CAF Power & Automation

On Board Energy Storage System

CAF

Why On Board Energy Storage System?

- Demand for increasingly cleaner and more efficient systems from an energy point of view.
- Growing concern about the visual impact of catenary in historical areas.

Alternatives

- Energy efficiency and solutions without catenary

Good / Medium / Bad

Energy Efficiency and Catenary Free Technologies — *Features*

		Infrastructure Cost	Life Cycle Cost	Availability	Safety	Energy recovery	Catenary free	Energy Transmission Efficiency	Provider dependency
Third Rail	Standard Third Rail	Low	Low	High	Low	-	Yes	High	Low
Third Rail	Controlled Third Rail	High	High	Low	Medium	-	Yes	High	High
Third Rail	Inductive	High	High	Low	High	-	Yes	Low	High
Reversible Substation		High	Medium	High	High	High	No	High	Low
Energy Storage	Infrastructure	Medium	Medium	High	High	High	No	High	Low
Energy Storage	Onboard	Low	Medium	High	High	High	Yes	High	Low

On-Board Storage Technologies

- After over 3 years of research to analyze, study, integrate and test different Energy Storage Solutions, such as:
  - Fuel Cells & Batteries (High Energy)
  - Flywheels, and Supercapacitors (High Power)

- Good
- Medium
- Bad

Features

	Life Cycle Cost	Energy density	Power	Fast charging	Availability	Safety	Maturity
Fuel-cell (Hydrogen)	Low	High	Medium	Yes	Medium	Low	Low
Batteries	Medium	High	Low	No	High	High	High
Flywheel	Medium	Low	High	Yes	Medium	Medium	High
Supercapacitors	Medium	Medium	High	Yes	High	High	High

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Batteries vs Supercapacitors

- Good
- Medium
- Bad

	Energy density	Power	Life expectancy (approx. number of cycles)
Batteries	High	Low	2.000
Supercapacitors	Medium	High	1.000.000

Energy density

- Directly related to running range
- Battery energy quality ≠ Supercapacitor

Power

- Supercapacitors: Allows charging at very high current. Ultra-rapid charging process: 20 sec
- Battery: Longer charging period.

Life Expectancy (No. of Cycles)

- Supercapacitors: 1,000,000 Cycles
- Battery: 2,000 Cycles

TRAINELEC: GREENTECH PRODUCTS

greentech by trainelec

Trainelec's green product line

ACR evoDRIVE

Focused on **energy saving**, based on: **Supercapacitors**

ACR freeDRIVE

Focused on **catenary-free operating mode**, based on an Hybrid Technology: **Supercapacitors and Batteries**

ACR evo DRIVE

- **Main Characteristics**
  - Energy supply optimization
  - Approximate energy saving 20%
  - Allows vehicles to run in catenary-free areas
    - Up to 100 meters of catenary-free area

- **EQUIPMENT**
  - DC/DC Converter
    - Supercapacitor charging and discharging Control
  - Modular Construction
    - 1 Supercapacitors Module

GRUPO CAF

ACR evo DRIVE

Estimated Saving

- Equipment Conditions
  - 2 UC modules: 1.5 kWh/box
  - 1 Box for one 32 m LRV: 1.5 kWh/LRV

ACR Saving:		**18 - 23% of the energy**
ACR weight factor:	—	**1% more energy**
Net saving:		**17% - 22% Saving**

ACR freeDRIVE

- **Main Characteristics**
  - Allows vehicles to operate in catenary-free mode
  - Improves Urban Landscape
  - Reduces Infrastructure Cost
  - Up to 1,400 meters catenary-free operating mode
  - Approximate energy saving 25%

- **EQUIPMENT**
  - DC/DC Converter
    - Supercapacitor/Battery charging and discharging Control
  - Modular Construction
    - 4 Supercapacitors Modules
    - 1 Battery Module

ACR freeDRIVE

Estimated Saving

- Equipment Conditions
  - 4 UC modules and 1 battery module per box: 18.1 kWh/box
  - 2 Boxes for one 32 m LRV: 36.2 kWh/LRV

ACR Saving:		**27% - 32% of the energy**
ACR weight factor:	—	**5% more energy**
Net saving:		**22% - 27% Saving**

Videos

URBOS Projects

LRVs & Streetcars

Photo	Project	Customer	Country	No. Of Cars	Structure	Deliveries
	Valencia Tram – 70% Low Floor	FGV	SPAIN	12x3 = 36 4x3 = 12	Mc-T-M	1993-1994 1999
	Lisbon Tram - 70% Low Floor	CARRIS	PORTUGAL	6x3 = 18	Mc-T-M	1995
	Bilbao Tram - 70% y 100% Low Floor	Euskotren	SPAIN	7x3 (70%LF) + 1x3(100%LF) = 27	Mc-T-Mc	2002-2004
	Tram Vélez-Málaga - 100% Low Floor	LRV Vélez Málaga	SPAIN	3x5 = 15	Mc-T-T-T-Mc	2006
	Metro Centro Sevilla	TUSSAM	SPAIN	4X5=20	Mc-S-T-S-Mc	2007
	LRV Sevilla – 100% Low Floor	LRV Sevilla	SPAIN	17x5 = 85 5x5=25	Mc-M-T-M-Mc	2008
	Vitoria Tram 100% Low Floor	Euskotren	SPAIN	11x5 = 55	Mc-T-T-T-Mc	208-2009
	Antalya Tram	Antalya Metropolitan Municipality	TURKEY	14x5 = 70	Mc-S-T-S-MC	208-2009
	Edinburgh Tram	Tie Ltd	UK	27x7 = 189	Mc-S-T-S-M-S-Mc	2010-2011
	Zaragoza Tram	SEM	SPAIN	21x5 = 105	Mc-T-T-T-MC	2012-2013

LRVs & Streetcars

Photo	Project	Customer	Country	No. Of Cars	Structure	Deliveries
	LRV Malaga 100% Low Floor	Metro de Málaga	SPAIN	14x5 = 70	Mc-S-T-S-MC	2011-2012
	Belgrado Tram	GSP	SERBIA	30x5 = 150	Mc-S-T-S-Mc	2011-2012
	Metro Centro Sevilla - Extension	MetroCentro	SPAIN	4x5 = 20	Mc-S-T-S-Mc	2012
	Granada Tram	Ferrocarriles de la Junta de Andalucía	SPAIN	13x5 = 65	MC-S-T-S-MC	2012
	Nantes	Nantes Metropole	FRANCE	8x5 = 40	Mc S T S Mc	2012
	Besançon Tram	Communauté d'agglomération du grand Besançon	FRANCE	19x3 = 57	Mc-S-Mc	2013-2014
	Stockholm Tram	Storstockholm Lokaltrafik AB (SL AB)	SWEDEN	15x3 = 45	Mc-M-Mc	2013
	Debrecen	Local Goverment of Debrecen City of Country Rights DKV Debreceni Közlekedési Zrt	HUNGARY	18+5=90	C-S-R-S-C	2012
	Houston	Metropoloitan Transit Authority of Harris County (METRO)	USA	39+3=117	Mc-M-Mc	2014
	Birmingham Tram	West Midlands Passenger Transport Executive	UK	19*3=135	MC-S-T-S-MC	2014
	Cuiaba Tram	SECOPA	BRAZIL	40X7=280	Mc-S-M-S-T-S-Mc	2014

Articulated Units – Streetcars

PROJECT

Valencia Tramway – 70% Low Floor

Customer

Ferrocarril Generalitat Valenciana

Country

Spain

Number of Cars 48

36 (12 articulated units of 3 cars)

12 (4 articulated units of 3 cars)

Structure

Mc-T-Mc

Deliveries

1993-1994
1999

Articulated Units – Streetcars

PROJECT

Lisbon Tramway - 70% Low Floor

Customer

Carris

Country

Portugal

Number of Cars **18**

18 (6 units of 3 cars)

Structure

Mc-T-Mc

Deliveries

1995

Articulated Units – Streetcars

PROJECT

Bilbao Tramway – 70% Low Floor

Customer
Euskotren

Country
Spain

Number of Cars 24
21 (7 units of 3 cars)

3 (1unit 100% LFT of 3 cars)

Structure
Mc-T-Mc

Deliveries
2002-2004

Articulated Units – Streetcars

PROJECT

Vélez-Málaga Tramway
100% Low Floor

Customer

Vélez Málaga Tramway

Country

Spain

Number of Cars 15

15 (3 Tramwyas of 5 cars)

Structure

Mc-T-T-T-Mc

Deliveries

2006

Articulated units

PROJECT

Metro Centro Sevilla

Customer

TUSSAM

Pays

Spain

Nº of cars **25**

25 (5 trains of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2008

Articulated Units – Light Metro

PROJECT

Sevilla LRV - 100% Low Floor

Customer

Metro Sevilla

Country

Spain

Number of Cars **85**

85 (17 LRVs of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2008

Articulated Units – Streetcars

PROJECT

Vitoria Tramway - 100% Low Floor

Customer

Vitoria Tramway (Euskotren/Euskotram)

Country

Spain

Number of Cars **55**

55 (11 Streetcars of 5 cars)

Structure

Mc-T-T-T-Mc

Deliveries

2008-2009

Articulated Units – Streetcars

PROJECT

Antalya Tramway

Customer

Antalya Metropolitan Municipality

Country

Turkey

Number of Cars **70**

70 (14 Streetcars of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2008-2009

Articulated Units – Streetcars

PROJECT

Edinburgh Tramway

Customer

Tie Ltd.

Country

United Kingdom

Number of Cars **189**

189 (27 Streetcars of 7 cars)

Structure

Mc-S-T-S-M-S-Mc

Deliveries

2010-2011

Articulated Units – Streetcars

PROJECT

Zaragoza Streetcars

Customer

SEM (Traza + Ayuntamiento Zaragoza)

Country

Spain

Number of Cars **105**

105 (21 Streetcars of 5 cars)

Structure

C-S-R-S-C

Deliveries

2010-12

Articulated Units – Light Metro

PROJECT

Málaga LRV - 100% Low Floor

Customer

Malaga LRV

Country

Spain

Number of Cars **70**

70 (14 LRVs of 5 cars)

Structure

MC-S-T-S-MC

Deliveries

2011-2012

Articulated Units – Streetcars

PROJECT

Belgrado Tramway

Customer

GSP

Country

Serbia

Number of Cars 150

150 (30 units of 5 cars)

Structure

Mc-S-T-S-M

Deliveries

2011-2012

Articulated Units – Streetcars

PROJECT

MetroCentro Sevilla EXTENSION

Customer

TUSSAM

Country

Spain

Number of Cars **20**

20 (4 units of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2011

Articulated Units – Streetcars

PROJECT

Granada Tramway

Customer

Ferrocarriles de la Junta de Andalucía

Country

Spain

Number of Cars **65**

65 (13 units of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2012

Articulated Units – Streetcars

PROJECT

Tramway de Nantes

Customer

Nantes Métropole

Country

France

Number of Cars 60

40 (8 units of 5 cars)

20 (4 units of 5 cars)

Structure

Mc-S-T-S-Mc

Deliveries

2012

Articulated Units – Streetcars

PROJECT

Besançon Tramway

Customer

Communauté d'agglomération du grand Besançon

Country

France

Number of Cars **57**

57 (19 units of 3 cars)

Structure

Mc-S-Mc

Deliveries

2013-2014

Articulated Units – Streetcars

PROJECT

Stockholm Tramway

Customer

Storstockholm Lokaltrafik AB (SL AB)

Country

Sweden

Number of Cars 73

45 (15 units of 3 cars)

28 (7 units of 4 cars)

Structure

Mc-M-Mc

Deliveries

2013-2014

Articulated Units – Streetcars

PROJECT

Tram Debrecen

Customer

•Local Government of Debrecen City of County Rights DKV Debreceni Közlekedési Zrt

Country

Hungary

Number of Cars **90**

90 (18 Streetcars of 5 cars)

Structure

C-S-R-S-C

Deliveries

2013 - 2014

Articulated Trains – Streetcars

PROJECT

Houston LRV

Client

Metropoloitan Transit Authority of Harris County (METRO)

Country

United States

Nº of cars 117

117 (39 trams of 3 cars)

Estructure

Mc-T-Mc

Delivers

2013-2014

Articulated Units – Streetcars

PROJECT

Birmingham Tramway

Client

West Midlands Passenger Transport Executive

Country

Unated Estates

Nº of cars **100**

100 (20 trains of 5 cars)

Estructure

Mc-S-T-S-Mc

Delivers

2014

Articulated Units – Streetcars

PROJECT

Cincinnati

Client

City of Cincinnati

Country

USA

Nº of cars

5 (3M) cars Base + 25 Optional

Estructure

Mc-T--Mc

Delivers

2015

Articulated Units – Streetcars

PROJECT

Cuiaba Tramway

Client

SECOPA (Secretaria Extraordinaria da Copa do Mundo FIFA 2014)

Country

Brazil

Nº of cars **280**

280 40 trains of 7 cars)

Estructure

Mc-S-M-S-T-S-Mc

Delivers

2014

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INDEX

1 INTRODUCTION

The purpose of this document is to answer the questions regarding the ACR Freedrive equipment for Washington DC Streetcar.

2 QUESTIONS & ANSWERS

Question #1

The District will consider designs which allow for the use of an in-street conductor which supplies power to the vehicle continuously while operating, a system with long gaps in the overhead supply and wired areas for recharging while operating (batteries), or a system which charges an on-board storage system only when stopped at station platforms (supercapacitors or flywheels). Which of these types of systems have you supplied vehicles (rail, bus, or other transport) for? Or, are in the process of supplying? Do you have any comments on the advantages or disadvantages concerning the three system types?

Answer #1

CAF has developed **its own concept** of equipment for energy efficiency and catenary free operation for streetcars.

The concept of this system proposed by CAF is the result of a long process of analysis, research and development.

CAF was looking for a solution that could provide both a high energy efficiency by recovering as much as braking energy from the train as possible and also enable the operation of the train without overhead lines.

CAF studied the different possibilities for energy efficiency and catenary free operation summarized in the following table:

Energy Efficiency and Catenary Free Technologies		Features: Infrastructure Cost	Life Cycle Cost	Availability	Safety	Energy recovery	Catenary free	Energy Transmission Efficiency	Provider dependency
Third Rail	Standard Third Rail	Low	Low	High	Low	-	Yes	High	Low
	Controlled Third Rail	High	High	Low	Medium	-	Yes	High	High
	Inductive	High	High	Low	High	-	Yes	Low	High
Reversible Substation		High	Medium	High	High	High	No	High	Low
Energy Storage	Infrastructure	Medium	Medium	High	High	High	No	High	Low
	Onboard	Low	Medium	High	High	High	Yes	High	Low

As a result CAF selected the **on-board energy storage concept** as it is the most competitive solution, with low infrastructure costs, to provide both a high energy efficiency and catenary free operation.

Also regarding the technology to be used CAF completed a rigorous study and comparison summarised in the following table:

Features

On-board Energy Storage System	Life Cycle Cost	Energy density	Power	Fast charging	Availability	Safety	Maturity
Fuel-cell (Hydrogen)	Low	High	Medium	Yes	Medium	Low	Low
Flywheel	Medium	Low	High	Yes	Medium	Medium	High
Batteries	Medium	High	Low	No	High	High	High
Ultracaps	Medium	Medium	High	Yes	High	High	High
Hybrid solution (UCs+Batts)	Medium	High	High	Yes	High	High	High

Fuel-cell technology was discarded because it is not mature enough for its application in the railway market, although it can be a promising technology for the future.

Flywheel technology was discarded for its low energy density and availability (mechanical system with complex integration) and safety issues.

Finally, CAF selected the **ultracaps** the only one to provide high power, fast charging, and good availability and safety characteristics. Ultracapacitors have medium energy density so CAF is also integrating **battery technology** to increase the energy capacity of the energy storage system and also, depending on the service, the batteries are sufficient to provide catenary free operation mode.

Ultracaps and batteries, even if they are mature proven technologies, are in constant evolution driven by the automotive industry, so there are **good expectations for** improvements on that technology and **significant reduction of costs**.

The energy storage system designed by CAF is called "**ACR Freedrive**" when the goal is catenary free operation mode, and "**ACR Evodrive**" when the focus is Energy Recovery. Both systems are **based on a fast charging process** in the train stations at the stops of the train with the main advantage of **very low costs on the infrastructure**.

The ACR Freedrive system is **modular** (up to 5 independent packs of ultracapacitors or batteries for each system), **configurable** (number of ultracapacitor and battery packs depending on the power/energy needed in each application) and **redundant**.

Question #2

A traditional streetcar is designed to operate from an overhead supply system operating continuously at either 600 or 750 Vdc. Would your company's offering place any special or *additional requirements concerning integration of the electrification system? Would your technology operate with a pantograph when not on a wireless section?*

Answer #2

The ACR Freedrive system is capable to operate with both 600 and 750 VDC nominal catenary voltage with voltage variations indicated in IEC 60850 standard.

Question #3 - In Street Conductors

Has the in-street conductor been utilized in areas which normally experience snow and ice in the winter? What material would you use for fabricating in-street conductors? Would the material show corrosion for the application of de-icing road salt? What provisions are made to prevent snow plow blades from damaging the rail?

Answer #3

CAF has not developed an in-street conductor system for catenary free operation mode.

Question #4 – In Street Conductors

Has the in-street conductor been installed in mixed use traffic lanes? Has it been installed in reserved lanes with normal traffic operating at right angles across it? Have there been any issues related to cleanliness resulting from contamination with rubber tire, oils, or autumn leaves?

Answer #4

CAF has not developed an in-street conductor system for catenary free operation mode.

Question #5 – In Street Conductors

How is the conductor installed in the street? Are there any restrictions on horizontal or vertical curvature of the pavement? How are crossings or turnouts implemented with the conductor rail? What clearances are required for other structures such as manholes and metallic covers?

Answer #5

CAF has not developed an in-street conductor system for catenary free operation mode.

Question #6 – Batteries

Which battery type do you have experience in applying, Lithium (Li) or Nickel Metal Hydride (NiMH)? What is the maximum acceleration rate and maximum speed normally used in these applications?

Currently, Nikel Metal Hydride batteries are used for ACR Freedrive system.

Usually, the maximum speed in catenary free operation zones is lower than the maximum service speed as those zones are usually located in historical and pedestrian areas.

Question #7 – Batteries

What are the design limits and emergency limits for charge/discharge levels of the batteries on your vehicles? Is the battery management system provided by the battery manufacturer, third party specialized supplier, or incorporated into the propulsion system? Are the individual cells monitored?

Answer #7

The charge and discharge levels of the batteries are directly related with the service life of the batteries.

In order to minimize the impact of the charge and discharge cycles in the battery life, for a normal operation mode, the DOD (Depth of Discharge) of the batteries depends on the operation condition of each solution but it should be around 10-25%.

The ACR system (developed by CAF) is composed by a DC/DC converter which manages the charge and discharge of the batteries.

The battery cells are grouped into modules. These modules are monitored (with temperature and voltage) in order to adapt and manage properly the charge and discharge cycles of the batteries depending on the reading values.

Question #8 – Batteries

The operating environment in DC has a temperature range of -15F to 106F. What will be used for the cold temperatures to ensure proper operation of the system? Do the high temperatures with added solar heat gain prove detrimental to the batteries? Is a heating and cooling system typically provided for the batteries?

Answer #8

When outside temperature is below 32ºF, a pre-heating of the batteries is needed. The pre-heating of the batteries can be made charging and discharging the batteries before the streetcar starts the service. In this way, the batteries are self-heated.

Another way for pre-heat the batteries is to install a heating cable in the air inlet of the battery module. In this way, when the battery module is forced cooled, the batteries are heated by the warm surrounding air.

As low temperatures, high temperatures affect the life of the battery. In order to mitigate these effects, the tops of the ACR box are protected against the solar radiation. Moreover, as mentioned above, the ACR system adapts the charge and discharge cycle of the batteries depending of the temperature of the batteries.

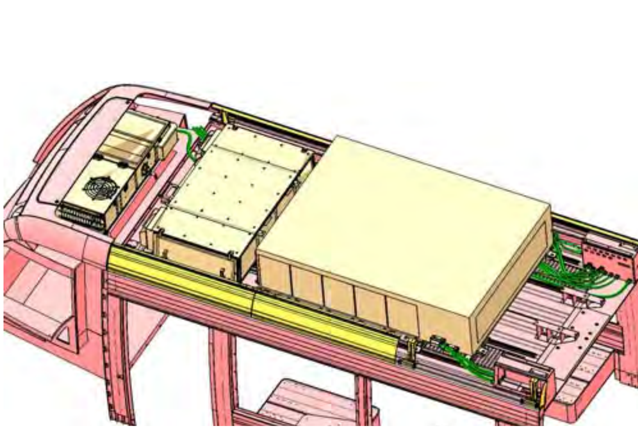
The forced air cooling is used for cooling the battery modules.

Question #9 – Batteries

There is a concern with impacts damaging Li batteries with fires resulting days later. This was observed during crash testing of the Chevy Volt. Are the batteries located in an area susceptible to impacts in traffic accidents? Have you established criteria for maximum impact shocks and have the criteria been validated by the battery manufacturer?

Answer #9

The ACR system is equipped on the roof of the streetcar as shown below.
The car builder designs the roof equipment in order to avoid the impact from traffic accidents and preserve passenger safety.



The batteries equipped in the ACR system are NiMh type. This type of battery is less sensitive to flammability than lithium battery. Nevertheless both battery modules and ACR box comply with ENFF 16101 and ENFF 16102 standards and mechanically robust complying with CEI-IEC 61373 (ver.2010) - Impact and Crash test standard.

Question #10 – Batteries

Batteries will be discharged during overhead gaps and recharged while operating in wired sections. As a “ball-park” approximation, if a streetcar traveled three miles off wire with 6 stops on an average 2% grade how long would the vehicle need to travel on wire to fully recharge? What would be the maximum current draw for battery recharging?

Question #11 – Batteries

If a stationary vehicle draws the maximum current for battery recharging in addition to the vehicle’s maximum auxiliary power requirement on a 106°F day in full sun with no wind, is it possible to heat a 350 kcmil overhead contact wire to the 160°F annealing temperature of the copper? If so, what measures may be taken to mitigate this concern?

The analysis should be done, taking into account wire sections and the consumed current.

For the stationary case, the current is regulated in each case, depending on the situation that the train will be stopped or not.

Question #12 – Supercapacitors

What is the time required to recharge fully depleted supercapitors at a stop? What level of current and voltage is this time based on?

Answer #12

The power required by the ACR equipment in a charging point depends basically on two parameters:

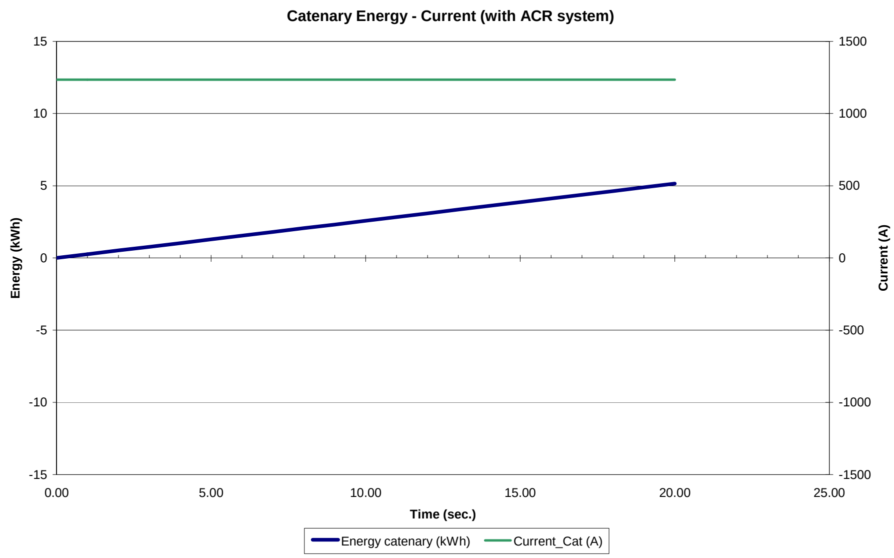
- Energy to be charged: After a catenary free zone, in order to fully charge the ACR equipment, it is necessary to recharge the energy in the charging point. This energy corresponds to the energy consumed in the catenary free zone.

- Charging time: Depends on the dwell time at stations. The ultrafast charge is performed while the passengers enter and leave the streetcar.

Average power = (Energy) / (Charging time)

For reference, to get an idea of the level of expected charging current, attached below catenary current values defined for the Zaragoza streetcar (streetcar of 32 meters).

- Ultrafast charging maneuver: 1300-1400A during 20 seconds



Question #13 – Supercapacitors

For a discrete charging system, would your firm recommend a traditional supply system with distribution via underground conduit or smaller discrete chargers at predetermined locations? If discrete chargers are possible, what is the range of AC supply voltages that could be accommodated? Can a one-line diagram of such a discrete charger be provided?

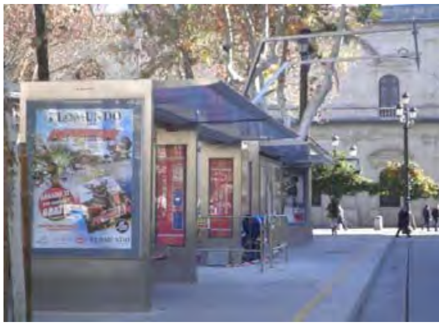
Answer #13

It is understood "discrete charging system" as ultrafast charging process.

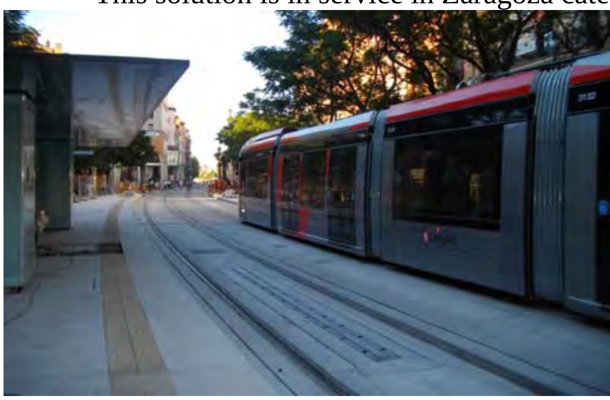
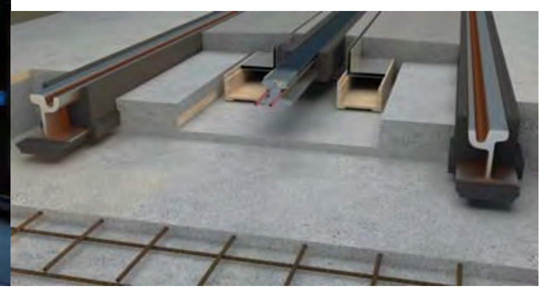
When the streetcar has to run through 2 consecutives catenary free zones, an ultrafast charging point is needed between both zones in order to charge the ACR equipment (if the equipment does not have enough energy to run catenary free through both zones).

The ultrafast charging process can be performed either from overhead catenary system or from ground system.

- The overhead catenary system consists of a short rigid catenary installed at the stops. The energy capture is made with a pantograph as shown below. This is a service proven solution in Seville catenary free streetcar. (2 + years in service)




- The ground system consists of a third rail which is powered only when the vehicle is over the rail. The energy capture is made with a shoes located in the bogie.as shown below. This solution is in service in Zaragoza catenary free streetcar.

Question #14 – Supercapacitors

If station spacing of one-half mile (800 m) on a 2% grade and the streetcars stops for traffic signals every 500 ft (150 m) is used, would your standard vehicle be capable of passing a stop without charging while operating with the maximum auxiliary load, including HVAC? What would be the anticipated charge level remaining at the second stop?

Question #15 – Batteries & Supercapacitors

Under lane-sharing scenarios, a Streetcar could be delayed considerably in traffic resulting in insufficient remaining charge to reach the next charging area. What is your strategy for minimizing this risk? Would additional storage capacity or capacity monitoring and load shedding (HVAC) be used? What is the possibility of recharging the vehicle in the street and what equipment would be recommended?

Answer #15

The sizing of the ACR system is always prepared under non-favorable simulation conditions (high loads, high accelerations/decelerations, etc…). This guarantees correct operation, with an appropriate safety margin, under normal operating conditions.

The system also includes intelligent available energy control systems to deal with any operating fault that could occur. In other words, if the train has route problems resulting in a delay (e.g. traffic jams, unforeseen (emergency) braking), the system can request that the train reduces the train performance as a preventative measure to prevent energy deficits in a specific section.

The definition and adjustment require that the preventive measures be prepared during project phase, performing a more detailed study of the route and final design of the train. In short, the preventative and corrective measures are as follows:

Preventative measures	**Activation conditions:**
(1) Consumption charge reduction request (mainly HVAC).	**(1) (2)** Activated when the energy level of the ACR units is less than a critical level defined for the route.
(2) Maximum train speed limit	
Corrective measures	**Activation conditions:**
(3) The use of the backup energy from the supercapacitors to reach the next stop	**(3)** This is activated when the useful energy of the ACR equipment runs out. In this case there is an extra 33% of energy that can be used under reduced power conditions in order to reach the next stop. Use of the supercapacitor backup energy is relegated to being used when the previous preventative measures have been applied but have not succeeded to prevent the ACR unit useful energy from running out.

The ACR equipment can be equipped with a battery module. In case of the backup supercapacitor energy is not enough for reaching the next charging point; the battery energy can be used as backup.

Question #16 – Vehicle Design Criteria

The District currently owns three T12 streetcars manufactured by Inekon and has three American-built versions of the Skoda T10 streetcars on order. These vehicles use the standard Czech width of 8 ft (2.46 m). What are the implications of continuing to use such European dimensions? Would you be interested in proposing on a small order of 8-10 cars with this width requirement? If no, what is the minimum order size you would be interested in? Would you prefer using the typical US width of 8 ft 8.3 in (2.65 m)?

Answer #16

Not Applicable

Question #17 – Vehicle Design Criteria

The District's current vehicle design criteria limit the length of the vehicles to 72.2 ft (22 m). Does this length permit sufficient space to mount energy storage devices on your standard vehicles? If not, what is the minimum length of vehicle your firm would be interested in providing?

Answer #17

The ACR equipment is modular and configurable. Thus, the required space for the energy storage system depends on the amount of energy installed in the ACR equipment. Depending on the customer requirements, it is necessary to perform simulations to correctly sizing the equipment.

Apart from the size of the ACR equipment, roof equipment distribution of the streetcar is required.

Question #18 – Retrofit of Existing Vehicles

The District currently has vehicles with lengths of 66 ft (20 m) and width of 8 ft (2.46 m). If these vehicles are to be operated on lines with wireless sections they will need to be retrofitted. What would be the approximate space requirements if your technology were to be retrofitted? Are there any proprietary components that would be required? Do you have any experience retrofitting the system to older vehicles manufactured by you or others? Would you be interested in performing the retrofit work as part of a new procurement?

Answer #18

The ACR equipment is modular and configurable. Thus, the required space for the energy storage system depends on the amount of energy installed in the ACR equipment. Depending on the customer requirements, it is necessary to perform simulations to correctly sizing the equipment.

Apart from the size of the ACR equipment, roof equipment distribution of the streetcar is required.

Seville catenary free streetcar was the first streetcar equipped with ACR system (first prototype in revenue service). This streetcar was an existing train that was refurbished to implement the new system. In this case it was necessary to change some electrical equipment in order to optimize the roof distribution. Each case is however different and a specific study should be done for the required units to check the feasibility of a modernization.

Question #19 – Specialized Equipment

What specialized equipment will be required to maintain your proposed energy storage and/or enhanced propulsion technology options? Will additional shop equipment or storage/charging rooms be required? Will test and troubleshooting procedures be impacted, particularly for high voltage storage devices on the vehicles? Please elaborate on the specific function and purpose of such equipment.

Answer #19

For ACR maintenance purposes, the supercapacitor energy has to be discharged with a discharger cabinet, for safety reasons

In the case of the batteries, they can not be discharged in order to preserve their service life. But it is important to remark that those batteries has been designed to work in a very low voltage conditions (around 150 V)

Question #20 – Training and Education

Will additional specialized training for vehicle maintainers, wayside maintainers, or vehicle operators be required? Will specialized personnel in any of these areas be required or would a *typical maintainer/operator with a high school diploma and standard maintainer/operator training be sufficient?*

Answer #20

The ACR system does not need any special maintenance apart from the cleaning and checking of the cooling circuit. The maintenance of the DC/DC converter is similar to other electronic component and the supercapacitors and batteries must be treated as conventional capacitors and batteries.

Thus, it is not required and expert maintenance team for ACR equipment, and does not require specialized personnel for the maintenance,

On the other hand all the training and education for those systems, will be provided by the car builder

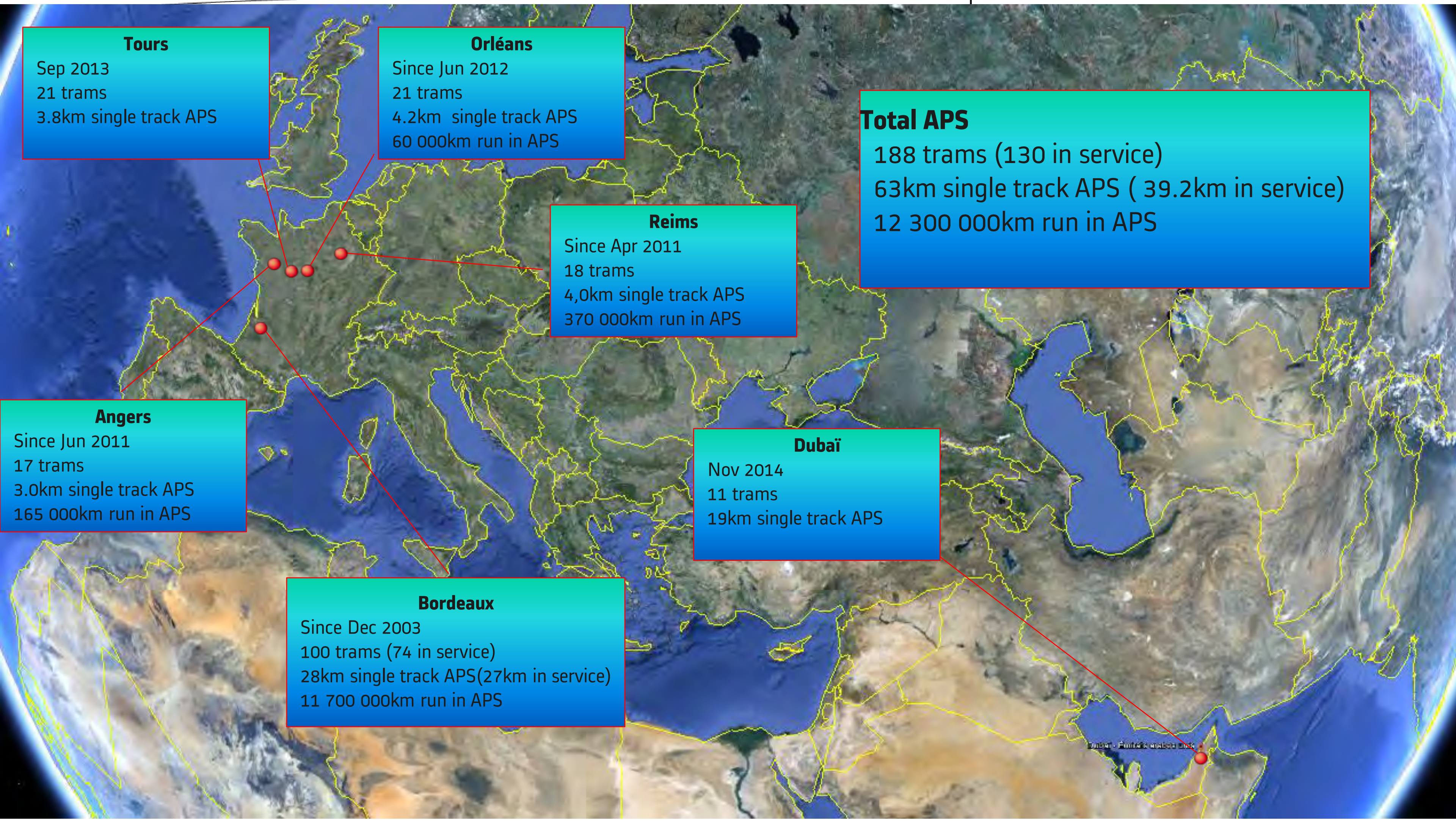
Alstom

APS SOLUTION

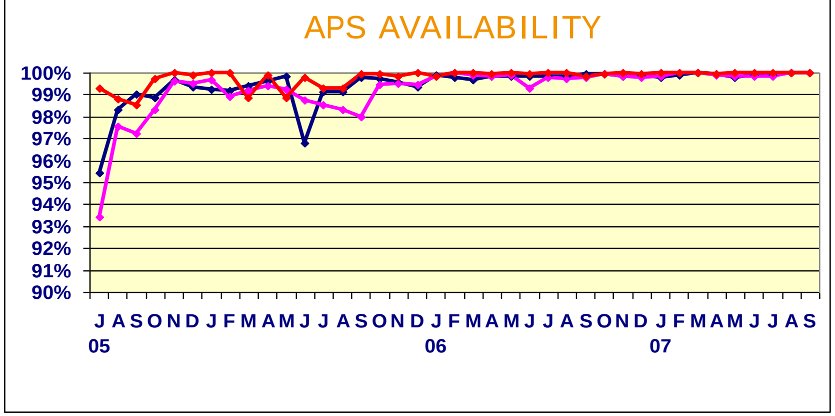
2013, March 8th

ALSTOM

AESTHETIC POWER SUPPLY – APS - Projects location



Bordeaux

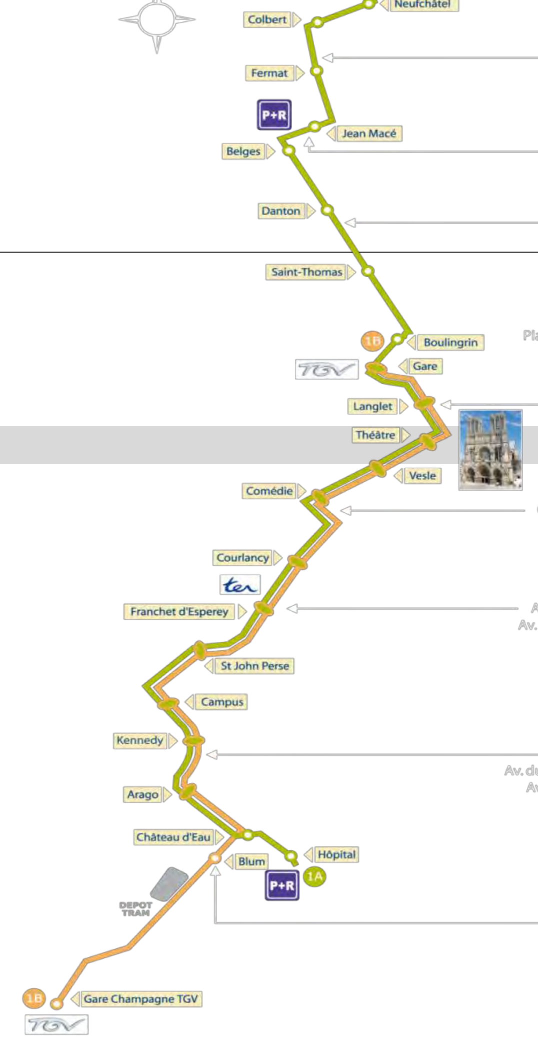


- Proven solution : 13.4 km out of 43 km
- 74 tramways (30 & 40 m types)
- No power restriction
- No risk of “empty tank”
- Complete intrinsic safety

- 8 millions kms run in passenger service
- Revenue service : end of 2003 (three lines)

ALSTOM

Reims



- Concession over 30 years
- 2 km out of 12 km
- 23 stations
- 18 tramways

Project start in July 2006

1st Run : September 2010

Passenger service : April 18th 2011

Angers

- 1,5 km out of 12 km
- 25 stations
- 17 tramways

Project start in November 2006

1st Run : December 2010

Passenger service : June 25th 2011

Particularity : 8% slope

TRANSPORT ALSTOM

Orléans

- 2,1 km out of 12 km
- 25 stations
- 21 tramways

Project start in September 2006

Passenger service : End of June 2012

TRANSPORT ALSTOM

Tours

- 2 km out of 15 km
- 30 stations
- 21 tramways (43 m version)

Project start in Sept 2010

Passenger Service : Autumn 2013

Dubai

The first city in the Gulf region to be equipped with a tramway transit system

- **19 km fully catenaryless**
- **13 stations**
- **11 tramways (43 m version)**

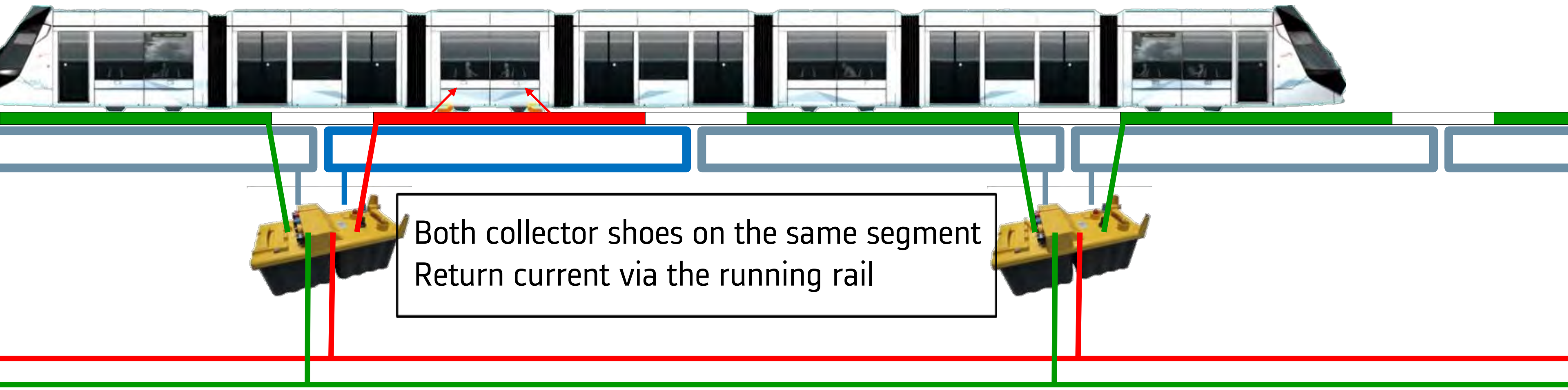
Project start in June 2008

New Passenger Service : 2014

APS Basic Principle

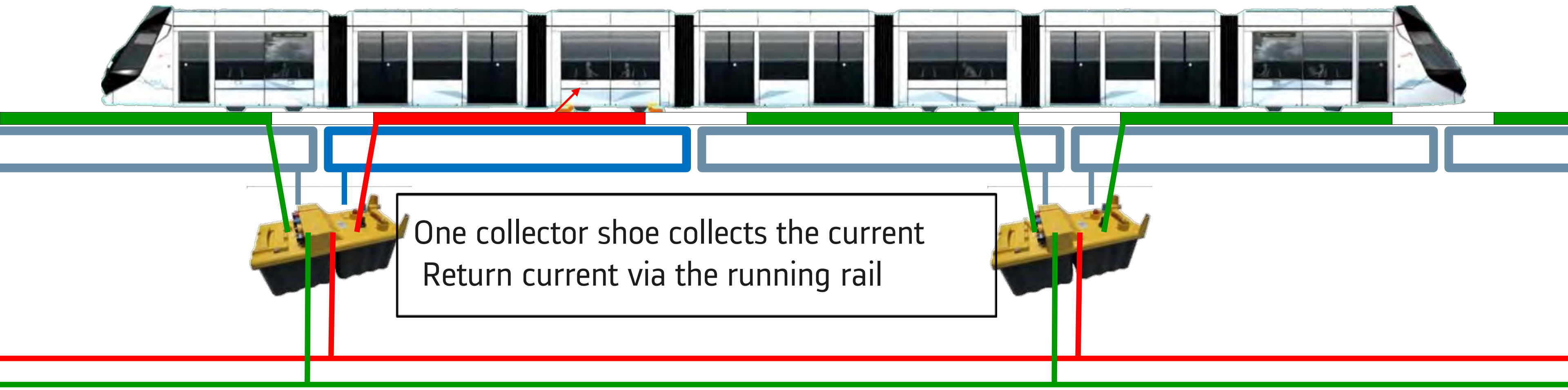
- ✓ Period : 11m / Conductive Segment 8m / Neutral zone : 3m
- ✓ Each power box drives 2 segments, a power box every 22m
- ✓ Tramways are 30 or 40m long, covering every live segments
- ✓ After tram passage, the segment is connected to the rail voltage

APS Basic Principle - distribution chronology

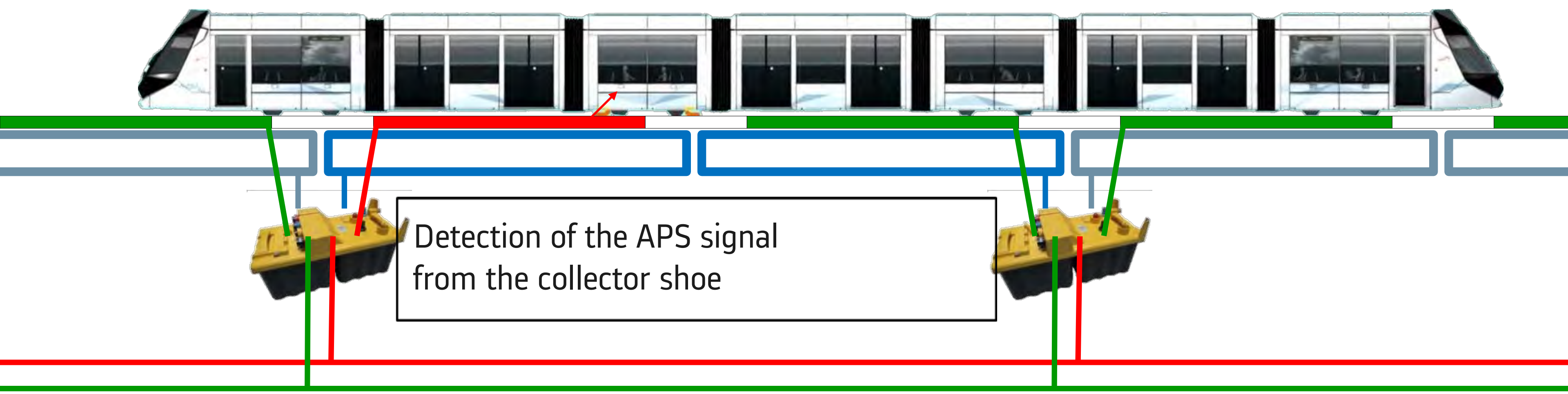


Both collector shoes on the same segment
Return current via the running rail

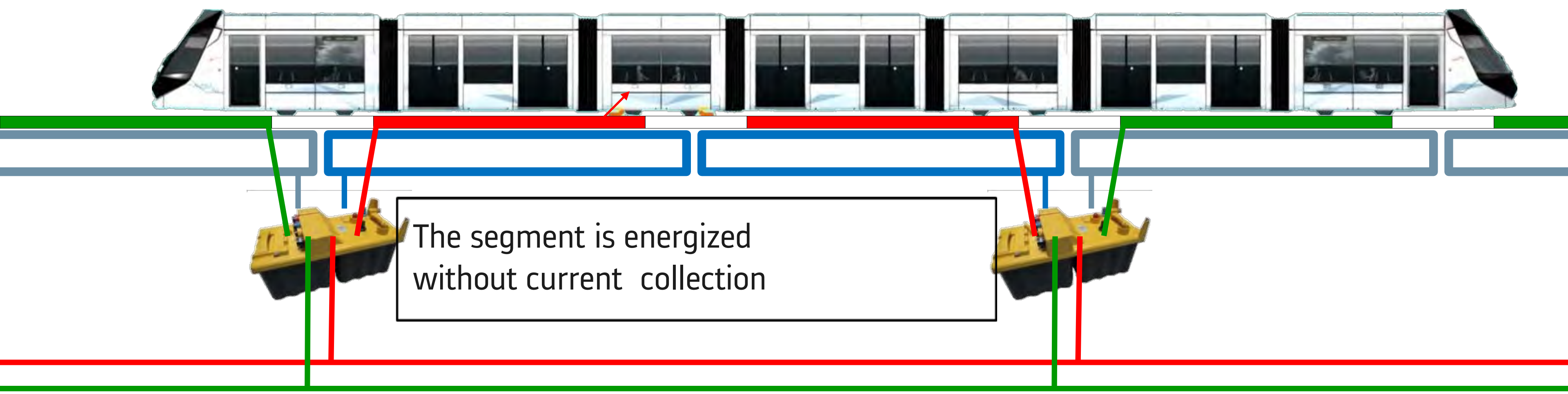
APS Basic Principle - distribution chronology



APS Basic Principle - distribution chronology



APS Basic Principle - distribution chronology



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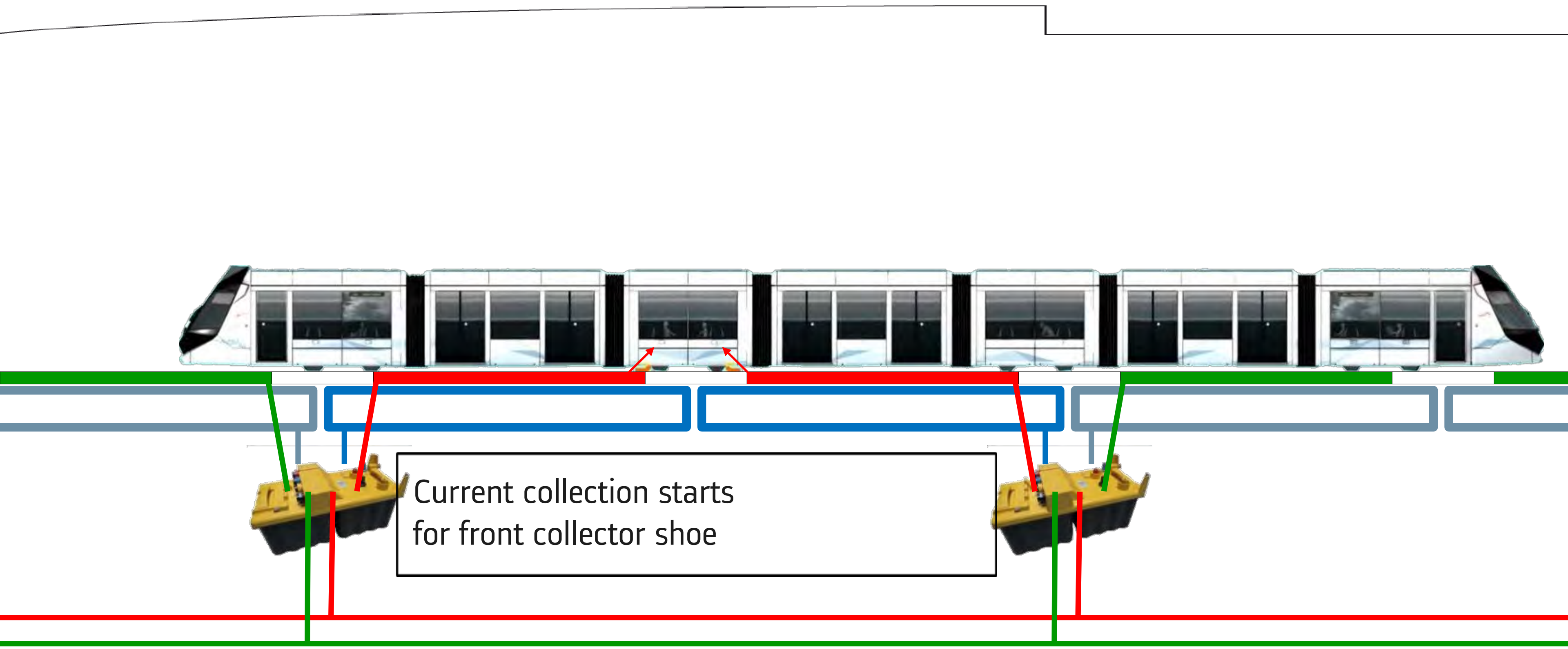
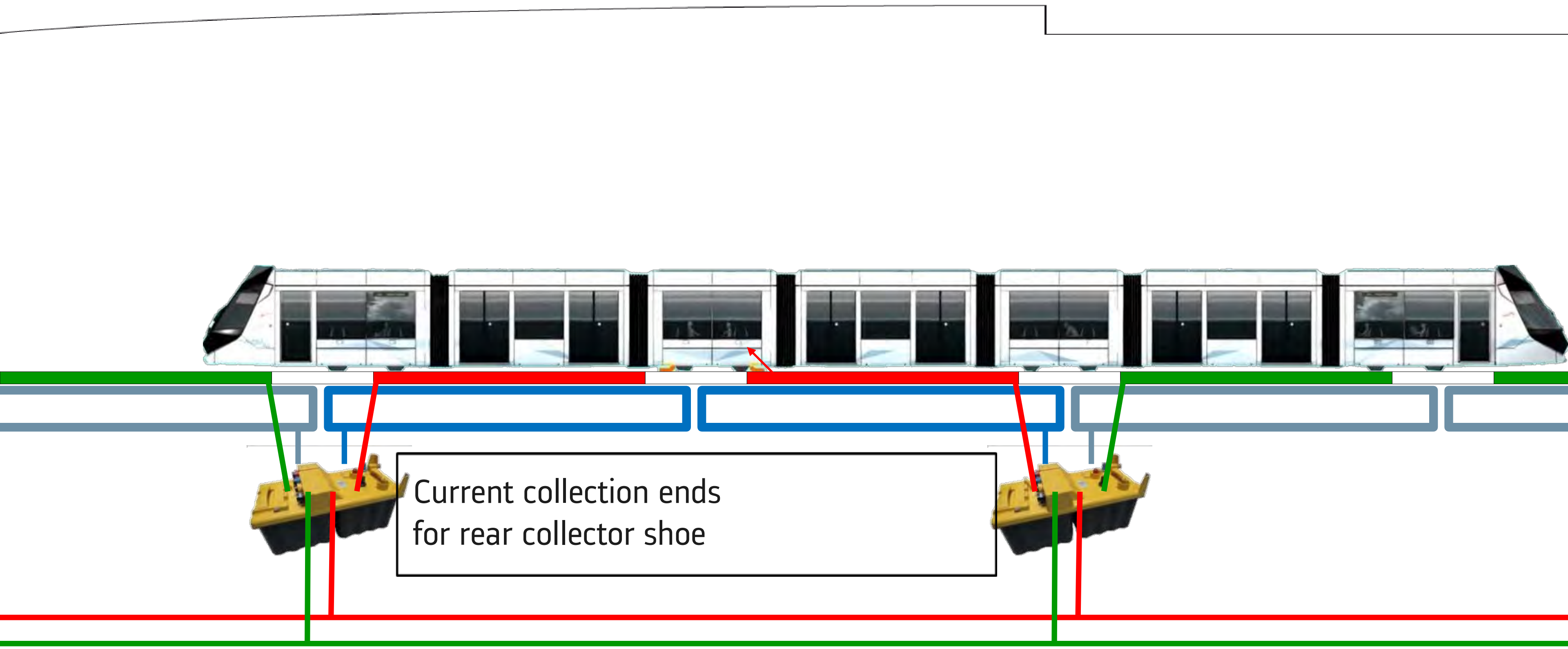
APS Basic Principle - distribution chronology

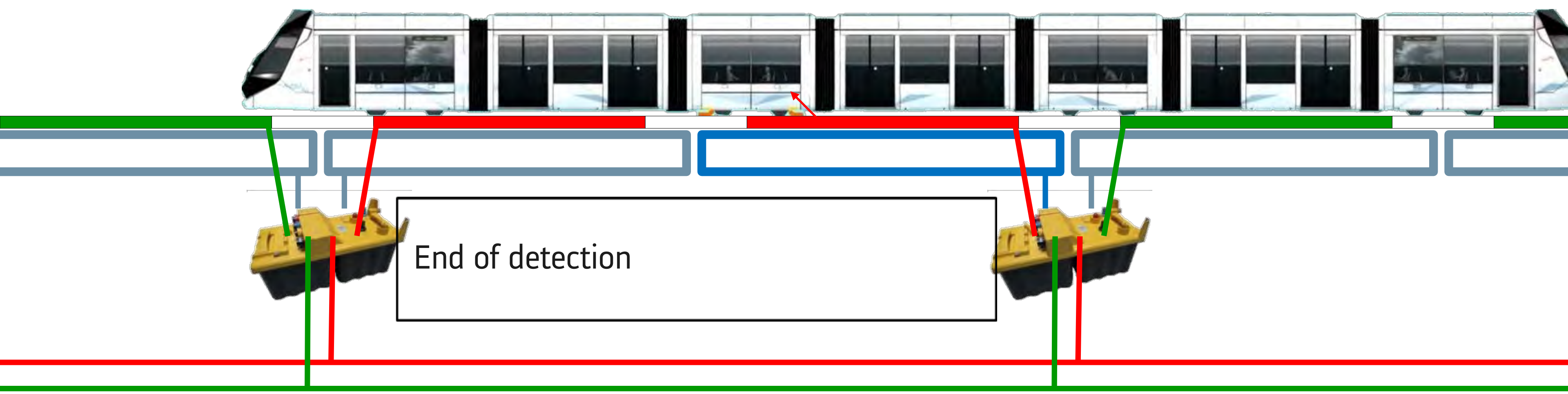


Current collection starts for front collector shoe

APS Basic Principle - distribution chronology

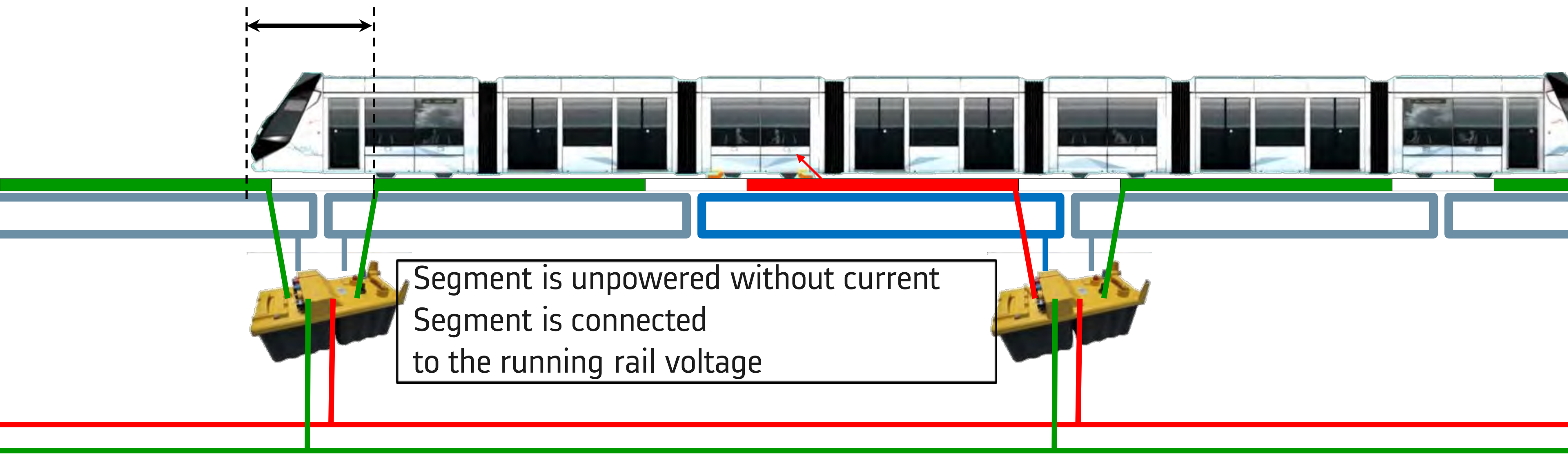


APS Basic Principle - distribution chronology

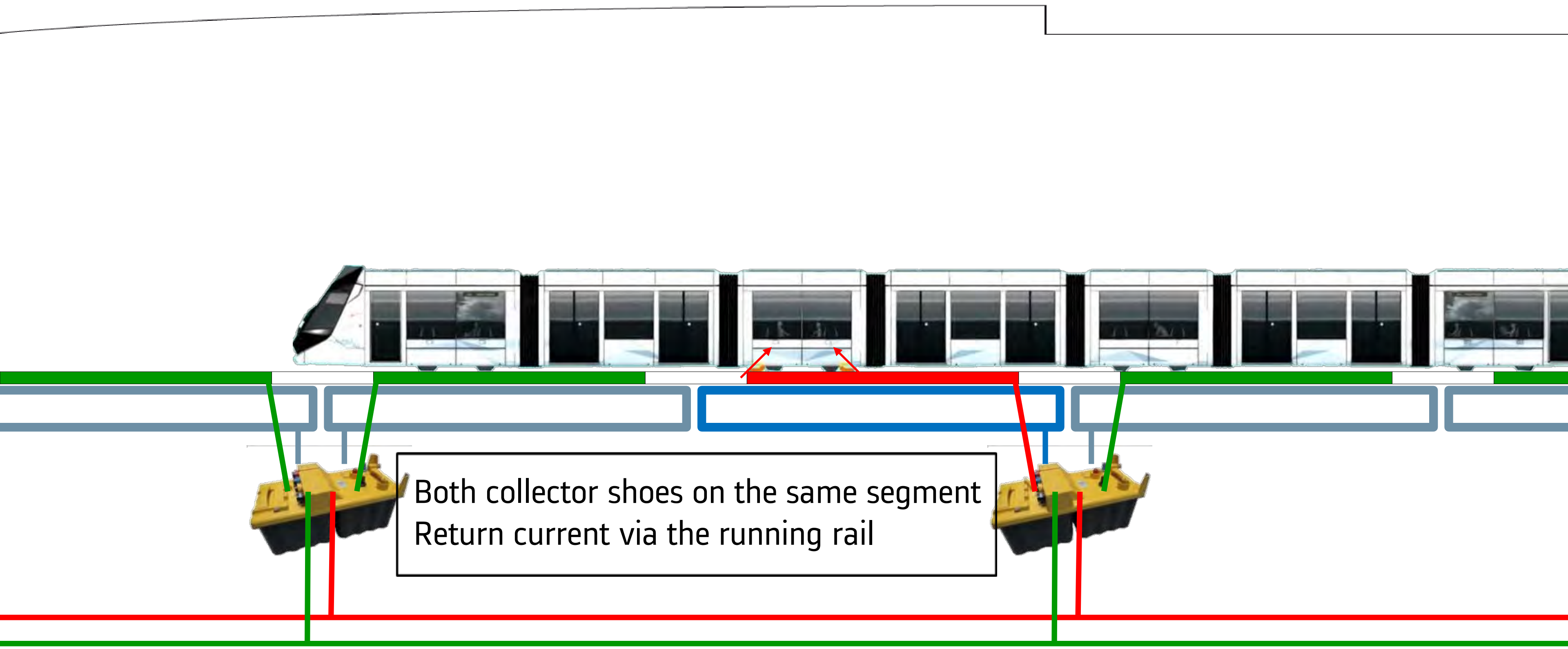


APS Basic Principle - distribution chronology

The tram still protects the segment

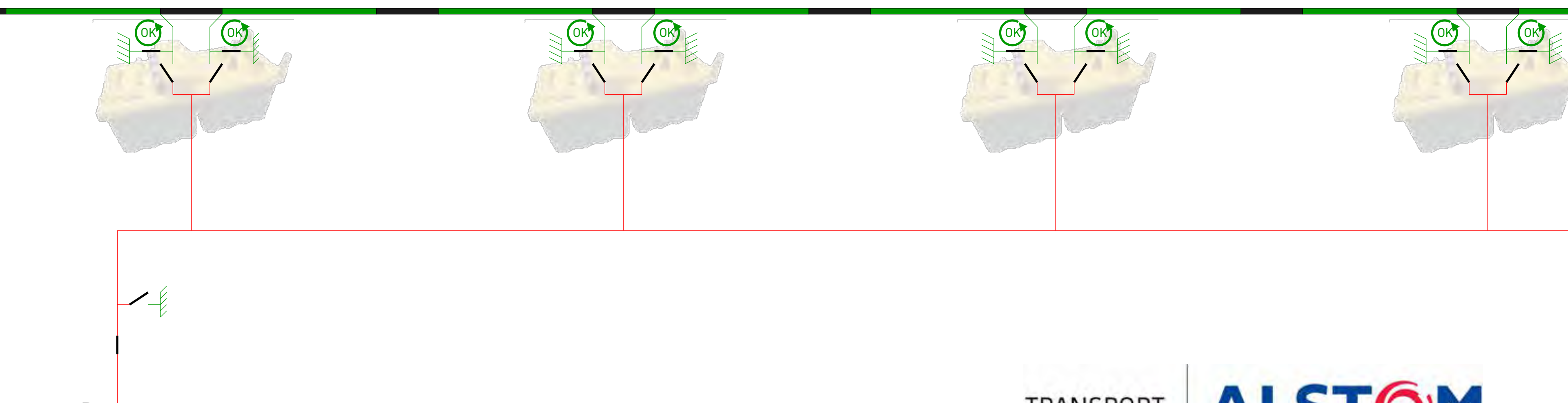


APS Basic Principle - distribution chronology



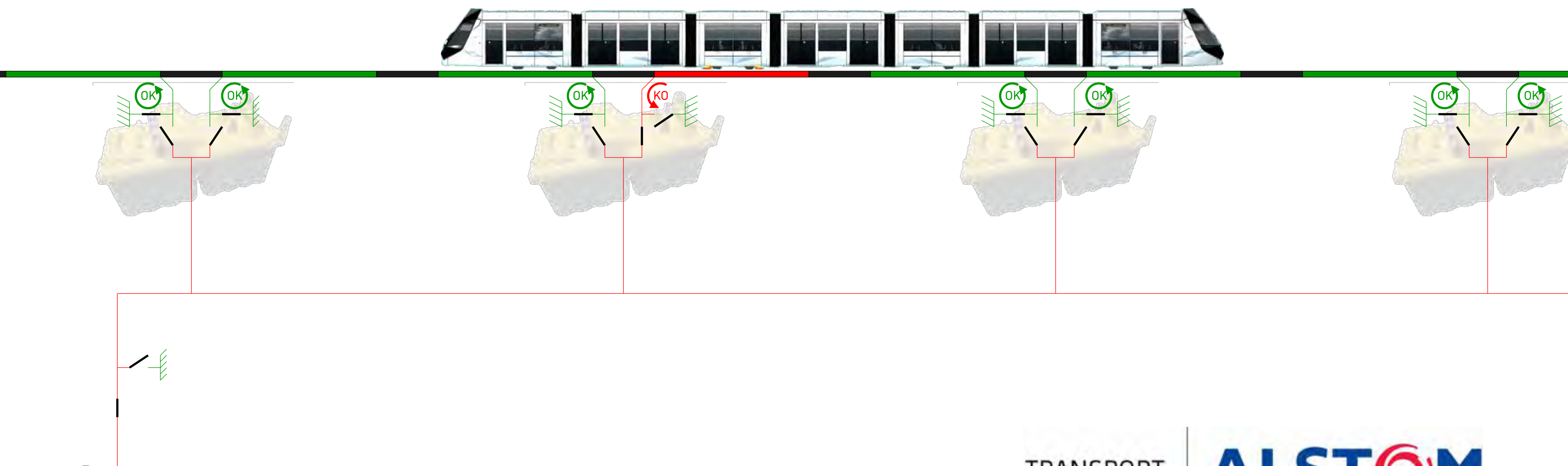
APS Basic Principle - Safety

- ✓Continuous and safety earthing verification
- ✓Static relays will not spontaneously close



APS Basic Principle - Safety

✓Lack of earthing during safety tramway detection is a normal status



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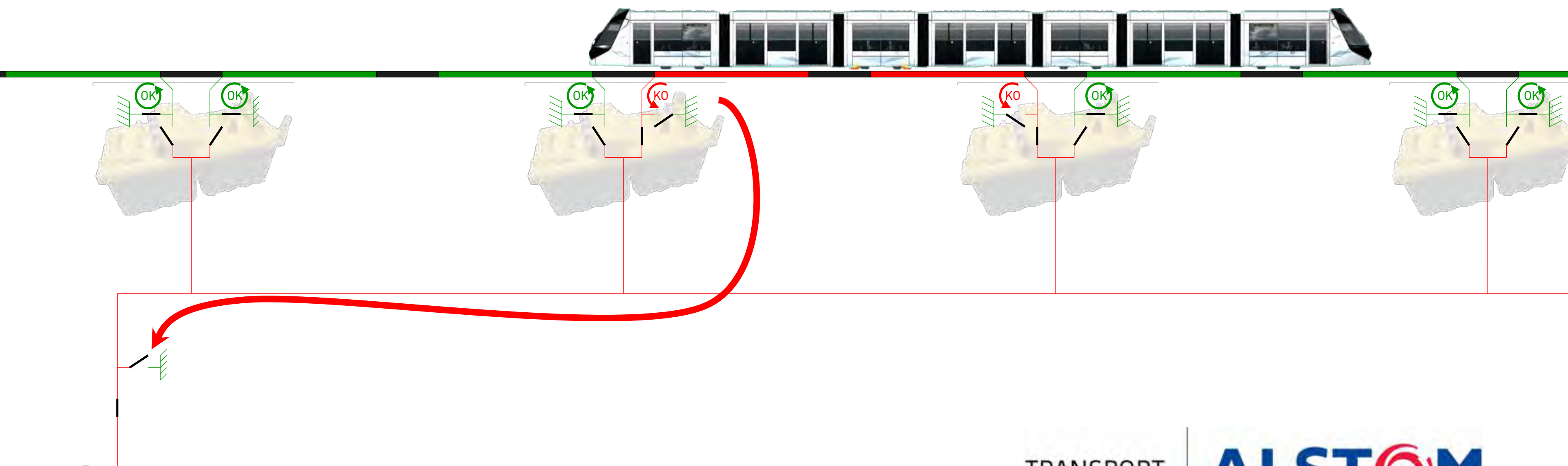
APS Basic Principle - Safety

- ✓Lack of earthing after tramway detection is <u>a failure.</u>
- ✓It is immediately and safely reported upstream (at the substation)



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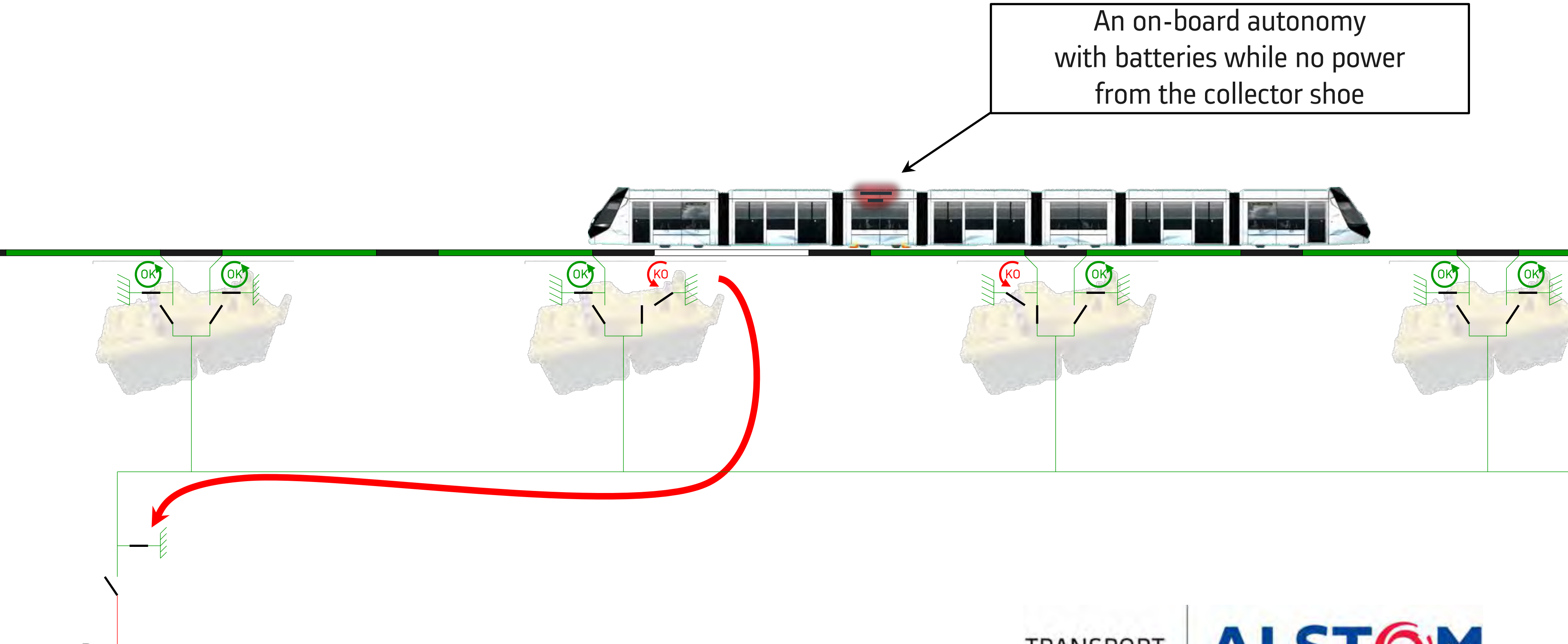
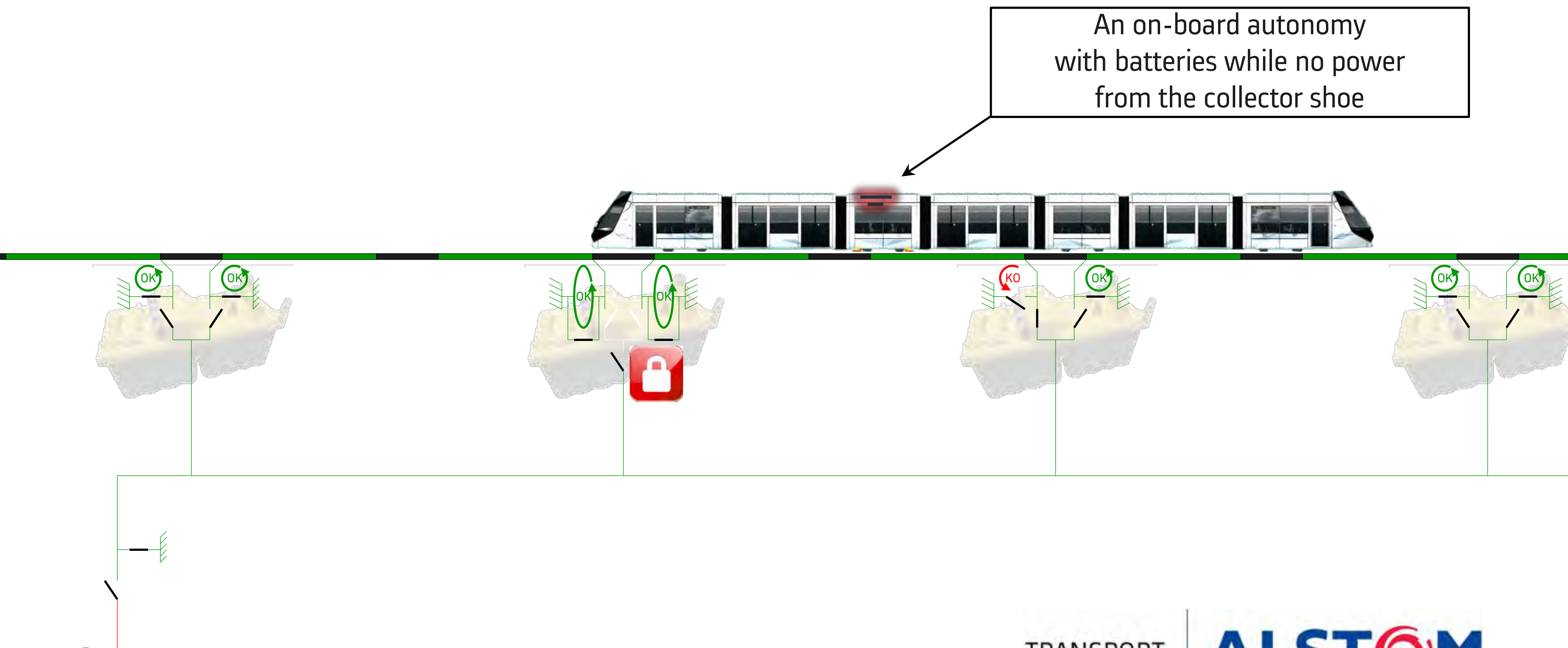
APS Basic Principle - Safety

✓The total section is unpowered and set in safe and restrictive status.



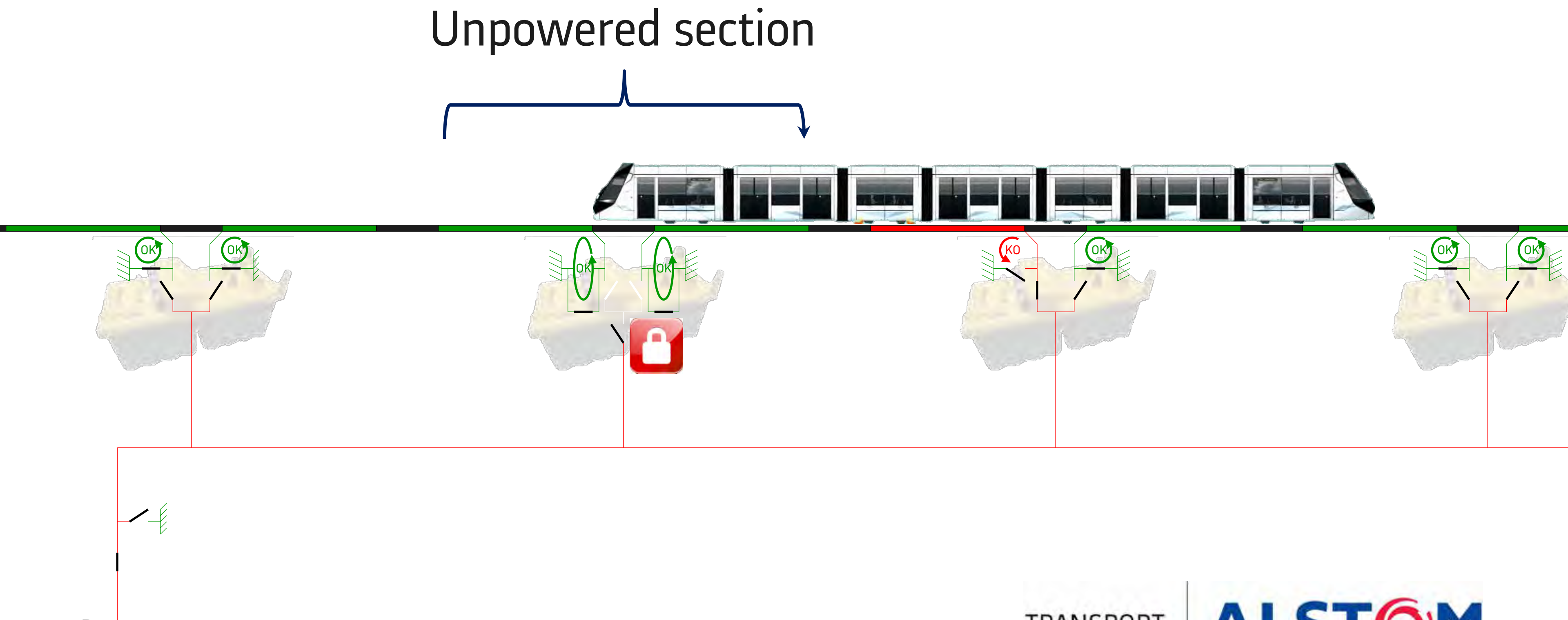
APS Basic Principle - Safety

- ✓Automatic or remote isolation of the power box
- ✓Second safety earthing verification circuit in the power box



APS Basic Principle - Safety

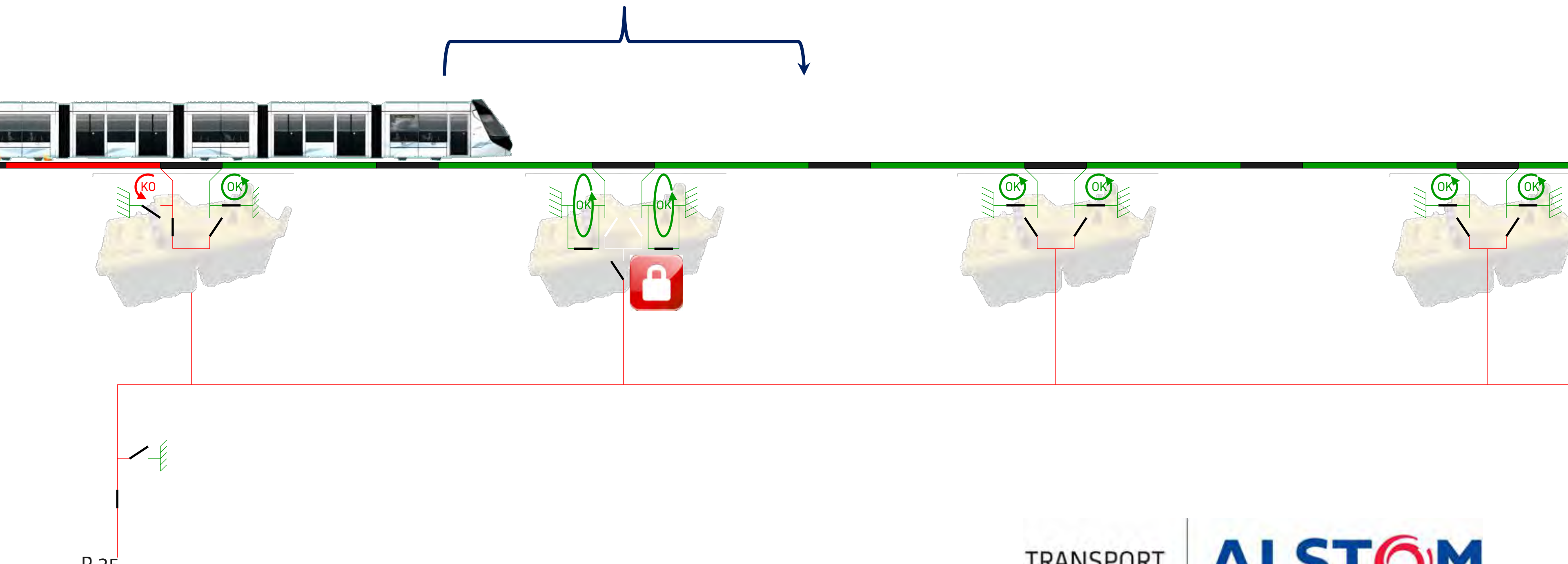
The operation resumes with an isolated box



APS Basic Principle - Safety

Next trams will run in autonomy mode on this isolated Power Box until replacement of the power box.

Unpowered section



APS Basic Principle - Safety

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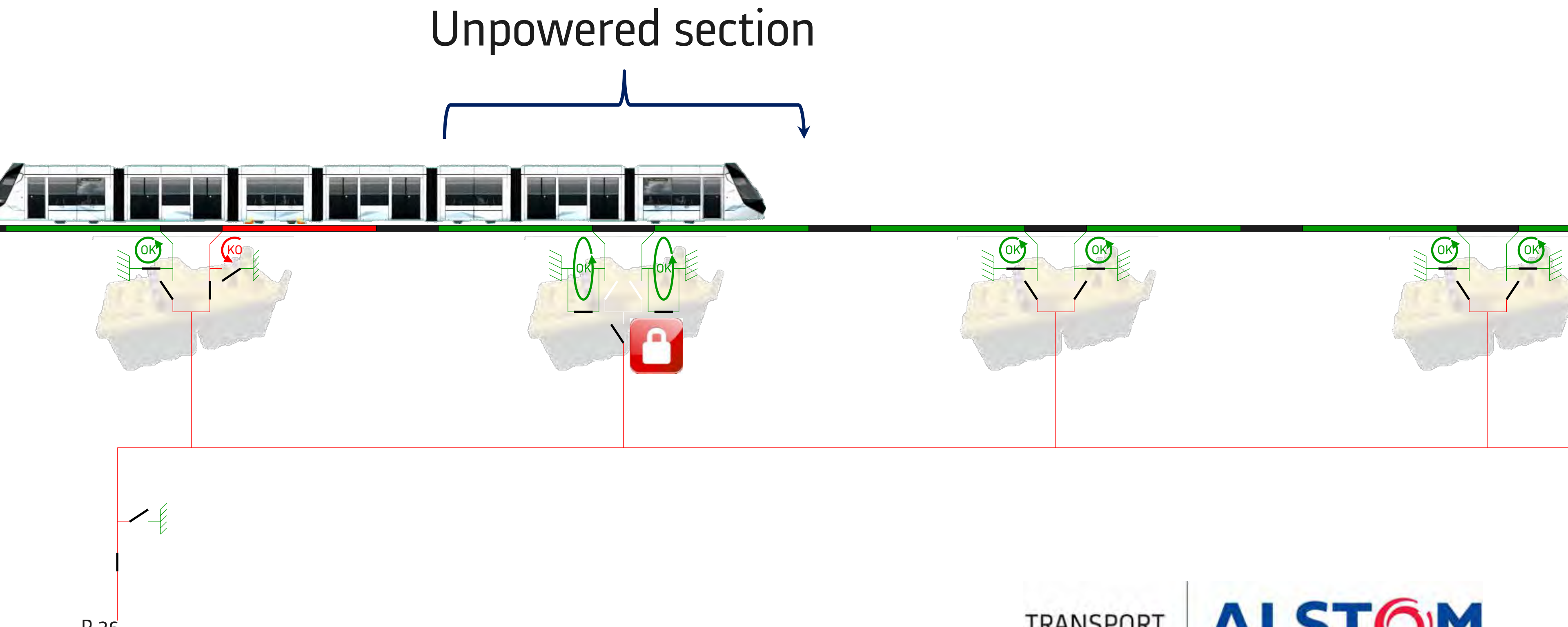

APS Basic Principle - Safety

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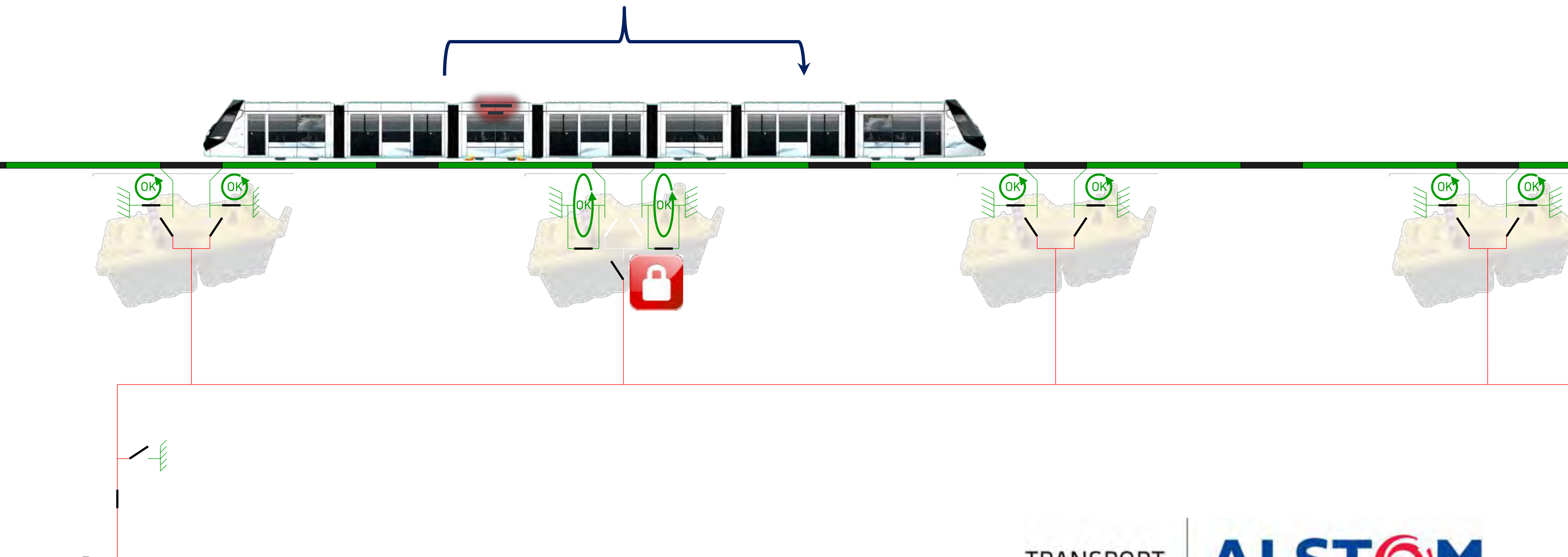
Unpowered section



APS Basic Principle - Safety

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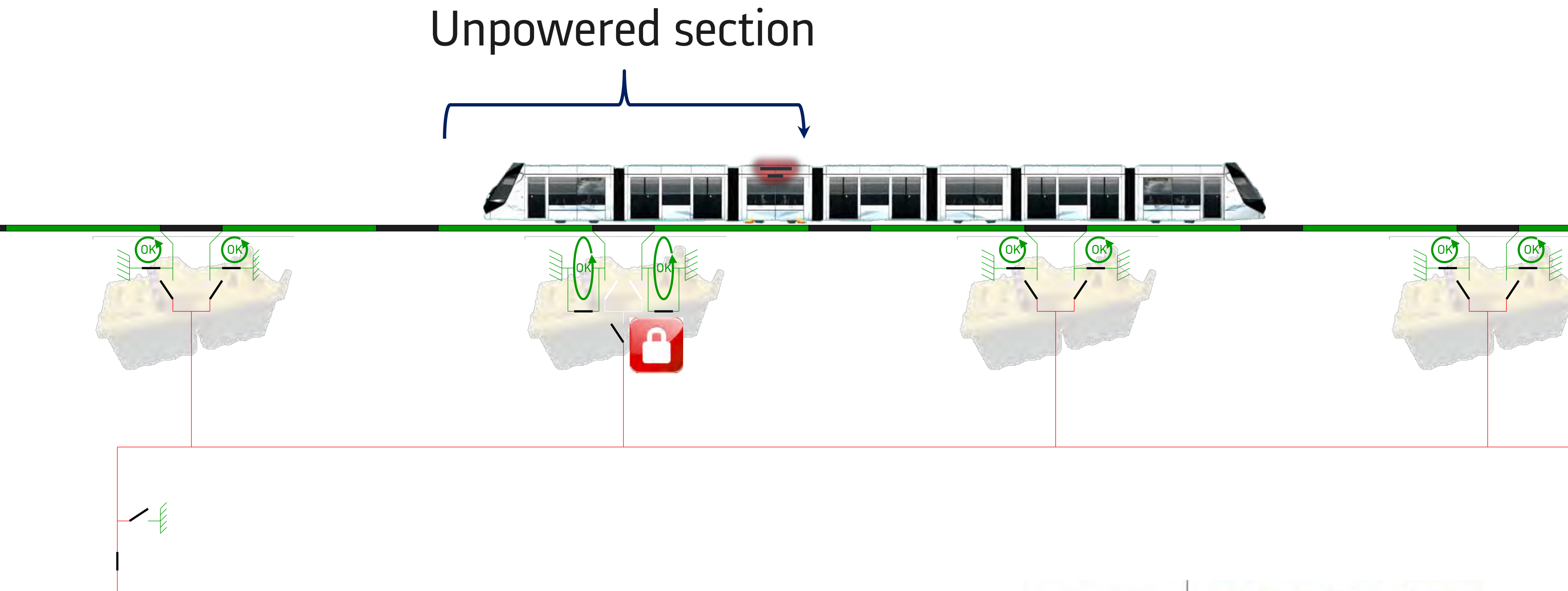
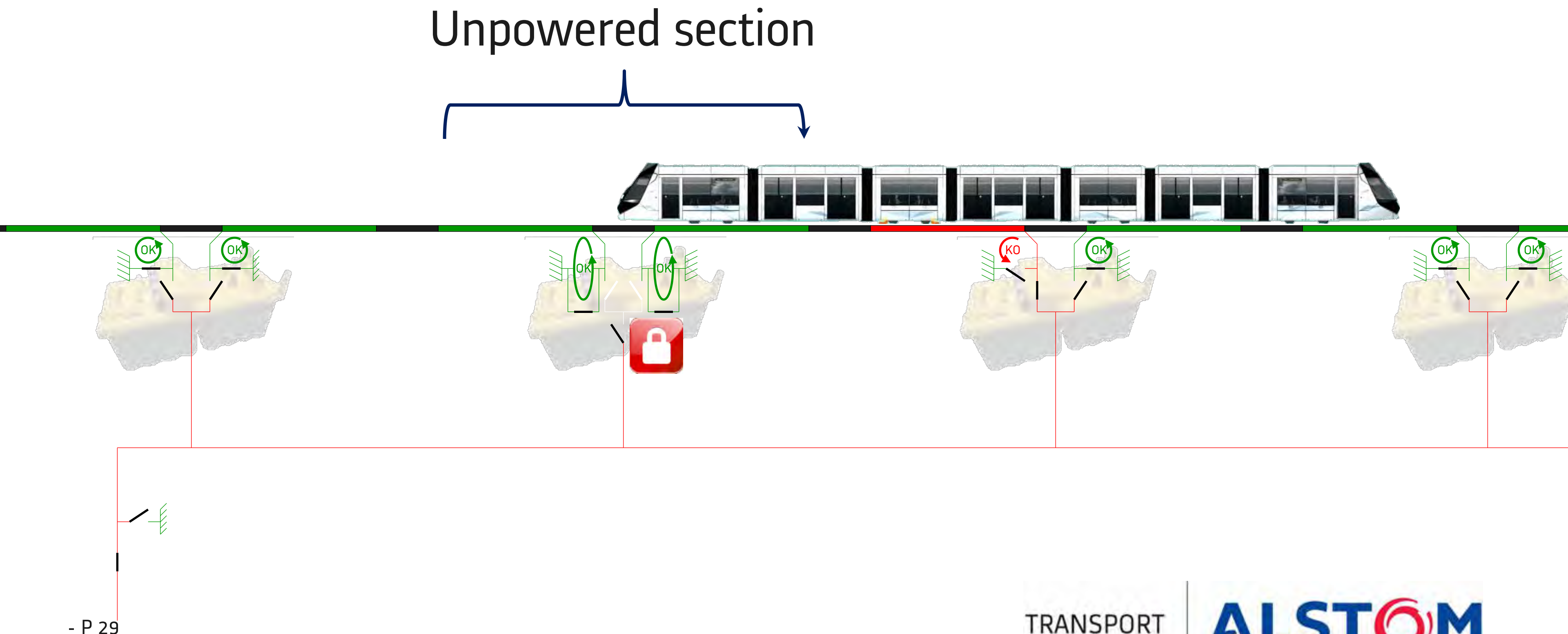


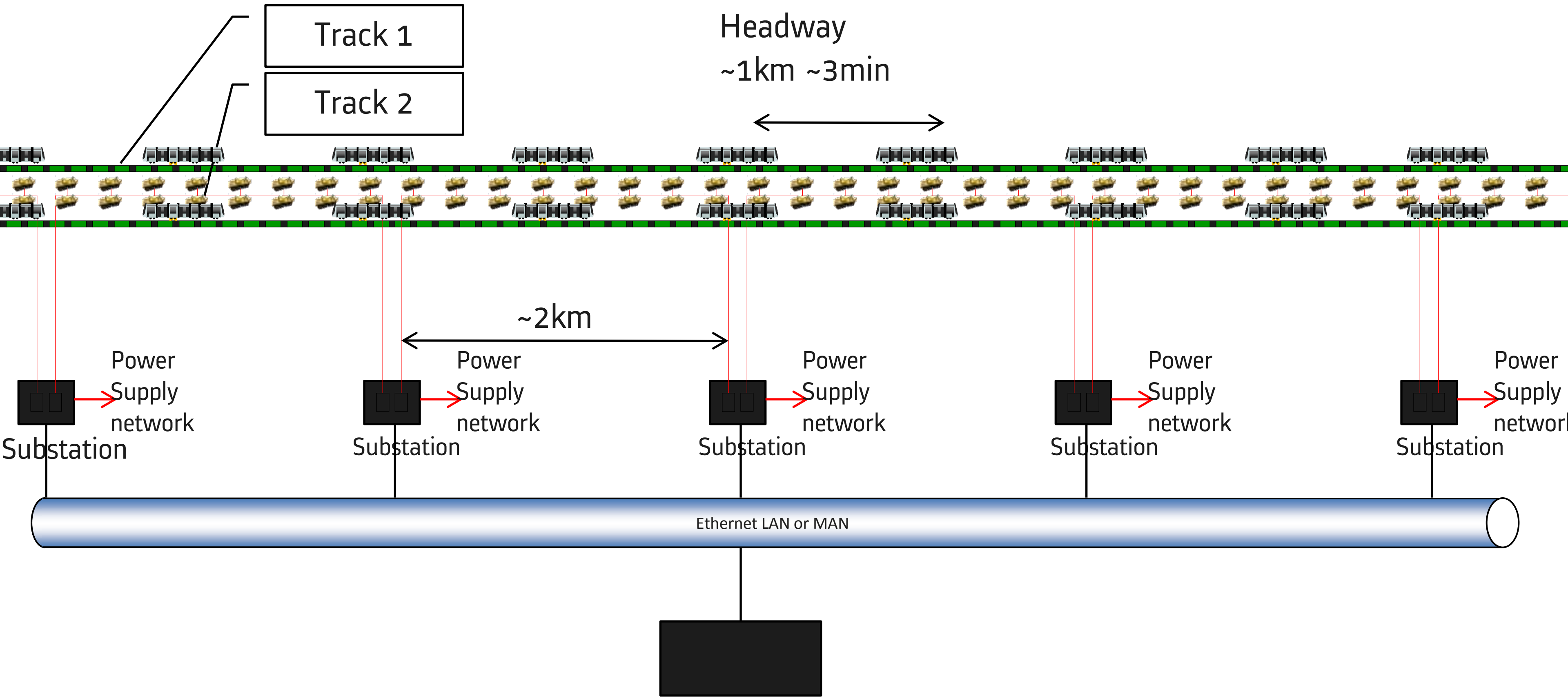
TRANSPORT ALSTOM

APS Basic Principle - Safety

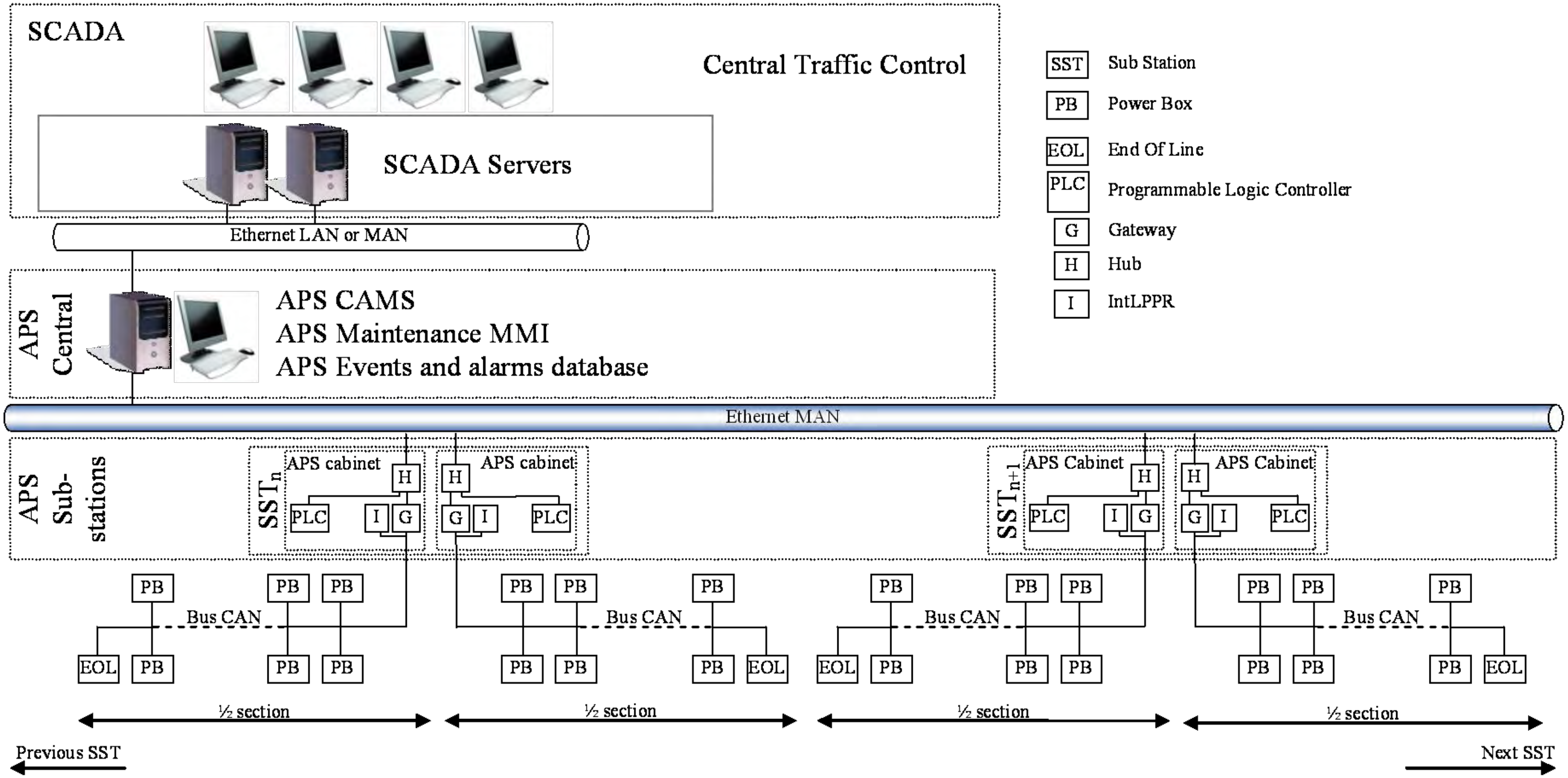
Next trams will run in autonomy mode on this isolated Power Box until replacement of the power box.



APS Basic Principle - Overall architecture

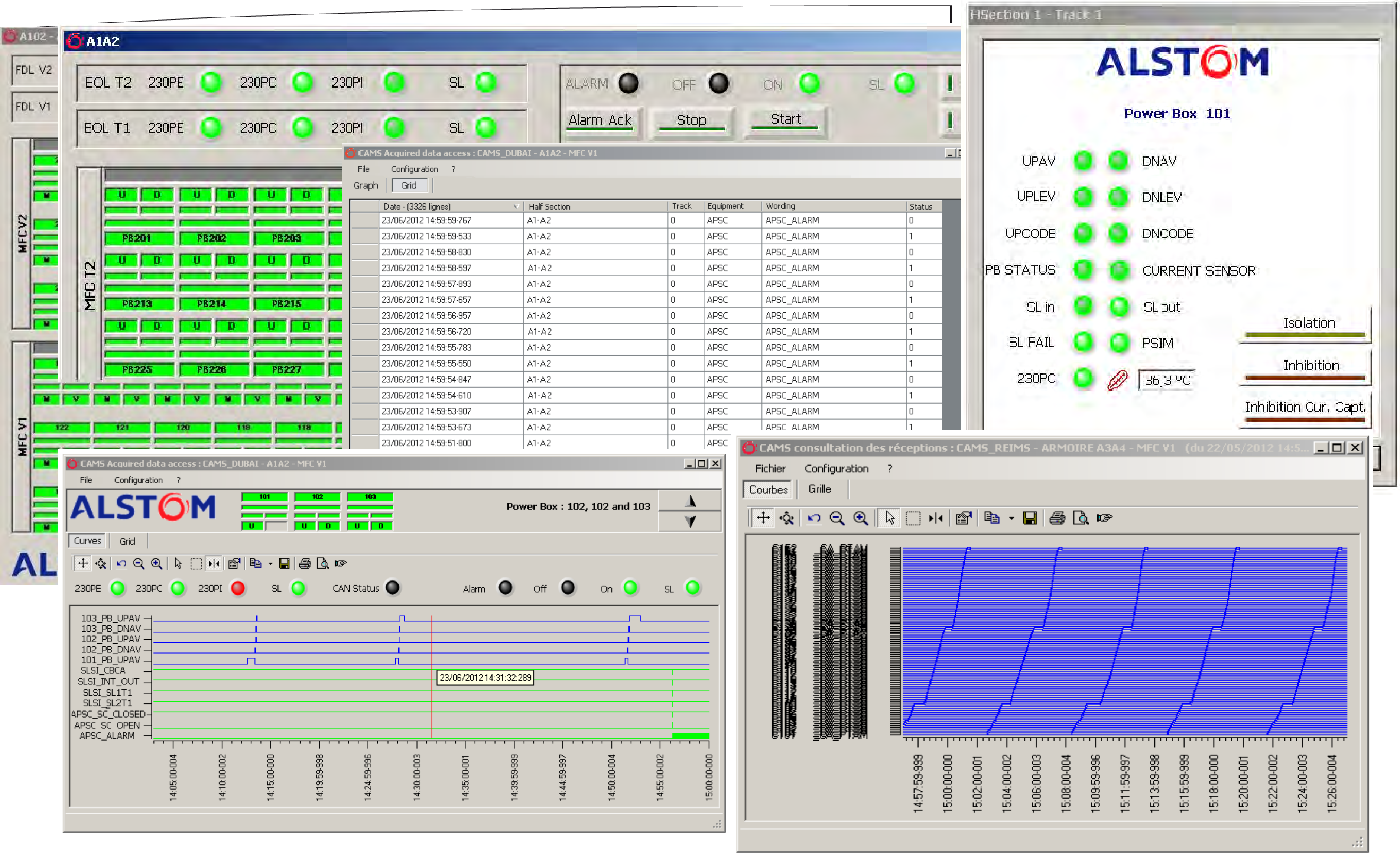


APS Basic Principle - Computerized Aided Maintenance System

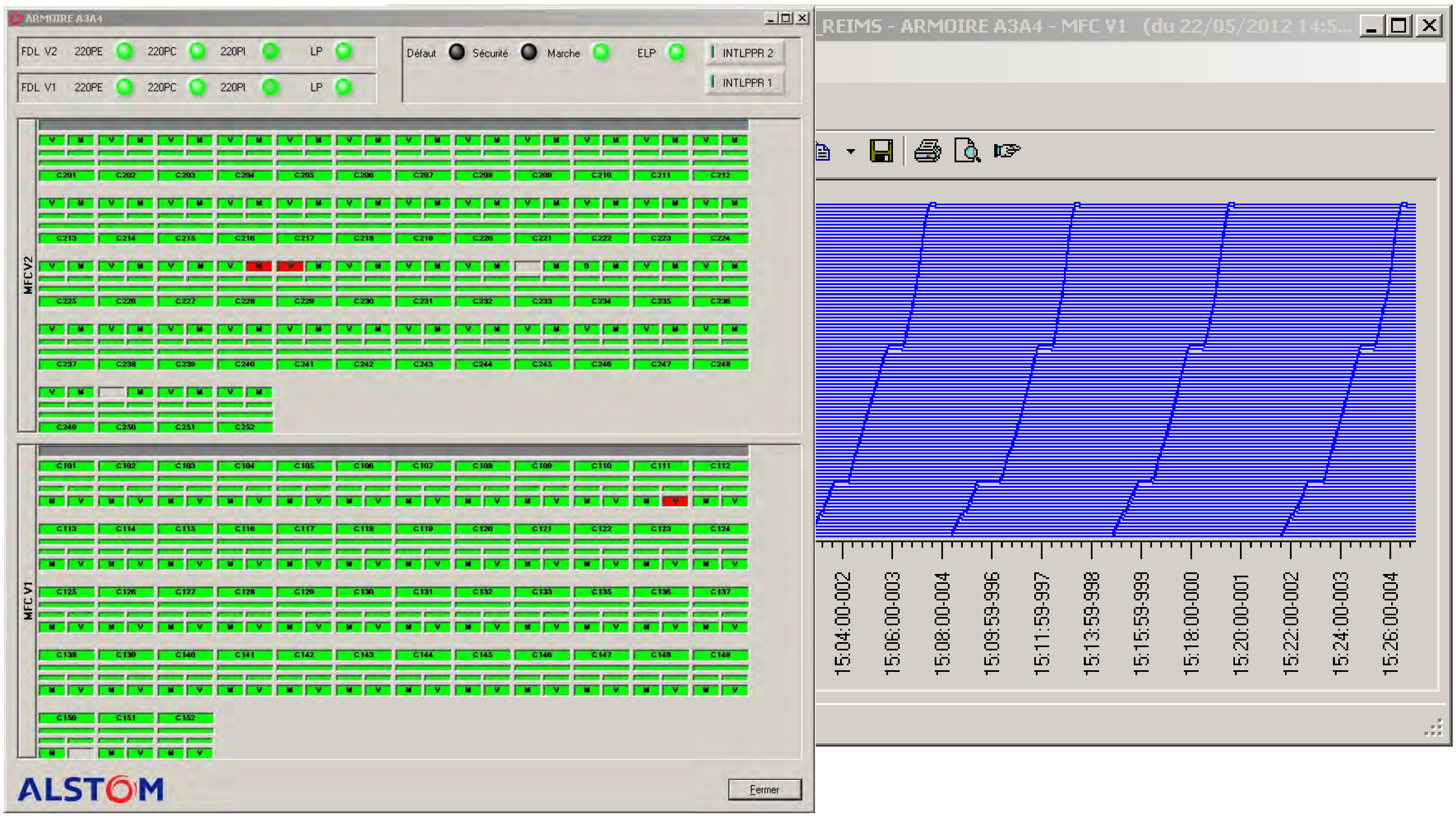


TRANSPORT ALSTOM

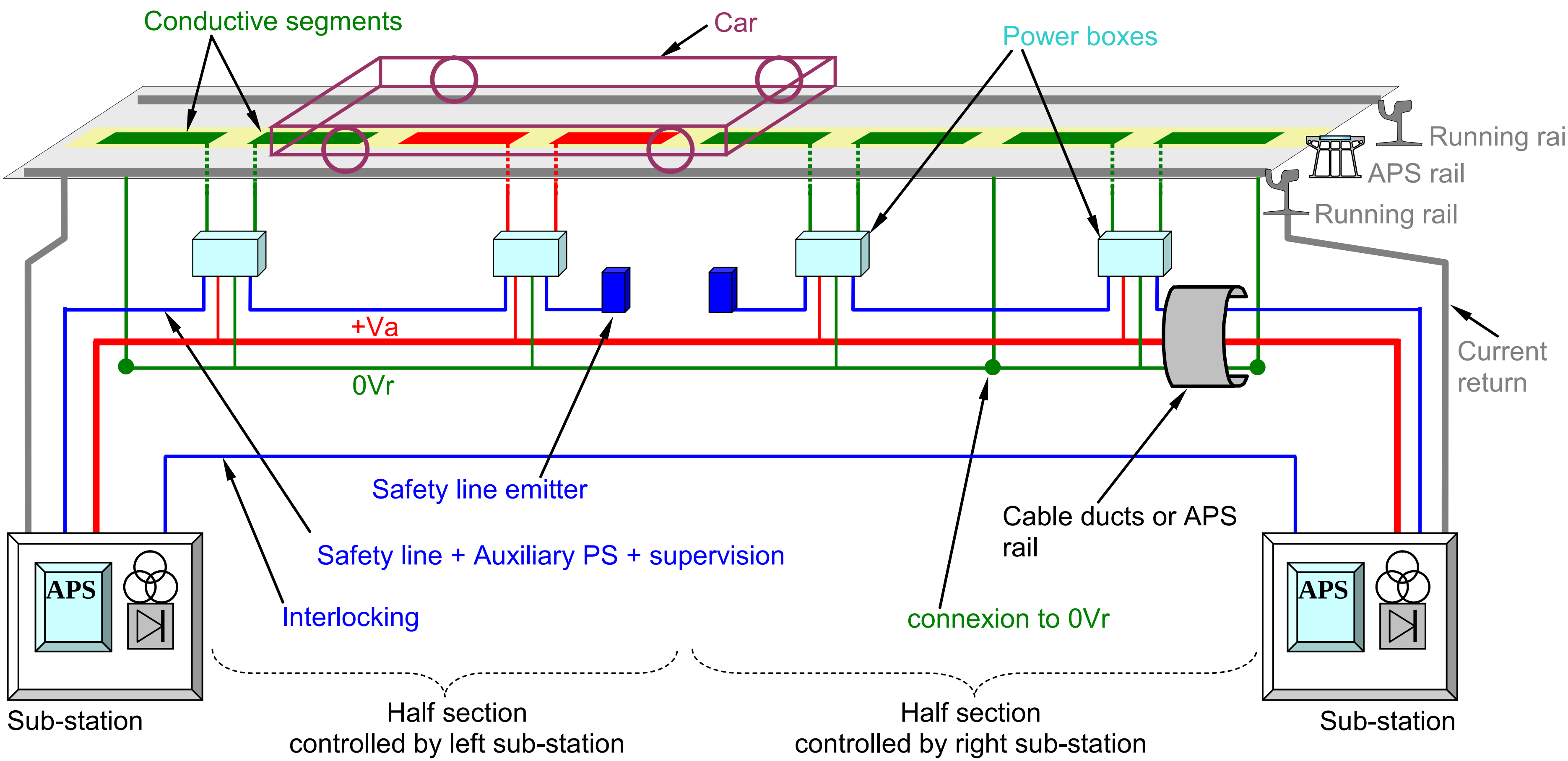
Real time supervision
1ms dating accuracy for power box for diagnostic



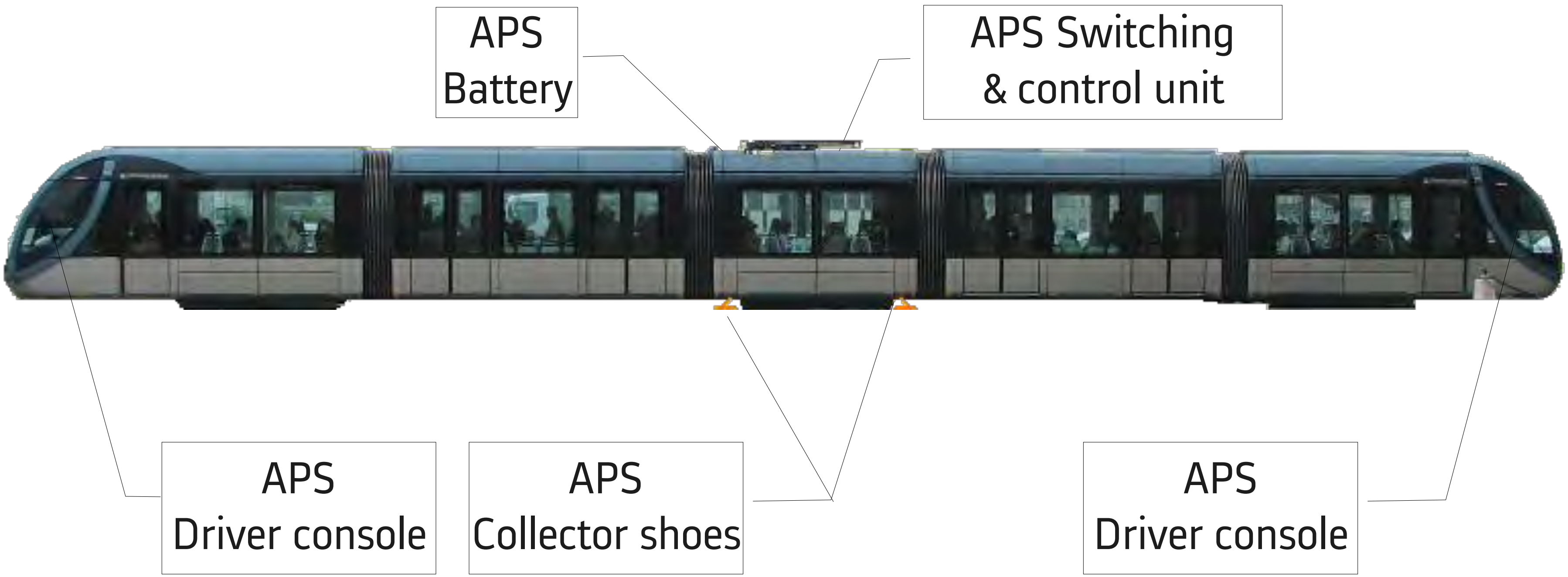
CAMS animation



APS – Simplified architecture



APS system : Main Components on board



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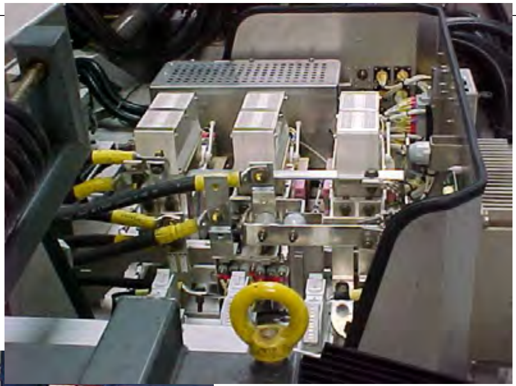
APS system : Main Components on board

- This equipment allows switching the power source from APS to OCS or Battery

It includes the APS safety emettor

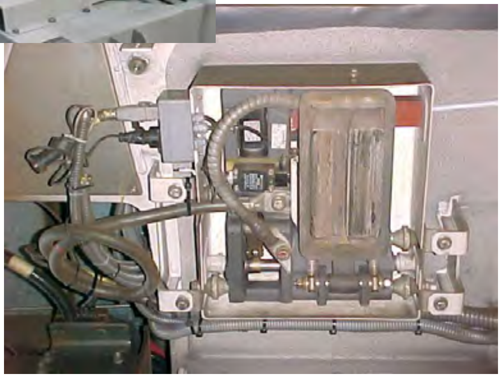


- Contingency APS battery to allow train motion in case of power box failure

It includes a battery charger 6 kVA and the battery (15 A.h)

- Collector shoes in contact with the APS rail to take traction current from the 750 V Conductor rail

It includes the APS coded signal antenna



APS Installation process - Civil works – Plateform preparation

- Civil works preparation (levelling, networks redirection, drainage pipes installation…)

Networks redirection:

CW final works:

APS Installation process - Civil works – Fundation slab

- Fundation slab pouring
- APS drainage pipes coming out of the slab are installed by CW

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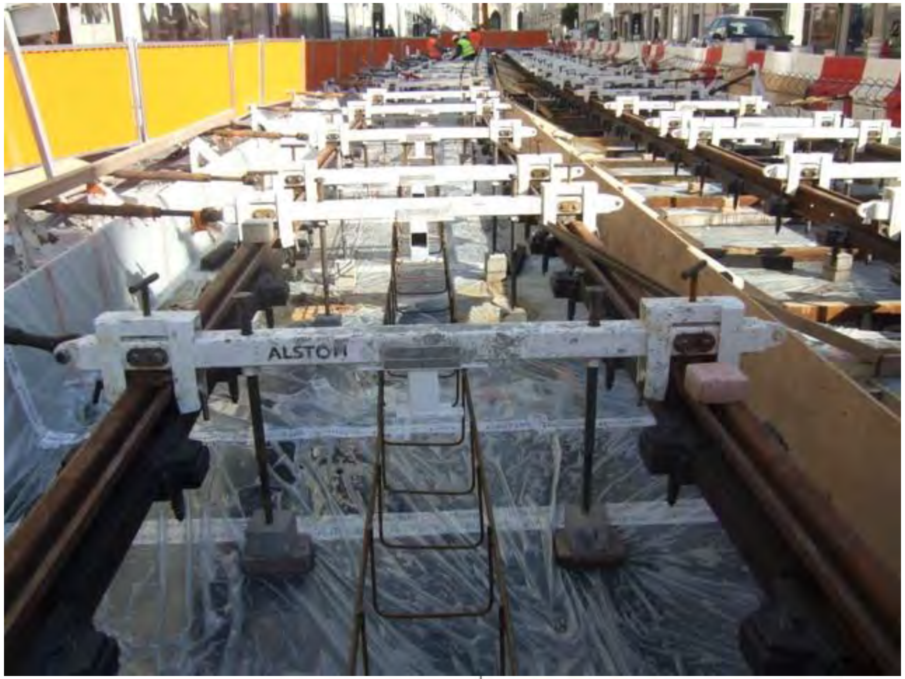
APS Installation process - Track – Rail positionning

- Track rails positionning with jigs

APS Installation process - Track – APS baseplates and re-bars

- Trackwork jigs are also used to hold APS baseplates and mesh for APS concrete

=> Jigs must be positionned by Track team according to APS calepinage



APS Installation process - Track – APS multitubular and chambers

- Track teams install:
  - APS multitubular
  - APS power boxes chambers

APS Installation process – Track slab

- Track slab pouring
- This slab holds APS baseplates and mesh

APS Installation process – transfer Track to APS

- APS controls Track works (equipments locations, number, condition...)

APS Installation process

- APS rails delivery

APS Installation process

- APS rail adjustment and control
- APS rail lies on baseplates positionned by Track teams
- APS rails location is controlled by APS quality team (millimetric precision):

APS Installation process

- APS formwork installation:
  - With metallic formwork in straight lines ;
  - With wooden formwork in cuves.

APS Installation process

- APS concrete pouring

APS Installation process

- Plateform after Track and APS works:

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APS Installation process

- Final design after paving

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ALSTOM'S CATENARYLESS SOLUTIONS

2013, March 8th

ALSTOM

AGENDA

1/

Customer's wishes

- Which expectations for ours customers ?

2/

Alstom's Service Proven Catenaryless Solutions

- Which solutions have been demonstrated as service proven ?

3/

Coming Alstom's Catenaryless Solutions

- Which solutions are we proposing now and which middle term solutions are we working on ?

CUSTOMER'S WISHES

1/	2/	3/
Customer's wishes	**Alstom's Service Proven Catenaryless Solutions**	**Coming Alstom's Catenaryless Solutions**
• Which expectations for ours customers ?	• Which solutions have been demonstrated as service proven ?	• Which solutions are we proposing now and which middle term solutions are we working on ?

CUSTOMER'S WISHES

1.1

A portion of line requested as without Catenary

- To preserve the beauty of historical areas or city centers
- To deal with existing Civil works constrains (limited gauge under bridge for instance)
- To maintain the real estate value
- To ensure fire brigade intervention

1.2

Full Catenaryless solution (No Catenary at all)

- To preserve all the project from overhead contact wires and poles as well

ALSTOM'S SERVICE PROVEN SOLUTIONS

1/

Customer's wishes

- Which expectations for ours customers ?

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Alstom's Service Proven Catenaryless Solutions

- Which solutions have been demonstrated as service proven ?

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ALSTOM'S SERVICE PROVEN SOLUTIONS

APS
Aesthetic Power Supply

- In operation from 2003 (Bordeaux), 4 cities equipped, 2 more in construction.

On Board Battery

- In operation since 2007 in Nice.

On Board Supercaps

- Experimentation in 2010 in commercial service with French RATP Authority.

TRANSPORT ALSTOM

ALSTOM'S SERVICE PROVEN SOLUTIONS

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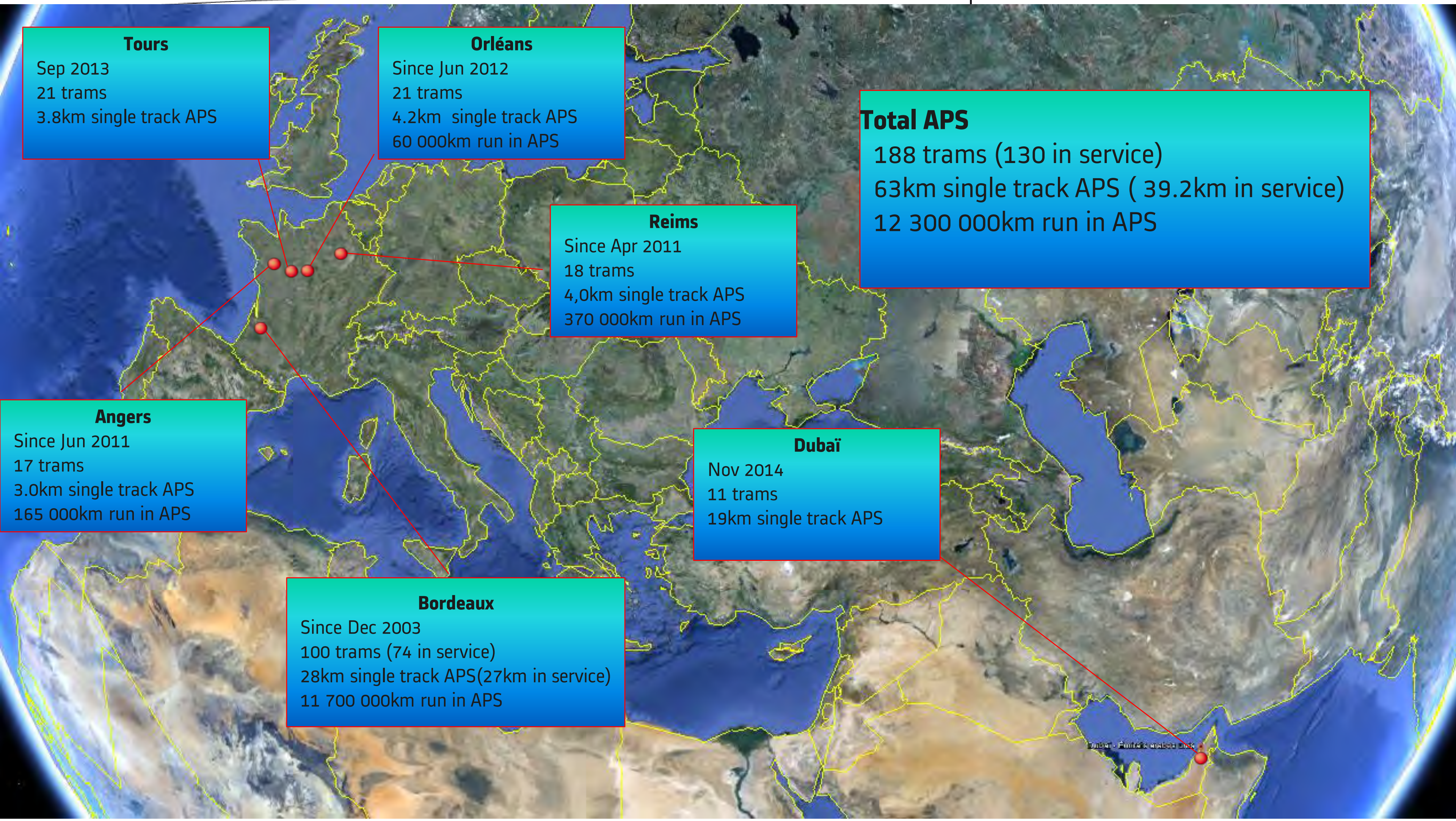
AESTHETIC POWER SUPPLY – APS

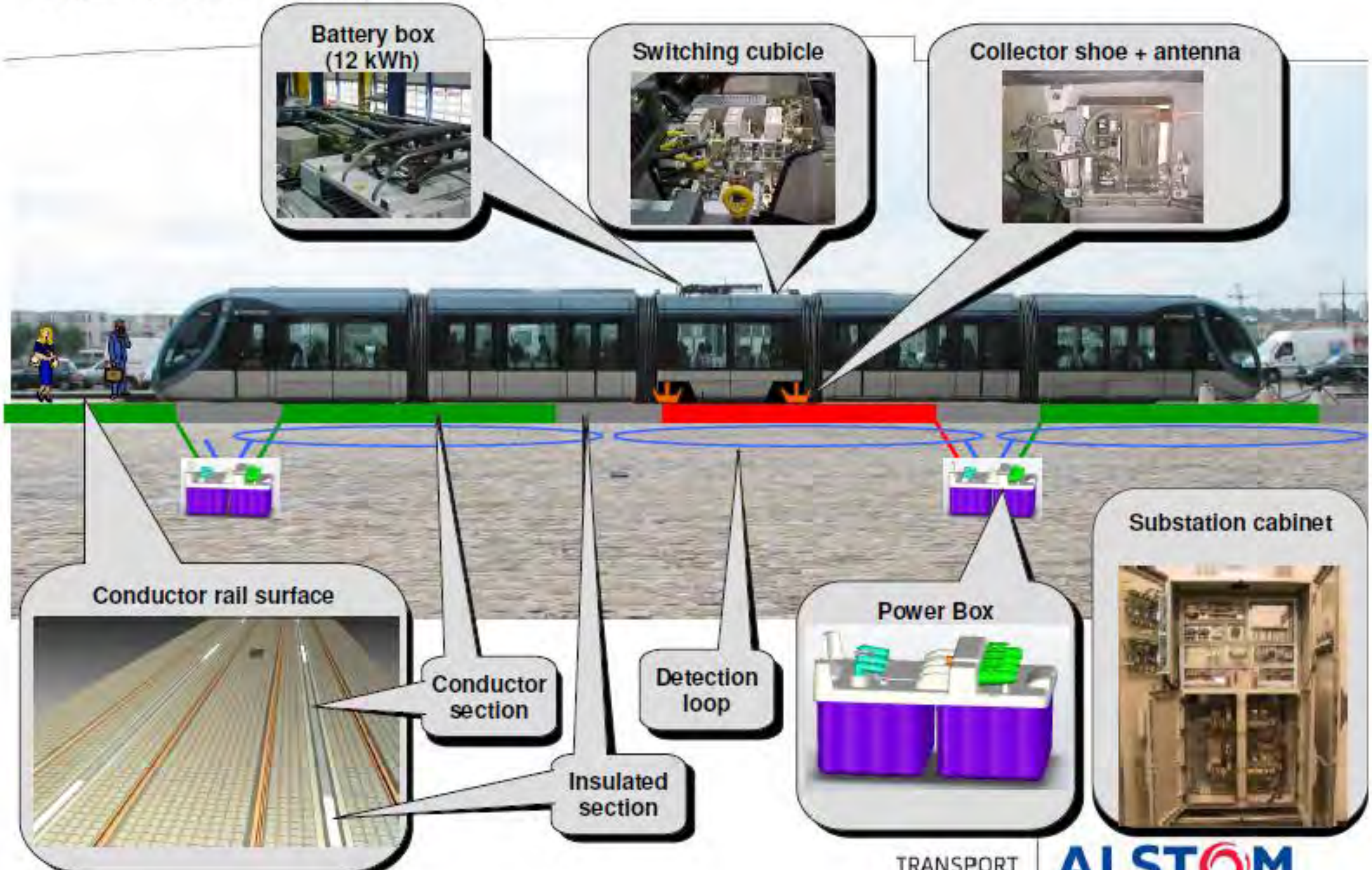
AESTHETIC POWER SUPPLY – APS - Projects location



APS Basic Principle

- ✓ Period : 11m / Conductive Segment 8m / Neutral zone : 3m
- ✓ Each power box drives 2 segments, a power box every 22m
- ✓ Tramways are 30 or 40m long, covering every live segments
- ✓ After tram passage, the segment is connected to the rail voltage

APS Main Components



TRANSPORT ALSTOM

APS

- Final result after paving

TRANSPORT ALSTOM

Our Service proven solutions

APS
Aesthetic Power Supply

- In operation from 2003 (Bordeaux), 4 cities equipped, 2 more in construction.

On Board Battery

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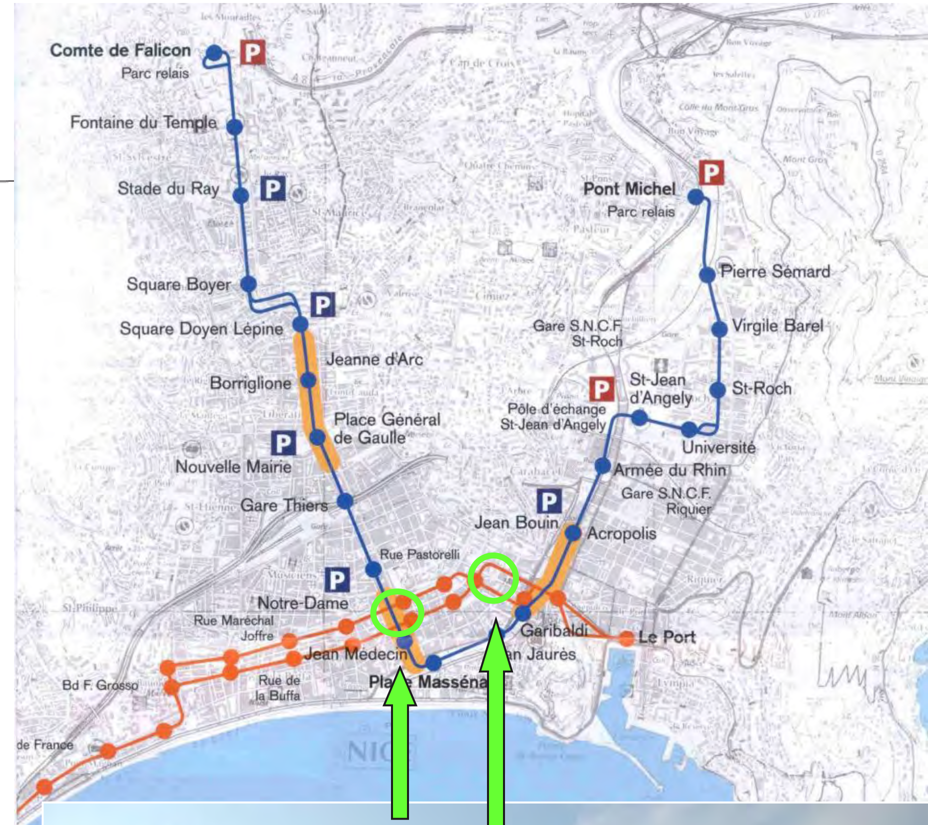
TRANSPORT ALSTOM

Tram without catenary
Batteries



- Service in Nice city 2007
- Two 450m sections for a total length of 9 km (8 km loading, 1 km unloading)
- NiMH battery technology (34 Ah)
- 30m Citadis Tramway

Our Service proven solutions

APS
Aesthetic Power Supply

- In operation from 2003 (Bordeaux), 4 cities equipped, 2 more in construction.

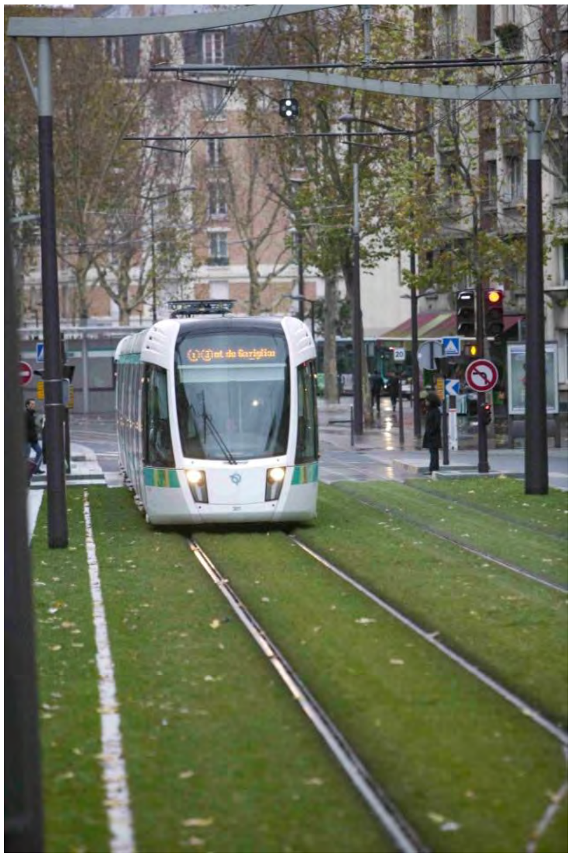
On Board Battery

- In operation since 2007 in Nice.

On Board Supercaps

- Experimentation in 2010 in commercial service with French RATP Authority.

On Board Supercaps
STEEM RATP

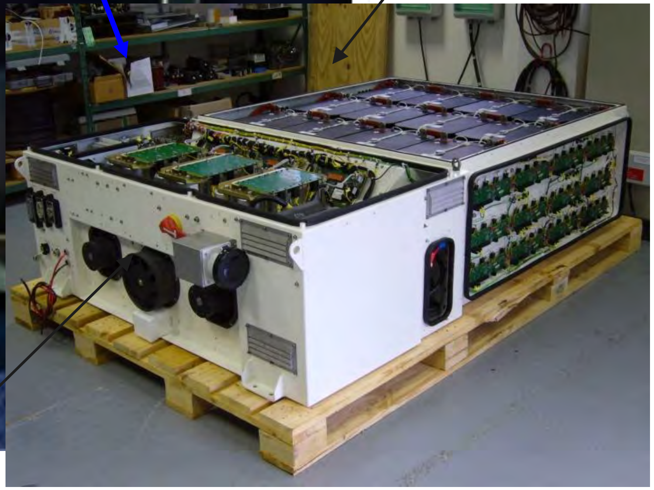


- Tramway 44 m long, 87 tons
- Running in autonomy (350m)
- Recovery of braking energy
- Quick recharge testing (20s)
- Operation in passenger service
- Supercapacitor solution

RATP INRETS PREDIT TRANSPORT ADEME

Agence de l'Environnement et de la Maîtrise de l'Energie

On Board Supercaps - STEEM
Tramset (n°301)roof modifications



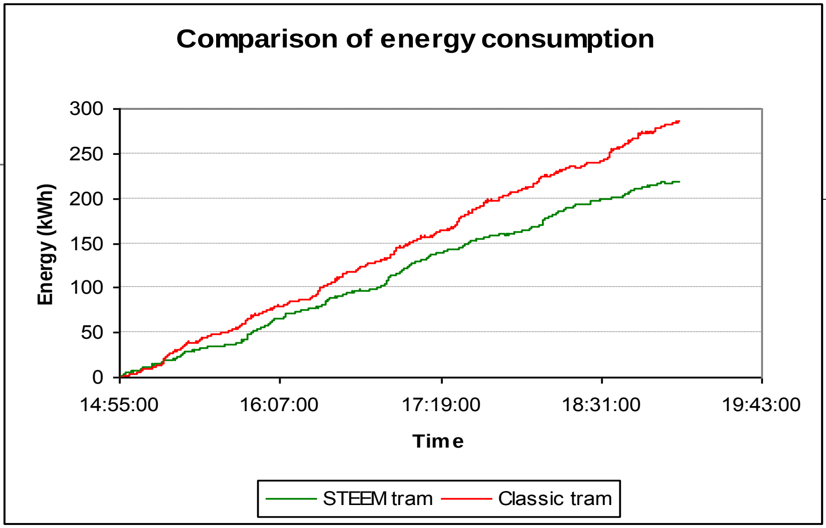
V= 2300 x 1600 x 590 mm

Weight : 1340 kg

On Board Supercaps
STEEM RATP

Characteristics:

E	1,62 kWh
P soc1	500 kW
Msc	720 kg
Recharge	20 sec



- Running in autonomy (350 m) demonstrated.

  Expected improvements through technology evolutions: in autonomy mode
  - more than two unscheduled stops (pedestrians, vehicles)
  - emergency breaks
  - long unscheduled stops induced by road congestion

  Are requiring energy from pantograph.

- Energy saving effect (measured in spring) :
  - daily: minimum 10%, maximum 18%, average 13%
  - highest savings : off-peak hours up to 30%

Winner of the « Technology for energy and environment » prize from PREDIT, May 2011, Bordeaux, Fr

COMING ALSTOM'S CATENARYLESS SOLUTIONS

1/

Business Case

- Which expectations for ours customers ?

2/

Alstom's Service Proven Catenaryless Solutions

- Which solutions have been demonstrated as service proven ?

3/

Coming Alstom's Catenaryless Solutions

- Which solutions are we proposing now and which middle term solutions are we working on ?

ALSTOM'S CATENARYLESS SOLUTIONS
The solutions we are proposing today

APS
Aesthetic Power Supply

- APS Architecture is not modified.
- Some APS components are enhanced.

On Board Supercaps and optimized APS

- Thanks to an on board autonomy (SC), APS installation is limited.
- Portions of line (such as switches, crossroads, curves) could not be equipped.

Catenary-less evolution and benefit

Full energy (APS)

Partial energy (optimised APS + Supercaps)

Catenaryless Benefit

- Safety, Comfort, Real estate value
- Rail Attractiveness compared to other solutions
- Sustainability with cleaner energy consumption

Depending the requirement expressed in terms of catenaryless by the customer, cost effectiveness will drive the choice between APS and optimised APS and Supercaps solutions.

The solutions for on board autonomy we will propose on middle terms

- Supercaps solutions are today's solution but technology evolution are not enough full of promises in particular when questionning the stored energy compared to the weight.

Flywheel

- Williams Hybrid Power - a division of the Williams group of companies that includes the Williams F1 Team - and Alstom Transport have signed an agreement that will see Williams Hybrid Power's energy storage technology applied to Alstom's Citadis trams by 2014.

FLYWHELL

Porsche

Nürburgring

2009

Audi

Le Mans 2012

- After several years of research into energy storage, Alstom has teamed up with Williams Hybrid Power to trial its composite MLC flywheel energy storage technology which offers potential fuel savings of 15% when installed in public transport applications (buses).
- Originally developed for the 2009 Williams Formula One car, Williams Hybrid Power's energy storage technology has since been introduced into applications such as London buses and the Le Mans winning Audi R18 e-tron quattro. The technology offers fuel savings and emissions reductions by harvesting the energy that is normally lost as heat when braking and turning it into additional power. It is ideally suited to trams because of their stop-start nature and high mass. Furthermore, the flywheel's rotor is made of composite material which is inherently safe because there is no metallic structure travelling at very high speed.

FLYWHELL - From Race Car to tramway…

This new technology solutions (flywheel) are intended to fit the available space on our tram sets roof.

Ian Foley, Managing Director of Williams Hybrid Power, commented: “*From the very beginning we highlighted trams as an ideal application for our technology and to be collaborating with the market leader on this project is very exciting. We both share a common goal – developing the next generation of green transport technologies – and this agreement will hopefully prove pivotal in finding a solution that not only cuts carbon emissions but crucially cuts costs for the end user.*’’

As a world leader in rail transport technology, Alstom is continuously looking to challenge and improve the energy efficiency of its trains,” said Dominique Jamet, Innovation Director at Alstom Transport. “ *We are proud to announce the collaborative project with Williams Hybrid Power that aims to deliver an innovative solution that does not only save energy but also re-use it to add more power to the tram while reducing energy use and CO2 emissions.*"

THANK YOU

TRANSPORT ALSTOM

www.alstom.com

WIRELESS POWER SUPPLY FOR TRAMWAYS

APS

MAJOR REFERENCES

France: in revenue service in Bordeaux, Reims, Angers, Orleans, ordered by Tours

United Arab Emirates: ordered by Dubai (tropical version)


CITADIS™ tramway in Bordeaux powered by APS technology (France)

GENERAL DESCRIPTION

APS is a service-proven power system for tramways supplying electricity at ground level and therefore eliminating intrusive overhead wires. The APS catenary-less solution preserves the aesthetics of city centers, reduces track width by eliminating poles, and optimizes safety. Advantages include: no power-supply limitation; a compatibility with all types of road surfaces; and the possibility for easy extension of rail system lines. Alstom offers APS as an infrastructure kit in addition to a CITADIS rolling stock contract or as part of a turnkey tramway system contract—to ensure that our customer receives an integrated service-proven solution. Alstom also offers APS within a track and tram-fleet renovation program.

THE KEY BENEFITS

- The only service-proven catenary-less tramway power-supply system on the market: in Bordeaux, since 2003, CITADIS™ tramways powered by APS have run over 11 million kilometers with a stabilized availability of over 99.7% on 13.5 km of double track.
- No power-supply limitation (as opposed to "tram-borne" power storage systems)
- High availability for optimum tram operation performance due to the simplicity of the concept based on a sliding contact of the same nature as standard metro/commuters third-rail current-collection systems
- Proven resilience in both degraded mode and disrupted conditions of service (traffic jam at intersection for instance)
- Comprehensive safety certification for passengers, pedestrians and road traffic
- Elimination of overhead obstacles (catenary) to firefighters' ladders
- Elimination of wayside masts allowing wider tram vehicles and more traffic in narrow streets
- Preservation of historic sites, trees along the track, and overall urban environment

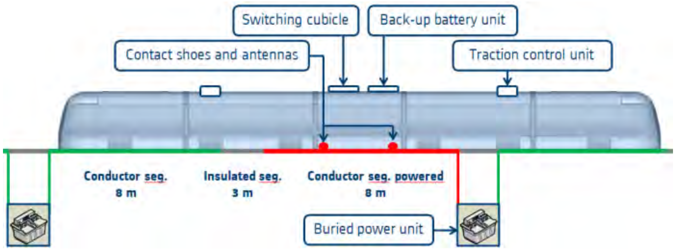
KEY FACTS & FIGURES

- **188 CITADIS™ tramways** powered by APS (130 in service) have run over **12 million kilometers** to date (Feb 2013)
- **63 km** of single track equipped with APS (40 km in service)
- Availability of **99.95 %** for a **2-km** double-track application
- **No power supply limitation:**
  - Full acceleration
  - Up to 60 KPH
  - HVAC running in hot climates
  - Steep gradients
- **Complete intrinsic safety**

Alstom Transport
48, rue Albert Dhalenne
93482 Saint-Ouen Cedex FRANCE

ALSTOM

MAIN COMPONENTS



- Switching and control unit: allows switching the power source between APS, catenary or back up battery.
- Contact shoes: collect traction current from the 750 V conductor rail segment.
- Antennas: emit a coded radio signal which allows detection of the vehicle by the adjacent power unit through a detection loop embedded in the third rail.
- Back-up battery unit: enables trams to run in the event of power cuts.

Power is supplied to the tram vehicle through a segmented street-level power rail embedded between the running rails in the axis of the track. Conductive segments switched off/on/off as the tram progresses, ensuring total safety for pedestrians. This third rail is made of 8 meter-long conductive segments separated by 3-meter insulating joints. Power is supplied to the conductive segments by buried power units. The electricity transmitted through the third rail is picked up by two contact shoes located on both sides of the tram central bogie.

AVAILABLE PRODUCTS

- Standard APS available dedicated for temperate climates.
- Tropicalized APS for extreme climatic conditions.

Standard APS power box

Tropicalized APS power box

KEY TECHNICAL FEATURES

> Functional features

The APS system replaces the catenary line by a proven-failsafe ground feeding system and provides the same performance as the catenary system with no power limitation.

> Configuration features

Power boxes and feeders can be either embedded between tracks or between rails, or installed under deck in case of bridge or viaduct.

> Electrical features

Power supply	750 V dc
Power consumption	Same efficiency as per catenary system

> Environment protection features

- Preserve urban environment and historical heritage
- Cope with any kind of road finishing, including grass
- Respect of EMC and acoustic constraints
- Excellent efficiency

> Environmental constraints

Outside temperature	+ 55°C max under shelter
Max. surface temperature	+ 85°C
Max. power boxes manhole ambient temperature in operation	+ 70°C

> Reliability features

Availability	99.95% for a 2 km double track application
MTTR (Mean Time To Repair)	10 minutes average
Life time	30 years

> Safety features

APS safety principle: conductive segments powered underneath tram vehicle only. As a consequence, all segments not “covered” by a tram are at the 0 V running rail voltage.
APS system’s safety has been proven through a dedicated Safety Case that was since confirmed by 5 certifying Authorities including CERTIFER and STRMTG.

ALSTOM

Supplier Questionnaire

The District of Columbia is currently conducting an Alternatives Analysis for the introduction of premium transit service from the Georgetown Waterfront to Union Station. As a part of this study, our technical team is charged with evaluating the feasibility of a variety of modes, including Streetcar, BRT, LRT and Premium Bus. To that end and as a part of the Streetcar evaluations, our team will also consider the feasibility of alternative propulsion and vehicle technologies in an attempt to comply with the original L'Enfant plan adopted in Washington, DC.

The operation of streetcars without overhead supply wiring is an emerging technology undergoing rapid innovation. With this in mind and realizing that the application of such technologies is greatly contingent upon factors that may not be known at this time, we are soliciting your input on the type of vehicles and their wayside requirements to facilitate the development of design concepts which maximize the potential for a competitive procurement process and minimize implementation, construction and long-term risks such as warranty and maintenance costs. Your responses and recommendations in response to any or all of the following questions would be greatly appreciated.

Question #1

The District will consider designs which allow for the use of an in-street conductor which supplies power to the vehicle continuously while operating, a system with long gaps in the overhead supply and wired areas for recharging while operating (batteries), or a system which charges an on-board storage system only when stopped at station platforms (supercapacitors or flywheels). Which of these types of systems have you supplied vehicles (rail, bus, or other transport) for? Or, are in the process of supplying? Do you have any comments on the advantages or disadvantages concerning the three system types?

ALSTOM has developed the following catenary-less solutions for light rail transit applications:

1. Full autonomy solutions using the APS in-street conductor
2. Partial autonomy solutions using batteries and/or super-capacitors
3. Hybrid solutions using a mix of technologies

1. Full autonomy solutions using the APS in-street conductor

The APS in-street conductor technology supplies power to the vehicle through a power line which is embedded in the street in the middle of the alignment, between the two running rails. The power is fed continuously to the vehicle through a live section of the APS power rail. As the vehicle runs along the line, power switches embedded in the street activate and de-activate the live section located under the middle of the vehicle.

APS is in revenue service in the following cities:

- Bordeaux since 2003
- Reims since 2011
- Angers since 2011
- Orléans since 2012

APS will be used on the following lines that are currently under construction:

- Tours where commercial service is planned in September 2013
- Dubai where commercial service is planned in November 2014

The APS in-street conductor proven technology has been delivered by ALSTOM for more than 15 years as part of an integrated electrification and vehicle solution for light rail networks requiring off-wire operation. ALSTOM's shoe collector equipment could be made available to rolling stock manufacturers and fitted to most light rail vehicles if a network and its fleet were to be expanded with the APS in-street conductor technology. Conversely, vehicles equipped with other autonomy solutions could be used on a network equipped with the APS in-street conductor technology.

This APS in-street conductor technology has acquired more than 7.5 million miles (12 million kilometres) of experience in revenue service. More than 25 miles (40 km) of single track are in operation with the APS in-street conductor technology today and 130 ALSTOM light rail vehicles are equipped with APS.

A full presentation of the APS in-street conductor technology and the projects mentioned above is given in appendix "APS Presentation 2013-03-08 V1.ppt".

The main advantage of the APS in-street conductor technology compared to partial autonomy solutions such as batteries or super-capacitors is that the vehicles can be operated with the same level of performance as with overhead catenary. More specifically, the benefits versus other catenary-less solutions are:

- no power limitations in slopes
- no distance limitations between stations
- no power limitations to auxiliaries and/or HVAC in downgraded modes of operation
- no power limitations at intersections or during unexpected service stops
- no special requirements impacting sub-station design and capacity

2. Partial autonomy solutions using batteries and/or super-capacitors

ALSTOM has also delivered partial autonomy solutions based on batteries and super-capacitors. Vehicles equipped with batteries are in service in Nice since 2007 and prototype vehicles equipped with super-capacitors have been delivered to RATP in Paris (STEEM technology, see video attached) and put into commercial service in 2009.

The main differences between batteries and super-capacitors are the following:

- Batteries allow the storage of a significant amount of energy but the rate at which the energy can be extracted (or recharged) is limited. Hence, their power is limited.
- Super-capacitors on the other hand are not power limited but the amount of energy that can be stored in a given volume is rather limited compared to batteries.

In order to accelerate a vehicle and to maintain its speed, a certain amount of power is needed. Super-capacitors are best able to meet the peak accelerations and speeds.

On the other hand, travel over a given distance requires a certain amount of energy. If the distance is too long, a super-capacitor will not have enough energy. Then, using a battery will be more appropriate.

In order to address this problem, one solution is to use a mix of both technologies, i.e. super-capacitors to accelerate the vehicle associated with batteries for longer distances and for vehicle rescue in emergency conditions. ALSTOM is currently developing this hybrid design.

Another partial autonomy technology which offers a good compromise between power and energy is the flywheel but this technology is only in its early development stage for rail applications.

It is important to note that for all on-board partial autonomy technologies, the energy storage system must also supply the auxiliary loads of the vehicle. The highest loads are the air-conditioning and/or the heating of the vehicle which are significant when compared to the requirement for tractive power (typically 30-40kW of power in a 90 foot streetcar or light rail vehicle). So, in practice, the distances which can be covered by these systems are greatly reduced when considering real operation with auxiliaries.

3. Optimal hybrid solutions using a mix of technologies

Based on its experience with both the APS in-street conductor technology and super-capacitors, ALSTOM is now proposing solutions which incorporate a mix of both of these technologies. The objective with this approach is to achieve the best compromise between the system's overall performance and its associated capital and lifecycle costs. This is achieved by implementing the APS in-street conductor only in areas where the energy needs are the most important, i.e. in stations for recharging, over long stretches of the alignment without stations, in steep grades, ahead of large intersections, etc.

Today, depending of the needs of each project, ALSTOM can propose the APS in-street conductor technology, batteries, or super-capacitors or a hybrid solution using both APS and super-capacitors

Before recommending any solution ALSTOM would evaluate the unique service requirements of each customer and would propose a system which would attempt to optimize the following tradeoffs:

- Operational requirements in terms of performance, headways
- Power and energy storage requirements versus vehicle weight and space constraints ;
- Recharging times versus dwell time and headway requirements
- Impact of recharging times on substation design
- Impact on service of degraded modes
- Estimated life of technology versus life of system and cost of replacement of power source
- Depending on the procurement scheme, the optimized compromise between capital cost and lifecycle cost.
- Technology Maturity of technology versus reliability requirements

A complete presentation of ALSTOM's present offer is given in appendix "ALSTOM's catenary less solutions Presentation 2013-03-08 V5.ppt".

Question #2

A traditional streetcar is designed to operate from an overhead supply system operating continuously at either 600 or 750 Vdc. Would your company's offering place any special or additional requirements concerning integration of the electrification system? Would your technology operate with a pantograph when not on a wireless section?

The APS in-street conductor technology's nominal voltage is 750 Vdc with a 900Vdc maximum and a 500Vdc minimum. The APS power boxes and cable ducts would need specific underground sections.

The APS power boxes and cable ducts have specific underground volume requirements. The APS power boxes have a footprint of 5 ft 3 inches x 2 ft (1.6m x 0.6m).

The APS cable ducts need to be positioned at a depth of 1 ft 4 inches (0.4 m) and have a cross-section of 2 ft x 8 inches (0.6 m x 0.2 m).

The Citadis streetcar will operate with a pantograph when not running on a wireless section.

Question #3 - In Street Conductors

Has the in-street conductor been utilized in areas which normally experience snow and ice in the winter? What material would you use for fabricating in-street conductors? Would the material show corrosion for the application of de-icing road salt? What provisions are made to prevent snow plow blades from damaging the rail?

APS has been utilized in area with snow (see the videos attached in appendix from the Reims project "video-2013-01-15-08-39-23-rotate.avi" and the Angers project "Neige hyper-centre Angers.mp4").

It is important to note that road salt is not to be used for de-icing. In cities where the APS in-street conductor technology is used, the operators and municipalities use a biodegradable de-icing fluid. Coordination is required between the municipality and the LRT operator to ensure that there is no salt exposure of the portions of the rail alignment equipped with the APS in-street conductor technology.

Use of snow plows over portions of the rail alignment equipped with the APS in-street conductor technology are not an issue. Plow blades equipped with a special rubber end can be used as an added precaution (as is the case in Bordeaux for example).

Question #4 – In Street Conductors

Has the in-street conductor been installed in mixed use traffic lanes?
Has it been installed in reserved lanes with normal traffic operating at right angles across it?
Have there been any issues related to cleanliness resulting from contamination with rubber tire, oils, or autumn leaves?

The APS in-street conductor technology and its associated power rail have been installed in mixed use traffic lanes (see pictures below).

Picture from Reims

Picture from Orleans

The APS in-street conductor technology can be installed in dedicated lanes or in mixed use traffic lanes with normal street traffic operating at angles across it.

In case of very heavy traffic a special maintainable section of the APS power rail can be installed. If damaged, this section of the power rail can be replaced within 4 hours when the service is not in operation or during scheduled maintenance periods.

There have been no issues related to cleanliness resulting from contamination with rubber tire, oils or autumn leaves during the past 10 years and 7.5 million miles of operation of the APS in-street conductor technology.

Question #5 – In Street Conductors

How is the conductor installed in the street? Give short explanation and provide APS technical sheet + APS ppt presentation.
Are there any restrictions on horizontal or vertical curvature of the pavement?
How are crossings or turnouts implemented with the conductor rail? We prefer hybrid solution please develop
What clearances are required for other structures such as manholes and metallic covers?

The APS power rail is positioned at a height 0.5 inches (12mm) above the Top of Rail.

There is a 2% slope from the APS power rail down to the running rail to avoid water puddles.

Crossings or turnouts are equipped with the APS power rail. In these situations, the APS power rail is installed at the same height as the Top of Rail to ensure a smooth transition of the collector shoes when crossing the running rails.

The APS technology data sheet is provided in appendix "APS_TGS Technical datasheet_08-04-13_SB_PM_V5.doc"

Question #6 – Batteries

Which battery type do you have experience in applying, Lithium (Li) or Nickel Metal Hydride (NiMH)? What is the maximum acceleration rate and maximum speed normally used in these applications?

ALSTOM has applied NiMH batteries on the Nice streetcar system which is in service since 2007. The maximum speed running on batteries is 19 mph (30 km/h) and the maximum acceleration rate from 0 to 19 mph (30 km/h) is approximately 0.45 m/s^2 in AW0 load (empty vehicle) and without any grade inclination.

The Nice project was developed nearly 10 years ago and ALSTOM would apply Lithium batteries on a similar project today since they are lighter and have a higher performance (although more costly).

The total current and power that can be drawn from the batteries will depend on the number of battery cells on-board the vehicle. Therefore, the maximum operating speed and acceleration will also vary with the number of batteries on-board the vehicle (see next question #7).

Question #7 – Batteries

What are the design limits and emergency limits for charge/discharge levels of the batteries on your vehicles? Is the battery management system provided by the battery manufacturer, third-party specialized supplier, or incorporated into the propulsion system? Are the individual cells monitored?

The design limits and emergency limits for charge/discharge levels will depend on the battery technology used.

In the case of the Nice project where ALSTOM has used approximately 2 tons of NiMH batteries with an average useful stored energy of 5kWh and a maximum useful stored energy in downgraded conditions of 15kWh, the maximum charge and discharge currents are respectively 22 Amps and 220 Amps. The maximum discharge power for this application is 200kW (approximately 100kW per ton of batteries).

The batteries are only discharged by about 10% to 15% in normal use in order to ensure a battery life of 5 to 8 years. In emergency situations, the batteries can be discharged much more (to less than 50%).

The Battery Management System (BMS) is provided by the battery supplier. However, the battery management system is incorporated into ALSTOM's propulsion system and ALSTOM is responsible for the energy management and other functional aspects of the vehicle controls.

The cells are not controlled individually. They are grouped in modules of 10 cells each module being individually controlled.

Question #8 – Batteries

The operating environment in DC has a temperature range of -15^{o}F to 106^{o}F. What will be used for the cold temperatures to ensure proper operation of the system? Do the high temperatures with added solar heat gain prove detrimental to the batteries? Is a heating and cooling system typically provided for the batteries?

In order to provide their specified performance, batteries must be maintained within a certain temperature range. ALSTOM's battery system is equipped with a cooling system (Battery Thermal Monitoring System) which maintains the cells at a defined temperature (depending on the season). The battery, battery charger, BMS and temperature control system are all integrated in a single equipment case.

For super-capacitors, similar considerations will apply even if they are more tolerant to temperature extremes.

Question #9 – Batteries

There is a concern with impacts damaging Li batteries with fires resulting days later. This was observed during crash testing of the Chevy Volt. Are the batteries located in an area susceptible to impacts in traffic accidents? Have you established criteria for maximum impact shocks and have the criteria been validated by the battery manufacturer?

In ALSTOM's off-wire rail applications, the batteries are located on the roof of the vehicle. The ALSTOM batteries are tested and validated to withstand shocks and vibrations as par the EN 61373 standard.

There are many different technologies grouped under the general category of "Lithium ion" batteries (about 25 different chemical and physical compositions exist on the market). Each has advantages and disadvantages with respect to power, energy storage capacity, service life, and safety. ALSTOM applies battery technologies which are the most suitable for a railway environment and which minimize fire risk. ALSTOM's design approach for streetcars and light rail vehicles is to install equipment on the roof in order to maximize space and accessibility for passengers and also due to the special low floor design of ALSTOM's vehicles. This has proved to be the best choice also in terms of impact protection and safety. Shock, crush, and puncture testing are part of the many validation tests carried out when selecting batteries for our applications. In any event, after a collision a complete examination (including some specific testing) of the vehicle and its systems would be performed before its release back into service.

For super-capacitors, the same principles and considerations would apply regarding installation on the roof and validation testing.

Question #10 – Batteries

Batteries will be discharged during overhead gaps and recharged while operating in wired sections. As a "ball-park" approximation, if a streetcar traveled three miles off wire with 6 stops on an average 2% grade how long would the vehicle need to travel on wire to fully recharge? What would be the maximum current draw for battery recharging?

A 60 ton vehicle traveling a distance of three miles off-wire with 6 stops on an average 2% grade would require approximately 30kWh of useful stored energy on-board in a normal mode of operations (including power for auxiliaries and HVAC). Our experience on the Nice Project has shown that the maximum recharge current for batteries meeting such an energy requirement would be of about 80 Amps and that the recharge time running on wire would be approximately 2 hours.

Question #11 – Batteries

If a stationary vehicle draws the maximum current for battery recharging in addition to the vehicle's maximum auxiliary power requirement on a 106°F day in full sun with no wind, is it possible to heat a 350 kcmil overhead contact wire to the 160°F annealing temperature of the copper? If so, what measures may be taken to mitigate this concern?

ALSTOM has not encountered such situations and we have not made the calculation but this risk seems unlikely since the maximum recharging power of batteries is typically several times lower than the discharge power. If the particular environmental conditions and recharge rate of the batteries were to confirm such a risk, the simplest solution for a vehicle under pantograph would be to double the number of contact wires used in the area of "charging at standstill".

Question #12 – Supercapacitors

What is the time required to recharge fully depleted supercapitors at a stop? What level of current and voltage is this time based on?

Base on ALSTOM's experience, the recharge time for a fully depleted 1,2kWh/300kW super-capacitor module is 18 seconds. The current will be approximately 400 Amps under a 750V catenary.

Question #13 – Supercapacitors
For a discrete charging system, would your firm recommend a traditional supply system with distribution via underground conduit or smaller discrete chargers at predetermined locations? If discrete chargers are possible, what is the range of AC supply voltages that could be accommodated? Can a one-line diagram of such a discrete charger be provided?

ALSTOM does not have experience with the distribution of small discrete chargers located along the alignment. It would seem that this type of solution could be less competitive in terms of wayside infrastructure than the in-street conductor technology. This solution would also likely have an impact and impact on trip time compared to the in-street conductor technology (recharging time at discrete locations).

Question #14 – Supercapacitors
If station spacing of one-half mile (800 m) on a 2% grade and the streetcars stops for traffic signals every 500 ft (150 m) is used, would your standard vehicle be capable of passing a stop without charging while operating with the maximum auxiliary load, including HVAC? What would be the anticipated charge level remaining at the second stop?

The route profile described above with recharging of the super-capacitors <u>at each station stop</u> would require the streetcar to have a useful stored on-board energy of approximately 7-9 kWh depending on the actual vehicle weight and size, HVAC characteristics, and tractive power characteristics. The corresponding system of super-capacitors would weigh roughly 6-7 tons. Fitting our standard vehicle with such super-capacitors would be impossible and would require a re-design.

If the intent of question #14 is to explore the possibility of recharging at traffic stops along the route alignment as opposed to recharging at station stops, then it is important to note that:

- each stop in the route profile described above would draw about 0.7kWh of stored energy ;
- recharging at traffic stops would require about 15 seconds at standstill ;
- recharging only at station stops would require about 2-3 minutes.

It is also important to note that even assuming recharging at determined stop points along the alignment, the streetcar would likely need to be given traffic priority over other vehicles and isolation from pedestrians may also be needed to avoid any unplanned prolonged stops that would drain the energy source and leave the vehicle stranded without power.

Question #15 – Batteries & Supercapacitors
Under lane-sharing scenarios, a Streetcar could be delayed considerably in traffic resulting in insufficient remaining charge to reach the next charging area. What is your strategy for minimizing this risk? Would additional storage capacity or capacity monitoring and load shedding (HVAC) be used? What is the possibility of recharging the vehicle in the street and what equipment would be recommended?

Our system will monitor charge level and, in case the charge level becomes too low, load-shedding will be applied (HVAC). This type of strategy was implemented on the Nice streetcar.

For in street charging, a small genset vehicle could be used. Another solution would be to have a towing vehicle.

Question #16 – Vehicle Design Criteria

The District currently owns three T12 streetcars manufactured by Inekon and has three American-built versions of the Skoda T10 streetcars on order. These vehicles use the standard Czech width of 8 ft (2.46 m). What are the implications of continuing to use such European dimensions? Would you be interested in proposing on a small order of 8-10 cars with this width requirement? If no, what is the minimum order size you would be interested in? Would you prefer using the typical US width of 8 ft 8.3 in (2.65 m)?

ALSTOM would not be interested in proposing an 8 foot wide vehicle even for higher quantities. We would propose our 8 ft 8.3 in (2.65m) wide "CITADIS Spirit" that has been specifically adapted to meet the unique needs of the US market. A high capacity version of that vehicle (48m length) will be built in ALSTOM's facility in upstate New York (production in 2015 through 2017 for base contract). This vehicle offers proven, industry leading technology as well as world-class design to integrate into the urban environment. This vehicle draws upon the experience of more than 1,600 CITADIS vehicles is service in more than 40 cities in 12 countries.

Question #17 – Vehicle Design Criteria

The District's current vehicle design criteria limit the length of the vehicles to 72.2 ft (22 m). Does this length permit sufficient space to mount energy storage devices on your standard vehicles? If not, what is the minimum length of vehicle your firm would be interested in providing?

Such small vehicle dimensions do not allow the use of any of the catenary-less solutions using batteries, super-capacitors or the APS in-street conductor technology.

1) Vehicle equipped with super-capacitors

A 22 m vehicle would realistically be able to accommodate only one or two super-capacitor modules weighing approximately 2-3 tons in total (depending on the technology and design) and with a total stored energy of about 2-3 kWh. In normal load conditions (i.e. AW3 load with a vehicle weight of approximately 50 tons), the vehicle would barely be able to run over a distance of 400 meters at a 2% grade and would not be able to re-accelerate in the event of an unplanned stop.

2) Vehicle equipped with batteries

A vehicle equipped with batteries would require a total average useful stored energy capacity of at minimum 16 kWh in the following operating conditions:

- 2 mile off-wire section at a 2% grade and a maximum speed of 20 mph (30kph)
- no unplanned stops on the route, no towing of vehicles
- 4 stations with one-minute dwell time at each stop
- normal auxiliary and HVAC loads

In these same normal operating conditions the on-board batteries should be designed to have a maximum useful stored energy capacity of approximately 30-40kWh for downgraded conditions and to allow for a sufficient battery life.

In such conditions and based on our experience on the Nice project the vehicle would require at least 6 tons of on-board batteries. A 22 meter vehicle with only 4 axles would not be able to accommodate 6 tons of on-board batteries due to layout and axle load limitations.

3) Vehicle equipped with APS technology

The safety case for the APS in-street conductor technology requires a vehicle length of at least 28m to ensure that the live section of the power rail is always in a protected area under the middle of the streetcar.

Moreover, for its integration under the vehicle, the APS shoe collector requires a non-motorized truck and therefore a vehicle length of at least 27m.

Question #18 – Retrofit of Existing Vehicles

The District currently has vehicles with lengths of 66 ft (20 m) and width of 8 ft (2.46 m). If these vehicles are to be operated on lines with wireless sections they will need to be retrofitted. What would be the approximate space requirements if your technology were to be retrofitted? Are there any proprietary components that would be required? Do you have any experience retrofitting the system to older vehicles manufactured by you or others? Would you be interested in performing the retrofit work as part of a new procurement?

ALSTOM has the largest experience in fleet renovation in the USA (including light rail vehicles). However, ALSTOM would not be able to perform such a retrofit work as part of a new procurement due to the impossibility of having a catenary-less solution applied to such vehicles (see answers to questions #16 and #17).

Question #19 – Specialized Equipment

What specialized equipment will be required to maintain your proposed energy storage and/or enhanced propulsion technology options? Will additional shop equipment or storage/charging rooms be required? Will test and troubleshooting procedures be impacted, particularly for high voltage storage devices on the vehicles? Please elaborate on the specific function and purpose of such equipment.

The testing of the traction system including the APS is fully integrated into the vehicle and is part of the automated function of the traction control system. Trouble shooting is also part of the automatic traction control systems.

No special specialized shop equipment will be required for the maintenance of the APS shoe collector.

Safety procedures are applied for the discharge and handling of high voltage storage devices. These form part of the maintenance instruction of the vehicles. The storage procedures are no different from those required for normal traction capacitors.

The APS system and the on-board energy storage devices will require the following specialized maintenance equipment and/or functions:

- a battery charge-discharge testing area (charging and discharging of batteries),
- an APS power box repair bench for troubleshooting and repair of the power boxes that activate and de-activate the live sections of the APS power rail depending on coded train signals,
- an APS SCADA control center that monitors and controls the power boxes on the line,
- a portion of the APS line in order to perform train testing

Question #20 – Training and Education

Will additional specialized training for vehicle maintainers, wayside maintainers, or vehicle operators be required? Will specialized personnel in any of these areas be required or would a typical maintainer/operator with a high school diploma and standard maintainer/operator training be sufficient?

No specific diploma required but specific training that has to be provided to the following categories of personel :

- wayside maintainer : maintenance procedures of Power boxes and substation power modules
- on-board maintainer : maintenance of batteries, battery chargers, collector shoes and antennas
- vehicle operator : operation of APS at the entrance and exit of APS in-street conductor areas

DISTRICT OF COLUMBIA DEPARTMENT OF TRANSPORTATION

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