead wires in the central district to allow Easter parades and processions to pass without restriction. ACR technology now allows for the entire inner-city portion to remain catenary-free year round.

National Investment: As CAF is a Spanish company, it was seen as desirable to support tram technology development from a national engineering firm.

Benefits

- Eliminated yearly wire removal/replacement costs.
- Improved downtown urban atmosphere.

Drawbacks

- Initial replacement costs high.

Assessment

Super-capacitor/battery hybrid trams in both Portugal and Spain have been extremely successful. While the range of these systems is limited they are well-suited to downtown core catenary replacement schemes and supporting catenary-free operations on shorter lines. Reliability has improved for both aforementioned networks and there are plans to expand catenary-free operation on the Almada-Seixal line.

Future Prospects and Transnational Relevance

Super-capacitor/battery hybrid trams have received significant attention in the last decade. With improvements in battery technology, reductions in the capital costs of super-capacitor modules, and greater energy recapture efficiencies from regenerative braking being developed super-capacitor and super-capacitor/battery hybrid trams have the potential to become the catenary-free choice for developed nations.

Transnational relevance

The technologies and approaches and city/region case examples on the reference resource are context-specific and reflect:

- the geographical context: for example the extent of the urban or regional rail (and/or tram) network and degered of electrification or non-electrification; density of traffic; extent of urban and rural areas; and physical urban conditions such as street width, environmental conditions, historic areas.
- the technical context: the national regime of technical standards for rail or tram infrastructure, rolling-stock vehicles, rail electrification power supply.
- the regulatory context: the national regime for matters especially safety standards, CO2 emissions, environmental impact.

Some of the technical and regulatory matters are EU-wide. A Sintropher Report on the technological and organisational aspects of innovative tram-based systems looks at the desirability of greater harmonisation across Member States where different standards exist (see references).

These potential low-cost solutions now need to be tested in different regional cases in EU Member States. There are some distinct physical differences:

- rail systems in most Member States were built at lower cost than in the UK, with fewer over-bridges and more at-grade road/rail crossings, which may reduce the benefits of some technological alternatives (e.g. discontinuous electrification).
- many areas have historic towns where conservation considerations make overhead catenary undesirable, increasing the advantage of battery-based solutions.
- in many European countries, in contrast to the UK, many urban tram systems have been maintained, or even constructed in the last 20 years, making tram-train solutions more relevant.

Even though the various approaches and case examples are context-specific, their transnational relevance is strong:

- the approaches offer a stimulus and possibilities for wider thinking by cities and regions in other European countries
- some or all of the various approaches might be potentially adaptable within the particular organisational and governance regime of another country, and technical and regulatory regime. For example the Governments' UK tram-train trial in Sheffield, Network Rail's UK trial with battery power for trains on a non-electrified heavy rail line in East Anglia, and (in Sintropher) Province Gelderland's feasibility studies for battery power to enable electric trains to operate on non-electrified routes in their regional network..

The reference resource should be seen from this perspective, as a means to promote knowledge transfer and learning across different NWE countries and regions.

Sources

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Further information

This paper was produced by UCL Bartlett School of Planning (Sintropher team members Charles King, Giacomo Vecia, Imogen Thompson) using desk research and expert comment. The paper reflects the views of the authors and should not be taken to be the formal view of UCL or Sintropher project

The European reference resource can be accessed on the following:

Sintropher project website

http://www.sintropher.eu/publications

POLIS website

http://www.polisnetwork.eu/sintropher or http://www.polisnetwork.eu/res/resources

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Co-funded by the INTERREG IVB programme for North-West Europe


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