PAULO GOMES, JORNADAS TECNICAS, CHILE, JULY 2019

ABB - your global partner in the Rail and Urban Transport

Enabling stronger, smarter and greener transportation

ABB in the rail industry

Today rail business in simple terms

2002

Repositioning of ABB in the railway business.
ABB becomes a growing independent electrical subsystem supplier

> 130

Traction Power System projects delivered since 1980

> 3000

Traction packages delivered to rail OEMs since 2003

Center of excellence in Geneva, Switzerland

$1.55 billion

In orders

Local presence and service support with engineering, manufacturing and services centers

Rail and urban transport electrification
Our global consultancy presence

Capabilities:

- Electrical Systems
- Economics
- Financial
- Digital

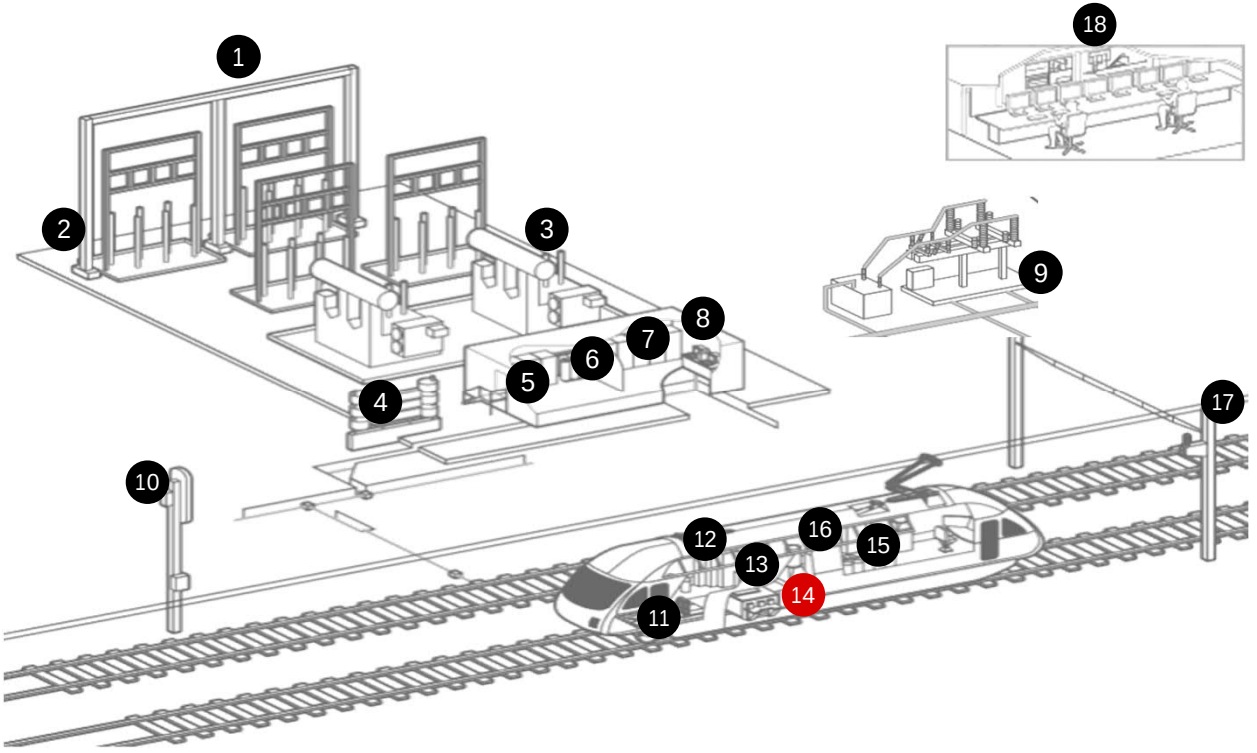
150
Consultants

8
Operations offices

ABB in the rail industry

Global portfolio for railway applications

1. Traction Substation and SFC
2. High Voltage Products
3. Power Transformers and Surge Arresters
4. Power Quality
5. Indoor Medium Voltage Switchgears
6. Distribution & Special Transformers & Rectifiers
7. Low Voltage Switchgear
8. Energy Management Systems
9. Outdoor Medium Voltage Modules
10. Communication
11. Motors - Generators – Turbochargers
12. Traction Fuses
13. Converters – Semiconductors
14. Traction Transformers
15. Low Voltage Components
16. DC circuit breaker
17. Outdoor Medium Voltage Products
18. Enterprise Asset Management & SCADA



Moving the world through innovation

Energy efficient and reliable infrastructure solutions

Keeping transportation on track for a greener future

ABB traction system provider

Solutions for all types of rail applications

ABB – your independent traction system partner for all applications

Very high speed and high speed trains

Mainlines

Metro lines

Electric bus lines

Light rail lines

Monorail lines

ABB power system provider

Reliable partner for power system studies

Traction and power system - Studies

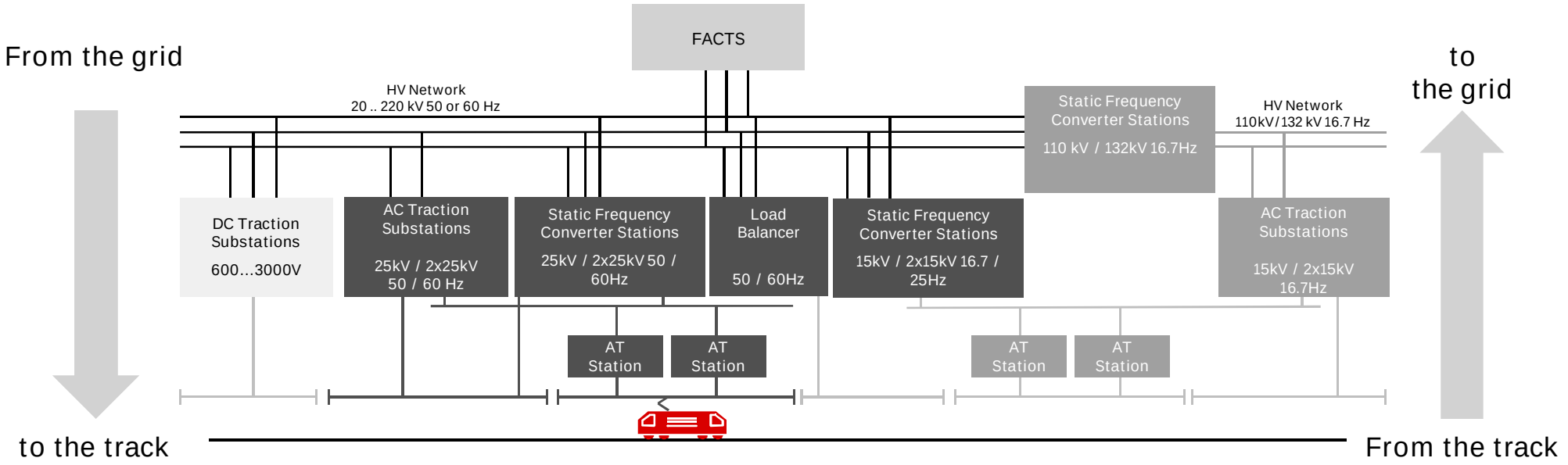
With powerful software tools and long standing experience, ABB specialized teams perform railway specific system studies, such as:

- Impact of railway traffic on feeding systems
- Load flow calculations, required substation sizing
- Determination of optimal and alternative traction feeding concepts
- Short-circuit and voltage drop calculations
- Hazard analysis and RAMS calculation
- Evaluation of rail-earth potential, etc.

Reliable partner for consultancy

ABB power system provider

Independent value-add traction power system provider



From the grid to the track, from the track to the grid

ABB power system provider

Reliable partner for DC rail infrastructure

1. Traction rectifier

2. Automatic Grounding system

3. Energy storage system

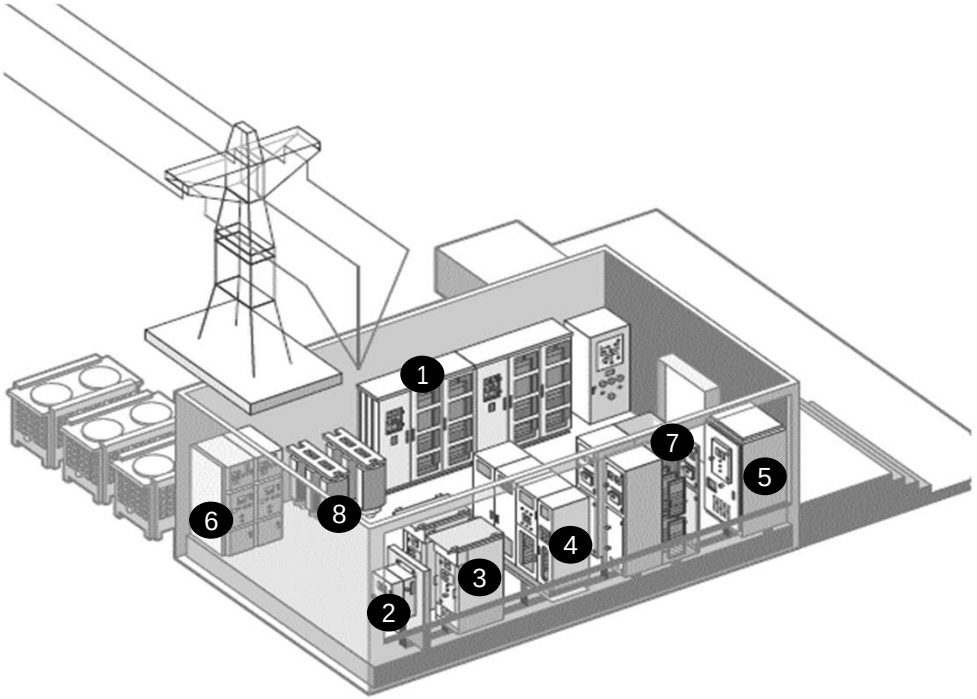
4. Energy recuperation system

5. Energy dissipation system

6. AC switchgear

7. DC switchgear

8. Transformers



TOSA – Enabling a new generation of electric buses

Flash-charging technology for sustainable e-mobility

1 The TOSA story

2 Intelligent energy management

3 Infrastructure

4 World's fastest flash-charging connection technology

5 On-board Equipment

6 Total Cost of Ownership and advantages

7 Digital solutions and References

The TOSA story
For sustainable mobility

The four partners of the pilot project “TOSA 2013”:

TPG: Operator

OPI: Project coordinator

SIG: Energy supplier

ABB: Technology provider

Solution dedicated to mass transit transportation (18m / 24m), high frequency (BRT), long route

Oct. 2010 — Partnership with SIG, TPG and OPI to do a feasibility study

May 2011 — kicking off of the demonstrator

May 2013 — UITP event in Geneva

June 2016 — TPG ordered 12 articulated buses with its infrastructure

Aug. 2017 — SEMITAN ordered 22 double-articulated buses with its infrastructure

May 2018 — L23 in commercial service

March 2019 — Presentation of the double-articulated bus at GIMS

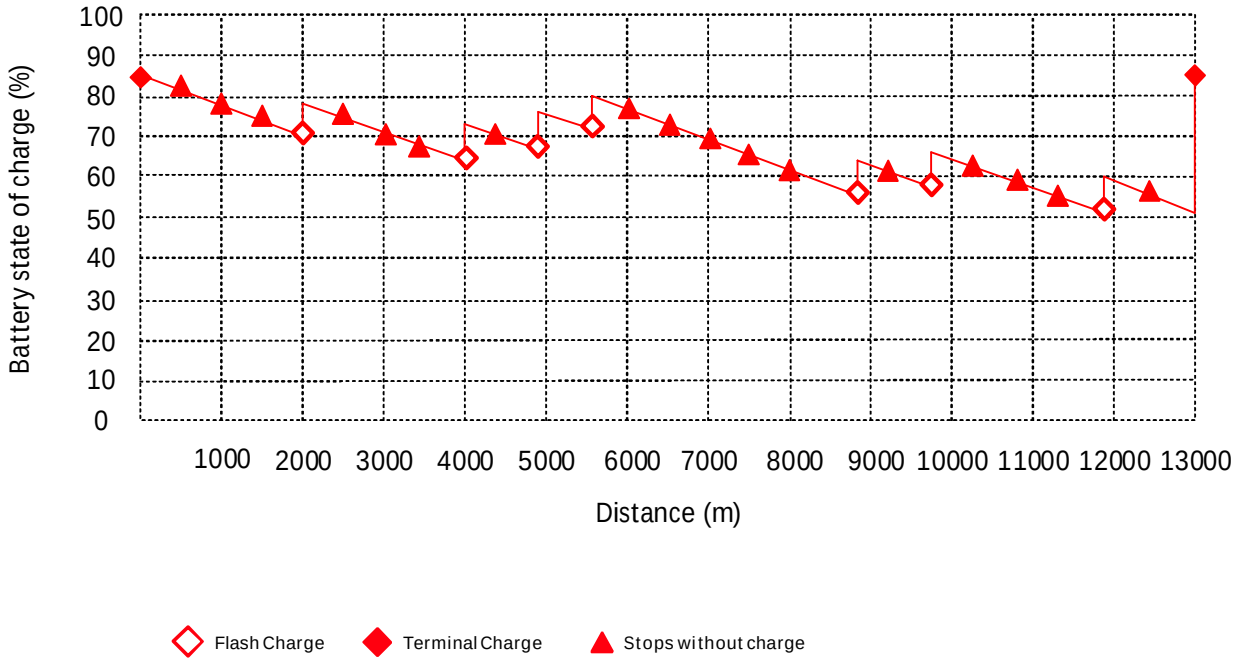
Flash technology: a new e-bus concept

Intelligent energy management

E-bus concept must be driven by operation and not by technology

- Flash charge to save time at terminal and not for autonomy reasons (time table)
- Flash charge while Passengers are embarking / disembarking (quick connections/disconnections < 1s)
- Flash charge to save buses (TCO) and space at terminal/depot
- Long on-board battery lifespan

High energy efficiency and cost efficiency



Operating using Flash technology

a new e-bus concept

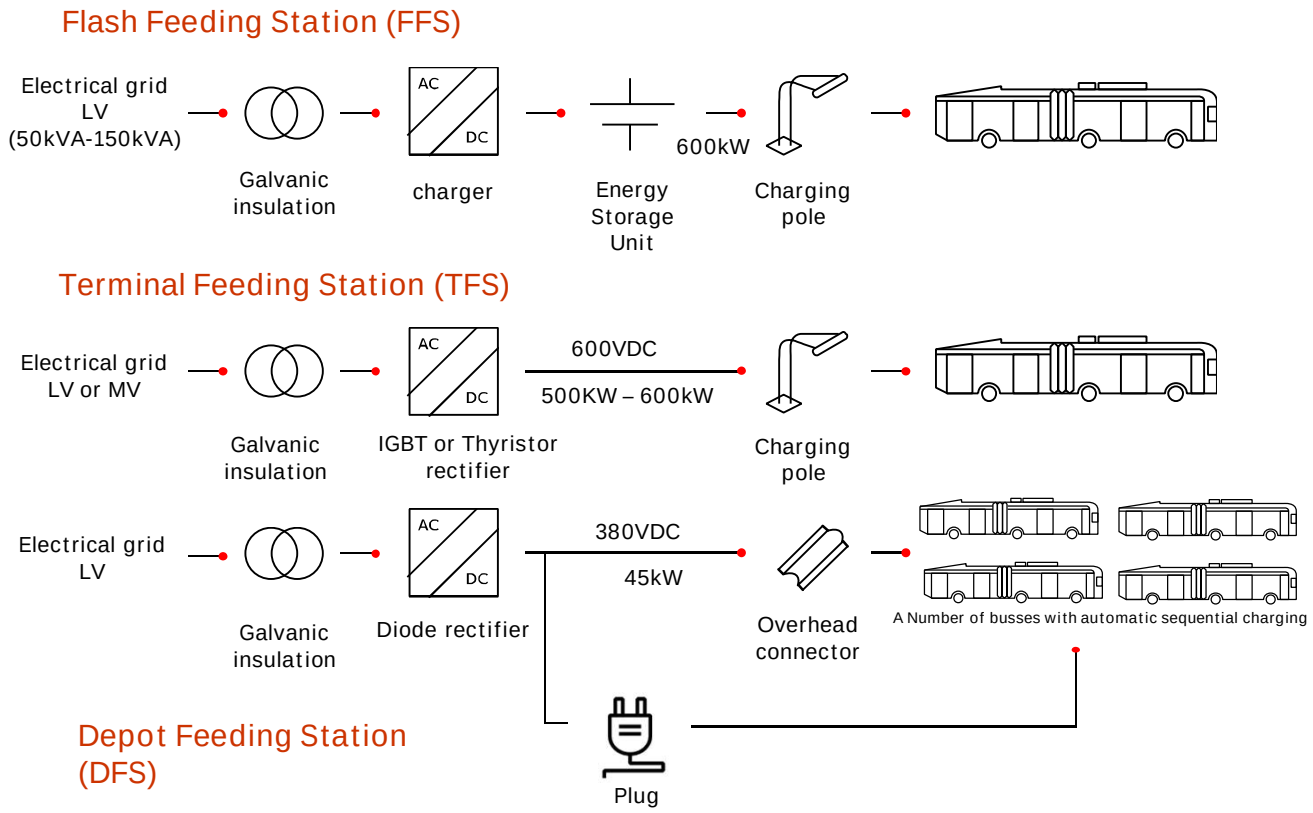
Infrastructure

Energy storage for peak shaving and local grid requirements

Three types of feeding stations

- Flash Feeding Stations (FFS) at selected bus stops (20 sec)
- Terminal Feeding Stations (TFS) (1-5 min)
- Depot Feeding Stations (DFS) (30 - 45 min).

DFS, TFS, FFS are feeding stations and not wayside chargers. The charger (inverter motors) is on-board (on the roof of the bus).



Quantity of flash-charging stations depends on route profile and service requirements

World's fastest flash-charging connection technology
<1 second to connect the bus to the charging point

Fully automatic energy transfer system (ETS)

Quick connections / disconnections < 1s

No communication between the bus and the infrastructure

- ☑ Long term compatibility: no dependency on version of BMS Protocol
- ☑ No delay due to the establishment of the communication

No positioning constraint (the bus is parked as with a diesel / gas bus)

- ☑ Bus direction: > +/1 m
- ☑ Distance from the sidewalk : 0 – 55 cm

Passive charging pole (moving part on the bus)

- ☑ Little or no on-site maintenance
- ☑ If motion fails, does not impact all buses
- ☑ No voltage on the overhead connector as long as the bus is not connected

1 The TOSA story

2 Intelligent energy management

3 Infrastructure

4 World's fastest flash-charging connection technology

5 **On-**board Equipment

6 Total Cost of Ownership and advantages

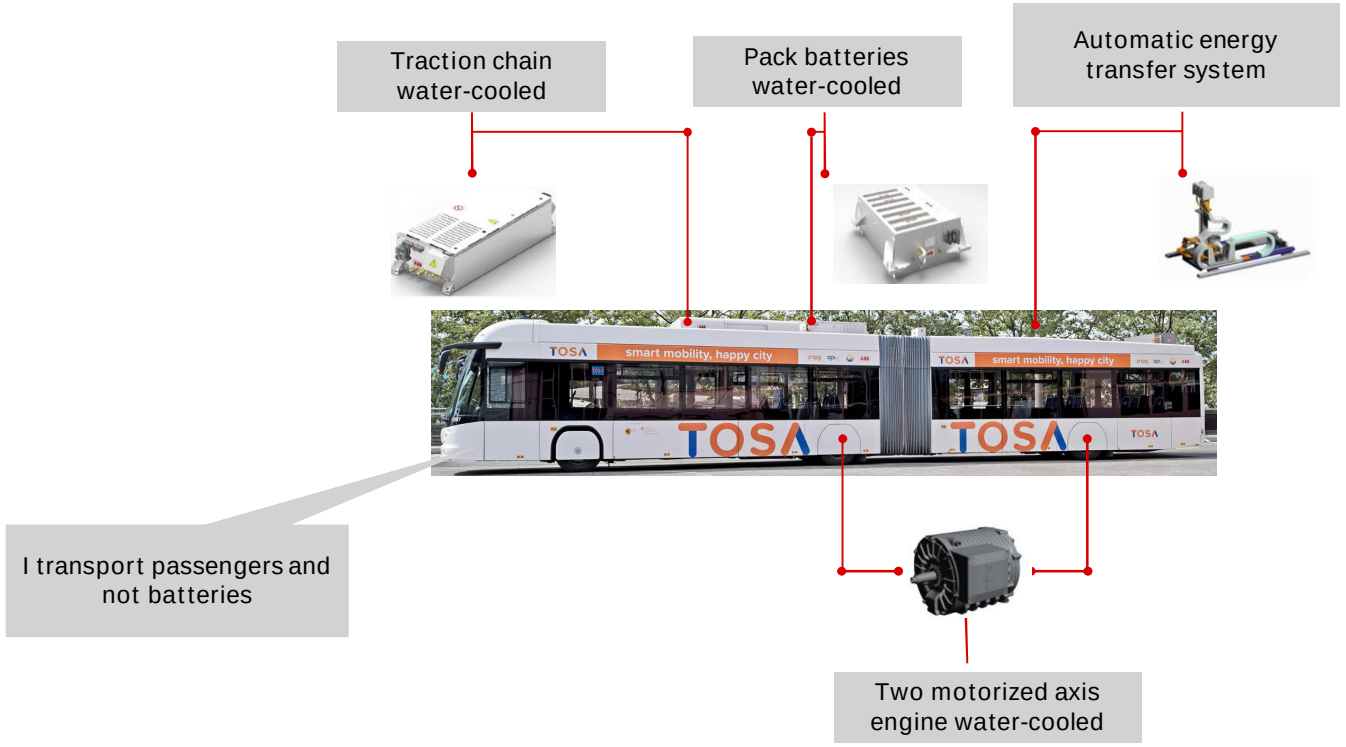
7 Digital solutions and References

TOSA a new e-bus concept

On-board equipment

ABB onboard drivetrain solutions:

- Highly integrated traction and auxiliary converter for roof-mounting
- Lithium-titanate battery unit
- The energy transfer system (ETS) makes the connection between the bus and the wayside
- Permanent magnet traction motors



Roof-mounting solution for higher capacity

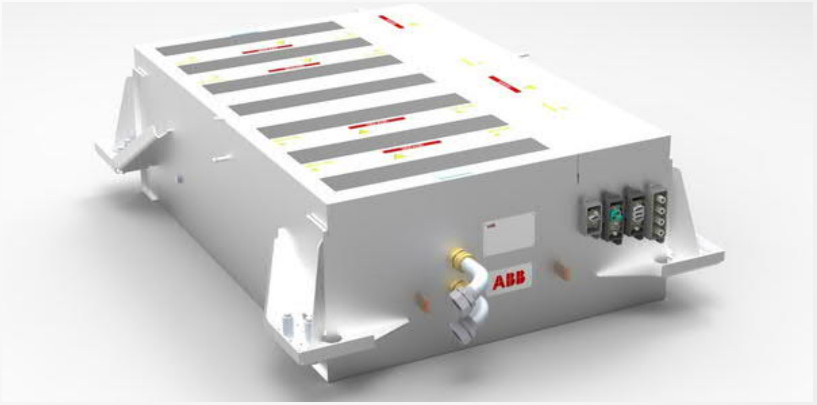
TOSA a new e-bus concept
Onboard equipment

Focus on the On-board battery

- ☑ Small batteries with minimal weight
- ☑ Energy recovery by applying brakes, deceleration and running downhill

Choice of the LTO Technology :

- ☑ Wide external temperature range (-30°C to 55°C)
- ☑ Density of power (charge / discharge): up to 10C several sec and 5-6C several minutes
- ☑ The safest technology on the market
- ☑ Lifespan (>10 years)



TOSA a new e-bus concept
Passengers capacity

114 at 4 pass./m2

133 at 5 pass./m2

(17.5 m2 + 44 seating)

156 to 4 pass./m2 (TBC)

182 to 5 pass./m2 (TBC)

(25.1 m2 + 56 seating)

I transport even more passengers and not batteries

TOSA a new e-bus concept
At a Glance

1. TOSA can be the best solution for:

☑ Long routes
Smaller the route is, the interest of TOSA decreases. However, TOSA can work on every lines

☑ Short stop times
Layover time at terminal needs to be SHORT.
Longer the layover time is, the interest of TOSA decreases.

☑ High Capacity and High Frequency lines
The ultimate goal of TOSA is to have the same time table and quantity of buses, as a diesel fleet .
Transport people, not batteries

☑ Buses of 18 - 24m (articulated and bi-articulated).
Usually related to the above characteristics, High Capacity, High Frequency and Long Routes

Operating TOSA

Total cost of ownership - requirements

Timetable	High-power in-route charging at selected bus stops and short layover time at terminal same driving hours and commercial speed as a diesel fleet
High-passenger capacity	All technology mounted on the roof (all floor for passengers) for articulated and double-articulated buses
Long-life battery	Thanks to in-route charging principle, the high-power/low-energy battery pack is used in its optimal operating range

Operating TOSA

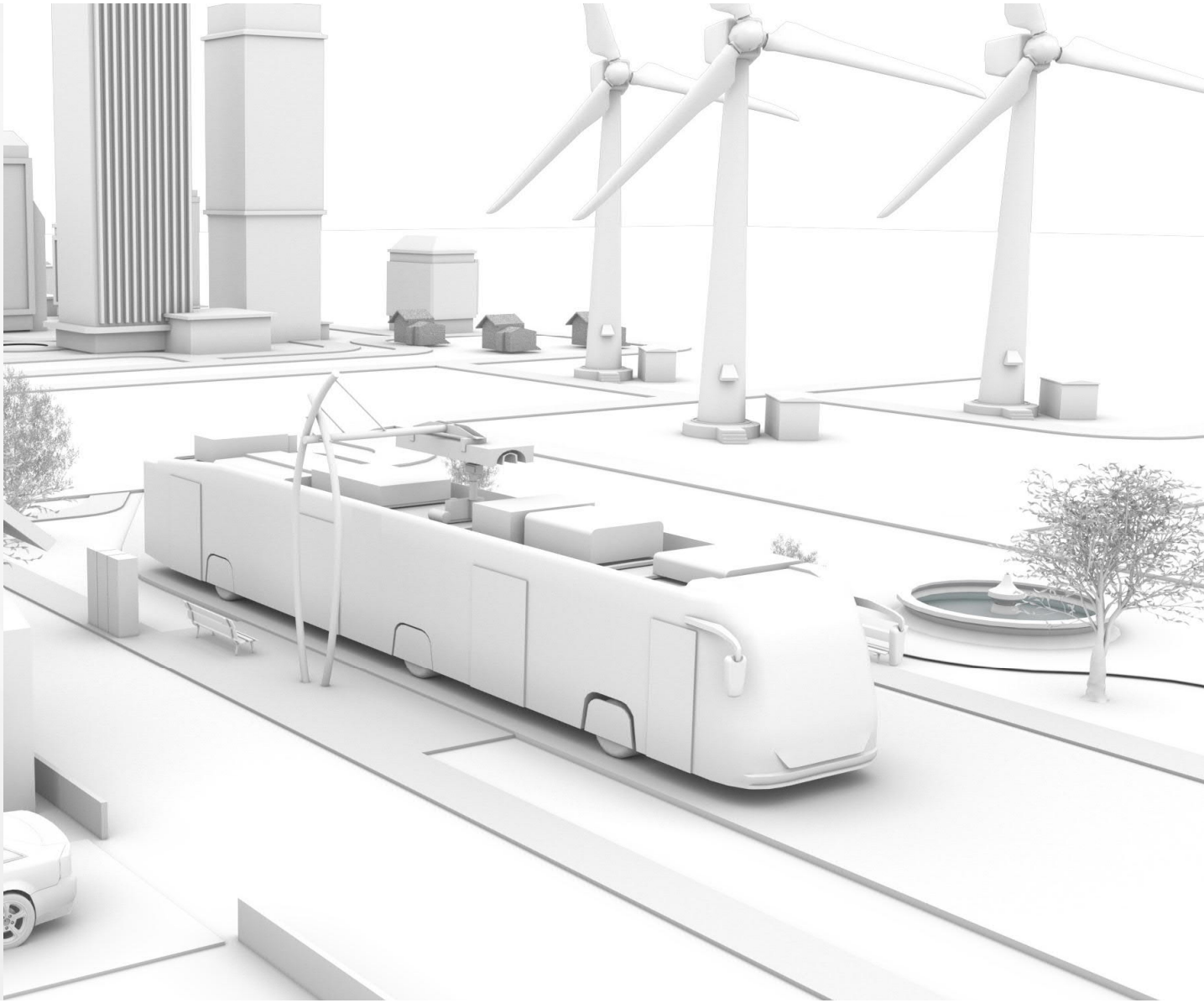
Total cost of ownership - requirements

Electrical grid	1	Connection fee and energy cost minimized through embedded peak shaving functionality
Frequency and BRT	2	In-route charging (20'') at selected bus stops (*) while passengers are disembarking and embarking and layover time compatible with high-frequency lines (up to 4,000 passengers/hour)
Light infrastructure at depot	3	Low-power connection (45 kW) mutualized charging for four buses (charge sequential). An automatic connection is generally chosen (buses in idle mode when they are not in charge).
Homogenous fleet	4	TOSA bus configuration (e.g. battery size) is line-independent. The line profile determines the required infrastructure

TOSA a new e-bus concept

Avantages

- ☑ Optimized battery (the route and stops are known)
- ☑ Quiet
- ☑ Flexible routing (not limited by overhead wires or rails)
- ☑ Buses spend most of their time out on the roads and not parked
- ☑ Rapid deployment as infrastructure needs are limited
- ☑ Transport people, not batteries



TOSA a new e-bus concept

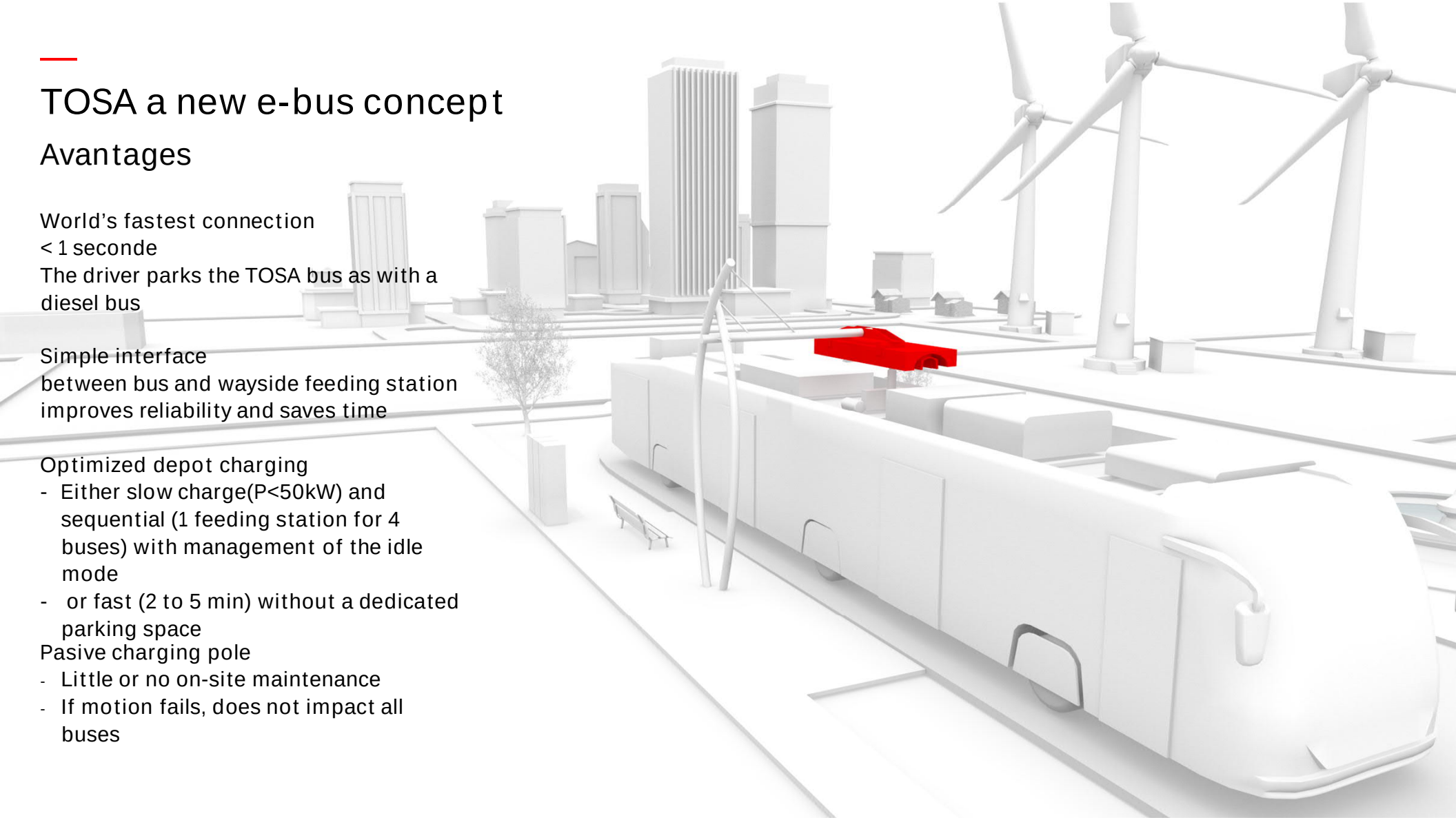
Avantages

World's fastest connection
< 1 seconde
The driver parks the TOSA bus as with a diesel bus

Simple interface
between bus and wayside feeding station
improves reliability and saves time

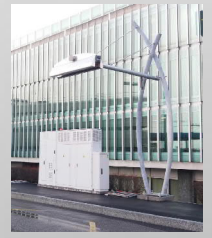
Optimized depot charging
- Either slow charge(P<50kW) and sequential (1 feeding station for 4 buses) with management of the idle mode
- or fast (2 to 5 min) without a dedicated parking space

Pasive charging pole
- Little or no on-site maintenance
- If motion fails, does not impact all buses



TOSA a new e-bus concept
SCADA and asset management

Line 23



SCADA

Supervision (SCADA)
Collection and arrangement of data

MAINTENANCE

Asset management- ELLIPSE
And maintenance cost

REPORTING

Energy efficiency monitoring

OPERATION CENTER

Operation real time monitoring

My Ebus

Sizing of infra and of on-board battery
With the following tools
Traffic simulation
Weather forecast
Robustness
Battery ageing

Energy management

Management of the electrical grid
Sequencing of charges
Electrical grid stabilization
Harmonic
Aggregation
Battery ageing (my Ebus)

TOSA a new e-bus concept
SCADA and asset management

Energy efficiency

- Detailed knowledge of energy consumption
- Optimizing Recharge Sequences
- Optimization of driver behavior

Real-time operation monitoring

- Improved availability and reliability
- Enhanced Exploitation Security
- Driver and Maintenance Support

Asset management

- Standardization of the business process
- Improve equipment uptime and reliability
- Reduce operations and maintenance costs
- Extend asset life

TOSA enables emission-free public transport in Geneva
Line 23, connecting Geneva's airport with suburban Geneva

Geneva,
Switzerland

Line 23

18.75m
bus length

133
passengers per bus

Technology

12 out of 50
stops flash-charging stations

600kW 20s
flash charging

Vital statistics

10,000+
passengers a day travel on the route

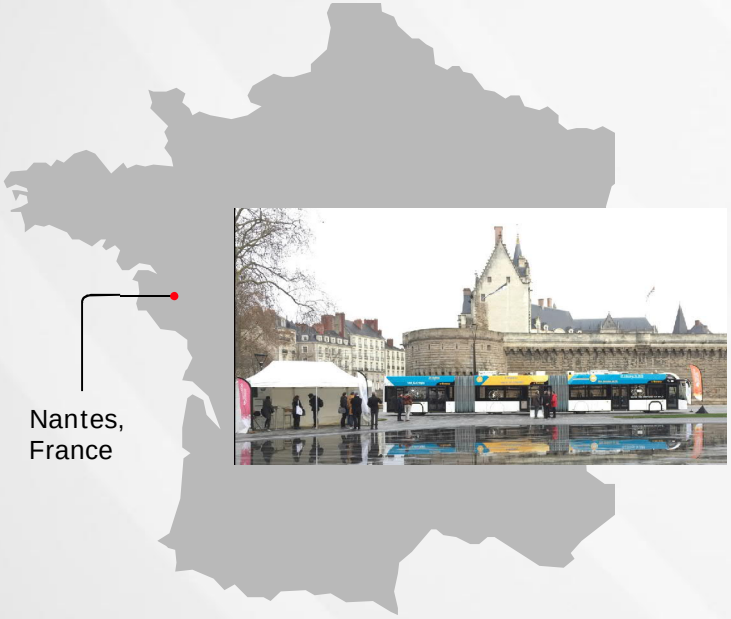
>600,000km
per year

Benefits

1,000t
CO_2
Reduction of emissions per year for 600,000 km

10 decibels noise level reduction
Half the noise pollution generated by diesel buses

TOSA enables emission-free public transport in Nantes
Line 4, connecting Foch Cathedral (downtown) with suburban Nantes



Line 4

24m
bus length

22
buses

>155
Passenger capacity per bus

1 Bus every

2 min **45** sec

Technology

6/34
stops flash-charging stations

600kW
10 to 40s
flash charging

I transport even more passengers and not batteries

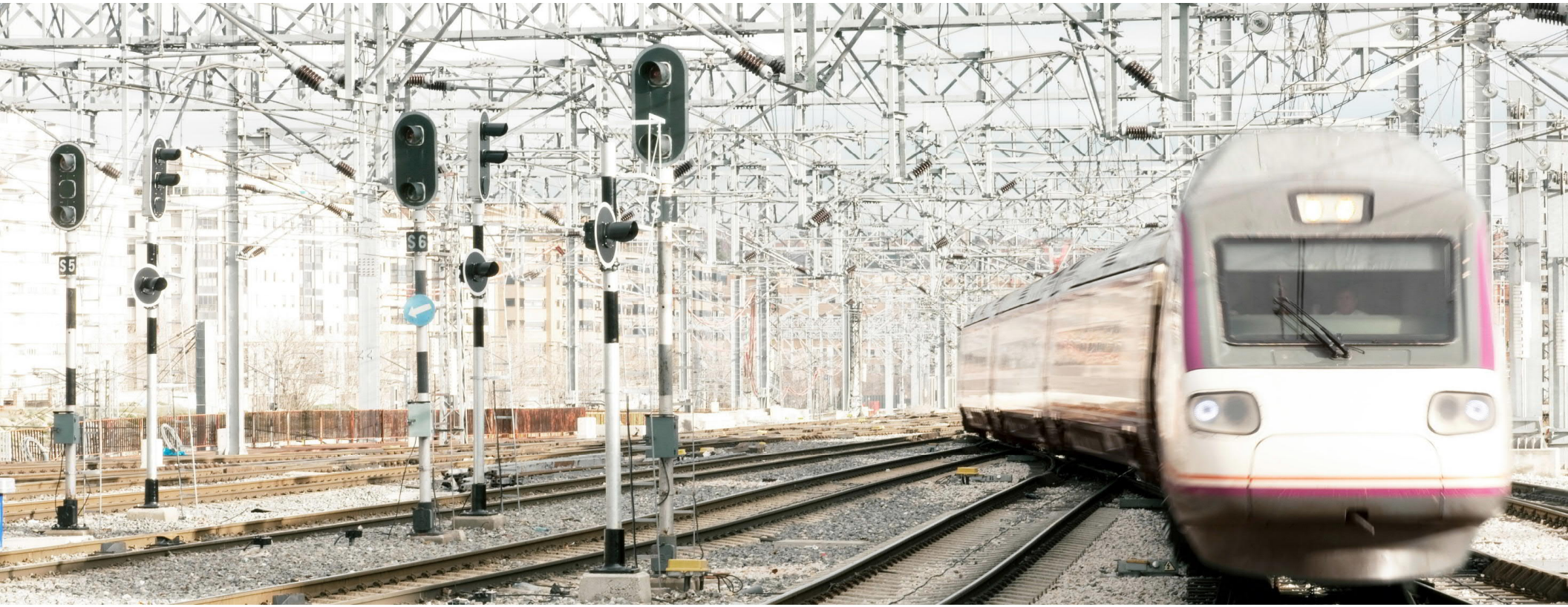


ABB Power Grids for battery-powered trains

Flash Charging stations for traction power supply

Why batteries?
The case for battery-powered trains

Growing market

The battery-train market is primarily driven by the increasing population which has led to the demand for rail transport and railway electrification across the globe.

The market is projected to grow at a CAGR of 5.15%. From a size of 445.4 MUSD in 2017 it is projected to reach 703.2 MUSD by 2025.

Key drivers

- No pollution
- Reduced maintenance
- Less infrastructure and years to complete
- Strong case for urban/suburban segment
- Market demand for innovations

Charging solutions

- High-capacity flash-charging technology
- Power system and battery modelling
- Smart robotic pantograph, ~ 20s to charge, 600kW

TOSA charging concept Intelligent energy management system

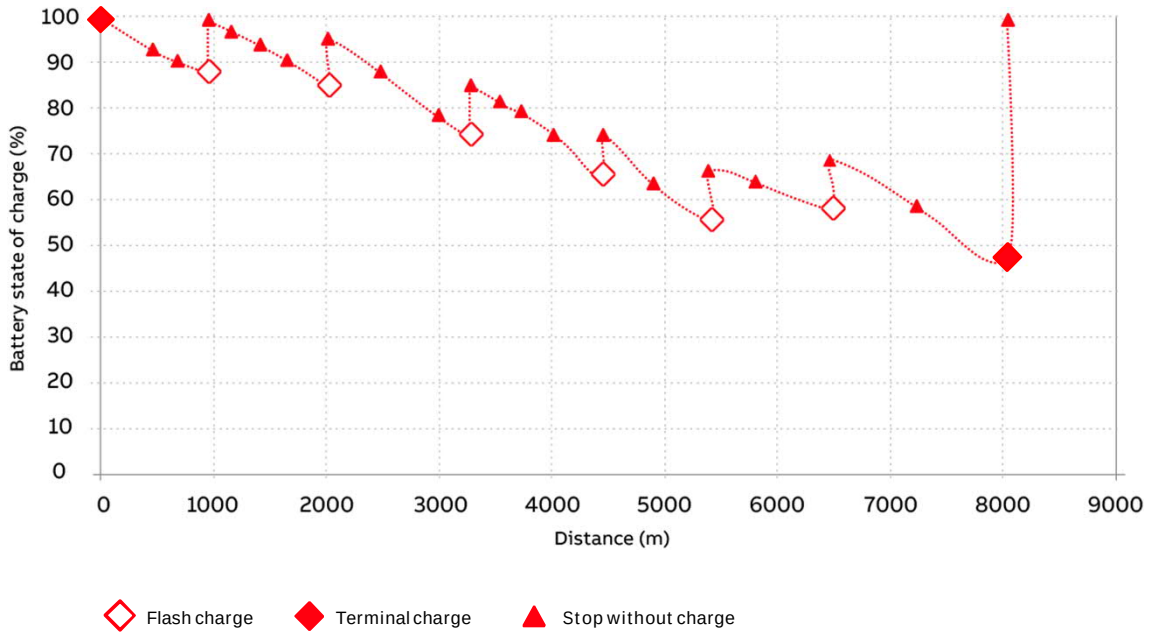
What is the Battery-powered trains autonomy?

Inevitably, when discussing batteries energy, one of the first questions people ask is how far it can go before needing to charge.

The real question is not "how far can it go?" but rather, how fast can it charge before going there again?

The combination of terminal and Flash chargers ensures the on-board energy storage is completely refilled at the end of the line without requiring longer stopping times.

High energy efficiency and cost efficiency



TOSA Trains flash charging

System infrastructure

Energy storage for peak shaving designed according to both local grid requirements and the Rail line's operational needs.

Three types of chargers:

- Flash-charging stations at selected
  - o stops (~ 20 seconds)
  - o 0,6 – 1,0 kVDC
  - o 600 kW
- Terminal feeding stations
  - o stops (6 ~ 10 min)
  - o 0,6 – 1,0 kV DC
- Depot stations
  - o Charge (0,5 ~ 1h)
  - o 0,6 – 1,0 kVDC

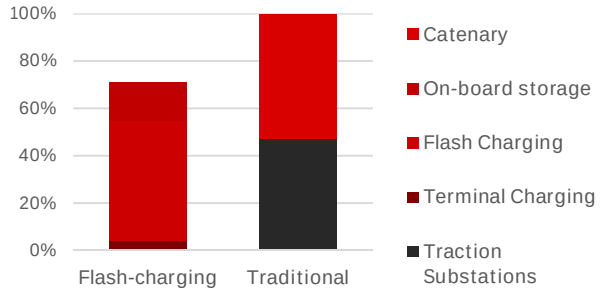
Flash-charging LRT
Catenary-free LRT – A Case Study

Key info

In 2018 a Transport Authority signed an agreement for the construction of two new tram lines

Feasibility study based on

- 20 Light Rail Vehicles
- ABB Power Grids' flash-charging stations at selected tram stops
- Headway: 7 minutes
- Waiting time at terminal: 6 minutes



Techno-economical benchmark

30% saving in infrastructure CAPEX (costs of 20 on-board energy storage are included)

Reduced OPEX and increased reliability due to absence of catenary

Further advantages:

- No return current through running rails
- No voltage drop on rolling stock (charging pole provides stabilised voltage)
- Reduced footprint and land requirements

Further opportunities

Studies in Progress: 13 projects around the World - 02 major rolling stock suppliers

- Germany (02 projects)
- Italy (04 Projects)
- Norway (01 Project)
- France (02 projects)
- UK (03 Projects)
- Brazil (01 Project)

ABB wayside equipment Flash-charging in DC

Charging Stations
- Line 01:
  - 2 TFS 500kW, MV
  - 23 FFS 600kW, MV *
  - 27 charging poles out of 44 stops
- Line 02:
  - 2 TFS 500kW, MV
  - 25 FFS 600kW, MV *
  - 29 charging poles out of 48 stops

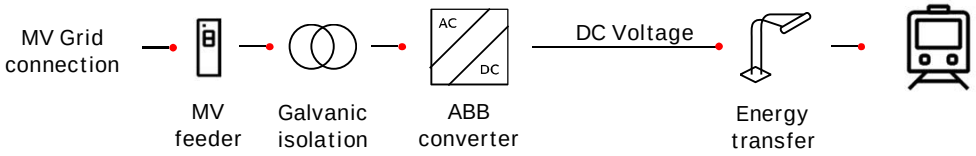
* Total amount of FFS might be reduced by 2 every extra minute at terminal

Alternative
- Connection in LV with wayside energy storage

Optional
- Network Management (SCADA)
- Enterprise Asset Management

Connection in Medium Voltage

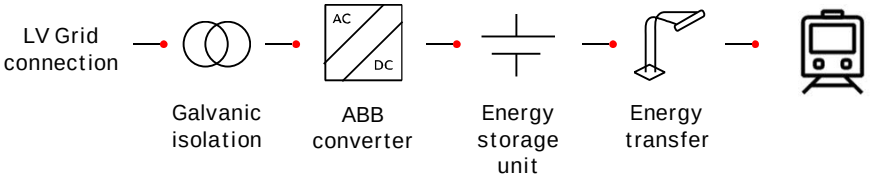
Terminal and Flash Feeding Station



Alternative: connection in Low Voltage

(depeding on network availability and connection fees)

Flash Feeding Station



Terminal Feeding Station

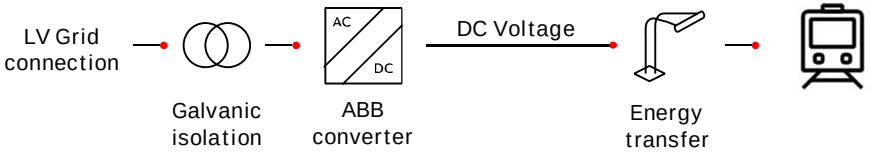


ABB on-board equipment
Energy Transfer System

Key features

- The system is “floating” no danger of electrical shock, the overhead only energised when the vehicle is connected
- The earth connection, first to make and last to break
- This earth connection between the vehicle and way-side is continuously monitored

Main Data

Mounting Location	Roof
Supply to motor drive	400 V AC
Length*	1600 mm
Width*	670 mm
Height*	450 mm
ETS Weight	~180 kg ± 5%

Number of ETS per train

ETS per train	1

<1s to connect, 20s 600kW flash

** All dimensions are without interface projections*

Flash-charging LRT
Case study on Pilot catenary-free LRT project – ABB BORDLINE® ESS Module

Main Data

Battery Chemistry	LTO
Nominal Capacity	30.5 kWh
SoC usable range	10...90%
Nominal Voltage	662 Vdc

Mechanical Data per 27.9 kWh Module

Mounting Location	Roof
Ingress Protection	IP65
Length*	1650 mm
Width*	1200 mm
Height*	525 mm
ESS Weight	~530 kg ± 5%

Number of ESS per train

ESS per train	3
Train installed capacity	91.5kWh

Mechanical Layout

** All dimensions are without interface projections*

Joint approach
Calculate the Energy Requirement

Identify the key parameters

Route (Length, altitude).

Commercial speed

Headway

Rolling Stock characteristics

Aux. Power consumption (HVAC, Heater)

System design/cost-optimisation tool

- Line(s) Timetable(s)
- Train/bus specs
- Battery specs
- Feeding stations specs
- Auxiliary specs

Rolling Stock simulation

- Cost model (bus, infra, battery, electricity
- Side constraints (location, power rating)

Optimization

- Timetable(s)
- Battery specs
- Charging stations specs
- Usage statistics

Battery ageing model

Macroscopic Traffic simulation

Sensitivity/ What-if analysis

Integration

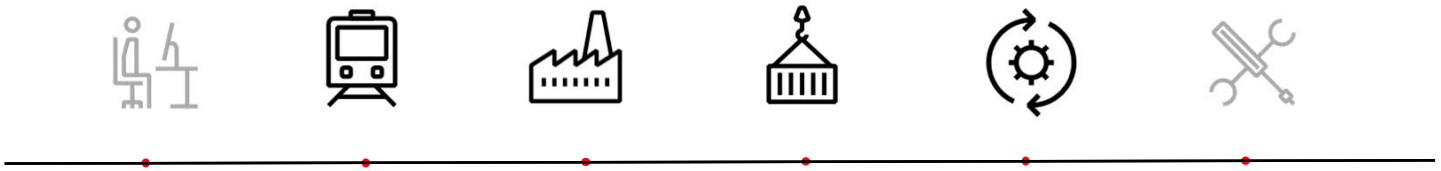
Design to minimise TCO

- Optimal battery dimensioning
- Optimal selection and placement of charging stations
- Detailed information on energy consumption, CAPEX, OPEX, TCO

ABB power system provider

Your partner in all phases of the projects

Supporting mobility projects from concept
to the conclusion and beyond:



Rail Industry, a new concept
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