FABRIC
Feasibility analysis and development of on-road charging solutions for future electric vehicles

Feasibility assessment for applying prototype solution 4 to other use cases

Deliverable No.		D3.6.3	
Workpackage No.	WP36	Workpackage Title	Design
Authors		R. Johansson (Volvo GTT), P. Vermaat (TRL)	
Status		Draft	
Dissemination level		Public	
Project start date and duration		01 January 2014, 48 Months	
Revision date		2016 - 04 - 27	
Submission date		2016-10-15	

This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 605405

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SELECTED ABBREVIATIONS

ABBREVIATION	DESCRIPTION
APS	Alstom Aesthetic Power Supply System for trams
BMS	Battery Management System
DoW	Description of Work
EM	Electro-Magnetic
EMC	Electro-Magnetic Compatibility
ERS	Electric Road System
EV	Electric Vehicle
FABRIC	FeAsiBility analysis and development of on-Road chargIng solutions for future electric vehiCles
FFI	Fordonsstrategisk forskning och innovation i.e. Strategic Vehicle Research and Innovation
HDV	Heavy Duty Vehicle
HV	High Voltage
ICE	Internal Combustion Engine
ICT	Information and Communication Technology
OCL	Overhead Contact Line
OEM	Original Equipment Manufacturers
PB	Roadside Power Box for power distribution
WP	Work Package

REVISION CHART AND HISTORY LOG

REV	DATE	REASON
0.1	16/02/2016	TRL: Deliverable structure, Table of Contents (first draft)
0.2	26/04/2016	Volvo: First complete draft sent to Scania and TRL
0.3	26/04/2016	Volvo: Draft sent for Volvo internal review
0.4	27/04/2016	Volvo: Added Report structure and Objective and minor fine tuning. Final draft sent to TRL
0.5	28/4/2016	Review by TRL, submit to peer review.
0.6	16/5/2016	Update according to peer review comments
0.7	14/10/2016	Update according to project officer and Alstom review comments
0.8	19/10/2016	Updates following client review

EXECUTIVE SUMMARY

The conductive on-road charging prototype developed by Alstom/Volvo within the Slide-in project has been assessed for its feasibility in application to all use cases defined for FABRIC. Potential adaptations of the system and possible limitations have been identified in this theoretical feasibility study and the overall results are summarised below in the following bullets:

- There are no fundamental impediments to using conductive on-road charging in all use cases, including cars and urban environments, defined for FABRIC in [2].
- All defined power requirements (3 – 200 kW) could be fulfilled with the same conductive ERS solution, and total efficiency for dynamic power transfer is typically higher than 93 %
- With adaptations e.g. shorter track segments, temporarily lowering voltage or redundant sensor systems, all defined charging modes (Static, Stationary en-route and Dynamic charging) and speed intervals (0-130 km/h) could be fulfilled with conductive on-road charging.
- Since this is a theoretical feasibility study not all answers can be answered to a high level of detail. Therefore further research is needed to assure 100% functionality and success of the Slide-In ERS.

1 INTRODUCTION

1.1 General

This deliverable will present a theoretical feasibility assessment of applying a conductive Electric Road System (ERS) solution (referred to as "*Solution 4"* in the DoW) to the use cases defined for FABRIC. Volvo and Alstom have together developed a conductive on-road charging prototype for trucks that is presently being tested at Volvo's test track in Hällered, Sweden. This conductive solution will be assessed for its feasible application to 'other' use cases in addition to large trucks, in particular, cars and urban environments. Volvo has undertaken this theoretical feasibility study, taking into account the requirements and specifications developed during SP3, and utilising the results available from testing of the prototype system. Any potential adaptations of the system, limitations and comparison against the specifications and additional requirements have been identified.

1.2 Contribution to FABRIC objectives

This deliverable contributes to the objectives of FABRIC by addressing directly the technological feasibility and economic viability of dynamic on-road charging of electric vehicles.

This in turn, responds to the need to assess the potential feasibility of a more extensive integration of electric vehicles in the mobility and transportation system, with a primary focus on dynamic wireless charging, as this enables the perceived drawbacks of on-board battery packs to be avoided. Volvo and Alstom share the vision to be part of and provide a central contribution to the evolution of e-Mobility worldwide, and this deliverable is one small piece of that puzzle.

1.3 Deliverable structure

Chapter 1 – introduces and describes the background and goal of the deliverable.

Chapter 2 – explains the methodology used and the reason why this route was chosen. The link to the other key deliverables is also explained.

Chapter 3 – describes the Alstom APS that is used for trams, since most of the solution 4 technologies and system thinking evolved from this. The major differences to the Alstom/Volvo conductive ERS solution are defined and explained. The main building blocks of the system, including the vehicle pick-up are identified and their functionalities described, as well as identifying the main interfaces of the system and describing their major features.

Chapter 4 – contains the feasibility analysis and results. The set of use cases defined for FABRIC have been considered and the "*descriptive scenarios of use"* and "*charging modes"* taken into account.

Chapter 5 – summarises the document and draws the final conclusions.

Chapter 6 – references.

2 METHODOLOGY

2.1 Introduction

This will be a theoretical study of the Volvo/Alstom conductive ERS application to other use cases than trucks. During planning of the task, the Work Package 36-team decided that use cases such as cars and urban environments, as well as the ones defined in D4.3.1 should be assessed. This complies well with the description of the task set out in the DoW:

“The existing conductive on-road charging prototype for trucks developed by Volvo and tested on their test track in Hällered, Sweden, will be assessed for its feasibility to be applied to other use cases, such as cars and urban environments. Volvo will undertake this theoretical feasibility study, taking into account requirements and specifications developed during SP3 and any available results from testing of the prototype system available to date. Potential adaptations of the system, limitations and comparison against the specifications and requirements will be identified.”

2.2 Methodology for Feasibility Analysis

2.2.1 Use cases for the charging solution

The set of use cases defined for FABRIC in D4.3.1, both in Table 4: *FABRIC demonstrable use cases* and in Table 5: *FABRIC feasible use cases* summarised in Table **1** below, have been considered in this feasibility study. Since the Slide-in conductive ERS project focusses mainly on the technology for dynamic conductive charging and not the foreseen ITS, D4.3.1 “*descriptive scenarios of use”* and ”*charging modes”* have been taken into account as well. The relation to the “*descriptive scenarios of use”* has only been described when the assessment showed that adaptation of the system was required or other limitations were found.

Table 1 Assessed use cases for Slide-in conductive ERS technology.

Use case	
1.	Driver and EV registration to a central FABRIC database
2.	Driver login to FABRIC
3.	User account management
4.	EV identification
5.	Charging assistance
6.	Charging management high-level and low-level (load balancing)
7.	Energy supply tariff modulation
8.	Charging and road infrastructure availability status updating
9.	Billing
10.	Planning of a trip
11.	Guidance to a charging facility or to a destination
12.	Dynamic route and booking management
13.	Emergency charging
14.	Integration of FABRIC with UTMC

2.2.2 FABRIC use cases to be analysed

As explained in 2.2.1 the Slide-in conductive ERS project focusses mainly on the technology for dynamic conductive charging (i.e. not the ITS services), hence the use cases from D4.3.1 “charging modes” and “descriptive scenarios of use” have been taken into account as well.

Charging modes:

- *Static charging*
- *Stationary en-route charging*
- *Dynamic charging*

Descriptive scenarios of use:

- *Driver scenarios of use*

- *Distribution system operator and energy retailer scenarios of use*
- *Road operator scenarios*

The properties of the Slide-in conductive ERS solution are assessed in relation to the *charging modes* and *descriptive scenarios of use* mentioned above.

3 DESCRIPTION OF THE CHARGING SOLUTION

The Slide-in ERS or Alstom/Volvo conductive ERS system is brought to the FABRIC project by Volvo in collaboration with Alstom. It will be assessed for its feasible application to other use cases in FABRIC solution 4. Note that the system will only be considered in a desk study and will not be subject to test track trials as is the case with FABRIC solutions 1 to 3.

This chapter describes and discusses the development of Alstom/Volvo ERS conductive power transfer solution for electrifying roadways. It includes a description of the general concept, safety, power calculations and efficiency.

3.1 APS, the precursor to the Slide-in ERS

The development of the Volvo/Alstom conductive ERS springs from the Alstom Aesthetic Power Supply (APS), and therefore this system will be presented below. The APS system is a conductive power transfer solution at ground level developed for tramways. This solution was developed to supersede the overhead line for aesthetic reasons and to offer an alternative solution to the cumbersome installation of poles in the crowded subsoil of city centres.

The APS system is in service in Bordeaux, Reims, Orleans, Angers, Tours, Dubai and Rio de Janeiro and has been ordered by the cities of Cuenca, Lusail and Sydney. To date, 200 Citadis trams equipped with APS have run over 23 million kilometres with an availability rate of over 99.7%. 78km of single track are currently equipped with APS. The safety of the APS system has been proven through dedicated studies and confirmed by five certifying authorities including CERTIFER and STRMTG, see [3] for additional info.

3.2 APS principle

3.2.1 System

The basic principle is a segmented power supply rail, which is fully integrated into the track platform. The APS presents no danger to persons or equipment. The principle consists of only supplying voltage to that section of the rail that is physically enclosed within the area occupied by the vehicle.

This system is designed to deliver the same power supply as an Overhead Contact Line (OCL) does, delivering to a running tramway a power up of 1,1MW with a voltage of 750VDC and a current of 1500A. The system is compatible with all existing tram lines including crossings and turnouts and it may be combined with classic OCL power supply equipment.

The power boxes (PBs), supplying energy to the APS tracks, are fed from 900kW substations installed every 2km as can be seen in Figure **1**.

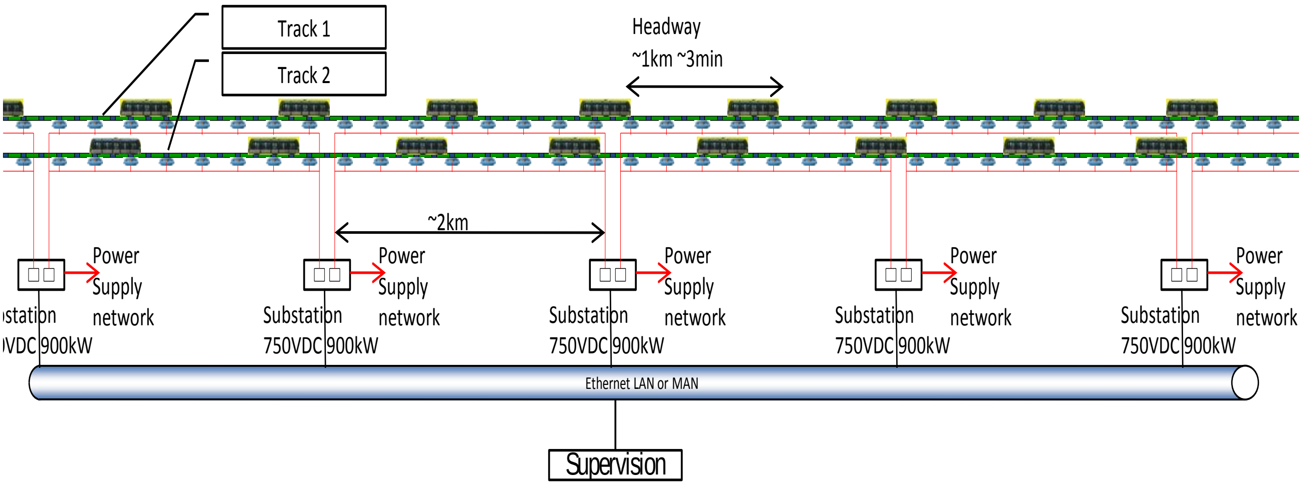

Figure 1 APS principle

3.2.2 Current collection

The tramway is equipped with 2 collector shoes sliding on the same segment, spaced more than 3m in order to ensure than at least one collector shoe collects the power if the second one is above a neutral zone.

3.2.3 On board equipment

The on board equipment for APS compatibility is made of:

- 2 collector shoes;
- The APS switching and control unit; and
- A battery to provide on-board autonomy when no power is delivered from the collector shoe.

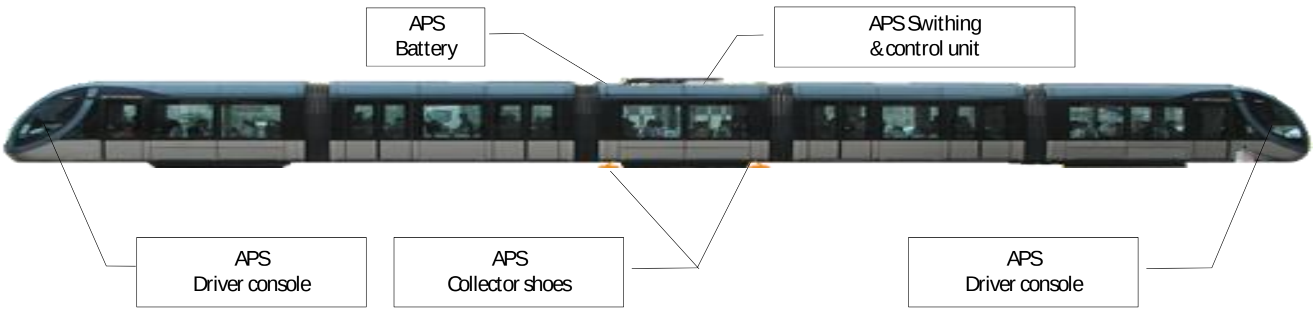

Figure 2 On board APS equipment

3.2.4 Infrastructure

The APS infrastructure is embedded in the track and is composed of power rail segments and PB manholes see Figure 3. The power to the tram is activated only when a connection between the tram and APS PB is established.

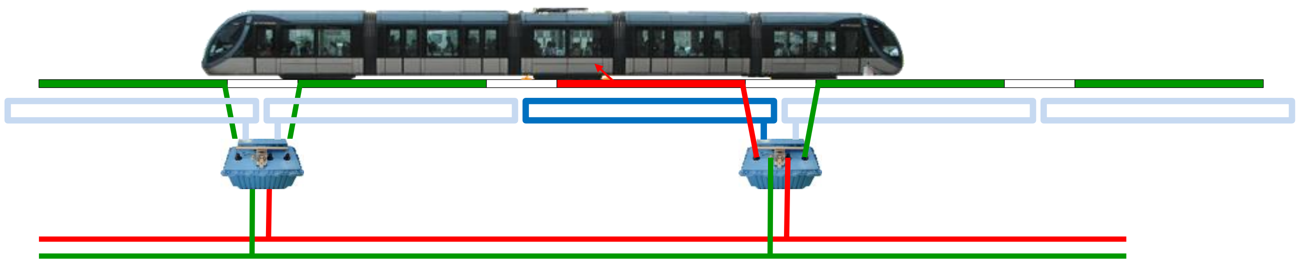

Figure 3 APS infrastructure components

The power rail segments have a maximum length of 11m. It is located in the centre of the track, between the running rails. Each segment is made of a conductive section of 8m and an isolating section of 3m, see Figure 4. The length of the isolating section allows crossing of specific zones, for example, crossing the running rail in turnouts or crossing switching mechanisms with an uninterrupted supply of energy. The infrastructure is fitted with a loop for tramway presence detection. The power rail delivers a segmented live polarity of the DC power source through the surface conductive layer, see Figure 5, and the other polarity is given through the running rail at a voltage very close to the earth voltage.

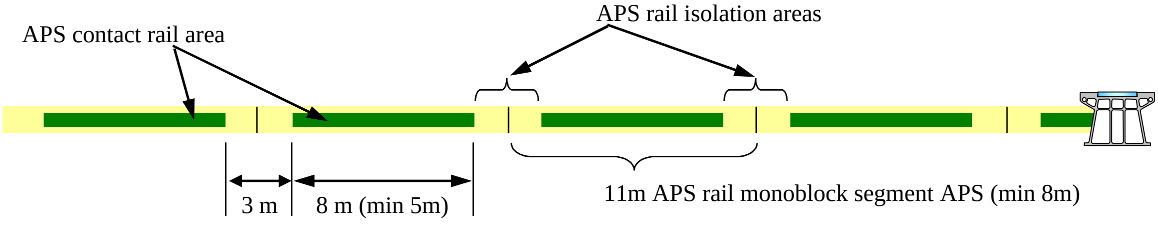

Figure 4 Description of the APS rail

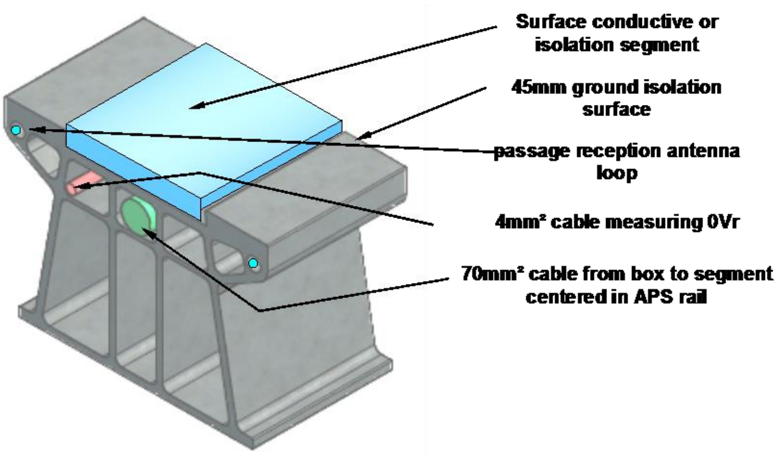

Figure 5 Cross section of the APS rail

The PBs are located in manholes between tracks, between rails or beside the tracks underground every two segments (22 m) along the line. Each PB contains all upstream and downstream segment switching and supply devices, as described in Figure 6, and is mainly composed of:

- Watertight envelope for protection of the electronic and power equipment from dust and liquids. It also protects the outside environment from electrical hazard;
- Power contactors (Co) to deliver the energy to each segment;
- Contactor (Cm) to connect the segment to the 0 Vr per segment;
- Electronic unit to manage the safety line between power boxes;
- Isolating switch (IS) to set the power box in an “isolated” status using redundant components, allowing continuously checking of the voltage of the APS segments. In the isolated status, the PB does not deliver power to the tramway anymore and must be physically replaced to recover the full service; and
- Communication unit reporting the PBs status to the sub-station and transmitting remote control for PB isolation or inhibition.

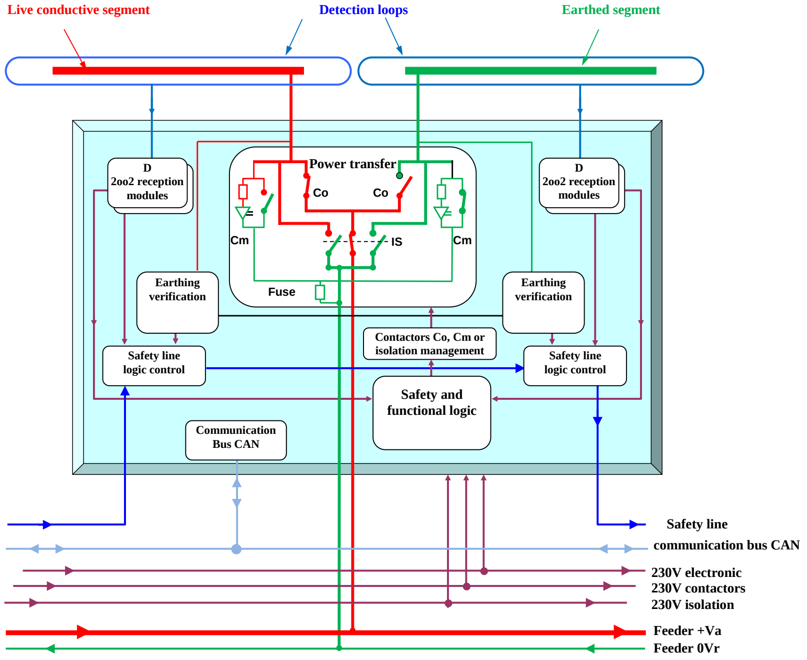

Figure 6 Power box

The PB design is called intrinsic safety: Any breakdown leads to the system being in a safe condition due to the absence of energy. Moreover, equipment on standby is safe and only active circuits may supply voltage to power segments.

The trams have dual collector shoes to collect current from the APS system. When one collector shoe enters a neutral area or an isolated PB, the power is drawn from the second collector shoe, see Figure 7. Co contactors only operate when the collector shoe is in the neutral area. This means that the Co contactor does not switch during a high charge to reduce the strain on the components.

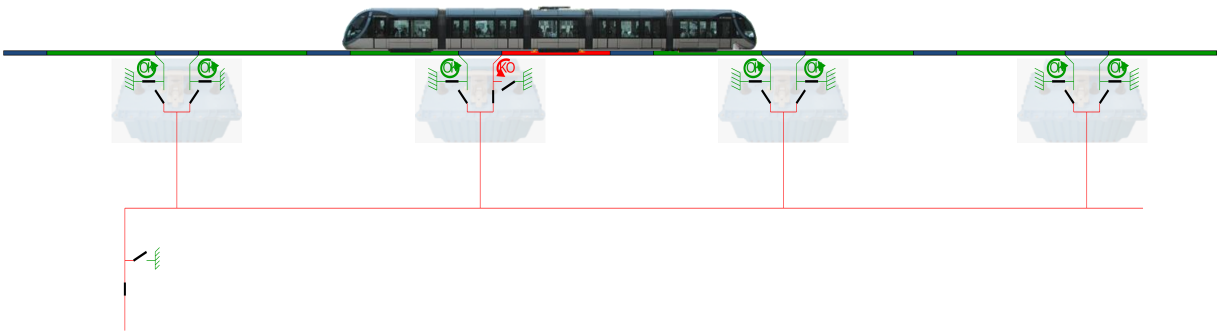

Figure 7 Current drawn from multiple collector shoes

The PB continuously transmits a safety signal to the substation. If the safety signal is not received, the APS equipment at the substation will immediately request an opening of the traction high speed circuit breaker and close its short-circuitor, ensuring safety for a whole section (2 km), see Figure 8.

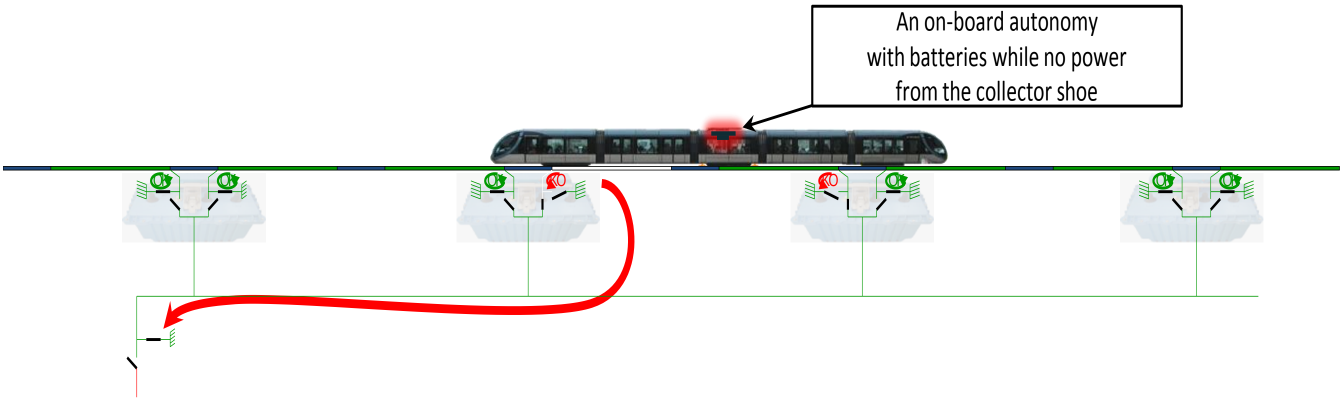

Figure 8 Function of the safety signal

3.2.5 Real time supervision

Supervision equipment (APS CAMS) offers the maintenance teams a facility to easily identify failed equipment, see Figure **9**.

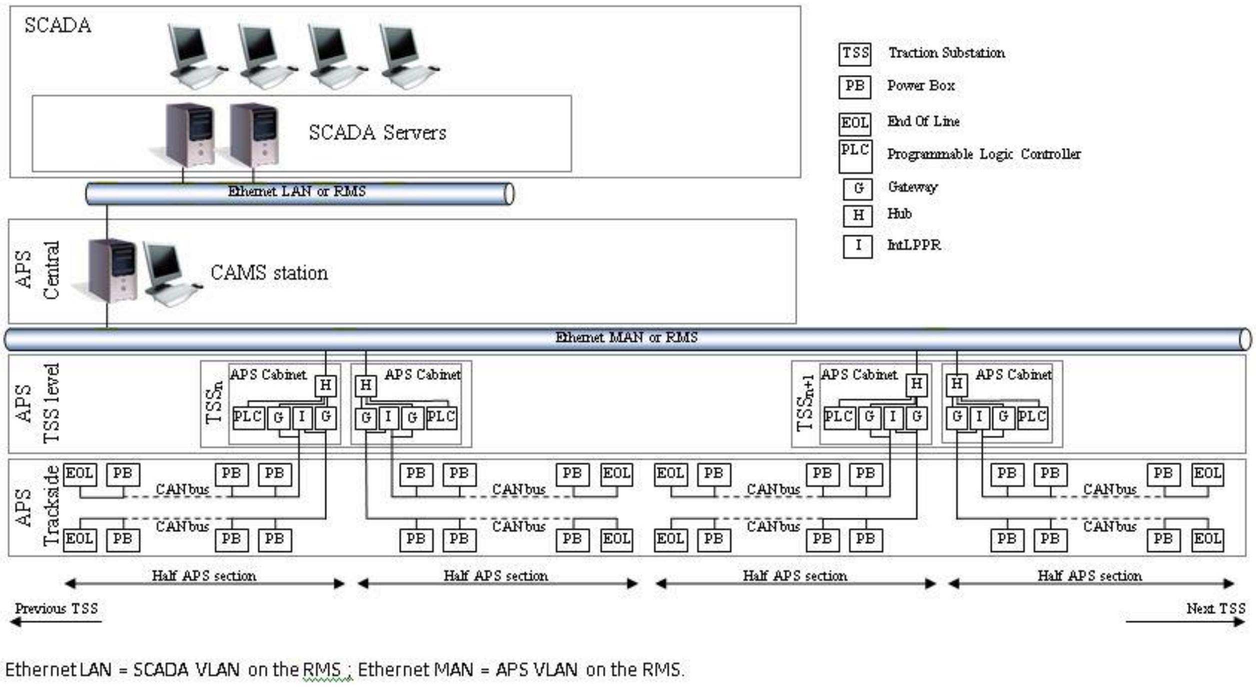

Figure 9 APS CAMS system

It is used for:

- Data logging of APS information;
- Issuing commands to the APS equipment for PB inhibition or isolation;
- Providing graphical and interactive views of APS information;
- Archiving of APS information for potential post-treatment;
- An ergonomic real time or historical monitoring of the APS data; and
- An interface to the SCADA system.

3.3 Differences ERS – APS

There are some significant differences between the APS system, designed for tramway in a cityscape, and an ERS. Some of the major differences are that different vehicles are utilising the ERS and the volume of traffic on the road.

3.3.1 Different vehicle sizes

In contrast to a tram system, where the vehicles are strictly controlled, there will be several different vehicles utilising an ERS. These vehicles, such as trucks and cars, have different lengths and the APS segments would be too long to be covered by the vehicle when alive, see Figure 10.

Figure 10 A car is significantly shorter than a tram and will not cover a whole APS segment.

With shorter vehicles the safety protection of the segment must be considered e.g. by shorter segments or by virtual zones in front of and behind the vehicle. Another implication is that it is impractical to have 2 collector shoes spaced with 3m for small cars. Further differences between a tramway system and a roadway are described in Table 2.

Table 2 Differences between tramway and road

Tramway	Road
Pickup fixed on the car body and cantered on the APS track thanks to the running rail, guiding the tramway.	Pickup lateral positioning autonomy required.
Current collection for one polarity. Return current on the running wheels.	Current collection for at least 2 polarities.
Current collection max power = 1100 kW.	Current collection max power = ~400 kW.

Different traffic conditions also imply additional challenges, see Table **3**.

Table 3 Challenges caused by different traffic conditions between a tramway and a roadway

Tramway	Road
1 tramway every 3 minutes	1 car every 2 seconds
2 tracks	Several tracks
Power 0,5 MW/km	Power 2 to 10 MW/km
Max power per segment: 1,1 MW	Max power per segment : ~400 kW
	

3.4 Adaptations of APS to ERS

The APS technology or principle is here adapted to the ERS. The sizing of existing components, designed for tramway should be optimised to match the actual ERS requirements. The PB switching technology must consider the number of switching points, which is much greater for ERS and the maximum power which is much lower for ERS.

3.4.1 Safety

The basic safety principle is based on a virtual moving zone in front of and behind the vehicle. As it is dangerous to stay in front of a running car, the electrification of the platform in the dangerous zone does not change the level of the risk. The minimum speed for powering up is a key for the calculation of the segments length and thereby the infrastructure cost/km. In the Slide-in project the minimum speed for powering up the track was set to 60 km/h. So, power will only be delivered to vehicles having achieved a speed of between 60 km/h and 100 km/h. A Road Safety Assessment is required.

Assumptions:

- Min speed = 60 km/h (17 m/s);
- Human time to escape = 1 sec;
- Min Distance between collector shoe and front / rear : l = 2 m;
- Sf = Sr ~ 17 m; and
- Result: Segment length = Sf + lc = 19 m.

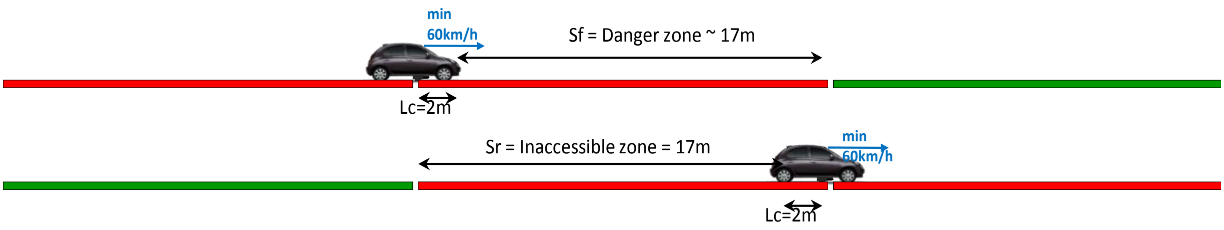

Figure 11 Description of the Danger size and an assumed safe segment length.

The speed detection in the ERS is located in a specific loop upstream to the segment that is to be energised and it is only activated by a vehicle capable of receiving the energy from the road at the correct speed, see Figure **12**.

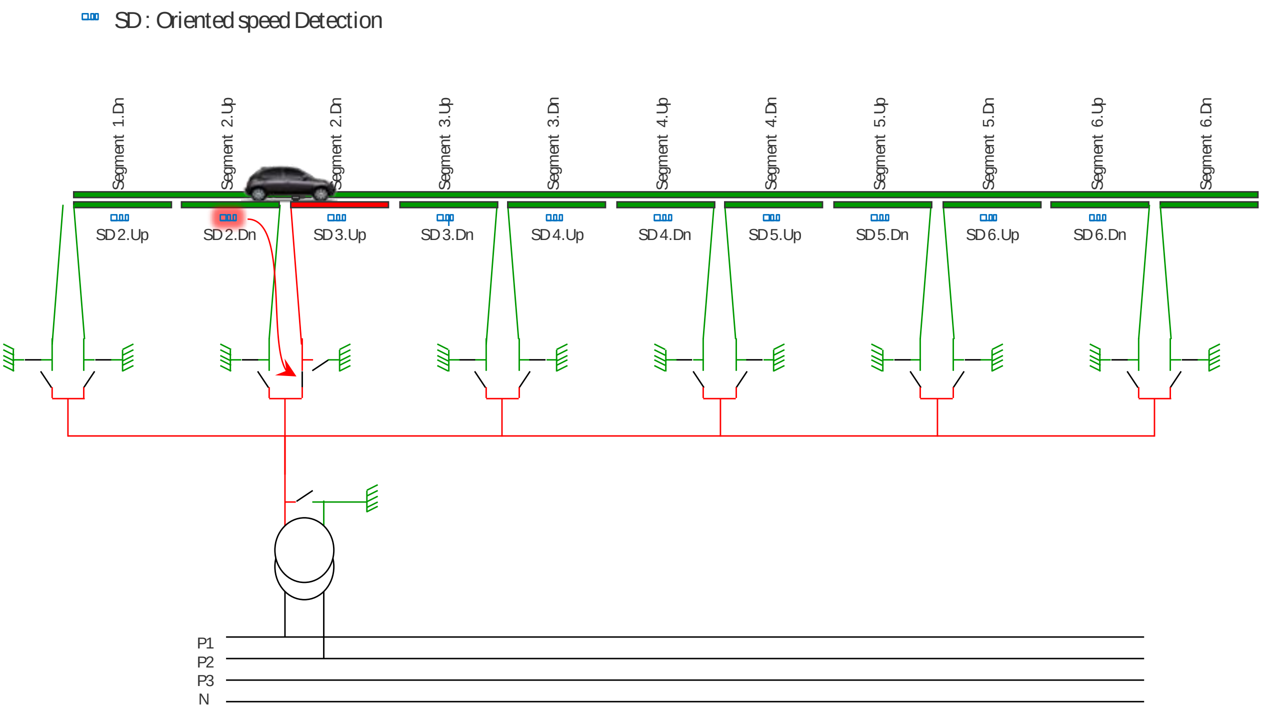

Figure 12 Energy activated by a capable vehicle within the correct speed limits.

Below in Figure 13 is a description of how the system could detect both the vehicle speed and direction to verify if the energy should be activated.

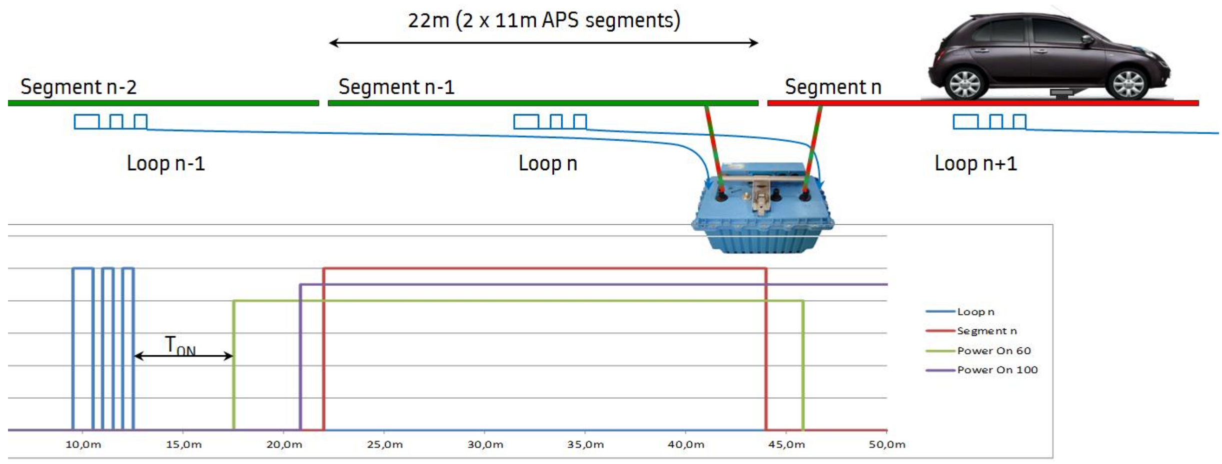

Figure 13 Detection of a ERS vehicle's speed and direction

3.4.2 Architecture

Substations with 750 VDC are located every 968 meters to feed the ERS. Dual APS cabinets are used to monitor and redundantly control the 22 PBs in each direction, see Figure **14**. In each direction of the track, 210 mm^2 copper cable is required for 750 VDC and additionally 210 mm^2 copper cable with 0 VDC for return current.

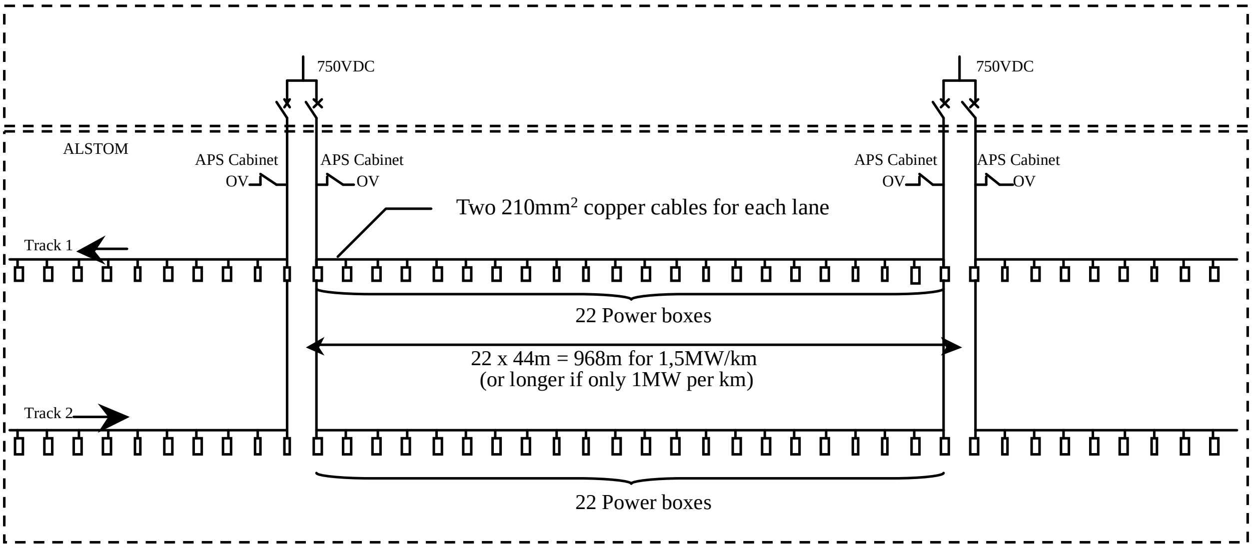

Figure 14 Alstom ERS system architecture

3.4.3 ERS Power calculation

The Power calculation is considered under maximum load in order to evaluate the minimum voltage available at the truck level.

The cable sizing is determined by the thermal sizing at nominal power, as a consequence of the required cable section, the voltage drop is lower than 60 V, which is reasonable for the on board traction equipment and for the voltage difference between the 0 V and the earth.

3.4.4 Maximum load assumptions:

- A set of trucks are running in a line, each consuming the maximum power of 120 kW, with an intermediate time between truck fronts of 1.66 s. This is equal to 1 second measured between truck rear and front as in the generic scenario. With a speed of 90 km/h, then the distance between the trucks is 41,5 m. The power distribution is authorised by the system up to 100 km/h. Nevertheless the electric sizing is based on trucks having the highest required power (120 kW) but with speed limited to 90 km/h.
- PB spacing is 44 m and the max power per PB is assimilated to a max power of 127 kW (120 kW / 41,5 m x 44 m).
- 210 mm^2 cables are used for feeding one lane and additionally 210 mm^2 for return current. One section of 210 mm^2 could preferably be realized with 3 x 70 mm^2 cables in parallel. The total length of 70 mm^2 conductor in the feeder cables will be roughly 6300 km. (6 conductors per lane, two lanes and 40 m of extra 70 mm^2 cable for various connections to/from the PBs on every 44 m of road)
- 22 PB between 2 substations (968 m)
- The sub-station delivers an output voltage of 750 V even at max load.

The maximum load configuration gives the following results (see table 4) **Error! Reference source not found.** and the voltage drop in each PB can be seen in the Figure 15 and in table 4.

Designation	**Symbol**	**Value**
Number of PB per 1/2 section per track	n	11
Power per truck	PT	120 kW
Power per PB every 44 m	P	127229W
Resistance Cable inter-PB	R	3.35 mOhm
Distance inter-PB	L	44 m
Distance inter-truck	LT	41,5 m
Distance inter sub-stations	LSST	968 m
Resistance Cu 20°C	Ro	1.610E-8 Ohm/m
Cable section	S	210 mm^2
Power requested by the trucks	PuserMax	1400 kW
Power delivered by 1/4 substation	P1DepMax	1510 kW
Efficiency at max power due to cables	Efficiency	92,7%
Sub Station max power (4 departures)	PSSTTot	6040 kW

Table 4 The configuration as result of the maximum load case

PB1 is the first power box closest to the sub-station while PB11 is the power box located in the middle of the section where the voltage drop is the most severe due to redundant feeders from two directions.

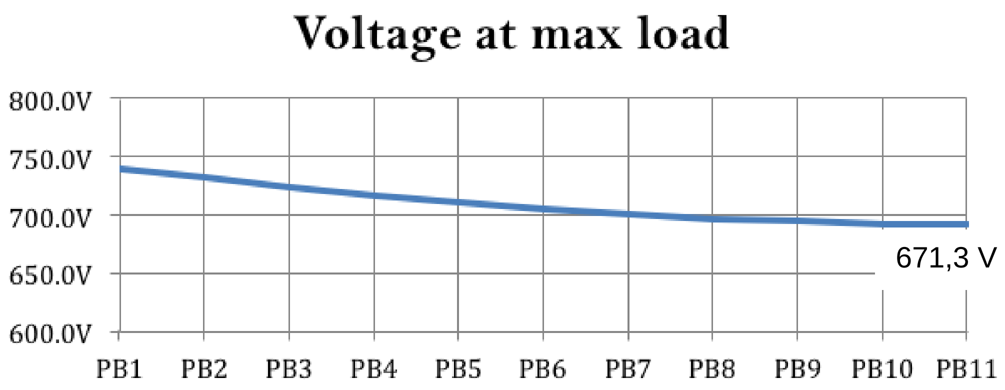

Figure 15 Voltage drop at each PB during maximum load case

Node	Voltage [V]	Track position [m]	Truck Current [A]	Feeder Current [A]
PB1	737,5	44	173	2013
PB2	725,9	88	175	1841
PB3	715,3	132	178	1666
PB4	705,8	176	180	1488
PB5	697,3	220	182	1307
PB6	690,0	264	184	1125
PB7	683,8	308	186	941
PB8	678,8	352	187	755
PB9	675,1	396	188	567
PB10	672,5	440	189	379

Table 5 Voltage drop visualized with truck position during maximum load case

3.4.5 *Average load assumptions:*

- An average load of 1500 kW per km for 2 tracks (up and down).
- Consequently an average of 33 kW per power box every 44 m.
- A maximum current density of 2,3 A/mm² in the cable.

The average load configuration gives the following results , and the voltage drop in each PB can be seen in Table **7**.

Designation	Symbol	Value
Average power per km 2 tracks	P	1500 kW
Average power per PB	P	33 kW
Current density	J	2.3 A/mm²
Average Power requested by the traffic 2 tracks 1 section	$P_{userMean}$	1452 kW
Average Power delivered by the substation	$P1_{DepMean}$	1479 kW
Efficiency at average power due to cables	Efficiency	98.2 %
Average number (nb) of trucks per 2 section tracks	nbTrucks	22

Table 6 The configuration as result of the average load case

Table 7 Voltage drop visualized with truck position during average load case

Node	Voltage [V]	Track position [m]	Truck Current [A]	Feeder Current [A]
0	750.0	0		493
PB1	746.8	44	44	493
PB2	743.8	88	44	449
PB3	741.1	132	45	404
PB4	738.7	176	45	360
PB5	736.6	220	45	315
PB6	734.8	264	45	270
PB7	733.3	308	45	226
PB8	732.1	352	45	181
PB9	731.2	396	45	135
PB10	730.6	440	45	90
PB11	730.3	484	45	45

3.5 Efficiency of the ERS

3.5.1 Conductive pick-up energy transfer efficiency

Measurement conditions:

- Vehicle accelerating from 0 km/h to 60 km/h;
- Dry weather conditions and approximately 20 °C;
- Voltage drop and leakage current were measured separately for increased accuracy;
- Approximately 20 m, 2x70 mm^2, copper cable from DC source to the vehicle; and
- Segments were turned on for a fixed time of 5 seconds.

Efficiency measurements

The voltage drop in the pickup was measured when nominal voltage (U_n) was applied between the track rails. A long signal cable connected to the power box and the measuring equipment on the vehicle measured the pickup voltage drop (U_{drop}) while the vehicle was moving, see Figure

16. An average voltage drop of 8.2 V was measured over one shoe at a constant 170 A_{dc} (I_n) (607 V_{dc}). A similar voltage drop is expected for the secondary shoe, rendering 16.4V in total. The varying degree of contact between pick-up and track rails can be seen as ripples in the graph.

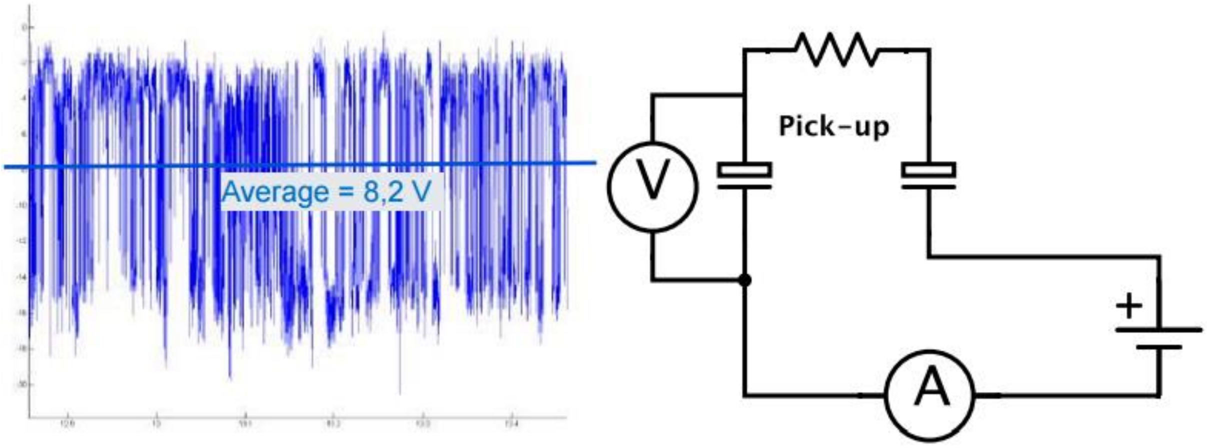

Figure 16 Left: Measured average voltage drop per shoe. Right: wire diagram

The leakage current between the track rails was measured under a non-load condition and with nominal voltage, see Figure **17**. With a constant 607 V DC applied to the track rails, the average leakage current (I_{leak}) was measured to 0.7 A. The leakage current per segment is highly dependent on the medium between the segments. The current ripples in the graph originate from the energy source that supplies the track rails.

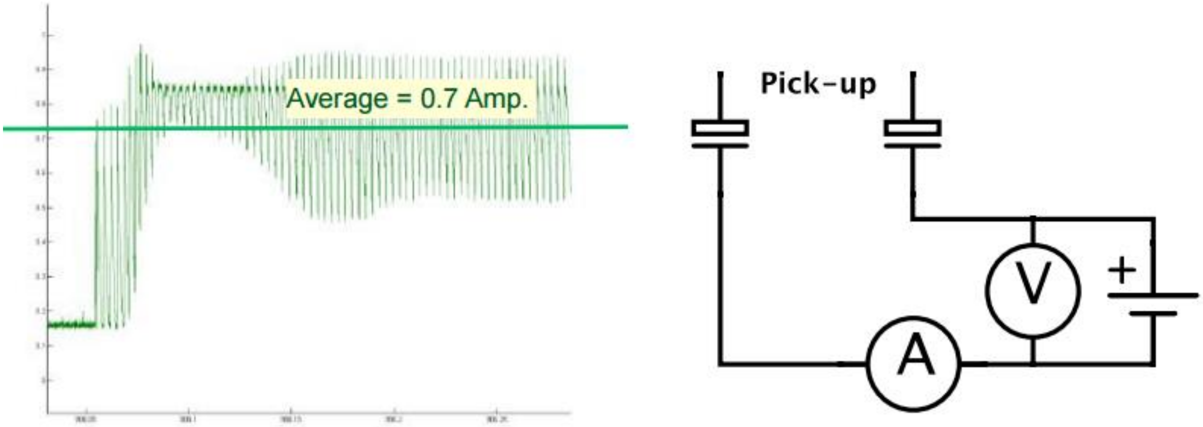

Figure 17 Left: Measured average leakage current. Right: wiring diagram

Efficiency results

The transfer efficiency was calculated to 96.9 % (n) with 103 kW nominal power. Of the total 3.1 % losses (3.2 kW), 0.4 % was leakage current and 2.7 % was losses from voltage drop.

$$n = \frac{P_{in} - P_{loss}}{P_{in}} = \frac{607\ V * 170\ A - (16.4\ V * 170\ A + 0.7\ A * 607\ V)}{607\ V * 170\ A} = 96.9\ \%$$

A conductive pick-up energy transfer efficiency of 97.2 % was calculated after removing the losses (approximately 0.3 %) that originated from the 20 m copper cable.

Accuracy of efficiency measurement

The combined accuracy of one voltage or current probe together with the oscilloscope was 4 % (ε U and ε I). During the tests the measurement accuracy of the losses (ΔP_{loss}) were ±160 W or approximately ±0.2 percent of the input power according to the below formula.

$$\Delta P_{loss} = \pm\sqrt{[I_{leak} * \varepsilon\ \mathrm{U} * U_n]^2 + [U_{drop} * \varepsilon\ \mathrm{I} * I_n]^2 + [I_n * \varepsilon\ \mathrm{U} * U_{drop}]^2 + [U_n * \varepsilon\ \mathrm{I} * I_{leak}]^2}$$

The total conductive pick-up energy transfer efficiency, including measurement inaccuracy, is therefore 97.2 % ±0.2 % thus in the range 97.0 % to 97.4 %.

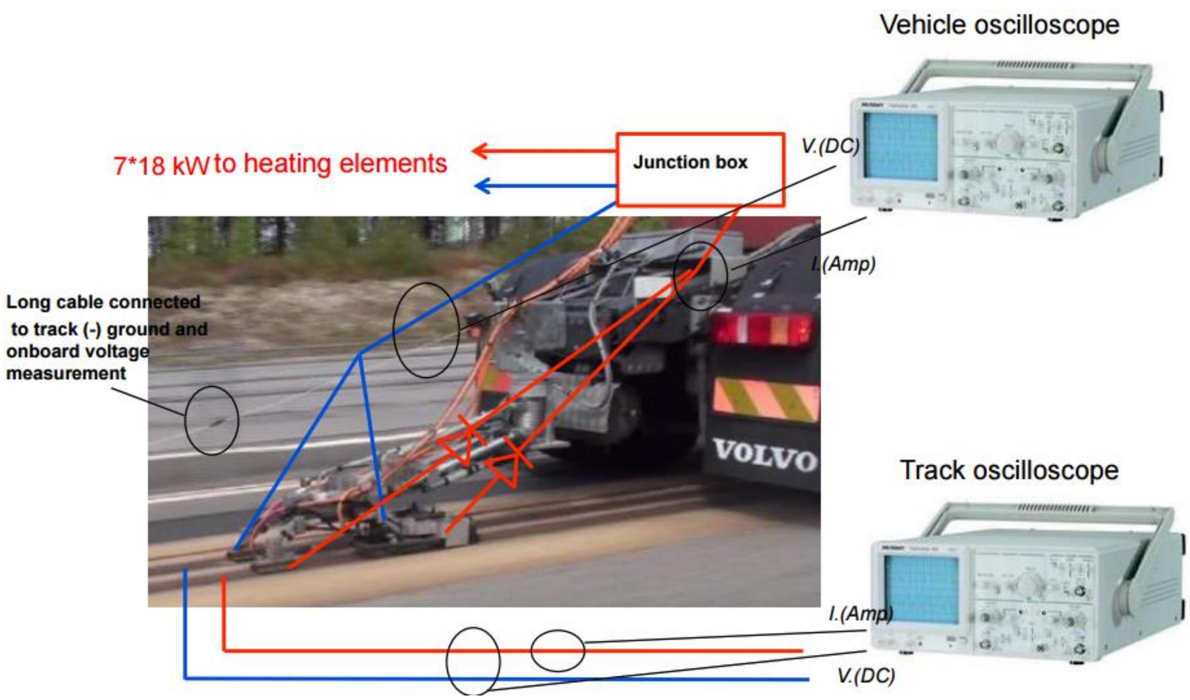

Figure 18 Measurement setup on first generation test vehicle

3.5.2 Roadside energy transfer efficiency

Estimating the efficiency of the ERS system is more complex than measuring energy transfer efficiency of the pick-up. The efficiency measurement depends on several different independent dynamic factors that make it difficult to give a definitive value in this report. One example is the cable material used and the number of ERS vehicles results in a voltage drop in the cables that is not linear with the power transferred. In this report copper cables are used and the cable losses estimated to 1.8 %. Another example is that a large proportion of the efficiency losses depend on the friction between the pick-up and the road, which is highly dependent on the road conditions, force applied, the vehicle speed and specific to the materials used. To give a preliminary example, measurements from the tram industry were adapted to the ERS circumstances earlier described in the generic scenario description and presented below in Table **8**. The material used in the pick-up shoes is cast iron, which approximately results in 20 % losses of the vertical force. The vertical force applied on the collector shoe on an APS tramway is 150 N. The corresponding force on the APS ERS pick-up is not known but is estimated to four times 37,5 N in the calculation.

Table 8 Scenario description for APS-ERS efficiency calculations

Designation	**Symbol**	**Value**
Section length	d	1000 m
Max number of vehicles per hour (see Table 10 in [1])	MbV	659
Force per shoe (20% of 37,5N)	f	7,5 N
Energy for 1 000m section: E = f * d	E	7500 J
Energy loss in 4 shoes multiplied with vehicles, NbV		19770 kJ
Average loss per 1 000m section (E*4*NbV / 3 600s)		5491 W
Average loss per 1 000m section in both directions		10983 W

Given the total power requirement 470 kW per km, the friction loss in the collector shoes is estimated to 2,33 %. This assumes that approximately 2 out of 13 vehicles are trucks, per kilometre in both directions, according to Table 10 in [1]. The global efficiency, including the voltage drop and current losses in the pick-up, calculated from the 750 V transformers to the vehicle on-board converter is calculated to be 93,3 %.

Table 9 Global efficiency calculation for APS-ERS

Designation	Relative Loss	Loss [W]	Power [W]	Comment
Total "User" power for 1 section (at trackside level)	NA		504193	Power at the on board traction equipment upstream the converter
Sub-station rectifier (transformer + rectifier)				Sub-station rectifier (transformer + rectifier) excluded
Cable losses	1,8 %	9075		Refer to previous section
Total required power at trackside level			495118	Sub-station power
Mechanical losses from collector shoe	2,3 %	10983		Mechanical losses of sliding contacts for 13 vehicles at 100km/h
Voltage drop and current losses from collector shoe	2,8 %	13556		Voltage drop and current losses in the pick-ups for 13 vehicles at 100km/h
Power available for on board traction			470579	
Total	6,72 %	33614	504193	
Global Efficiency		**93,3 %**		

It is important to note that this is an early estimation in a specific scenario. It is based on the available technology for trams and the data from early measurements and informed conjecture. Future tests will provide more information and an accurate efficiency measurement.

3.6 Maintenance

The PB faults are tolerated by the system thanks to on board autonomy. PB replacement can be scheduled by maintenance. PB faults are identified on the Computerized Aided Maintenance System (CAMS). The conductive ERS must be free of ice or snow in order to allow an electrical contact with the collector shoes. Alstom have a clear view about the maintenance of APS track in cities and suggests it will be similar for ERS equipment maintenance. But further studies are

required in coordination with track installers and maintainers. How this is done and other maintenance issues will be addressed more thoroughly in the work to be done.

3.7 Limitations

The safety principle delivering the voltage at ground level in front of and behind a running vehicle prevents hazards for pedestrians, nevertheless, there are other potential victims:

- Motor cyclists may follow cars close enough that they could access to the live voltage. Consequently, the principle does not protect reckless motor bikers unless the segment size is shortened to fit more or less under the vehicle.
- Animals which could have a shorter response time or might survive a vehicle drive-over due to their size. An electric shock for an animal could lead to an accident of the vehicle as some animals might not be able to flee due to electric shock or the sight of an unusual reaction of the animal might provoke a reaction by the driver.

These use cases have not been tested in the Slide-in project. Already today animals may interfere with traffic, and it is technically difficult to judge how partly-electrocution would increase danger or possibly even decrease it compared to today's situation with animals in traffic. Still after experiencing 23 million km run with APS, no electrocuted animals have been recorded. Some Alstom developers think it is the electronic noise that scares animals away from the tramway when in service. However Alstom have experienced children under the tramway but none was electrocuted or killed because in the APS system a specific basket protects from this kind of event.

3.8 Flexibility

The current design limitation of the APS switching is 1MW per vehicle, which is much more than that required by trucks today (120 kW on Slide-In project), providing flexibility in 10 to 15 years if the ERS demanded power increases. It will also be possible to upgrade to higher power switching capabilities. If the solution has been designed for a limited power on this demonstrator (120 kW) at level of PBs, or cables, or substations, a power increase is possible with a step by step upgrade of HV distribution (30 kV), substations upgrade (every km), additional cables and PBs upgrade without traffic interruption. During the transition, the power distribution will be interrupted by sections of 1km, which will have almost no impact when in operation with hybrid cars.

3.9 Cost

The estimated cost for the Alstom ERS system is based on the APS technology delivered for the test track. It includes the procurement costs of the APS Beams (including branching boxes), APS PBs, APS Cabinets, MFC cables and antenna cables for detecting the vehicles.

Nevertheless, it should be noted that the present costing of the ERS does not include any installation costs, engineering costs or safety studies.

Separate cost estimations have been done regarding the feeder cables specified in chapter 3.4.3. The cost for such a cable is mainly governed by the copper price[1], which means that the cost could be assumed to scale roughly linearly with the amount of copper and with the transferred power.

The cost[2] estimated for the Alstom ERS double track based on an average load case is about 1 M€/km. The 5760 km of 70 mm^2 feeder cable is estimated to cost around 61 k€/km in the average load case and 270 k€/km in the maximum load case.

It is important to note that the APS technology approach has been adapted to the ERS. The sizing of existing components, designed for a tramway would require optimisation to match actual ERS specifications, as described in chapter 3.3. For example the PB switching technology must consider the number of switchings, which is much greater for ERS, and a maximum power that is much lower.

3.10 Details of Vehicle

An ERS vehicle must be slightly modified to allow connection to the ERS. This chapter describes the vehicle setup that has been used in the Slide-in project and the expected impact on future ERS vehicles in terms of efficiency, safety and weight.

3.10.1 Overview of test vehicle for conductive ERS system

The principle of the ERS system for trucks was to add new interface components to the existing vehicle hybrid set-up, thereby enabling electrical energy transmission between a conductive road and the vehicle high voltage propulsion system.

---

[1] Within Slide-in project the copper price was fixed at 6,1 €/kg

[2] When applicable the currency rate 8,9 SEK/€ was used.

As an example, the base for such a vehicle system should be a hybrid drivetrain, i.e., a truck equipped with both a diesel combustion engine, and an electrical motor, driven with electrical power from a voltage source, such as an on-board high voltage battery system.

Below in Figure **19** is a principle illustration of an available Volvo hybrid configuration, showing the main components of a split driveline in a hybrid with 2 torque sources.

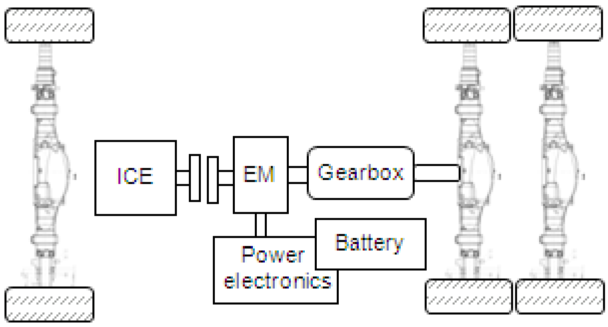

Figure 19 Hybrid vehicle illustration

For a complete system test, it will be mandatory to equip the vehicle with an electric motor, and some kind of suitable energy layer to facilitate transition between electric mode and the ICE mode, though during development phase of the interface components to ERS, this is not necessary.

Thus, in the slide-in project the first generation truck was a traditional diesel engine truck, that facilitated testing of the new components (pick-up, power to vehicle adapter), without actually performing complete system tests on a hybrid truck.

The test truck was equipped with a resistor bank for electrical energy dissipation, relevant test equipment and an extra battery source for component development. As the vehicle was not equipped with an electric motor, the electrical power that was transmitted from road to vehicle was dissipated in the resistor bank system.

A FFI funded follow-up project to Slide-in is currently on-going – see 3.10.7 Future development.

3.10.2 Test vehicle for conductive ERS system

Below in Figure 20 is given a system overview of the test vehicle used in the project:

Added new subsystems for the test vehicle are:

1. Extra 24 V battery for pick-up control;
2. Resistor bank for power dissipation;
3. Power to vehicle adapter;
4. Camera + display for driver support;
5. Cameras for logging;
6. Pick-up mechanical component;
7. Pick-up control box; and
8. Radio emitter (including antenna) for ERS.

Bullets 1-5 are only for test purposes and will not be needed in future EVs. However there are other components that may be needed:

- To charge the battery while driving (not only transfer power for traction) an on-board charger or DC-DC converter is needed as well;
- Filter components for surge protection; and
  - Surge arresters
  - Inductors
- Power control.
  - Contactors including pre-charge circuit
  - Fuses
  - Voltage sensors
  - Current sensor
  - Isolation monitor

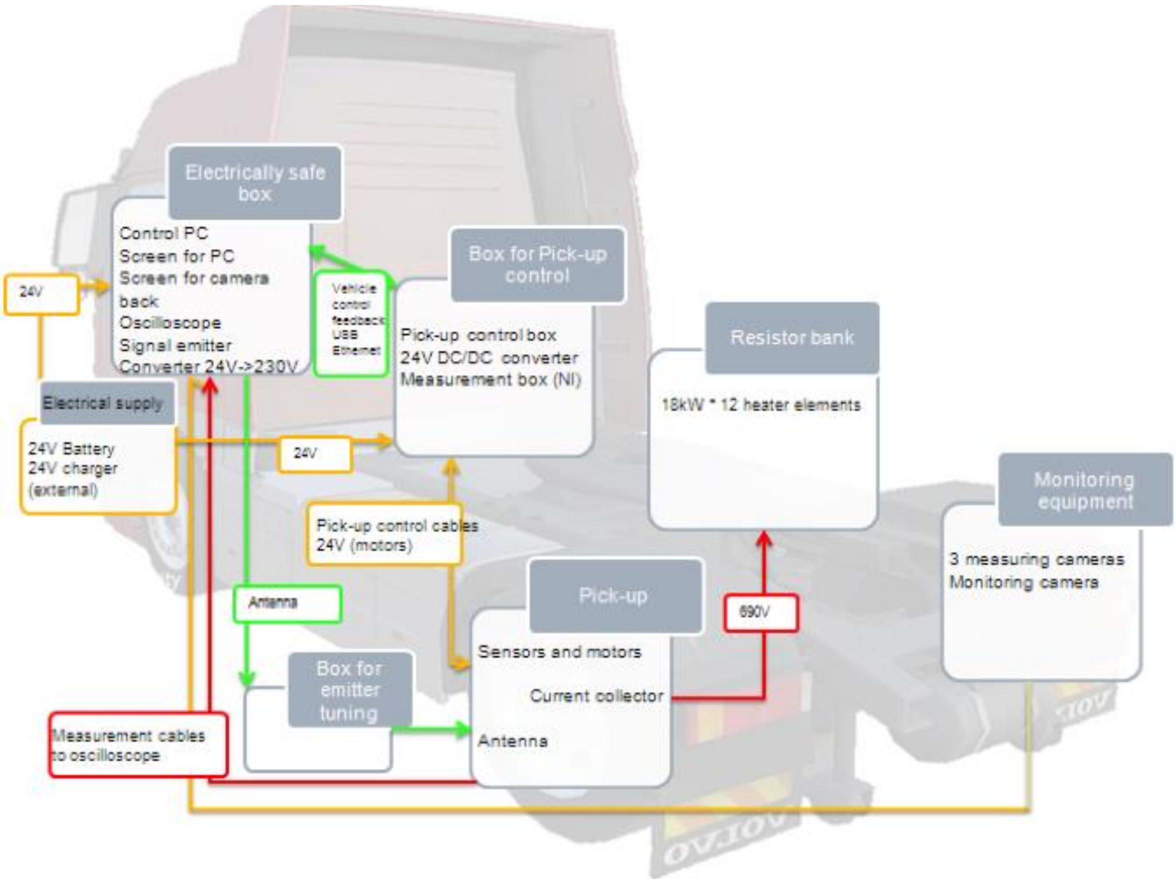

Figure 20 Test vehicle (system overview)

3.10.3 Pickup's for conductive ERS system

The Slide-in project designed two different pick-up prototypes to enable physical contact between the vehicle and the road rails:

- The "turning pickup": where lateral movement was controlled by a turning, rotational movement, facilitated by an electrical motor that is attached to the vehicle body. The vertical movement of this turning pickup prototype was enabled by a linear electrical motor, which was part of the pick-up moving body. See left picture in Figure **21**.
- The "linear pickup": where lateral movement was controlled by a linear movement, along a straight axis between the 2 main frames of the vehicle body. The vertical movement of this linear pickup prototype was enabled by a pneumatic actuator, which was supplied with (high pressure) compressed air from the vehicle pneumatic system. See right picture in Figure **21**.

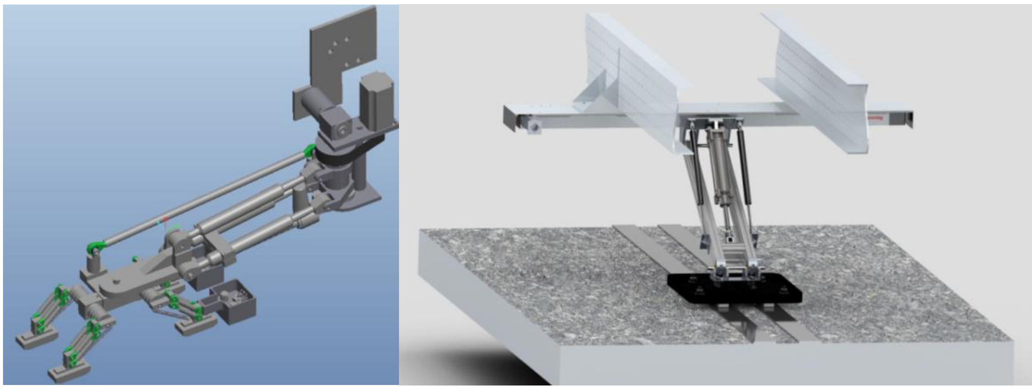

Figure 21 Conductive project pickup prototypes

Both of these pickups have been installed onto the FH test truck, and both of them have been tested. During early development, in the project, the pickups were tested mounted at the rear of the truck. The turning pickup was designed so that it can be installed under the vehicle, see Figure **22**, and positioned safely (in a home position), securing vehicle 25cm of ground clearance, when it was not in operating mode.

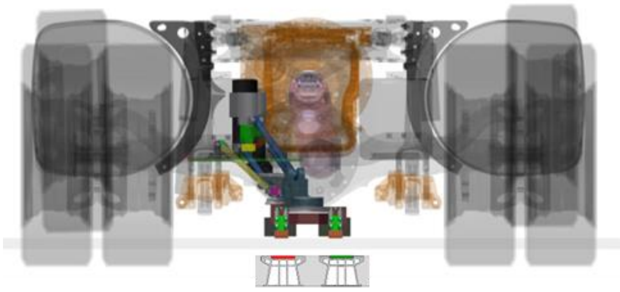

Figure 22 Truck with pick-up and road with two parallel rails

3.10.4 Maintenance

The collector shoes are components that will experience “wear and tear” from mileage usage. These must be included in future cost estimates as these will most likely be a part of the vehicle that will be replaced during service intervals.

Experience from the tram industry, at much higher transmitted power, was that collector shoes are replaced every 20000 km of usage.

Other added components shall be designed so that these do not need service intervals.

3.10.5 Weight and dimensions

The estimated weights and dimensions of added components for next generation prototype vehicle are:

- Pickup (80 kg and 140x40x70 cm)
- Power converter: (50 kg and 70x60x20 cm)
- Cables, surge arresters, inductors, contactors, control electronic etc. (100 kg and 60x50x50 cm)

These are the weights and dimensions of the prototype designs. In the future when technology have been industrialized, these weights are likely to be reduced significantly.

3.10.6 Vehicles that do not need to carry all electrical energy on board could of course reduce battery size significantly. For a HD vehicle this reduction is much larger than the added weight and volume of the vehicle components needed for utilizing conductive ERS.Cost

Electromobility is in an early stage of development; containing new designed components in extremely low volumes, thus no proper cost figures are available for vehicle components. For APS-ERS cost estimation see 3.9.

3.10.7 Future development

A FFI funded follow-up project to Slide-in is currently on-going. In this project a long haul heavy duty hybrid truck will be tested with a new generation pick-up. Here the electrical energy will be used for propulsion and/or battery charging. Late in 2016 the first test runs are planned on the Hällered test track. The latest pick-up design requirements include foreign object collision requirements so that larger objects with higher weight should not make pick-up come loose or loose parts. This have however not yet been verified.

4 FEASIBILITY ANALYSIS AND RESULTS

4.1 Introduction

The Volvo/Alstom conductive ERS system will be assessed for its feasibility to be applied to other use cases defined in FABRIC, see [2]. Note that the system will only be considered in a desk study and will not be subject to test track trials as is the case with FABRIC solutions 1 to 3. The use cases chosen in 2.2.1 and 2.2.2 have been analysed in sub chapters below.

4.2 Slide-in vs. FABRIC demonstrable use cases

The Slide-in solution has been assessed for the FABRIC demonstrable use cases below.

Table 10 Slide-in vs. FABRIC demonstrable use cases.

Use case		Slide-in relevance	Same as Fabric?
1.	Driver and EV registration to a central FABRIC database	No support for this use case has been implemented in the Slide-in solution but there is no technical reason why this could not be done.	No
2.	Driver login to FABRIC	No support for this use case has been implemented in the Slide-in solution but there is no technical reason why this could not be done.	No
3.	User account management	No support for this use case has been implemented in the Slide-in solution but there is no technical reason why this could not be done	No
3.	EV identification	The Slide-in test track has implemented EV identification as	Close

		a mean to only energise the road segments below the vehicle i.e. “in order to authorize an EV to charge”. There is no support for creating custom charging profiles that fit the specific vehicle since it is not needed when such a profile would be controlled by vehicle on-board charger anyway. There is no support for billing purposes but there is no technical reason why this could not be done.	
4.	Charging assistance	The Slide-in test track has implemented functions to provide the driver with “information regarding the charging process”. However since the tracks are easily spotted by the driver and the wiggle tolerances are large there is no need for driver assistance to ensure alignment. Note that in contrast to the wireless systems there is no penalty of downgraded performance/efficiency when being off the ideal course. This is demonstrated for dynamic charging, but in theory is true for all modes: Static, stationary and dynamic.	No
5.	Charging management high-level and low-level (load balancing)	The power that reaches the EV depends on many parameters and it has to be carefully controlled. Two types of power management have been implemented in Slide-in: 1) high level restriction of available power to the infrastructure secured by an industrial generator set and individual fuses in all power boxes. (For the APS tram system there is a system already in service that guarantees the security of the grid) 2) low level power management in every EV controlling charging and traction power.	Close
6.	Energy supply tariff modulation	No support for this use case has been implemented in the Slide-in solution but there is no technical reason why this could not be done.	No
7.	Charging and road infrastructure availability status updating	No support for this use case has been implemented in the Slide-in solution but there is no technical reason why this could not be done. It is used for the APS tram system already in service.	No
8.	Billing	Though both current and voltage are continuously monitored in the vehicle (i.e. energy consumption could be calculated) this use case has not been implemented in the Slide-in solution. Still there is no technical reason why this could not be done.	No

4.3 Slide-in vs. FABRIC feasible use cases

The Slide-in solution has been assessed for the “FABRIC feasible use cases” below. Note that these “feasible use cases” are to complement the technology demonstration-focused use cases with functionalities that are either currently available as off-the-shelf products, or are under research and development in current EU funded research projects. Since these products and services are already being developed, it would not be efficient to repeat and re-develop them within the Slide-in conductive ERS project. One could expect though that with the appropriate interfaces in place, these products and services could be integrated seamlessly in a future, feasible conductive ERS system. The foreseen use cases that apply to a system such as Slide-in conductive ERS and extend its user friendliness are the same as the ones identified as “FABRIC feasible use cases”, see Table **11** below.

Table 11 Slide-in vs. FABRIC feasible use cases.

	Use case	Rationale	Feasible use in Slide-in solution
1.	Planning of a trip	This is a mainstream functionality present in almost all modern vehicles. Current navigators allow for detailed route planning, including passage from specific POIs. Traffic information and ETA estimation are not uncommon. ITS research projects have focused heavily on the subject and each exploits dynamic navigation and mapping for its own purposes such as ecological driving.	This functionality may allow the pre-booking of charging facilities Along a route, taking into account the range of the EV.
2.	Guidance to a charging facility or to a destination	This is a very common functionality. Research projects focus on exploiting open standards and maps for ITS routing.	Leading the EV towards a charging facility based on dynamically updated charging facilities database.

	Use case	Rationale	Feasible use in Slide-in solution
3.	Dynamic route and booking management	Dynamic routing is a functionality of all GPS navigators and it is activated when the vehicle deviates from the route. Smart re-routing is the objective of several ITS projects based on different criteria.	In real traffic conditions, major delays compared to the planned time of arrival at a pre-booked charging infrastructure are to be expected. This is why a system that automatically makes the necessary booking and rerouting adjustments without the interference of the end-user is very desirable. The same system can be used in cases the infrastructure goes offline unexpectedly.
4.	Emergency charging	This functionality does not contribute to the technology assessment of Slide-in prototypes but focuses on user convenience in the future when EVs are adopted by the public in a large-scale.	This is a functionality that is foreseen to exist when electromobility is widespread and dynamic ERS systems are common. This functionality reduces range anxiety by providing a means to charge the EV without prior planning. However this will be done in a structured and organized manner so as to guarantee the good operation of the overall system but also discourage this practice.
5.	Integration of Slide-in with UTMC	This is a foreseen functionality/system service for the road operators. However this is a feasibility use case because of different UTMC systems and standards that cannot be address within Slide-in and because it does not contribute to the technical assessment of dynamic conductive charging.	Slide–in charging infrastructure should be integrated with Urban Traffic Management and Control systems to ensure good traffic flow and enforcement.

4.4 Slide-in vs. FABRIC "*charging modes*"

The properties of the Slide-in conductive ERS solution are assessed in relation to the charging modes mentioned below:

- *Static charging*
- *Stationary en-route charging*
- *Dynamic charging*

The safety principal, see 3.4.1, with *“virtual moving zone in front of and behind the vehicle*.” used within Slide-in could not be used during static and stationary en-route charging if the powered segment length makes it possible to reach the energised tracks. Hence to be able to support these charging modes other measures need to be taken e.g.:

- Shorter track segments that could be “hidden” under the vehicle (additional screens/fences around track/pick-up may be required);
- Lower the voltage below safety limit (60V) at low or zero speed. Note that this would decrease available power for charging to 15 to 30 kW per segment and also the on-board charger will have to support these low voltages.
- Redundant sensor systems detecting foreign/living objects that could shut down the power if needed; and

If one or more of the measures above are taken the conductive ERS are believed to support the use cases mentioned in chapter 5 *Charging modes* of [2].

4.5 Slide-in assessment for the Car use case

The properties of the Slide-in conductive ERS solution are assessed in relation to use cases involving cars. Potential adaptations of the system, limitations and comparison against the specifications and requirements will be identified.

4.5.1 Pick-up size

As was mentioned in 3.3.1 the Slide-in ERS infrastructure has been adapted to different vehicle sizes, such as cars. The vehicle equipment e.g. the pick-up developed for truck use within the Slide-in project was obviously over dimensioned for this usage. The physical dimensions are excessive for standard vehicles. However, there is no technical reason why an appropriate pick-up could not be developed for cars. Understandably, this development needs to be done by, or in close cooperation, with the car OEMs. Note that one of the reasons the Slide-in pick-up was designed as large in scale, was to take up any large lateral movement. This may however not be needed if the vehicle has a steering actuator system that could guide the EV to follow the track.

4.5.2 Power transfer and voltage

The power requirements (40 kW vs. 120 kW) are much less for cars, but since power/current is controlled by the EV and not by the infrastructure, this is no restriction for car usage. Note however, that with the current technology solution for infrastructure, the EV would need to support the same voltage as the truck i.e. approx. 750 V. Since the most common car powertrains work at 300-500 V today, this implies the following adaptation to a car or light duty use case (unless the car powertrain are designed for ERS/750 V directly):

- For charging the EV battery the on-board charger would typically need a lower output voltage compared with the ones needed for typical trucks/buses (but no need for any additional components); and
- To use the ERS power for traction you would need a more powerful on-board charger or DC-DC converter, to be able to support both battery charging and traction power simultaneously. Alternatively you would need to adapt the powertrain inverter to support the higher voltage.

4.5.3 Power transfer efficiency

The transfer efficiency is believed to be lower for EVs that need less power e.g. light duty vehicles compared to heavy duty vehicles. This is due to the:

- Leakage current, that is independent of power transfer, make up a bigger part of the power transferred; and
- Mechanical losses from the collector shoe are not linear to power transfer and make up a bigger part of the power transferred.

4.5.4 Component weight and dimensions

The weights and dimensions of added components are believed to be lower for EVs that need less power e.g. cars and light duty vehicles compared to heavy duty vehicles. This is due to the:

- Pickup need:
  - smaller cables;
  - smaller contact shoes;
  - smaller actuators; and
  - less height adjustment (when ground clearance is lower).
- Filter components for surge protection:
  - Smaller Surge arresters; and
  - Smaller Inductors.

- Power control
    - Smaller contactors.

However the power converter may not be much lighter (less power) if it is needed for traction power as well as battery charging power, see 4.5.2.

4.5.5 Vehicle Speed

Vehicle speeds defined for power transfer within FABRIC [2] is 0 – 130 km/h and within the Slide-in project 60 – 100 km/h. The Slide-in test track is designed with trucks running on a highway in mind, and in Europe, there is a legally enforced 80 km/h (maximum speed) for trucks with trailers and 90 km/h for rigid trucks.

However, if the road surface conditions are without bumps etc. and the pick-up has been designed accordingly, the conductive ERS should be able to support the higher vehicle speeds required for the car use case. As a comparison, trains with pantographs on catenary systems transfer much higher power and utilise the same principal technology (one metal part pushed towards and sliding against another one), whilst running at speeds > 200 km/h.

4.6 Slide-in assessment for urban environments use case

Below, properties of the Slide-in conductive ERS solution are assessed in relation to use cases with vehicles in urban environments. Potential required adaptations of the system, limitations and comparison against the specifications and requirements will be identified.

4.6.1 Infrastructure

As was mentioned in 3.1 the APS has been adapted for trams running in the city i.e. the urban environments use case. However, the Slide-in ERS differs in some important aspects and measures needs to be taken.

- The safety principle, see 3.4.1, with *“virtual moving zone in front of and behind the vehicle*.” would need to be adapted with shorter track segments when used at the lower speeds anticipated in urban environments. This will mean more PBs etc. and increased infrastructure cost/km, but at the same time more vehicles/km would be charged;
- For *Static* and *Stationary en-route charging,* see 4.4; and
- Road maintenance e.g. snow removal.
    - If salt is used to melt the snow/ice on ERS or nearby roads this may end up on the conductive tracks and increase the conductivity/leakage current. Hence, efficiency will go down and the track material will migrate because of galvanic

corrosion => shorter life time. If salt could not be avoided and track life time becomes a problem other track setups with shorter active periods

4.6.2 Sound emissions

When the contact shoes are sliding along the track a sound will be created. This sound will be drowned out by the sound of tyres etc. at highway conditions. However, when the speed is reduced in an urban environment, the tyre noise will decrease and it may be possible to hear by the contact shoes sliding along the track.

The sound levels have not been measured in the Slide-in project, but the APS system for trams has been in service in urban environments since 2003, without complaints about the sound from the contact shoes sliding along the track. EVs will in most circumstances produce less noise than trams (rubber instead of steel wheels etc.), but if an issue, may have to be solved by other means e.g. with sound shields or absorbers in vicinity to the pick-up.

4.6.3 Arcing

If contact is lost during power transfer an arc (discharge through the air) could occur. Arcing could happen but infrequently under normal conditions. If the track has not been used in a long period of time it may rust (depending on material choice) and this makes the electrical contact worse hence more arcs would occur until the track have been “polished” by several vehicles.

An arc (typically lasting milliseconds) could disturb other drivers under certain circumstances e.g. if not aware this could happen or if focusing eyes on the arc itself when being close.

The risk of being dazzled is higher if the surrounding is dark i.e. if there are no lamp-posts or other traffic hence. In urban environments also other than drivers may be disturbed and likelihood of sabotage that affect contact (e.g. painting the conductive track) are higher. On the other hand the eventual arc may be drowned out by other vehicle and infrastructure lights.

Arcing is not thought of as being a problem today but if testing shows otherwise improved pickup design or visual shielding should reduce the problem to negligible levels. Additionally, since arcing is adding to the wear and tear of vehicle mechanics and electronics the OEMs are motivated to design a pickup that keep the arcs to a minimum.

4.7 Other aspects

4.7.1 Safety and misuse of foreign object

The latest pick-up is designed so that larger objects with higher weight should not make pick-up come loose or loose parts but there could still be issues with small stones/chip coming in contact with the pick-up and flying towards other vehicles. If these kinds of issues arise some ideas with shields of brushes etc. could be tested in the future. Regarding larger objects it could be possible to include added safety by camera or radar prediction of larger objects so that pick-up could be elevated in case of foreign object detection.

Misuse is always a risk but not believed to be at larger extent than what is seen in traffic at present. Today roads and rail-, tram industry could also, and is actually also experiencing disturbance due to sabotage and misbehaviour. APS-ERS is another system that may experience a similar level of misbehaviour; however APS-ERS system is in contrast to many other railway systems capable of detecting conducting foreign objects and shut-down the system with the built-in safety mechanism.

4.7.2 Drivability

Driveability i.e. what impact the conductor arm will have on e.g. manoeuvrability could be assessed by lateral acceptance of the vehicle while maintaining dynamic charging. In contrast to inductive charging this is dependent of vehicle OEM design only and not related to ERS infrastructure. The pick-up design in Slide-in has +/-30cm lateral acceptance and hence no extra features like lane keeping system are necessary. This has so far been verified with simulations done by Swedish National Road and Transport Research Institute (VTI) in the report *"Electric Road Systems in Driving Simulator. Design, test, evaluation and demonstration of electric road systems and electric vehicles by using virtual methods"* [4].

A demonstration environment in a driving simulator was developed in order to test and evaluate ERS concepts and electric vehicles driving on ERS. A user study was conducted, where 25 drivers drove a 40 kilometre long route, both with a hybrid truck on ERS and with a conventional truck with no ERS. Driving on ERS showed no significant difference to the driver's experience of safety and aesthetics or the driving behaviour compared to no ERS. The exception was average speed which was 2 kilometres / hour higher when driving on ERS. The energy consumption decreased 35 per cent on ERS.[4]

5 CONCLUSIONS

Main conclusions could be summarized as:

- There are no fundamental impediments to using conductive on-road charging in all use cases, including cars and urban environments, defined for FABRIC in [2].
- All defined power requirements (3 – 200 kW) could be fulfilled with the same conductive ERS solution and total efficiency for dynamic power transfer is typically higher than 93 %
- With adaptations all defined charging modes (Static, Stationary en-route and Dynamic charging) and speed intervals (0 -130 km/h) could be fulfilled with conductive on-road charging.

See more detailed conclusions below.

5.1 Slide-in vs. FABRIC ITS use cases

None of the services of *FABRIC demonstrable use cases* [2], are identical to the ones in the Slide-in conductive ERS system but two are similar:

- EV identification; and
- Charging management high-level and low-level (load balancing).

One could expect though that with the appropriate interfaces in place, all products and services of the described ITS use cases in *FABRIC demonstrable use cases* and *FABRIC feasible use cases* [2], could be integrated seamlessly, in a future Slide-in conductive ERS system.

5.2 Slide-in vs. FABRIC charging modes

The properties of the Slide-in conductive ERS solution are assessed in relation to the charging modes, *Static charging, Stationary en-route charging* and *Dynamic charging.*
The Slide-in conductive ERS project only demonstrates dynamic charging but the other two charging modes have been judged to be feasible with some reworking e.g. track segment length and shielding.

5.3 Slide-in vs. Car use case

The following properties of the Slide-in conductive ERS solution have been found to be affected in a use case with cars or light duty vehicles:

1. Pick-up size would have to be and can be smaller in cars than in trucks;

2. Power transfer will likely be lower in cars, but since ERS voltage is the same, the on-board charger and/or traction inverter needs to be adapted accordingly;
3. Component weight will be lower for low power requirements in cars; and
4. Power transfer efficiency will be somewhat lower at lower power transfer i.e. for cars;
5. Car vehicle speed is higher than trucks, but could most likely be supported with smooth road conditions defined as a requirement.

Most properties (1-3) show advantages and/or lower cost in the car or light duty use case compared to the heavy duty use case.

5.4 Slide-in vs. urban environments use case

The following properties of the Slide-in conductive ERS solution have been found to be affected in an urban environments use case:

- Infrastructure;
  - Need of shorter track segments (< 19 m) to support power transfer at lower speeds than 60 km/h.
  - Short track segments that fit under EV's and shielding or sensors to support charging at standstill.
  - Road maintenance e.g. snow removal need special processes and tools
- Arcing
  - Arcing could happen but is not considered a problem today and especially not in an environment with a lot of other light sources.

6 REFERENCES

[1] Viktoria Swedish ICT, “Slide-in Electric Road System Conductive project report”, Volvo GTT, Gothenburg, 2014
[2] FABRIC D4.3.1 “Final use cases definition”
[3] http://www.alstom.com/products-services/product-catalogue/rail-systems/Infrastructures/products/aps-ground-level-power-supply/
[4] http://www.vti.se/sv/publikationer/elvagar-i-korsimulator-design-test-utvardering-och-demonstration-av-elvagstekniker-och-elfordon-med-virtuella-metoder/