26/Nov/2024

Session 3: In Motion Charging, Batteries and Energy Management

Marta WORONOWICZ, Klaus Peter CANAVAN

TRAINING AGENDA

- Battery chemistry
- Basics on electrics (Power vs Energy, charging and charging time)
- Basics of electrical bus
- Difference between In Motion Charging buses and battery buses
- Double insultation requirement
- Current collector (how to connect2charge)
- Charging e-buses using the In Motion Charging infrastructure

DEFINITIONS

Trolley bus:

electric bus that draws power from dual overhead wires using spring-loaded trolley poles (Wikipedia)

IMC:

In Motion Charging

IMC buses charge traction batteries "en route" enabling off-wire operation for long distances.

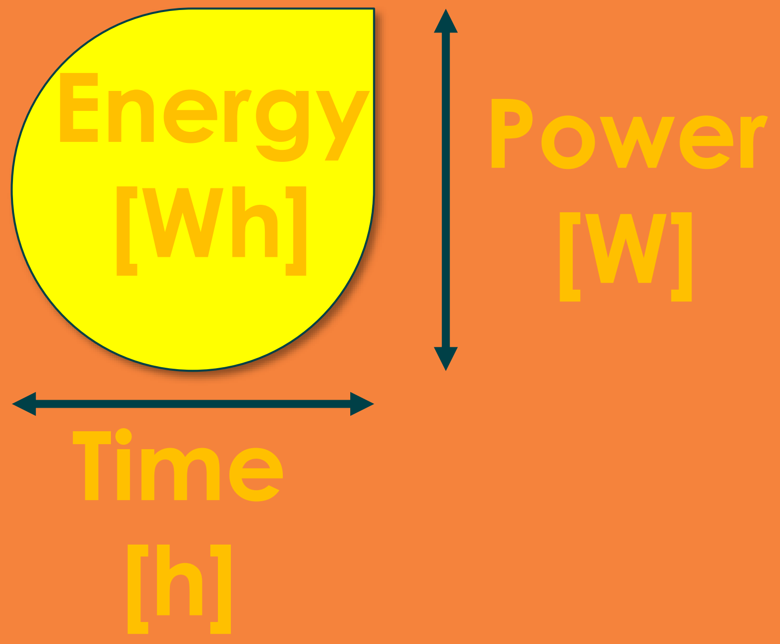
Additional charging options: depot (e.g. using standard CCS connector)

A well-designed IMC system allows to simplify infrastructure (reduce overhead by 70%). Outskirts and additional routes can be served without wire.

The Physics

Energy = Power x Time

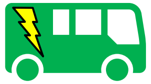
What is the difference between kW and kWh?

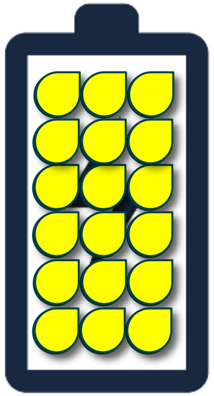


HOW DOES THE ENERGY GET TO THE BUS?

Battery discharge during the day

0h 9h 18h

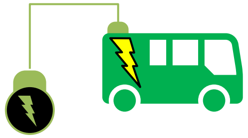




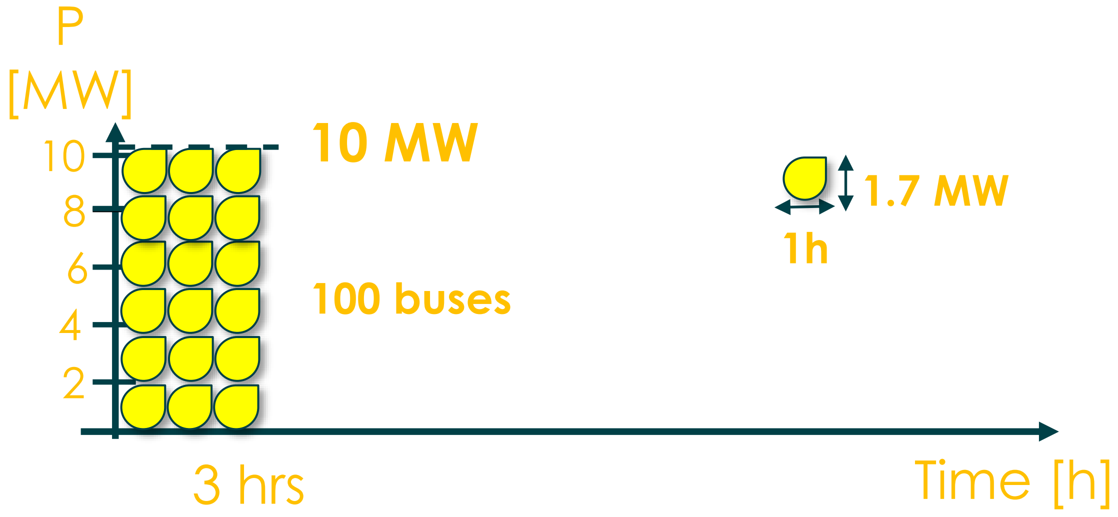
e.g. 300 kWh per bus per day (18 h of service)

HOW DOES THE ENERGY GET TO THE BUS?

Depot charging (overnight)



30,000 kWh consumed
Time to recharge: 3 hrs

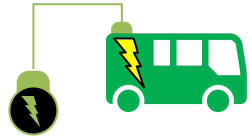


30,000 kWh / 3h = 10 MW
or 100 kW per bus

time for charing = bottleneck → large amount of power required

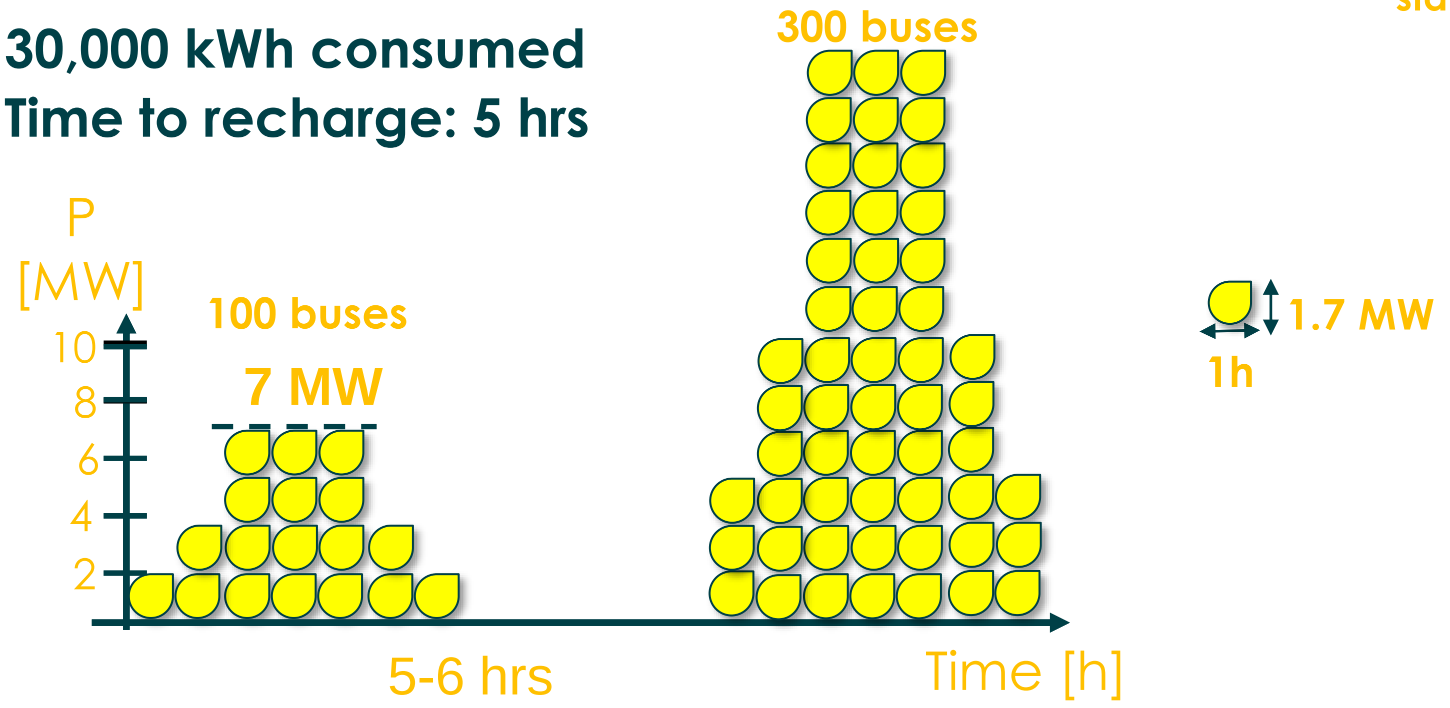
HOW DOES THE ENERGY GET TO THE BUS?

Optimized depot charging (overnight)



30,000 kWh consumed

Time to recharge: 5 hrs



Optimized charging pattern → power required reduced
But what if we need to charge 300 buses…

INFRASTRUCTURE REQUIREMENTS

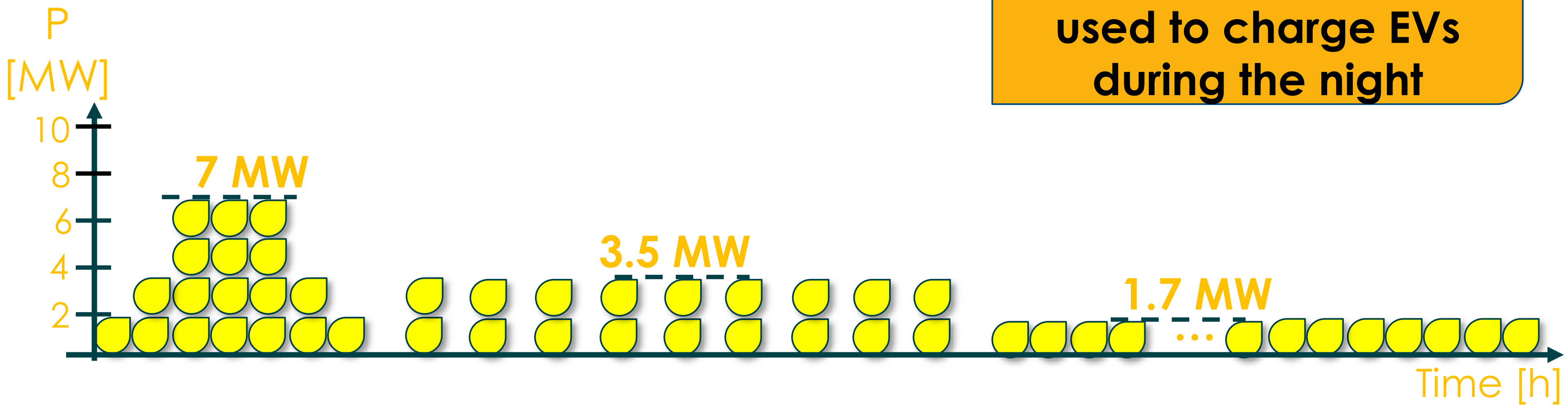
Depot charging, opportunity charging and IMC

Overnight:
19% utilization

Opportunity:
37% utilization

IMC: 75% utilization

Remaining 25% can be used to charge EVs during the night



IMC infrastructure requires lowest installed power and has highest utilization → lowest substation cost

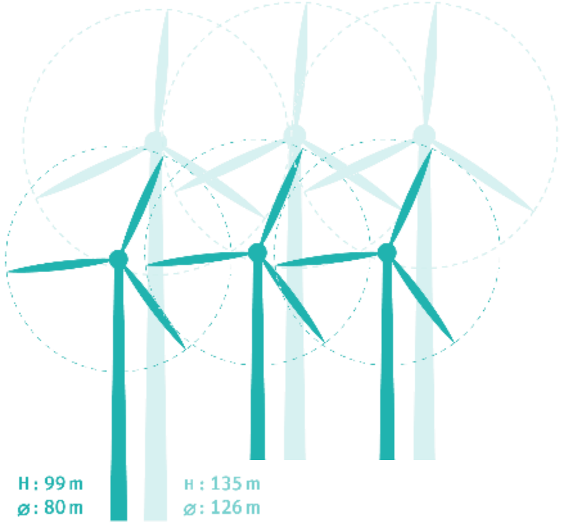
INFRASTRUCTURE REQUIREMENTS

Depot charging for 100 buses

Overnight charging at 100kW: 100kW x 100 buses = 10MW
Energy for 3 hours of charging: 300kWh per bus or 30MWh total

Typical IMC bus substation: 750V x 1000A = 0.75MW

10 MW used for 3h deliver 30 MWh
10 MW used for 18h deliver 180 MWh



→ Depot for 100 battery buses needs installed power of 13 substations!
10MW / 0.75MW = 13 substations (175 small / 4-5 large wind turbines)
And same installed power yields about 6x more electric miles!

DIFFERENCE IMC / BATTERY BUS

IMC

- Traction batteries charged en route
- Battery capacity optimized (energy, weight, cost) for the local requirements of the operator
- A powerful battery allows the same driving performance as a trolley bus

Bus needs to operate to create revenue

Time is money = money is time

Carry passengers not batteries

No need for additional buses and operators

Battery Bus

- Traction batteries are charged in the depot during the night
- Challenging requirements for charging infrastructure
- High charging power during the night

OR

- Batteries are charged at stops (opportunity charging)
- Minimum charging times required to get to the SOC needed to operate the next route
- Delays in the schedule are hard to compensate
- Wait times may require additional buses and operators

DIFFERENCE IMC / BATTERY BUS DEPOT

IMC

- Parked bumper to bumper, mirror to mirror
- Smallest possible parking/depot area

Battery Bus

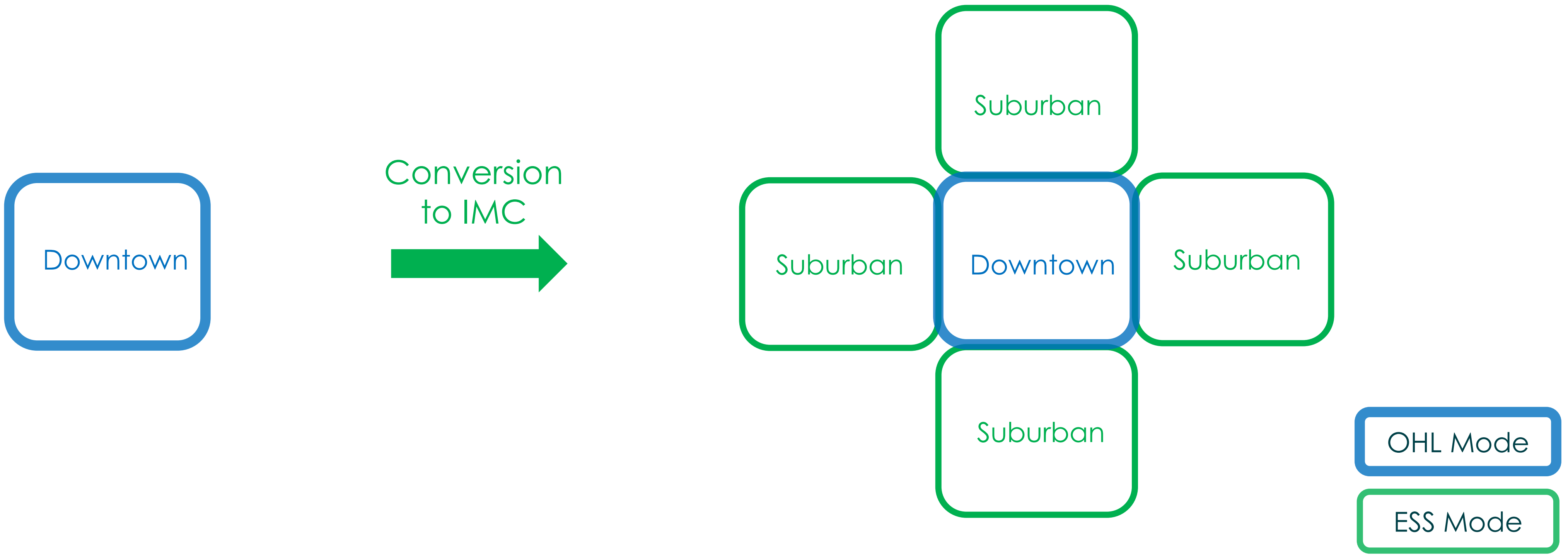
- Space needed for charging infrastructure, fire safety…

kiepe. UITP

Philip Tong photo, flicker - KVB

IMC

Applications for IMC



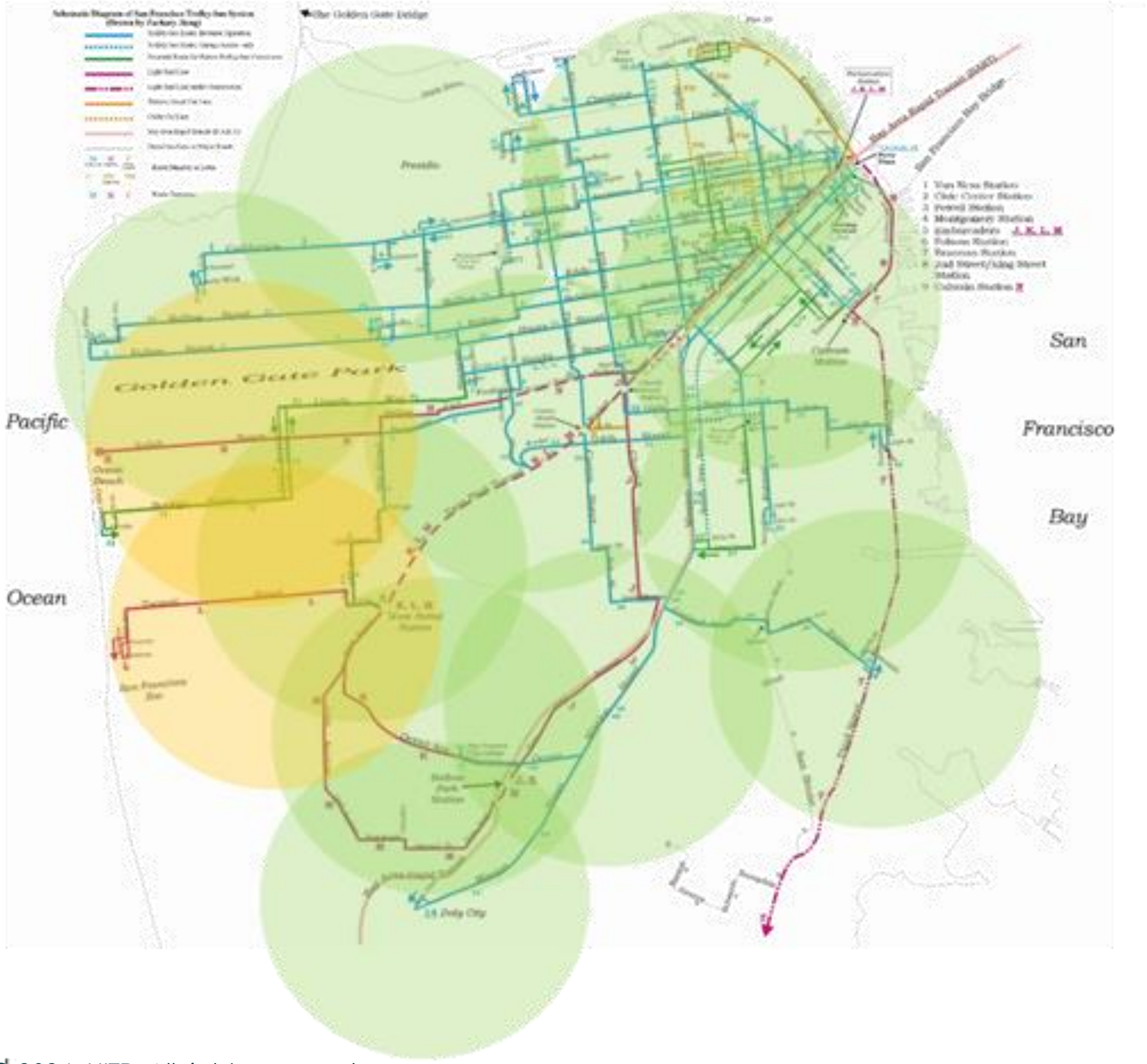
- Extension of the existing over headline (OHL) routes using battery mode
- Decarbonization by switching from Diesel to IMC

IMC

Applications for IMC

- “De-cluttering” of downtown areas, especially of historic old town areas
- Less “spider webs” at intersections

IMC



Extend trolley routes by 2x 1.5 miles using IMC

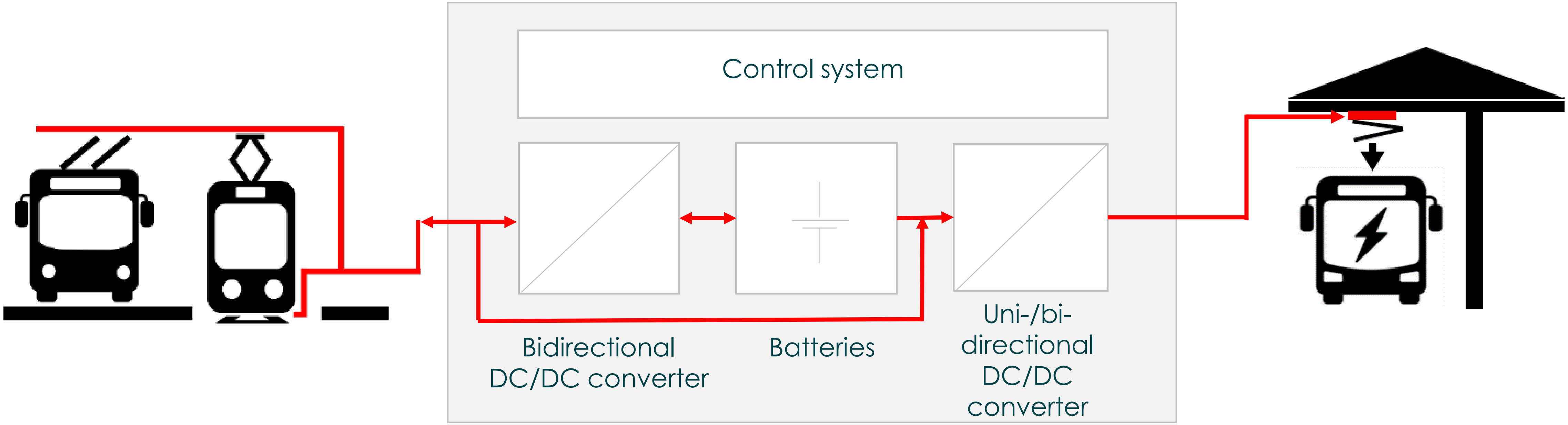
Extend trolley routes by 2x 1.5 miles using streetcar terminus

Use of existing Infrastructure

IMC alternatives?

 Klaus P. Canavan photo

CHARGING SOLUTIONS



IMC / streetcar overhead line
- Regeneration of energy
- Stabilization of power

Converter connected directly to overhead line
- Storage of regenerated energy
- Peak shaving and load balancing
- Controller for charging

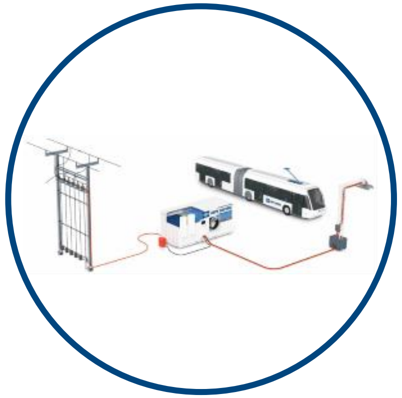
Battery bus charging station

Use of existing overhead line infrastructure

PRODUCT EXAMPLES

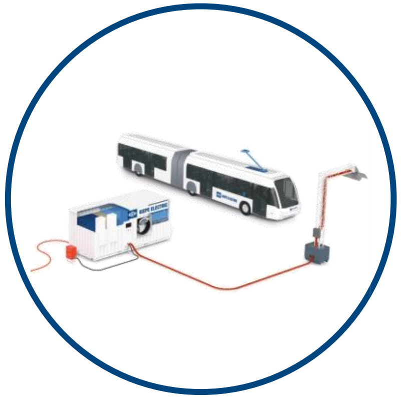
© Furrer+Frey

City K-Charger
Charging with pantograph
100 – 800 kW



Mainline K-Charger
Charging stations
with 100 - 800 kW

Overhead Line
3x480VAC, 60 Hz



Mobile K-Charger
Mobile Charging
Station 100 - 800 kW

Megawatt K-Charger
Charging of e-trucks
1000 - 3000 kW

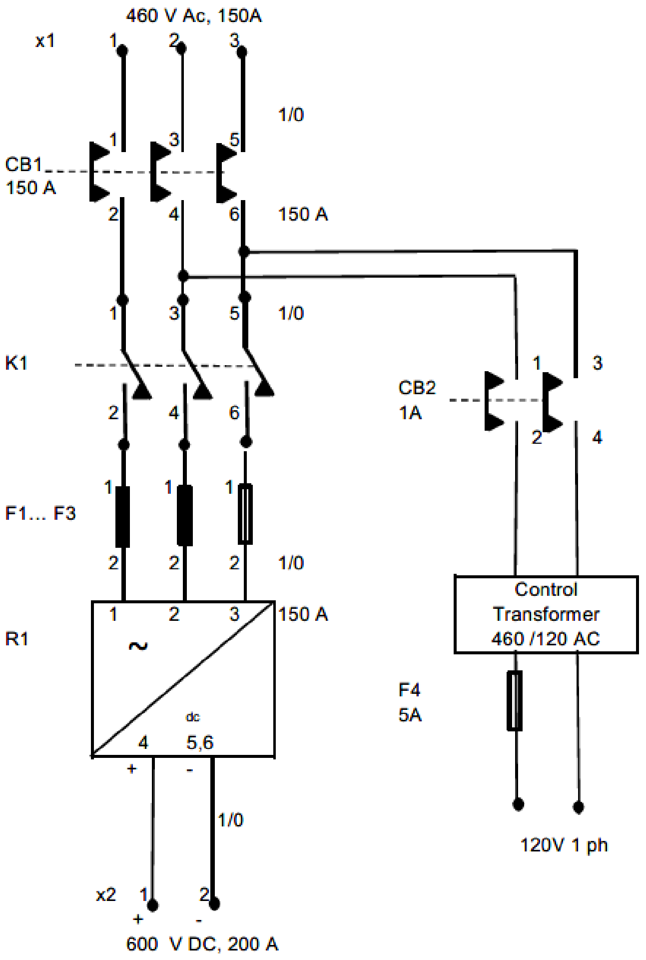
EV K-Charger
Power Supply for EV-Wallboxes
100 – 800 kW

Depot K-Charger
Charging of battery bus
e.g. 2 x 100 kW

Standard K-Charger
Charging with 100 - 200 kW

Trolley Bus K-Charger
Charging Station for IMC bus
100 - 300 kW

IMC BUS INFRASTRUCTURE



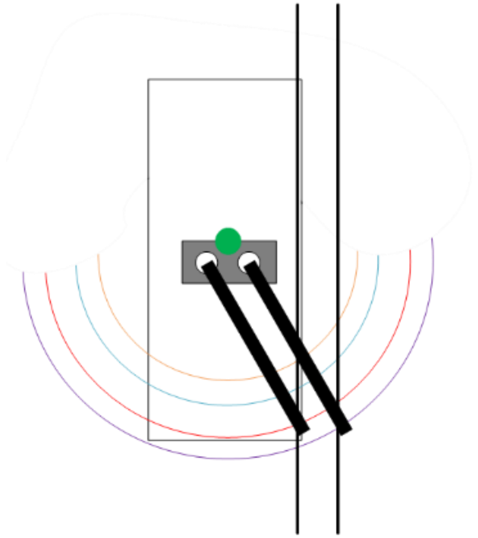
- Simple 600/750V DC voltage source
- Only passive rectifier and switchgear required
- No communication with external charging station interoperability!

 RP online photo (BOB Solingen)

CONNECT TO CHARGE

Ways to connect to the charging infrastructure

- Traditional
  - Manual re-wiring, requires the operator to leave the bus
- Automatic using troughs
  - At dedicated spots, requires precise alignment of the bus
- Fully automatic
  - Either at dedicated stops
  - With or without troughs
  - With or without possibility to move laterally



 Matthew Lee photo used with permission, other photos: KP Canavan

RELEVANT STANDARDS

IEC 63076:2019 (based on EN50502 / with reference to various other IEC standards)
Railway applications - Rolling stock - Electrical equipment in trolley buses
Safety requirements and current collection systems

ECE R-107
Uniform provisions concerning the approval of category M2 or M3 vehicles with regards to their general construction
Annex 12 (additional safety requirements for trolley buses)

3.10.12. Each of the insulations of voltage Class B equipment onboard the trolleybus shall be tested with an AC power supply at test frequency of 50 - 60 Hz for 1 minute.

The test voltage (U_{Test}) for wiring and components at the trolleybus shall be:

Basic insulation:	$U_{Test} = 2 \times U_{Nm} + 1{,}500$ V
Supplementary Insulation:	$U_{Test} = 1.6 \times U_{Nm} + 500$ V

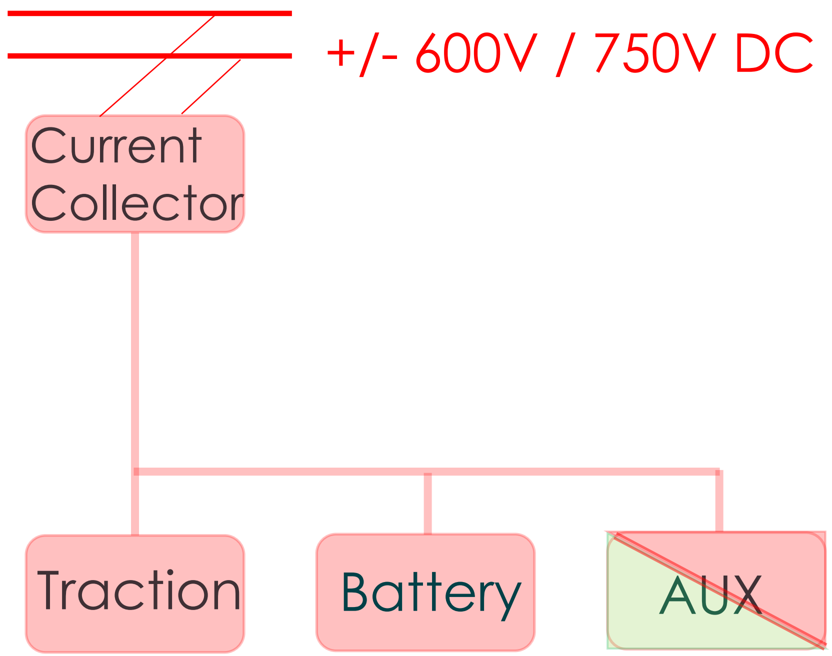
For circuits double insulated from overhead line voltage, the test voltage (U_{Test}) shall be at least 1,500 V, or:

Basic Insulation:	$U_{Test} = 2 \times U_{Nm} + 1{,}000$ V

The equivalent DC test voltage is $\sqrt{2}$ times the AC value.

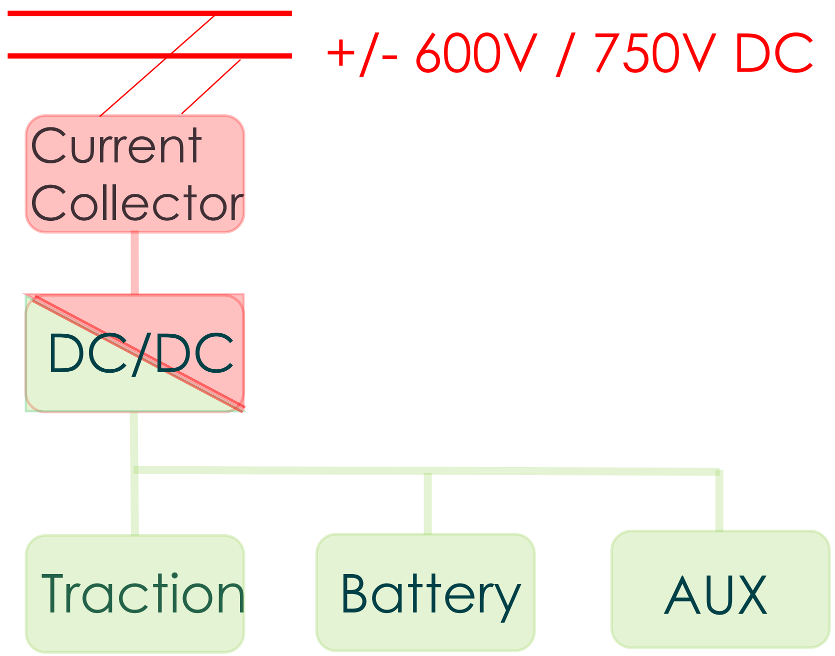
For example: ECE R-107 Annex 12 / IEC63076: 2019

IMC BUS ARCHITECTURE



- Double insulated traction
- Traction equipment directly connected to overhead line
- No conversion losses
- Regenerative braking into overhead line and onboard (battery and aux.)

IMC BUS ARCHITECTURE



- Galvanic insulation from overhead line using DC/DC converter
- Components downstream of DC/DC can be standard battery bus single insulated design if standard is met
- Current collector and DC/DC require double insulation
- Insulation monitoring (hot coach detector)
- Insulation of doors!
- Regeneration into battery

BATTERY BUS CHARGING

- DC/DC converter = trolley line interface and on-board battery charger

FLEXIBILTY AND INTERMODALITY OF THE TROLLEY BUS GRID

IN THE TROLLEY BUS SYSTEM IT IS POSSIBLE TO INSTALL:

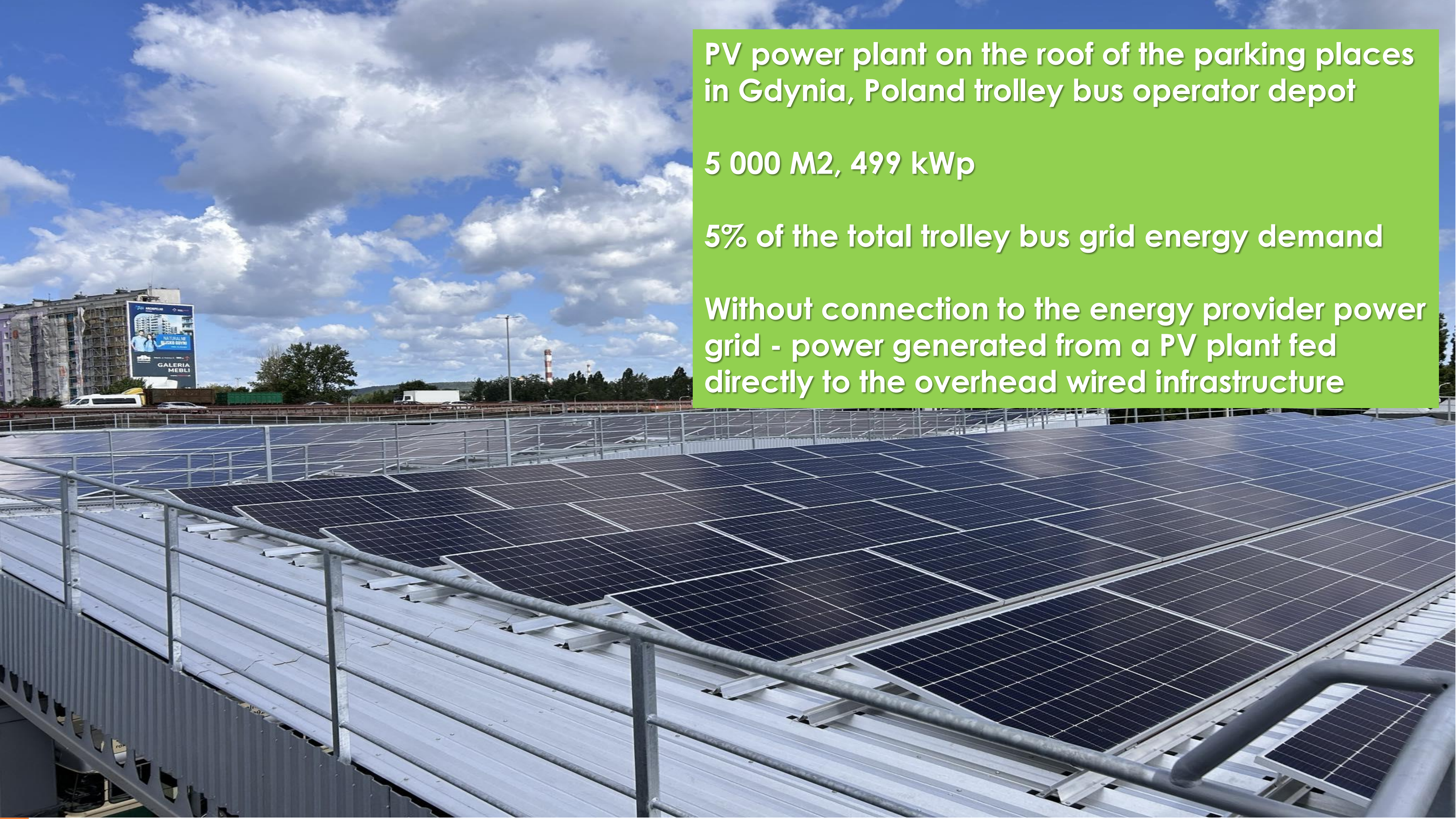
- A photovoltaic power plant feeding solar power directly into the trolleybus grid
- Energy supercapacitors
- Charging points for other EV vehicles

PV power plant on the roof of the parking places in Gdynia, Poland trolley bus operator depot

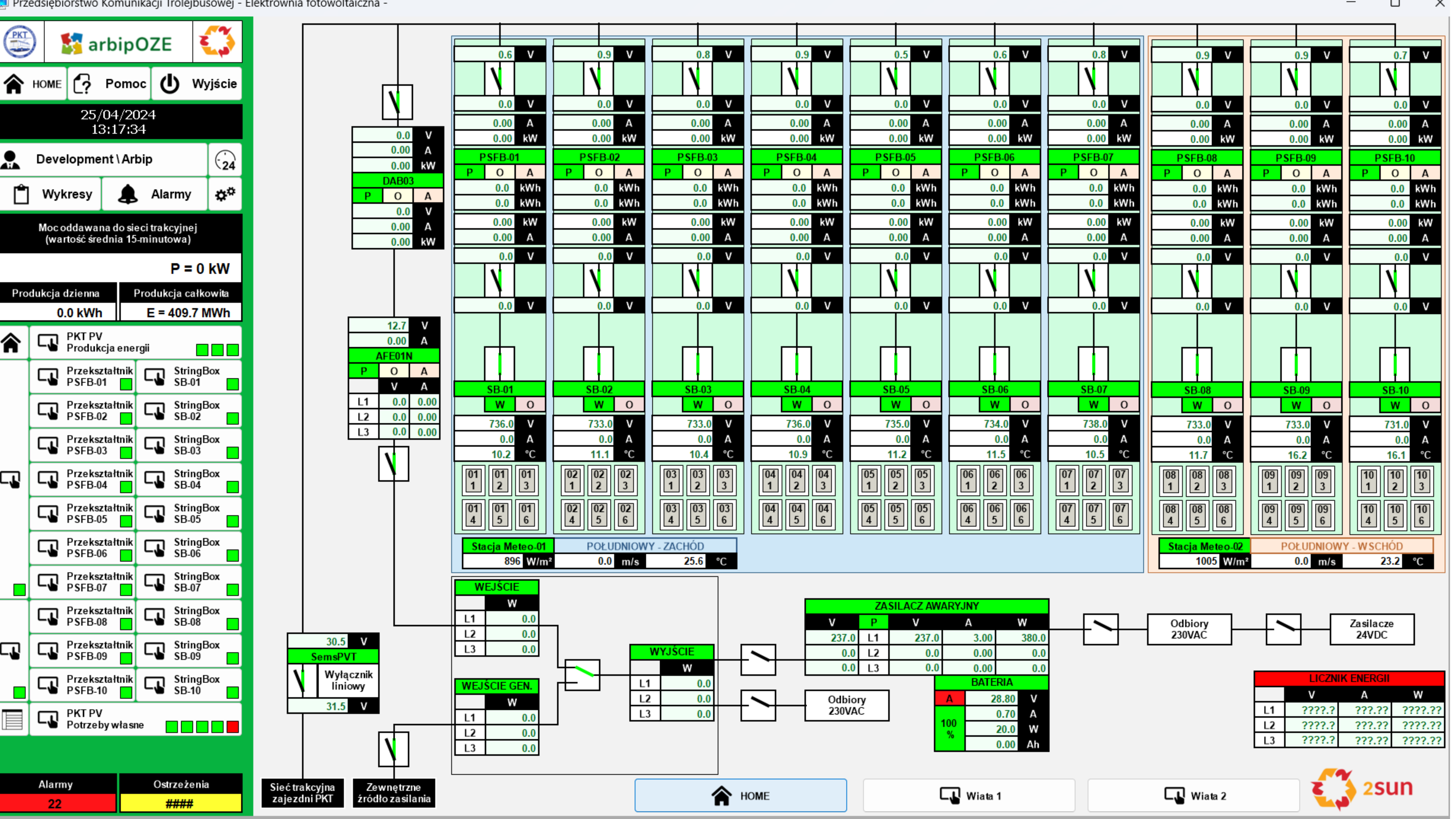
5 000 M2, 499 kWp

5% of the total trolley bus grid energy demand

Without connection to the energy provider power grid - power generated from a PV plant fed directly to the overhead wired infrastructure




DANTYSZKA 2



Przedsiębiorstwo Komunikacji Trolejbusowej - Elektrownia fotowoltaiczna -
arbipOZE
HOME
Pomoc
Wyjście
25/04/2024
13:17:34
Development \ Arbip
Wykresy
Alarmy
Moc oddawana do sieci trakcyjnej (wartość średnia 15-minutowa)
P = 0 kW
Produkcja dzienna
0.0 kWh
Produkcja całkowita
E = 409.7 MWh
PKT PV Produkcja energii
Przekształtnik PSFB-01
StringBox SB-01
Przekształtnik PSFB-02
StringBox SB-02
Przekształtnik PSFB-03
StringBox SB-03
Przekształtnik PSFB-04
StringBox SB-04
Przekształtnik PSFB-05
StringBox SB-05
Przekształtnik PSFB-06
StringBox SB-06
Przekształtnik PSFB-07
StringBox SB-07
Przekształtnik PSFB-08
StringBox SB-08
Przekształtnik PSFB-09
StringBox SB-09
Przekształtnik PSFB-10
StringBox SB-10
PKT PV Potrzeby własne
Alarmy
22
Ostrzeżenia
####
DAB03
AFE01N
SemsPVT
Wyłącznik liniowy
30.5 V
31.5 V
Sieć trakcyjna zajezdni PKT
Zewnętrzne źródło zasilania
PSFB-01
PSFB-02
PSFB-03
PSFB-04
PSFB-05
PSFB-06
PSFB-07
PSFB-08
PSFB-09
PSFB-10
SB-01
SB-02
SB-03
SB-04
SB-05
SB-06
SB-07
SB-08
SB-09
SB-10
Stacja Meteo-01
POŁUDNIOWY - ZACHÓD
896 W/m²
0.0 m/s
25.6 °C
Stacja Meteo-02
POŁUDNIOWY - WSCHÓD
1005 W/m²
0.0 m/s
23.2 °C
WEJŚCIE
WEJŚCIE GEN.
WYJŚCIE
ZASILACZ AWARYJNY
BATERIA
28.80 V
0.70 A
20.0 W
0.00 Ah
100 %
Odbiory 230VAC
Zasilacze 24VDC
LICZNIK ENERGII
HOME
Wiata 1
Wiata 2
2sun

Przedsiębiorstwo Komunikacji Trolejbusowej - Elektrownia fotowoltaiczna -

PKT arbipOZE

HOME | Pomoc | Wyjście

26/04/2024
15:10:22

Development \ Arbip

24

Wykresy | Alarmy

Moc oddawana do sieci trakcyjnej (wartość średnia 15-minutowa)

P = 13 kW

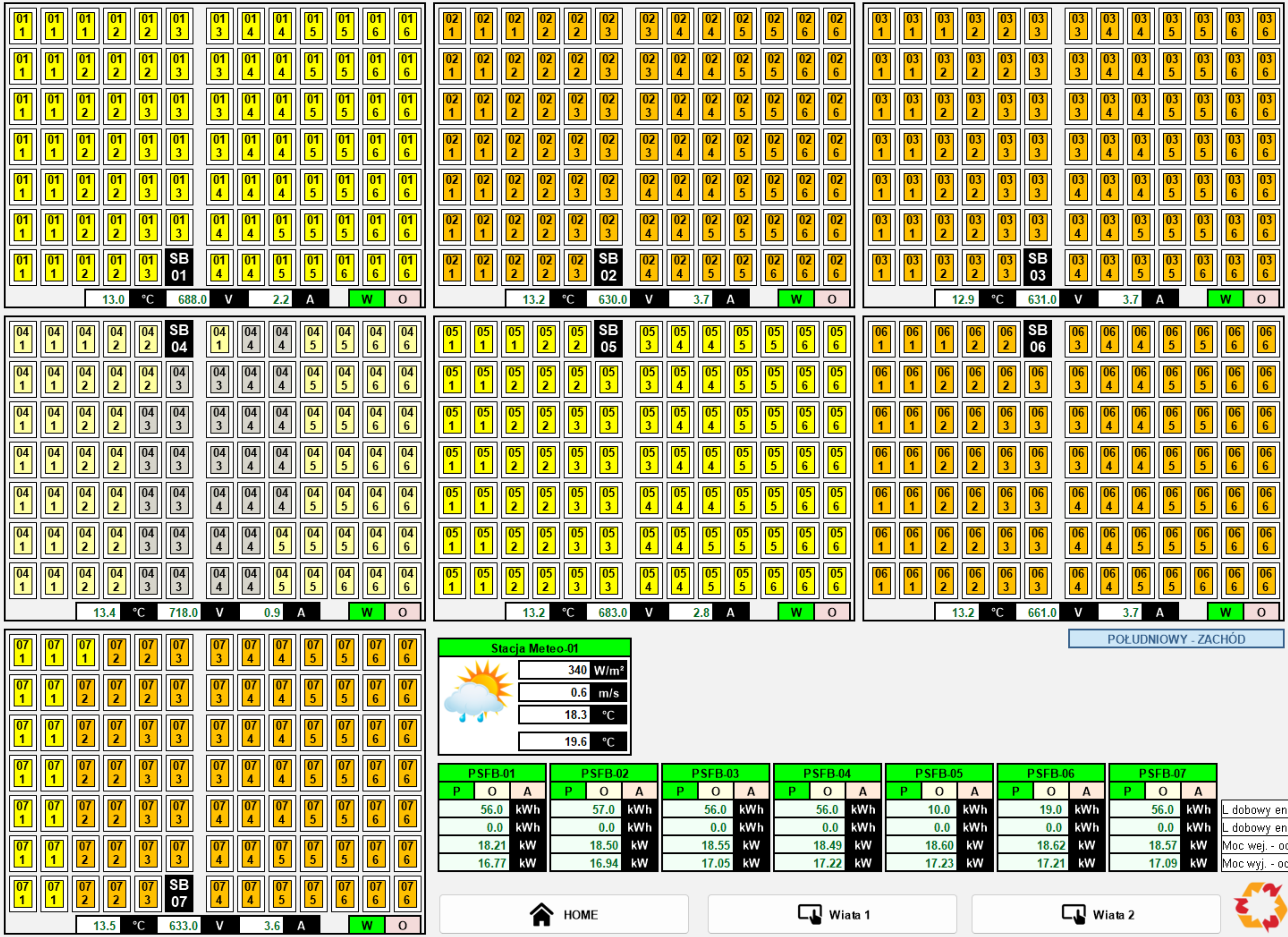
Produkcja dzienna	Produkcja całkowita
697.1 kWh	E = 1106.8 MWh

PKT PV
Produkcja energii

Przekształtnik PSFB-01	StringBox SB-01
Przekształtnik PSFB-02	StringBox SB-02
Przekształtnik PSFB-03	StringBox SB-03
Przekształtnik PSFB-04	StringBox SB-04
Przekształtnik PSFB-05	StringBox SB-05
Przekształtnik PSFB-06	StringBox SB-06
Przekształtnik PSFB-07	StringBox SB-07
Przekształtnik PSFB-08	StringBox SB-08
Przekształtnik PSFB-09	StringBox SB-09
Przekształtnik PSFB-10	StringBox SB-10

PKT PV
Potrzeby własne

Alarmy	Ostrzeżenia
30	####



W/PV
0
50
100
200
300
400
500

Średnia dobowa

0.0	°C
0.4	m/s
SE - °C - SW	
12.4	12.4
SE - W/m2 - SW	
238.2	238.2

POŁUDNIOWY - ZACHÓD

Stacja Meteo-01

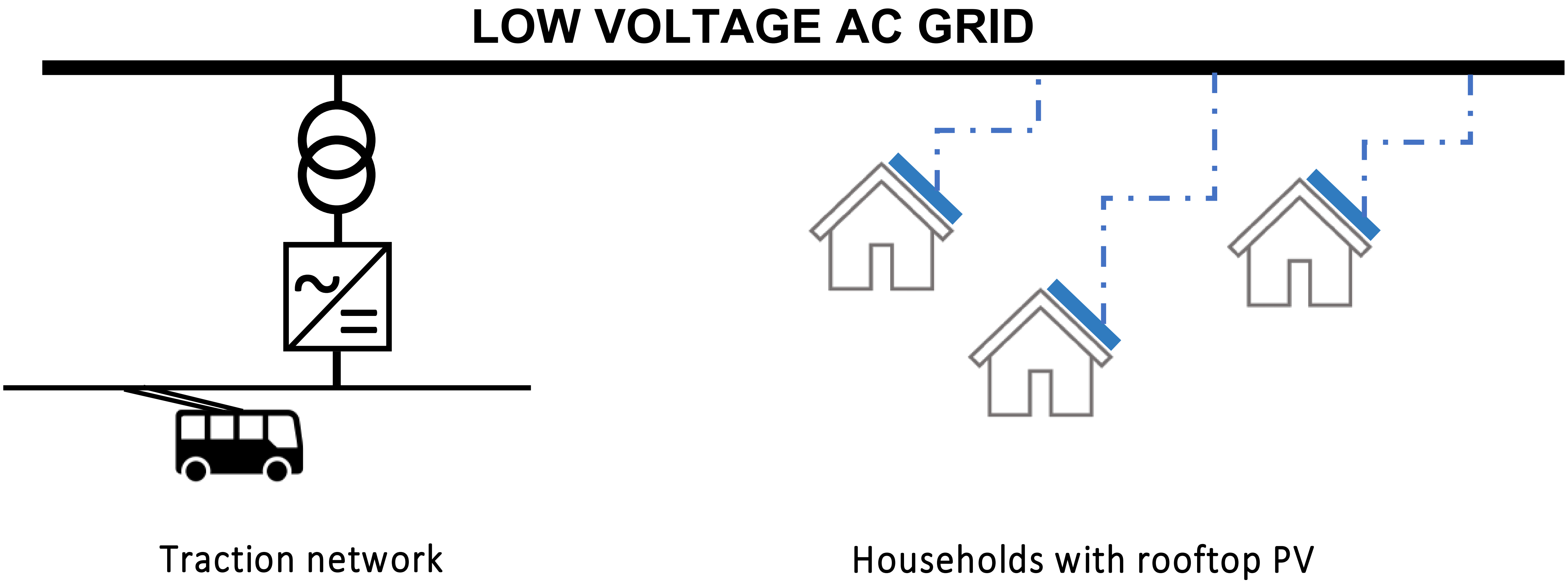
340	W/m²
0.6	m/s
18.3	°C
19.6	°C

	PSFB-01		PSFB-02		PSFB-03		PSFB-04		PSFB-05		PSFB-06		PSFB-07		
	P O A		P O A		P O A		P O A		P O A		P O A		P O A		
	56.0	kWh	57.0	kWh	56.0	kWh	56.0	kWh	10.0	kWh	19.0	kWh	56.0	kWh	L dobowy en. oddanej do trakcji
	0.0	kWh	0.0	kWh	0.0	kWh	0.0	kWh	0.0	kWh	0.0	kWh	0.0	kWh	L dobowy en. pobranej z trakcji
	18.21	kW	18.50	kW	18.55	kW	18.49	kW	18.60	kW	18.62	kW	18.57	kW	Moc wej. - od strony PV
	16.77	kW	16.94	kW	17.05	kW	17.22	kW	17.23	kW	17.21	kW	17.09	kW	Moc wyj. - od strony trakcji

HOME | Wiata 1 | Wiata 2

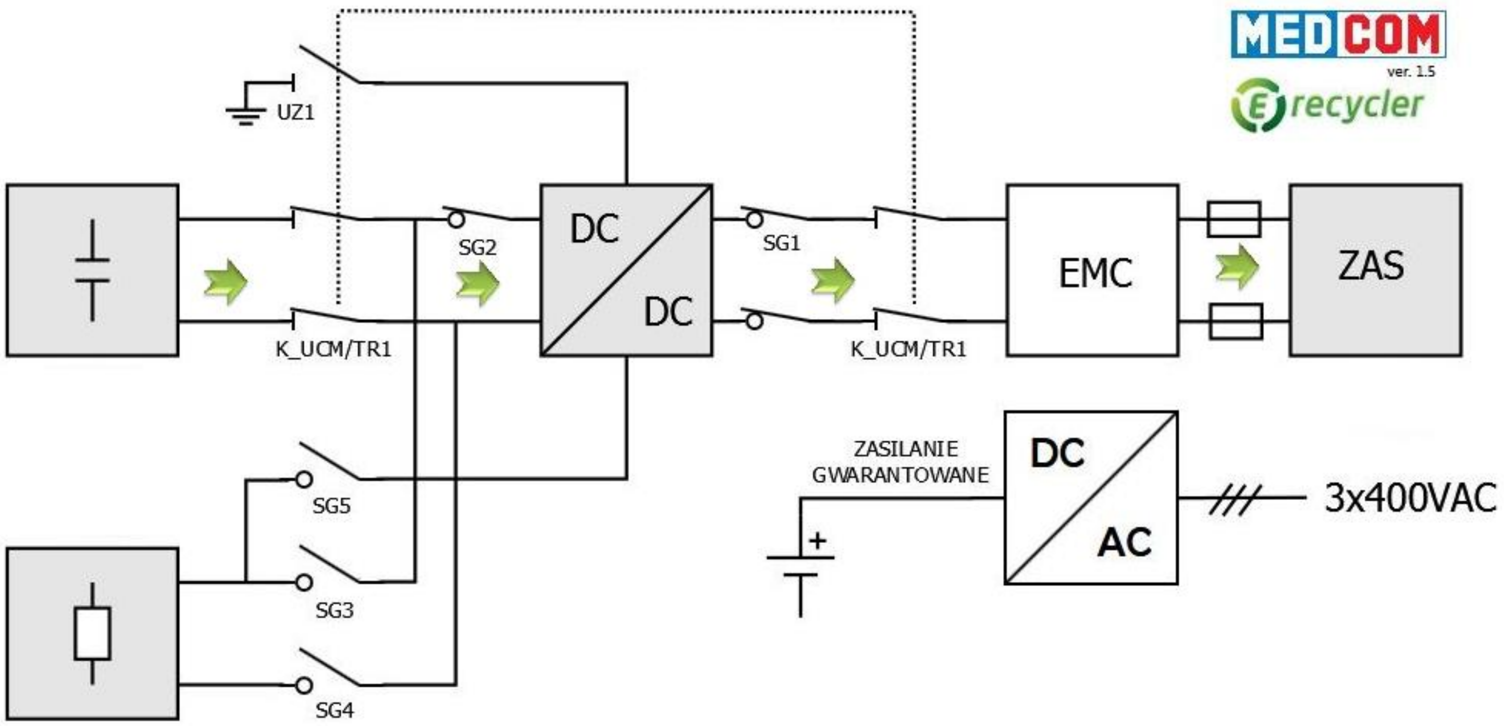
2sun

Studies on shared PV system between residential and traction grids



SUPERCAPACITOR STORAGE ENERGY SYSTEM

Capacity 1.5 kWh
Max. Power 500 kW
Producer MEDCOM




UCER-01 - OPERATOR
ROZDZIELNICA 15kV PKT

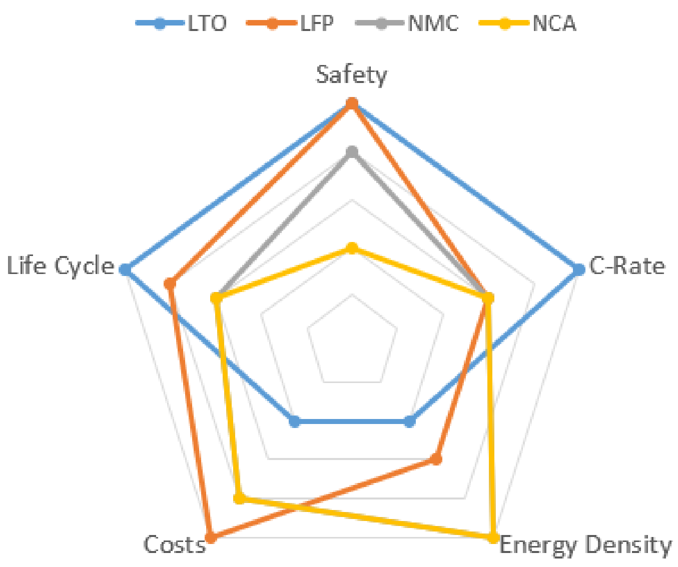
ENERGY SAVINGS

A supercapacitor for storing braking energy – installed in one of the substations placed in the hilly area of the city

20% energy savings on the section

BATTERY CHEMISTRY

Cell Chemistry	LTO	LFP	NMC	NCA
Pros	• Very High Safety • Very high Cycle Life • Fast Charge/ Discharge C-Rate	• Very High Safety • Low costs	• Highest Energy Density	• Highest Energy Density
Cons	• Lowest Energy Density • High costs	• Lower Energy Density	• Lower Safety	• Lower Safety



ORIGINS OF IMC TROLLEYBUSES IN GDYNIA

In 2009 - preparation for the fleet modernization co-financed by EU funds

Basic requirement for the new fleet – auxiliary drive allowing for autonomous operation of trolleybuses

Diesel drive

- long distatance
- flexibility
- popular solution

Battery

- promising technology
- zero emission
- easy maintenance („all electric“)

Decision makers

BATTERIES USED IN GDYNIA TROLLEYBUSES

Ni-Cd battery

- capacity: **6-16 kWh**
- range: **3-5 km**

Li-Ion battery

- capacity: **27 & 69 kWh**
- range: **ca.15 & 30 km**

LiFePO4 battery

- capacity: **40 kWh**
- range: **ca. 20 km**

LTO battery

- capacity:
  58 (12m) & 87 kWh (18m)
- range: **ca. 35 km**

PKT GDYNIA
3088
PKT
SOLARIS
GA 9318V

IMC IN USE - REGULAR OFF WIRE OPERATION IN GDYNIA 50 % OF THE LINES ARE EXTENDED (9 OF 18)

Automatic lowering and raising of current collectors

OTHER EUROPEAN IMC LIGHTHOUE EXAMPLES

- Biel, Switzerland
- Solingen, Germany
- Cagliari, Italy
- Prague, the Czech Republic
- Arnhem, the Netherlands

Take aways

Energy = Power x Time

Electrification requires Power and Space

IMC buses carry passengers not batteries (low power, less space)

IMC buses can re-wire automatically

Mixed use of IMC infrastructure is possible (observe standards)

IMC: key technology to help remove roadblocks to electrification

QUESTIONS?

THANK YOU!

trolleymotion.eu

woronowicz@trolleymotion.eu

kiepe-group.com

klauspeter.canavan@kiepe-group.com