

WP6: Freight loco of the future



D6.4 Evaluation of cost effective, small and decentralized energy storage systems



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Leader of this Deliverable:	Bombardier Transportation GmbH Holländische Straße 195 DE – 34127 Kassel
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Report Contributors

Name	Company	Details of Contribution
Andrea Mazzone	BT CH	Task leader



Executive summary

This report provides a short explanation about why, from the partners point of view, it is not advantageous to specify and develop a concept respectively an architecture for small and decentralized Energy Storage Systems (ESS) for a <u>further</u> improvement of the energy efficiency of a locomotive.

As per Description of Action (DoA), the presence of small and decentralized ESS could improve the overall energy efficiency and allow to:

- implement start-stop functionalities
- reduce auxiliary consumption using harvested braking energy.

The electrical schematics of an electrical locomotive show that apart from the high voltage network of the traction chain itself (pantograph, main switch, line converter, DC-link, motor converter and motor) there are two electrical distribution circuits: AUX AC 480V and AUX DC 110/24V mainly for the Train Communication and Management System (TCMS).

All auxiliaries are connected to these two distribution circuits. The idea of having <u>small</u> and <u>decentralized</u> energy storage systems (ESS), even though being interesting at a first glance, adds only complexity – in every sense, mechanically, electrically and from a control point of view. Some examples:

- 1. For the AC auxiliary network, which feeds subsystems with high power requirement, apart from the energy storage system itself, a DC/AC converter for ESS with DC output (e.g. batteries) or an AC/AC inverter for ESS with AC output, such as e.g. flywheels, would be required. They require space and add weight. For most of the components, there is no room available close by. Furthermore, as part of the AC network has variable frequency, these converters must be controlled, increasing the complexity of the converters themselves. And as usual, complex systems, being a further source for failures, deteriorate the availability and reliability of the overall system.
- 2. For the DC auxiliary network, the integration is less complex as for the AC network. But the network is already being fed respectively backed up by the vehicle battery. Adding further batteries or splitting the vehicle battery into smaller and decentralized ones, is not advantageous.

It is beyond all questions that ESS allow to implement some specific functions and to improve the overall energy efficiency of vehicles if they are charged by energy harvesting systems. For electrical locomotives, the only significant way of energy harvesting is to recuperate braking energy. All others means, such as harvesting vibration, solar or heat energy are either not effective enough or still not economically/technically viable. In order to harvest braking energy, <u>large</u> ESS are required, as already described in various studies, including the ones done in S2R FFL4E and S2R FR8HUB on hybrid propulsion systems for freight and shunting locomotives or on the full electric last mile propulsion concepts. Splitting and decentralizing such large ESS is either physically not possible, for instance in case of a flywheel, or not convenient in case of batteries.

Summarizing the above, while it makes sense to have onboard energy storage system capable of recuperating braking energy and providing the energy to all systems on the locomotive, no advantages are seen in splitting and decentralizing them.

The implementation of special functions, such as the mentioned start-up functionality can either be implemented using the existing vehicle, or, if available, by a large recuperation battery.



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Abbreviations

AUX	Auxiliary
DEME	Diesel Electric Multi Engine
DoA	Description of Action
ESS	Energy Storage System
S2R	Shift2Rail
TCMS	Train Communication and Management System



1 Introduction

FR8HUB WP6 "freight loco of the future" aims at defining and developing concepts, systems and subsystems of future freight locomotives for a maximum improvement of the energy efficiency of the locomotive alone, in the train consist or within a fleet. Task 6.3 shall evaluate whether a cost-effective energy efficiency improvement is possible with small decentralized ESS, summarizing the results in this deliverable D6.4.

In a first step, possible functions & systems that would profit from such concept shall be listed (Chapter 2). The analysis shows that from today's perspective it is not advantageous to integrate <u>small</u> and <u>decentralized</u> ESS. Therefore, the compilation of the most suitable energy storage system (ESS) and the needs for new rolling stock is not further pursuit (following subtasks). For the interested reader, an extensive overview on ESS is provided in deliverable D6.1.

2 Functions and Subsystems profiting from ESS

2.1 Subsystems

In state-of-the-art locomotives, typically 3 types of electric networks can be distinguished:

- 1. The high voltage / high power network of the traction chain, which starting from the pantograph includes main switch, traction transformer, line converter, DC-link, motor converter, the motors, gears and some other components such as filters.
- 2. The AC 480V auxiliary network (Figure 1) with fixed and variable frequency feeding all auxiliary components requiring relative high power, such as e.g. the traction motor blowers, the cooling tower blower, the blower for the brake resistor, the battery charger, the HVAC system and many more.



Figure 1: AC AUX Network



3. The DC 110/24V mainly for TCMS, but also feeding systems like the wheel sliding protection, digital train radio, energy meter, etc. The DC network takes its energy from the AC AUX circuit via the vehicle battery charger module (Figure 2).



Figure 2: DC AUX Network (partly greyed out)

For the topic here discussed, subsystems connected to both auxiliary networks (AC/DC) may be interesting. Both schematics (Figure 1 and 2) give a good overview on how the auxiliary subsystems are electrically connected to the main energy source, being it the DC link. The DC link provides the energy trough the auxiliary inverters and transformers to the AC Auxiliary network. From there, through the vehicle battery charger all DC components are powered.

All subsystems are connected to the same electrical circuit. Considering that for most systems a stable and constant power supply must be provided, many of them either being safety relevant (e.g. head lights, or radio) or critical from an operational point of view (traction motor blower), strongly influences the specification to an ESS and its adjacent components such the necessary converters.

- The ESS would need to be able to provide the energy with the required power whenever necessary and for the given time.
- For the AC AUX network, controlled converters would be required.
- Thereafter, the ESS would need to be recharged. The energy for it would either come from the given power supply network (thus, not reducing connection effort), or would require an own independent power source (additional system, with space and weight demand, ideally close by), for instance an energy harvesting system. The latter idea is unrealistic, as most of these energy harvesting systems (e.g. vibration energy harvester, solar panels) are either intended for low energy applications or require a certain size which is not available on locomotives.

A short look at Table 1 shows that small ESS will not be able to provide the required power and energy for the connected subsystems. Furthermore, such ESS would require a bidirectional DC/AC converter (3 phases), for charging and discharging, adding complexity (mechanically, electrically, from a control point of view) and consequently reducing the reliability and availability of the overall system.

A closer look at Table 2 shows that for some components small batteries could fulfill the power and energy demand. However, all these components are already powered resp. backed up by a battery, the vehicle battery. Splitting and decentralizing the vehicle battery would, same as for the AC network, increase complexity (mechanically, electrically, from a control point of view) and consequently reducing the reliability and availability of the overall system. Also, life cycle costs are expected to increase as the maintenance of several systems is less efficient than for one single system.



Abbreviation	Description	
Variable freq	uency loads supplied 480 V / 20 … 60 Hz	l with 160
TMB1	Traction Motor Blower 1	7.6
TMB2	Traction Motor Blower 2	7.6
TMB3	Traction Motor Blower 3	7.6
TMB4	Traction Motor Blower 4	7.6
CTB1	Cooling Tower Blower 1	8.6
CTB2	Cooling Tower Blower 2	8.6
BRB	Brake Resistor Blower	33.3
		80.7
Abbreviation	Description	
Constant free	uency loads supplied . 480 V / 50 … 60 Hz	d with 400
TCP1	Transformer Coolant Pump	4.8
TCP2	Transformer Coolant Pump	4.8
CCP1	Converter coolant Pump 1	2.4
CCP2	Converter coolant Pump 2	2.4
CIF1	Converter cooling Fan 1	1.1
CIF2	Converter cooling Fan 2	1.1
ACO	Main air compressor motor	21.0
HVAC CAB1	HVAC unit Cab (Cab occup	6.0
HVAC CAB2	HVAC unit Cab (Cab not or	3.0
MRB1	Machine Room Blower 1	0.0
MRB2	Machine Room Blower 2	0.0
1PhLoad	277V 60Hz consumer group	12.1
BCH P1	Battery Charger module 1	2.3
BCH P2	Battery Charger module 2	2.3
BCH P3	Battery Charger module 3	2.3
WCH Left	Windscreen Heater Left Ca	1.4
WCH Right	Windscreen Heater Right C	1.4
WCH Left	Windscreen Heater Left Ca	0.0
WCH Right	Windscreen Heater Right C	0.0
Bogie 1	Sander Heatings	0.2
Bogie 2	Sander Heatings	0.2
Floor 1	Floor/niche heating Cab 1	2.0
Floor 2	Floor/niche heating Cab 2	0.0
		58.6
		[kVA] 139

Table 1: Max loads [kVA] of the various
subsystems connected to the AC network

Electrical circuit / name of device	W / piece
Battery Contactor	244
Wheel Slide Protection	102
Parking Brake / Towing Mode	36
Energy Meter	0
Horn 660Hz	5
Horn 370Hz	5
Train Radio	245
Lighting Cab 1/2	72
Lighting MR	292
Brake Control 1	41
Brake Control 2	22
110V EBO/EP	22
110V/48V Converter EBO/EP	22
110V/24V Converter 1 CAB1	304
110V/24V Converter 2 CAB1	304
110V/24V Converter 3 CAB1	304
110V/24V Converter 1 CAB2	168
110V/24V Converter 2 CAB2	168
110V/24V Converter 3 CAB2	168
110V DC LVC	82
110V DC HAC	48
Fan COM	18
TCMS Control Units Primary	150
TCMS Control Units Secondary	105
I/O Modules Primary	90
I/O Modules Secondary	82
Bus Coupler Primary	31
Bus Coupler Secondary	55
I/O Modules Brake Control	8
Display Cab 1 DD CCD	18
Display Cab 2 DD CCD	18
Display Cab 1 DD TDD	18
Display Cab 2 DD TDD	18
Data recorder	15
Fire Extinguishing System	61
Aux. Compressor	990
Pantograph	72
Emergency Brake Loop	20

Table 2: Nominal power [W] of the varioussubsystems connected to the DC network

There are some locomotive applications known to use independent ESS.

• Diesel locomotives often use dedicated starter batteries for their engines. One example is the Bombardier Diesel Electric Multi Engine (DEME) locomotive. The locomotive is powered by four 560kW diesel engines. Instead of having starter batteries, every engine has a supercapacitor-based starter module. With this approach, a maintenance free start-stop



functionality (as known from the automotive world) could be implemented. The starter modules are connected to the AUX circuit by dedicated charger.

• The pantographs of locomotives are lifted by a pneumatic system. In order to be able to lift the pantographs (locomotive main power supply and consequently the air power compressor is not available) a certain amount of air is required. This air is stored in a dedicated air reservoir which is filled by a dedicated auxiliary air compressor, which is either powered by the vehicle battery or by the AUX network when the locomotive is in operation. Another OEM of railway vehicles has implemented a concept with a gas cartridge (=ESS) which provides air to raise the pantograph. The dedicated air compressor can by either removed or reduced in size. The concept has not been further pursuit, as, to our knowledge, the maintenance and operational requirements were not beneficial.

It becomes evident that these are particular/singular cases which have not become best practice.

2.2 Functions

There are several vehicle functions candidates that require or may profit from an onboard ESS, mainly when the locomotive is not connected to the overhead line or when it is turned off. Apart from customer specific function, there are also some required by norms and standards.

- The emergency lightning must be on for at least 90 min, as specified in TSI.
- The emergency call must be possible also when the train/locomotive is turned off. The NNTR Italy requests for at least three hours. Thus, the train radio most be powered up for the requested time period.
- The pneumatic wheel slide protection needs to be always active. It becomes relevant especially when locomotives are being towed. This function often defines the battery size, as is requires a significant amount of power when active. Some customers have requested the function to be active up to 7 days, assuming that a locomotive can be towed through Europe for such a long period of time.
- In France, the automatic block signaling (allowing to recognize the existence of a vehicle on track) is implemented by an electrical device called track circuit. When a vehicle is turned off and not moved, the electrical contact between rails and wheels deteriorates. The *boucle de chantage* secures the well-functioning at any time and needs to be powered by the vehicle battery.
- Remote wake up requires communication gateways to be powered at all times.
- The start-up functionality already mentioned in Section 2.1. was implemented with dedicated ESS, where the ESS does not really lead to a better energy efficiency of the locomotive. The reason for that specific implementation has a technical background.

The vehicle auxiliary battery is specified and designed to provide enough energy for most of the functions and related sub-systems. Th EN 50547 - Railway applications - Batteries for auxiliary power supply systems - specifies rechargeable lead acid and NiCd-batteries for 110 V voltage auxiliary power supply system for railway vehicles. For instance, it specifies the requirements related to discharging. Other battery technologies (e.g. Li-Ion) are not covered by the standard.

From a functional point of view, splitting the vehicle battery it into several smaller units is not advantageous. It would increase the certification and again the maintenance efforts.



3 Summary

Chapter 2 provides an overview of the most relevant subsystems in a state-of-the-art freight locomotive and some functions relying on ESS.

Chapter 3 lists some of the functions that require power autonomy. Some of them are requested by norms, others come from customer requirements and from specific implementations. All the systems implementing the mentioned function are today powered by the vehicle battery. Most locomotive manufacturer use lead acid or NiCd batteries and therefore fulfil the EN 50547.

All systems connected to the DC network and the related functions are already backed up by a battery and can run when the locomotive is not connected to the overhead line, such as for instance the TCMS or the wheel slide protection. It is safety relevant and requires a certain stability of the power supply.

It is less complex to design one battery fulfilling all requirements, starting from technical ones, such as energy content, voltage, power supply quality and stability, and continuing with further ones related to maintainability (physical access, maintenance intervals), weight distribution, etc..

Functions and systems that require larger power and energy provision, ideally would feed either into the AC AUX network or directly into the DC link, as traction and recuperation batteries do. These ESS are large and ideally placed in one physical location.

After this closer look it becomes evident that it is not advantageous and for many of the components not possible to implement a concept based on small and decentralized ESS with currently used AUX network architecture. Consequently, further deep dive (further subtasks) will not provide more details or insights.