Welcome to the best practice workshop

BATTERY TRAINS

Proposed by the UIC Energy efficiency and CO₂ Emissions Sector

Organised by the Sector’s Chairpersons:

Bart Van der Spiegel, Infrabel,
Gerald Olde Monnikhof, ProRail.
Philippe Stefanos, UIC
BATTERY TRAINS

- The meeting will be recorded.
- Please remain on mute while the speaker is active.
- Please keep your camera off while the speaker is active.
# Workshop timeline

**10 h  First part**

- **Arup**
  - Robert Davies

- **Transport and Mobility Leuven**
  - Christophe Heyndrickx

- **TUC Rail**
  - Paul Tobback

**11 h  Second part**

- **SNCF**
  - François Degardin
  - Bogdan Vulturescu
  - Matthieu Renault
  - Benoît Gachet

- **Siemens**
  - Katrin Seeger

- **Eaton**
  - Akos Labady
ARUP ROLLING STOCK

Battery Train Procurement

Robert DAVIES
Global Rolling Stock Leader - Arup

UIC battery trains - 19 May 2021 Online Workshop
# Rolling Stock

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Welcome to Arup

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists, working across every aspect of the built environment.

Together we help our clients solve their most complex challenges – turning exciting ideas into tangible reality as we strive to find a better way and shape a better world.

We

• Design quality infrastructure and experiences for people and communities
• Deliver major programmes and develop high performing organisations
• Integrate complex new technologies and systems
• Unlock financial value for investors, asset owners and operators
• Optimise performance and value from existing and new assets
Traction battery – operations concept

Example modes
Independent Battery Powered
Independent Battery Powered with hydrogen fuel cell
Bi-mode with AC external pantograph
Bi-mode with DC external pantograph or power rail
Bi-mode with diesel engine

Rail systems
Light Rail
Metro
Regional and Suburban
High speed and Intercity
Freight
Track Plant and Engineering Trains
Rolling Stock – Battery Solution

Battery power
- Auxiliary equipment
- Traction power
  - Independent
  - Bi-mode

New Build or Retrofit?

Why battery
- Sustainable
- Emission neutral
- Autonomous power
- (Go anywhere)
- Market driven

Specification
- Performance
- Range
- Capacity
- Charger
- Service life
- Whole life cost

Why battery
- Sustainable
- Emission neutral
- Autonomous power
- (Go anywhere)
- Market driven

Specification
- Performance
- Range
- Capacity
- Charger
- Service life
- Whole life cost
Route options

Informed by Policy
Route demand Feasibility Sustainability Investment Whole life cost

Direct costs
Capital investment Maintenance Energy consumption Operations

Indirect costs
Carbon emissions Air quality Potential incentivisation
Battery capacity

Example system capacity
Baseline train with capacity 16 tonne x 8 axles

I need my battery train to provide a…

Local Shuttle service

- Range 45km
- Speed 75 km/h
- Battery 250 kWh
- 10000 cycles per year
- 3 ton battery

End of mainline Branch line service

- Range 90km
- Speed 75 km/h
- Battery 500 kWh
- 1000 cycles per year
- 5 ton battery

Extended mainline Performance service

- Range 90km
- Speed 125 km/h
- Battery 1000 kWh
- 1000 cycles per year
- 10 ton battery

Simulation model
- Power delivery
- Energy capacity
- System architecture
Battery lifecycle

Service cycles
Sensitive to depth of discharge
Control system health monitoring
Condition management
End of life recovery

Supply chain
Mature battery solutions

Technology watch
Energy density

<table>
<thead>
<tr>
<th>Energy</th>
<th>36.8 kWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (typical)</td>
<td>430 kg</td>
</tr>
<tr>
<td>Discharging power max*</td>
<td>334 kW</td>
</tr>
<tr>
<td>Charging power max*</td>
<td>184 kW</td>
</tr>
<tr>
<td>Continuous power*</td>
<td>97 kW</td>
</tr>
<tr>
<td>Capacity</td>
<td>46 Ah</td>
</tr>
<tr>
<td>Voltage nom.</td>
<td>799 V</td>
</tr>
<tr>
<td>Cycle life**</td>
<td>&gt; 7,000 cycles</td>
</tr>
<tr>
<td>Dimension (L x H x W) in mm</td>
<td>1,844 x 750 x 216</td>
</tr>
</tbody>
</table>

Projected battery performance improvements

Source: RSSB
Future proofing – investment risks

Lifecycle commitment
Battery cycle management
Obsolescence management

Battery module upkeep
Refurbishment
Periodic replacement
End of life recovery

Mode demand
Independent / charger
Bi-mode

Performance potential
Technology watch
Hybrid battery / power device

Long life asset
Trains ordered today potentially in service to 2060
Battery train – entry into service

Mature regulatory approach
Interoperability
Component regulation
Common safety method

Commercial investment
Technical
Performance
Service agreements
Whole life costs

V&V
Traction battery sub-system
Rolling stock system
Rail systems integration

Railway applications – Rolling stock - Onboard lithium-ion traction batteries (IEC 62928:2017)
Thank you from the Arup team
Questions

Discussion

Robert DAVIES
Global Rolling Stock Leader - Arup

Thank you for your attention.
TRANSPORT & MOBILITY LEUVEN
ELECTRIFICATION AND OTHER ALTERNATIVES TO DIESEL TRACTION
AN APPLICATION FOR BELGIUM
Elektrificatie van het Belgische spoorwegnet of het gebruik van andere duurzamere vervoerswijzen om de dieseltractie te vervangen

CONFIDENTIEEL

Rapport voor: FOD Mobiliteit en Vervoer

Datum: 11/12/2020

Auteurs: Christophe Heyndrickx, Sebastiaan Boschaans

Public since 19/2/2021
Making rail transport more sustainable

Only about 60% of tracks in Germany are electrified.

40% of railway lines non-electrified in Germany, 43% in France.
Belgian Situation

A large set of lines around Ghent

Charleroi-Couvin

Genk-Bilzen
‘Alternatives for diesel’ in Belgium

- **Passenger trains**: electrification of lines versus alternatives
- 6 (+1) scenarios:
  - Electrification in 2035 (BAU scenario – end of lifetime MW41)
  - Electrification in 2025
  - Battery train in 2025
  - Hydrogen train in 2025
  - New diesel train in 2025
  Compare with zero scenario (diesel until eternity - 2100)
  - **High** and low valuation of emissions (**DG MOVE**/FPB)

- **Freight train**: limited energy density + nog viable alternative usin hydrogen (possibly in the future)
- Quick-scan analyses voor L21c en L204/L55
Battle of the T(ra)i(n)tans

Electric (EMU) / diesel (DMU)  
Battery (BEMU) / Hydrogen (FCEMU)
1. Large impact of maintenance cost
2. Energy cost for hydrogen comparable to diesel at 2€/kg
3. Hydrogen trains most expensive / electric trains cheapest
4. Infrastructure cost battery train 0-40% of ‘standard electrification’
Overall energy efficiency of hydrogen not much better than diesel
Environmental benefits hydrogen comparable for non-CO2 emissions (PM/NOx/..)
+ Low efficiency & vulnerability fuel cells (replace every 2-3 years)
Monte Carlo analysis

Sensitiviteitsanalyse volledig - Hoge emissie waarderingen

Monte Carlo: Generate results using a triangle distribution -> 1000 NPV simulations => proxy for sensitivity and distribution of result

Commercial ‘selling point’ hydrogen
Sensitivity for maintenance cost -> ceteris paribus
Large impact for hydrogen & battery train -> not enough to change ranking
Sensitivity for energy cost -> only relevant for hydrogen, but less than maintenance cost
Differences by line

**Geraardsbergen**
Battery train looks more interesting

**Ronse-Eeklo**
Standard electrification

**Charleroi**
Battery + partial electrification may outweigh high cost of full electrification
Freight lines

L21c (Genk – Bilzen) very high NPV due to large time benefits & bottleneck situation + electrification of Mol-Hamont

<table>
<thead>
<tr>
<th>Impact</th>
<th>Jaar</th>
<th>ENPV (30 jaar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatijdbaten (Mln. €)</td>
<td>1.782</td>
<td>32.60 €</td>
</tr>
<tr>
<td>Emissiebaten (optie) (Mln. €)</td>
<td>0.076</td>
<td>1.39 €</td>
</tr>
<tr>
<td>Onderhoud (Mln. €)</td>
<td>-0.35</td>
<td>-7.08 €</td>
</tr>
<tr>
<td>Totaal (Mln. €)</td>
<td>1.385</td>
<td>26.91 €</td>
</tr>
<tr>
<td>Investering in bovenleiding (Mln. €)</td>
<td>12.50</td>
<td>14.01 €</td>
</tr>
<tr>
<td>NPV (Mln. €)</td>
<td></td>
<td>12.50%</td>
</tr>
<tr>
<td>IRR (%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

L204 (Gent N. – Zelzate) used more intensively than L55 (Wondelgem-Zelzate-Terneuzen)

L204 has a ‘marginally’ positive score for electrification
L55 very negative -> co-benefit with passenger market possible?
Other solutions for freight transport

Both medium/high speed as well as mono/dual fuel combustion engines are being developed.
Vectron Dual Mode

Dual mode electric/diesel
Conclusion

• On European market -> substantial amount of lines presently not electrified
• In Belgium largely electrified, but limited amount of lines non-electrified + freight transport often has substantial problems bridging last-mile (port lines often non-electrified)
• Market analysis, including substantial sensitivity analysis, shows that either full or partial electrification of trains is the best solution
• Hydrogen trains in the present analysis show a number of disadvantages, though this may be compensated in the future
• Freight trains: future in hybridisation, either with hydrogen or with a dual mode (diesel/electric). Problem -> cost disadvantage + low range
DANK U!
Questions
Discussion

Christophe Heyndrickx

Thank you for your attention.
TUC RAIL INFRASTRUCTURE INTERFACES

Actual & future battery charging possibilities
interoperability & standards

Paul TOBBACK
Lead Design Engineer & OCL expert

Battery trains Online Workshop - 19 May 2021
Find the *really* new kind of rolling stock and look for the differences!

**Introduction**

What about the infrastructure?
Challenges for the OCL (Overhead Contact Lines) & power supply (energy subsystem)

Legal (EU): TSI’s (Technical Specifications Interoperability) & (parts of) EN-standards when referenced

Technical: standards (UIC550, UIC552, EN50546, EN50119, EN50367, EN50388, etc. and their IEC counterparts)

Legal or technical, these documents were not written for trains with batteries for traction purposes !!
Kick off 17/03/2021
Up till now participation from different stakeholders like infra managers, railway undertakings, lessors and Notified Bodies:
  • Trafikverket / Bane NOR / Infrabel / SNCF / DB / ÖBB / ČD / RFI / Angel Trains / Sconrail

UNIFE (rolling stock manufacturers) judged it too early to support it already
Despite non-participance by UNIFE a clear interest was expressed during bilateral meetings with Siemens Belgium and Bombardier, but no priority for ERA (European Railway Agency)
→ unofficial TF, but not forgotten by ERA and the EC (European Commission)
→ please join if interested and contact your representative body

In parallel on technical level:
Cenelec workstream in CLC/SC9XC for a TS on “Railway applications - Fixed installations - Requirements for charging stations for accumulator electric traction units based on separate contact line sections”.
  ➢ Corresponding CLC WG 25 to further work on the scope and draft the proposed way forward
  ➢ The contact line section is not connected to other overhead contact line systems of electrified railway lines and is fed separately
Objectives Joint Task Force

• Facilitate interoperability and support the EU Green Deal

• Key objective short term:

  interoperability requirement proposals for TSIs on short term objectives to allow and facilitate full charging of trains with batteries, without changing other existing requirements neither without blocking other modes of operation for battery train charging purposes by April 2021 (for next TSIs 2022 version)

• Long term objectives:
  o provide inputs for European standardisation needs
  o reduce costs for the ENE subsystem enabled by the usage of battery trains
Key topics Joint Task Force

In order to design correctly the OCL for battery trains while charging, it seems necessary to:

1) define the train needs
2) then work on OCL

1) Power demand from the batteries?

3 Examples with proposals from Stadler for BaneNOR (15kV AC):

- 2 MW = BEMU (common example in many countries and tested/in operation already; “Aramis”, FLIRT)
- 3 MW (385ton train with 7 cars or last mile freight train; “Athos” locomotive = Eurodual)
- 4 to 5 MW (1200ton freight train; “Porthos” locomotive = Euro9000 with battery tender)

Train operation studied for Norwegian cases, e.g. a 729km line Trondheim-Bodø, to be only partly electrified over a total of 210km (28.81%, 8 separate electrified sections)
Key topics Joint Task Force

- **Short term**: main issue: actual requirements on Current at standstill for DC systems only (because of much lower voltages compared to AC systems and thus higher currents to have enough power for auxiliaries like heating & air conditioning in modern rolling stock)

  proposal introduced to include requirements for AC-systems in TSI ENE (energy) and L&P (rolling stock), but referring to actual limits in the standards → to be discussed with ERA

- A summary of all actual possibilities for charging at standstill & auxiliaries and their limits (2 MW at best):

<table>
<thead>
<tr>
<th>Solution</th>
<th>System voltage</th>
<th>Max current</th>
<th>Max power</th>
<th>Standard</th>
<th>Current collector</th>
<th>Plug UIC 552</th>
<th>Shore supply plug</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current collector</td>
<td>25 kV ac 50 Hz</td>
<td>80 A</td>
<td>2.0 MVA</td>
<td>EN 50367</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 kV ac 16.7 Hz</td>
<td>80 A</td>
<td>1.2 MVA</td>
<td>EN 50367</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.0 kV dc</td>
<td>200 A</td>
<td>0.6 MW</td>
<td>TSI ENE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5 kV dc</td>
<td>300 A</td>
<td>0.5 MW</td>
<td>TSI ENE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plug UIC 552</td>
<td>3.0 kV dc</td>
<td>800 A</td>
<td>2.4 MVA</td>
<td>UIC 552</td>
<td>315 A</td>
<td>0.9 MVA</td>
<td>BE national rule</td>
</tr>
<tr>
<td></td>
<td>1.5 kV dc</td>
<td>800 A</td>
<td>1.2 MVA</td>
<td>UIC 552</td>
<td>600 A</td>
<td>0.9 MVA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5 kV ac 50 Hz</td>
<td>800 A</td>
<td>1.2 MVA</td>
<td>UIC 552</td>
<td>600 A</td>
<td>0.9 MVA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.0 kV ac 16.7 Hz, 22 Hz, 50 Hz</td>
<td>800 A</td>
<td>0.8 MVA</td>
<td>UIC 552</td>
<td>600 A</td>
<td>0.6 MVA</td>
<td>ÖBB more common value</td>
</tr>
<tr>
<td>Shore supply plug</td>
<td>400 V ac 50 Hz 3&quot;</td>
<td>63 A</td>
<td>0.044 MVA</td>
<td>EN 50546</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>400 V ac 50 Hz 3&quot;</td>
<td>125 A</td>
<td>0.087 MVA</td>
<td>EN 50546</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>400 V ac 50 Hz 3&quot;</td>
<td>600 A</td>
<td>0.416 MVA</td>
<td>EN 50546</td>
<td></td>
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</tr>
</tbody>
</table>
Key topics Joint Task Force

• 4 existing target systems for power supply from the OCL through the pantographs

• Towards a 5th power supply system: 15kV AC 50 Hz for countries using already 15kV 16.7 Hz (D, A, CH, SE, N, …) ? Increasing the frequency on separate charging facilities has a number of advantages for infrastructure, even regarding the public grid from which the power is sometimes taken, without major consequences on rolling stock, thus reducing overall investment costs.

• Plug solutions have limited power, but can be sufficient for slow charging (≥ 60min), e.g. overnight in stabling yards, using (smart) multiple socket units and offered as a service, with different management, metering and invoicing (per kWh or just per hour).
what about the **BE case** (mostly 3kV DC)?

Study TML ! Infrabel & SNCB strategy 2040 !
SNCB: “no H$_2$ please, only EMU (or BEMU)”
Benchmarks Railway electrification in Europe

Percentage geëlektrificeerde lijnen EU (Europese comissie – Transport, 2016):

- 95% (14/280 km niet-geëlektrificeerd)
- 86% (500/3600 km niet-geëlektrificeerd; 2023, reizigersnetwerk: 96%)
- 76% (740/3100 km niet-geëlektrificeerd)
- 72% (1500/5500 km niet-geëlektrificeerd)
- 57% (12000/29000 km niet-geëlektrificeerd)
- 53% (19000/41000 km niet-geëlektrificeerd)
- 34% (11000/16000 km niet-geëlektrificeerd)
Remaining non-electrified main lines for passengers (2023):

- L.86 De Pinte - Ronse (ca. 29km single track, 3 km double)
- L.122 Melle - Geraardsbergen (ca. 29km double track)
- L.58 Gent-Dampoort - Eeklo (ca. 15km single track, 3,5km double)
- L.82 Aalst - Burst (ca. 11km)
- L.132-134 Charleroi - Couvin (ca. 30km single track, 20 double)

140 / 3600 km = 3,9% of the main network
Renewal Strategy OCL & substations

After 20 years
→ mid-life upgrade substation

After 40 years
→ renewal substation
→ mid-life upgrade OCL

After 60 years
→ mid-life upgrade substation

After 80 years
→ renewal substation
→ re-electrification with OCL ? Partly ??

What will the situation be over 10 years ? An OCL is built for 80 years !
When BEMUs and hybrid locomotives are generally used, future simplifications of the OCL network can be considered

For the remaining 5 non-electrified passenger lines in BE:

- flexibility in scope and timing of electrification

In the long term:

- Avoid difficult/expensive (re-)electrification (tunnels/turnouts…)
  → Better for punctuality and maintenance costs

- Less power demand on weak spots of the network / public grid
  → Less investment needed just for one rush hour train per day

- Possibility to run through earthed route sections
  → Less impact of work possessions/detours

- Possibility to avoid non-profitable re-electrifications (e.g. 12.5km branch line Pepinster-Spa, but which did continue a long time ago?; electrified >50 years ago)

L132 tunnel with interlaced tracks (and many more obstacles and difficulties)!!
What part to electrify if not the complete route?

There can be huge differences in cost/km a few km further on a route!

Depends on mainly the terrain for OCL, but on the number of substations (cost/unit, not per km!) to be built and their specific locations with possibilities to connect to the public grid (invest in underground cables or overhead contact lines?).

Here or here on L132?
Electrification revisited: never forget the H₂-option
(but that's another workshop)

L.132-134 Charleroi - Couvin (ca. 50km, the longest non-electrified main line in BE): H₂-pipelines in the immediate vicinity and even crossing the railway network!
And close to the start of the non-electrified part, but a bit further from the stabling yards & workshops!!

HEMU = BEMU with about 30-40% of the battery energy and a FC-range extender!
Key topics

EVOLUTION of STANDARDS in TSI ENE:

EN50119:2019: new version! *Transpose changes in IEC 60913*

EN50367:2020: amendment 2021 finished on 14/04/2021, waiting for comments and vote; adapted regarding current at standstill

EN50388-1 and 50388-2: still under revision, but including some elements on battery train operation
Solutions

e.g. From the actual legal 300A under 1,5kV DC to 500A
Tübingen (D) 15kV AC – 80A/pantograph – ROCL = Rigid OCL

https://www.swtue.de/geschaeftskunden/energie/strom/voltap.html
On the INFRA side

Reinforced OCL – e.g. SNCF RER C (Dourdan) / Depot Sweden (Västerås) / Metro Line 5 India (Delhi)

Profile to be added on an existing catenary to better dissipate the heat at the contact point between the contact wire and pantograph Reinforced OCL
On the RST side

SNCF SALTO project (nothing new !):
• At standstill, a mobile copper strip on the pantograph is raised to the OCL
• It is lowered as soon as the train exceed 8km/h
• Under 1,5kV, the equipment was tested up to 500 A and it worked. It could probably work with higher values.
On the RST side

“Kasperowski” contact strips (nothing new again! Still used e.g. in BE, FR and CH on older type of heavy pantographs):

But some problems in winter time with frost on the contact wires: Cu melted because of arcs
On the RST side

Use of Cu inserts in the centre of the contact strips

*Revue Générale* des Chemins de Fer, Decembre 2015, p.15-21
research/projects

current at standstill: (on going) tests by RSSB (UK), TU Dresden (D), IfB (Infrabel), RFI, Ricardo (NL/F), etc. → EN50367 Annex A3.

to evaluate possibilities of charging from an OCL (rigid or flexible) under real circumstances (identify margins between more common circumstances and rare worst cases)
Overview of ongoing tests on current at standstill


With plain carbon contact strips, depending on the configuration:
- 140N static contact force instead of 70N as usual in AC systems
- 2 rigid OCLs with a CuAg 120mm² wire, spaced 40 cm apart
it is possible to go from the actual legal 80A to 220A !
→ 3,3 MW under 15kV AC
→ 5,5 MW under 25kV AC !

→ With Cu impregnated carbon contact strips, this can even be improved.
Overview of ongoing tests on current at standstill

On contact wire with the reinforcement profile: SNCF test has demonstrated that it works under 1.5kV up to 1000A during 30 minutes with a pantograph used on AGC trains (copper contact strips!)
Overview of ongoing tests on current at standstill

RFI: from the actual legal 200A to 300A under 3kV DC without need to change infrastructure? We would even need 400A!

Infrabel: tests done in January 2021 on twin contact wires: huge margins towards temperature limits on new flat bottom wires (as required by EN50367 Annex A.3), but far less on worn wires due to contact force imbalances.

SNCF/PRoRail (1,5kV DC networks): more tests to be done soon (divergent results)

From previous tests by SNCF:

- Important parameter is the contact surface, more than the contact force
- 2 wires/1 wire or 2 strips/1 strip, it is not sufficient to divide by 2 or 4, test needed
- The more contact points the better
  - Increase the contact force increase the contact surface → Favourable
  - Increase the number of wire increase the contact surface → Favourable (even if spaced a few cm apart)
On the RST side (part 2) – possible future solutions?

Carbon contact strips with integrated Optic Fibre to actively monitor in real time and under real environmental conditions the temperature of the contact point(s) instead of the current (and not the contact forces to assess dynamic behaviour as already done in e.g. the UK)

→ Functional requirement on the critical parameter instead of an indirect one (but difficult to measure and manage, hence all the tests with divergent results)
→ Direct and automatic possibility on the trains themselves to cut power demand at standstill to protect the infrastructure
→ Only if necessary when the passive solutions presented above are not sufficient
Monitor the temperature of the contact point(s).

This could be needed to avoid tripping by the circuit breaker feeding the section and send a message to the trains to cut power demand in case more than 1 train is charging, without individually passing the temperature (or current) threshold, and there’s too much current demand in total (which in DC would be surprising compared to traction current, but maybe not in AC).
As for the battery cars, trains may have different battery charging strategies

- a) *Long time charging cycle*: energy taken from OCL per pantograph corresponds to the capacity of existing OCLs (300A for 1500 V; 200 A for 3000V; 80 A for AC)
- b) *Medium* charging cycle: charge in a shorter time, with higher current
e.g. for 1500 V DC: 600 A 5 min, then 300 A indefinitely
- c) *Quick charging cycle*: charge in 15 min
e.g. for 1500 V DC: 1000 A 15 min, then 500 A 30 min and 300 A indefinitely

→ We need charging management, certainly for multiple trains, considering State of Charge (SoC) of the batteries, timetable, *auxiliaries*, etc. Link to control & command systems to pass coded messages between infra & rolling stock

→ Pay attention to high inrush currents when switching on!
Hence 15kV AC 50 Hz !!
Questions

Discussion

Paul TOBBACK
Lead Design Engineer & OCL expert

Thank you for your attention.
BREAK
Break

Railways and UIC members are invited to join the UIC project:
“H2TR - Operating hydrogen powered trains”
In partnership with the IEC

If interested, please reach out to stefanos@uic.org

Restarting at 11h05
Break

Restarting at 11h05

https://uic.org/events/battery-trains

Online workshop coming up next:
September 2021
Call for speakers on **stationary energy storage**, contact stefanos@uic.org
## Second part

<table>
<thead>
<tr>
<th>Company</th>
<th>First Name</th>
<th>Last Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>SNCF</td>
<td>François</td>
<td>Degardin</td>
</tr>
<tr>
<td></td>
<td>Bogdan</td>
<td>Vulturescu</td>
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<td>Siemens</td>
<td>Katrin</td>
<td>Seeger</td>
</tr>
<tr>
<td>Eaton</td>
<td>Akos</td>
<td>Labady</td>
</tr>
<tr>
<td></td>
<td>Matthieu</td>
<td>Renault</td>
</tr>
<tr>
<td></td>
<td>Benoît</td>
<td>Gachet</td>
</tr>
</tbody>
</table>
SNCF
BATTERY Trains PROJECTS

- François DEGARDIN
  - Energy project manager at the Innovation & Research Department of SNCF
  - Leader of the regional hybrid train project and biogas feasibility study

- Bogdan VULTURESCU
  - BEMU project manager at Innovation & Research Department of SNCF

- Matthieu RENAUPT
  - Technical manager at SNCF Voyageurs rolling stock engineering centre
  - In charge of the regional hybrid train and regional battery train projects

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  - Technical manager at SNCF Voyageurs rolling stock engineering centre
  - In charge of the regional hybrid train and regional battery train projects

- Benoit GACHET
  - Product director high capacity regional trains, Alstom
SNCF BATTERY TRAINS PROJECTS

UIC Workshop

Battery trains

19/05/2021
Agenda

1. SNCF Context
2. Quick overview of diesel hybrid and hydrogen hybrid train projects
3. Deep dive into AGC battery train refurbishment project
Solutions portfolio
Overview of hybrid train projects
Hybrid train

**Principles**

- **Internal combustion engine Removed**
- **Replaced by Energy Storage System**
- **Recover, store and reuse braking energy**

**Energy Storage System**

- Power converter
- 5 battery packs
- Liquid cooling unit

- Batteries packed by FORSEE Power
- Cells : LTO Technology (Toshiba)
- Power : ~ 300 kW discharge ~ 500 kW charge per ESS
- Total capacity : ~ 70 kW.h per ESS
- Pack voltage : ~ 800 V (nominal)

**Next steps**

- 2021 : Modification of 1 train set
- 2021/2022 : Testings
- 2023 : Commercial operation (1 train set)
- 2024 : Go / NoGo for deployment
- Stakeholders:

  - Grand Est
  - Aquitaine
  - SNCF
  - ALSTOM
Hydrogen train

**Principles**

- Diesel engines and gazole tanks removed
- Replaced by H2 fuel cells and batteries
- Batteries recover brake energy, and assume power peaks

**Energy Storage System**

- Cells: LTO Technology (SAFT)
- Pack voltage: ~ 800 V (nominal)
- Total capacity around 100 kW.h per ESS
- Power: ~ 250 kW discharge
  ~ 300 kW charge
- Liquid cooling

**Next steps**

- End of March 2021: Contracts signed
  (12 new train sets)
- End of 2023: Testings
- End of 2025: commercial operation
  (1st train set)
- Stakeholders:
BATTERY TRAIN
AGC BEMU PROJECT

UIC Workshop
Battery trains
19/05/2021

Bogdan Vulturescu (SNCF)
Matthieu Renault (SNCF)
Benoit Gachet (ALSTOM)
Fleet: Automotrice Grande Capacité

700 trainsets of the AGC family:
- X76500 class: 163 trains 100% diesel
- B81500 class: 185 trains, dual mode (1.5kVdc & diesel)
  – 160km/h max, 130/240 places (3/4 coaches)
- B82500 class: 141 trains, dual mode (1500Vdc/25kVac & Diesel) – 160km/h max, 130/240 places (3/4 coaches)
- Z27500 class: 211 trains 100% electrical

- 2004-2011 Supplied by Bombardier at SNCF
- 2022-2032 Midlife maintenance - to give potential for another 20 years
Retrofitting principles

- 20 years old trainsets retrofitting (build before TSI) – **first time in Europe**!
- Diesel propulsion removal and replacement with NMC Li batteries, on both motor cars (1M T 2M)
- **Train software modification**
# BEMU features

<table>
<thead>
<tr>
<th>Feature</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Autonomy</strong></td>
<td><strong>80km + reserve</strong> (20km or 1hour comfort AUXILIAIRES at full power; autonomy corresponding to only 50% of DoD used !)</td>
</tr>
<tr>
<td><strong>Traction</strong></td>
<td>Identical to original BGC: 160km/h, 1.8MW under catenary &amp; 1MW under non-electrified line, braking energy recovery (new)</td>
</tr>
<tr>
<td><strong>Battery full charge time</strong></td>
<td>40min (running under catenary or under 25kVAC at standstill) 60min (at standstill under 1.5kVDC)</td>
</tr>
<tr>
<td><strong>BEMU coupling</strong></td>
<td>Inter-BEMU &amp; with the rest of the AGC regional non-modified fleet (BGC and ZGC)</td>
</tr>
<tr>
<td><strong>DC/DC converter redundancy</strong></td>
<td>4 DC/DC converters, each driving 4 traction battery units (50kWh, 800V) – liquid cooling</td>
</tr>
<tr>
<td><strong>Distance gauge (km) estimation</strong></td>
<td>The driver knows, on live, the “equivalent distance” remaining energy</td>
</tr>
</tbody>
</table>
Energy management

Traction under catenary
Main battery charging mode
(10-90% of the energy)

Braking under 1.5kVdc & 25kVac
Secondary battery charging mode
(10% of the energy)

Standstill charge (terminal)
Main battery charging mode
(10-90% of the energy)

Running under non-electrified line
Traction/braking by battery
16600km electrified lines in France
5100km non-electrified (or partially electrified) compatible with 80km BEMU one journey autonomy (12000km non-electrified lines in France).

100% km electrified lines + 42% km non-electrified lines
84% of the journey distances are less than 80km.
### Relevant area – Journey operation analyze

<table>
<thead>
<tr>
<th>Journey</th>
<th>Distance Range</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Journey with 150 to 200 km CFO</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Journey with 120 to 150 km CFO</td>
<td>96%</td>
<td></td>
</tr>
<tr>
<td>Journey with 100 to 120 km CFO</td>
<td>94%</td>
<td></td>
</tr>
<tr>
<td>Journey with 80 to 100 km CFO</td>
<td>91%</td>
<td></td>
</tr>
<tr>
<td>Journey with 65 to 80 km CFO</td>
<td>84%</td>
<td></td>
</tr>
<tr>
<td>Journey with 50 to 65 km CFO</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Journey with 35 to 50 km CFO</td>
<td>68%</td>
<td></td>
</tr>
<tr>
<td>Journey with 20 to 35 km CFO</td>
<td>60%</td>
<td></td>
</tr>
<tr>
<td>Journey with 5 to 20 km CFO</td>
<td>53%</td>
<td></td>
</tr>
<tr>
<td>Journey 100% under catenary</td>
<td>42%</td>
<td></td>
</tr>
</tbody>
</table>

84% of the journey distances are less than 80km.

1. **Operation modification**
2. **New infrastructure**
3. **Increase the onboard storage**
Relevant area – daily operation analyze

Stop/parking time during day: 33 min, 62min, ... 181min enough to charge the battery.
Trip duration: 73min

Journey distance: 60km
Lyon ⇒ Bourg-en-Bresse
(549km daily operation)
X% of these long daily operation are compatible with our AGC BEMU (eg. shuttle Lyon ↔ Bourg-en-Bresse daily op).

38% + X% of the daily operation are less than 80km – compatible with our AGC BEMU without any infrastructure/rolling stock modification.
Increase the relevant area – Daily operation analyze

Stop/parking time during day: 33 min, 62min, ... 181min enough to charge the battery.
Trip duration: 73min

1. Stop/parking time modification
2. New infrastructure
3. Increase the onboard storage / fast charge

Journey distance: 60km
Lyon → Bourg-en-Bresse
(549km daily operation)
Increase the Relevant area – Daily operation analyze, round trip exemple

1. Stop/Parking time modification
2. New infrastructure:
3. Increase the onboard storage / fast charge
Increase the Relevant area – Daily operation analyze, round trip exemple

1. Stop/Parking time modification
2. New infrastructure:
3. Increase the onboard storage/fast charge
First use cases – without any infrastructure modification

300 à 1000 tCO2e avoided/year, annual emissions of 180 to 650 cars for only one BGC!

<table>
<thead>
<tr>
<th>Diesel</th>
<th>Battery train</th>
</tr>
</thead>
<tbody>
<tr>
<td>~8,5 kgCO2éq/km</td>
<td>0,5 kgCO2éq/km</td>
</tr>
<tr>
<td>6 to 10 kgPM/an</td>
<td>0</td>
</tr>
<tr>
<td>1 to 3 tNOx/an</td>
<td>0</td>
</tr>
</tbody>
</table>
Marseille – Aix

Roulement graphique

Etat de charge batterie
Partners
Projet milestones

Experimentation Kick-off (1st phase)

First trains retrofit

Dynamic tests

July 2023

KPI Evaluation

2024 February Go / No Go

2nd Phase

14 janvier 2021

Q3 2021

Q4 2021

Q4 2022

End of conception phase

ERA go
**AGC BEMU**

### Principles
- Batteries are mainly charged by catenary but are also used for recovering braking energy.
- Batteries provide energy for traction and auxiliaries consumption.
- Dual mode train: catenary-battery

### Energy Storage System
- Battery system designed by LECLANCHE
- DCDC designed by AT
- Power per ESS: ~600 kW discharge ~500 kW charge
- Total capacity ~400 kWh per ESS (~200 kWh used)
- Reserve capacity ~60kWh per ESS
- Pack voltage: ~800 V (nominal)

### Next steps
- 2021: Notice To Proceed, Kick Off project
- 2021/2022: Tests
- 2023: Commercial operation (5 train set)
- 2024: Go / NoGo for deployment

**Stakeholders:**
- Région Sud Provence-Alpes-Côte d’Azur
- Occitanie
- Nouvelle-Aquitaine
- La Région Auvergne-Rhône-Alpes
- Région Hauts-de-France
- SNCF
- ALSTOM
Questions
Discussion

François Degardin (SNCF)
Bogdan Vulturescu (SNCF)
Matthieu Renault (SNCF)
Benoit Gachet (ALSTOM)

Thank you for your attention.
SIEMENS MIREO PLUS

A strong train now becomes even stronger
The Mireo Plus combines the latest alternative traction systems with the lightest EMU

- **1900**: First battery locomotive
- **1909**: “Wittfeld-Akkumulator-triebwagen”
- **2017**: Start of development of Mireo Plus

**Timeline**

- **2018**: Test bench operation of fuel cell
- **2019**: Desiro ML Cityjet eco prototype for ÖBB
- **2020**: Mireo Plus B Ortenau
- **2020**: Mireo Plus H prototype with DB
Extensive experience gained during development and testing

Battery System
- Active in design of battery systems for mobility applications since 2009
- Co-design with experienced partners I-ME Actia and Toshiba
- Owner and distributor of the battery systems
- Excellent results from passenger operation with Cityjet eco have confirmed a reliable, robust and long-lasting battery system

Hydrogen System
- Active in H2 systems since 1960s
- Applications in marine business as well as for electrolyzers laid foundation to enhance this technology for mobility applications
- Experienced partner Ballard Power for development of the next generation fuel cell system
- The new fuel cell system has been extensively tested in a system test laboratory for > 2000 hours operation to optimize the interaction between fuel cell and battery system
Desiro ML Cityjet eco in successful passenger service for more than one year

- Operation in battery mode: > 65,000 km
- Battery capacity: 528 kWh
- Traction power: Up to 2.6 MW
- Range in daily operation: ~80 km
- 140 km/h in AC-mode
- 120 km/h in battery mode
- Achievements:
  - No downtime; high reliability of batteries
  - Operating parameters could be optimized
  - Validation platform for simulation modeling
- Operated in height difference of 325 m
- No restrictions in hot summertime detected due to active cooling
- Reduced range due to active heating (65 km)
- Routes throughout all regions in Austria

Timeline:
- 07/2017: Start of development
- 08/2019: Homologation certificate received
- 09/2019: Passenger operation on 11 different routes throughout Austria
- 12/2020: Trial operation successfully completed
Mireo Plus –
For operation on non electrified lines

**Mireo**
For electrified lines

**Mireo Plus**
All Mireo advantages in one hybrid platform with all positive characteristics of the Mireo family: energy-saving, flexible interior, low maintenance and life cycle costs

**Mireo Plus B**: Battery solution for lines that are partially electrified; range: 80 – 120 km

**Mireo Plus H**: Hydrogen solution for long distances without catenary; range: 600 – 1,000 km

2-Teiler: 47 m, max. 130 seats

3-Teiler: 63 m, max. 180 seats

$V_{\text{max}}$: 160 km/h

$P_{\text{max}}$: 1.700 kW

High performance: 2 powered bogies to ensure reliable operation even under challenging conditions
The first project of Mireo Plus is Ortenau network with battery hybrid drive

- Contract award: April 2020
- Vmax: 140 km/h
- Catenary-free operation: ~80 km
- Level platform access: 550 mm

- 20 Mireo Plus B two-car trains
- Maintenance for 29.5 years
- 120 seats

Client:
Regional Office for Rail Vehicles Baden-Wuerttemberg

Start of operation: 12/2023
The Mireo Plus B meets demanding operational requirements without a continuous overhead catenary

- EMU performance
- High energy efficiency / low power consumption thanks to SiC
- Charging below overhead catenary and quick charge
- Low lifecycle costs

1. Flexible battery size – long ranges possible
2. LTO technology for long battery life
3. 160 km/h in both overhead catenary and battery operation
4. Overhead catenary operation at 15 kV/16.7 Hz or 25 kV/50 Hz
The Mireo Plus H is applied in a research project with DB Regio

120 seats

Mireo Plus H
2-car

Project start
23.11.2020

Vmax
160 km/h

Range
600 km

Rapid refueling in max.
15 minutes

Start of trial operation
2024

1,7 MW
traction power
The Mireo Plus H meets demanding operational requirements without an overhead catenary

<table>
<thead>
<tr>
<th>EMU Performance</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High energy efficiency / low power consumption thanks to SiC</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Vmax 160 km/h</strong></td>
<td>3</td>
</tr>
<tr>
<td><strong>Low lifecycle costs</strong></td>
<td>4</td>
</tr>
</tbody>
</table>

1. Highly efficient fuel cell – long ranges possible
2. LTO technology for long battery life
3. Intelligent system for rapid refueling
4. Low power consumption, e.g. through use of waste heat from fuel cell for passenger air-conditioning
Ambitious targets are achieved through innovative hybrid traction building blocks

**HD8 Next Generation fuel cell**
- Higher power density
- Longer lifetime, lower life cycle cost
- Higher efficiency

**H2 tanks**
- Modular concept
- +10% H2 storage capacity

**DC – DC converter**
- SiC technology (compact, light and low losses)

**Hybrid control software**
- Optimized operation through predictive energy management
- ~ 5 – 15% energy savings

**Powerful battery family**
- Safe chemical cells
- High-power charging
- Long lifetime
The Mireo Plus B makes the most of the existing infrastructure

Battery operation

Input:
10 – 110 kV
50 Hz

Output:
15 kV/16.7 Hz
or
25 kV/50 Hz

1 Charging below existing overhead catenary (including during travel)

2 Charging at the recharging section at the intersection (including during travel)

3 Charging at the recharging point at the terminus (charging only while stationary)
Suitable infrastructure is the prerequisite for the efficient use of the Mireo Plus H

Refueling process

1 Vehicle is connected one car at a time to the dispenser: **Start of the refueling process**

2 Hydrogen is pumped in: **Refueling process**

3 Rated pressure is reached at the hydrogen tank: **End of the refueling process**

Rapid refueling in approx. 15 minutes

Continuous data transfer over standardized interface (e.g. pressure, temperature)
Case study

Proven in Austria
#years of experience in all weather conditions

Feasible in Belgium
comparable distances
comparable height differences (Charlerloi-Couvin)
or flat (e.g. Eeklo-Ronce)
comparable electrification ratio on most diesel lines

Infrastructure characteristics Belgium
Catenary voltage 3kV DC
Maximum 200A during standstill
Maximum 2400A in motion
A charging possibility will be required in Couvin
Questions

Discussion

Katrin Seeger
Siemens Mobility - Head of Battery Technology
Commuter & Regional Trains

Thank you for your attention.
ON-BOARD ENERGY STORAGE FOR CATERNARY FREE SECTIONS

Eaton

Powering Business Worldwide

Akos Labady
Sr. Field Application Engineer, Eaton Electrical/ELX

UIC online workshop, 19May2021
products for rolling stock and infrastructure
Eaton offerings for energy storage:
- Lilon based systems
- PbA based systems
- Supercapacitor based systems
- Hybrid supercapacitors
EDLC aka. Supercaps

- Supercaps are symmetrical devices comprised by activated carbon electrodes at both anode and cathode sides
- Charging and discharging are electrostatic processes – no chemical reactions
- Cycle life is practically unlimited
- Charge and discharge can be done at the same speed and fashion in seconds
- Voltage drops linearly by the energy delivered
Lilon batteries

- Lilon batteries are asymmetric devices comprising of graphite anodes and metal oxide cathodes (Co, Mn, PO4, Fe, Ni combinations)
- Charge and discharge are electrochemical processes
- Cycle life is limited due to degradation (electrolyte oxidation, Li oxide buildup on anode and cathode surface, structural damage etc.)
- Discharge profile is flat, delivering quasi constant voltage
NEW - LiC aka. Hybrid Supercaps

- Hybrid supercaps are asymmetric devices comprise of a Li doped graphite anode and activated carbon cathode.
- The charge movement is done electrochemically mainly but in significantly lower deepth as in case of the LiIon battery. This results a very high ~500.000x cycle life and very fast responsiveness to high C rate discharges.
- As there are no metal oxides used the hybrid supercaps are not posing any risk of fire or thermal runaway.
Technology Comparison

**Li-ion Battery**

+ Highest energy density
+ Lower self discharge – years
+ Cost per Wh

- High current recharge shortens life
- Higher internal resistance limits power
- Must manage thermal load
- Operating temperature range -10 to +40°C
- Require sophisticated battery management system
- Must oversize to reach longer life times >5 years
- Sustainability – rare earth metals
- Safety to manage
- Cycle life: 3k-10k

**Hybrid Supercapacitor**

+ High energy density provides fast recharge in minutes
+ Long life time: 10 years at 20°C
+ Long cycle life: 500k (HS), 250k (HSL)
+ Safety: no thermal runaway, short circuit does not cause fire
+ Simple cell management and charging circuit
+ Operating temperature range -15°C/+70°C

Low self discharge for longer life when paired to primary batteries – individual self discharge in months

- Cost per Wh
Example - overhead line free sectioned line

150ton train
3000VDC line
50km distance between charging lines
50km average speed on main line
300-500kWh stored energy on-board by LiIon batteries or hybrid supercapacitors

60min 300kW discharge followed by 10min 600A recharge

10min 1800kW charge  →  60min 300kW discharge  →  20min 900kW charge
Required energy storage per technology

Hybrid Supercapacitor
(lithium doped graphite / activated carbon)
- Charge voltage = 3800-4000VDC
- Nominal voltage = 3600VDC
- Min discharged voltage = 2500VDC
- Installed capacity = 550kWh
- Theoretical lifetime = 75MAh or 25million km assuming ideal cell management and moderate temperature level
- Size = 36m³
- Weight = 25-30tons

NMC
(lithium / nickel manganese cobalt oxide)
- Charge voltage = 3800-4000VDC
- Nominal voltage = 3200VDC
- Min discharged voltage = 2700VDC
- Installed capacity = 2160kWh
- Theoretical lifetime = 68MAh or 20million km assuming ideal cell management and moderate temperature level
- Size = 16m³
- Weight = 20-25tons

No actual product displayed
Advantageous Use Cases

Hybrid SUPERCAP

- Short distances to cover with stored energy <50km sections
- In case high current available for charging
- In case safety is critical – tunnels/subways
- In case braking energy is more to utilize (downhills)
- In case higher acceleration rates are appreciated (uphills, urban transport)
- When wider temperature either cold or hot is an issue

Li-Ion BATTERY

- Can cover 100+km with one charge
- More cost efficient solution over 50km
- May be overnight charged to save the number of charging sections and extend battery life
- Available solution as per 2021
Questions

Discussion

Akos Labady
Sr. Field Application Engineer, Eaton Electrical/ELX

Thank you for your attention.
Stay in touch with UIC:

www.uic.org

#UICrail

Slides and recording to be made available on the event page
https://uic.org/events/battery-trains

Call for speakers is open for a workshop on stationary energy storage systems, please contact stefanos@uic.org

Thank you for your attention.