경전철 무선전력전송 기술

Introducing KRRI's Wireless Power Transfer Technology for Railways

2023. 08.

Korea Railroad Research Institute (KRRI)

Gunbok Lee

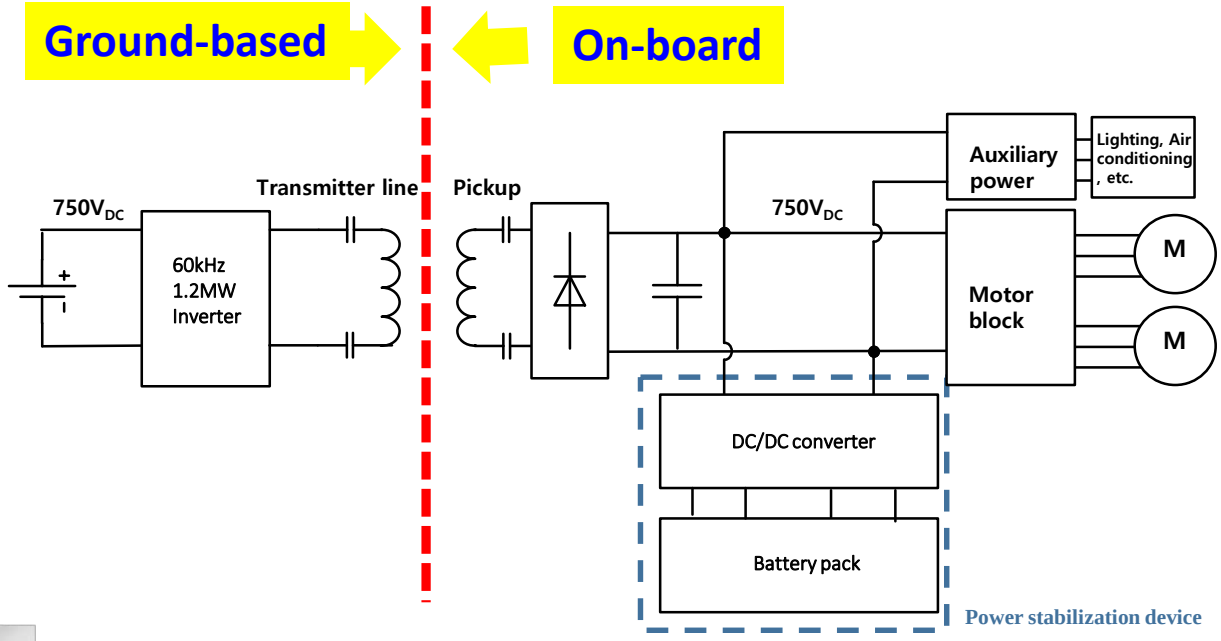
Korea Railroad Research Institute

Contents

Introduction to WPT for Railways and development

Principle of WPT system for LRT

- WPT Block Diagram



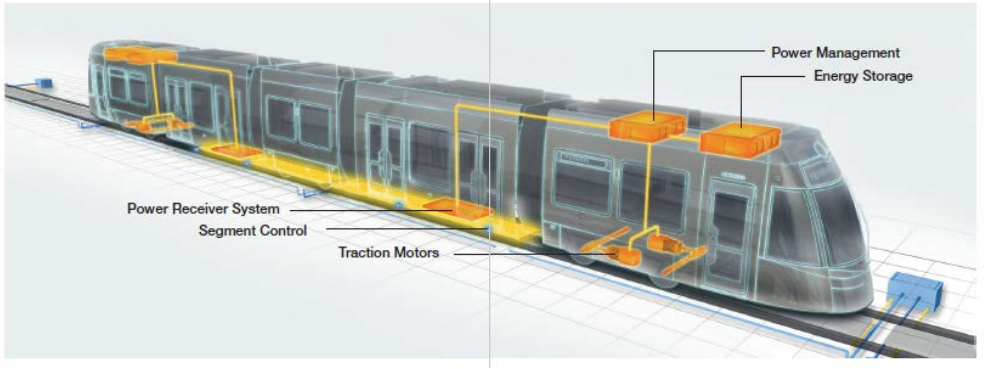
Transmitter Line

Transmitter Line (buried)

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

▪ International



(Germany, 2010) Bombardier: Implemented WPT system for trams, tested on a 0.8 km test track

(Spain) CAF, IK4-IKERLAN	(Japan) RTRI	(Japan) Toshiba	(German)Aerospace Center	(Norway)
				
Developed a 50kW wireless charging system in 2017. Tested on CAF RUBES tram	Attempted to develop a 300kW wireless power transmission system for railway vehicles in 2016, developed a 50kW system	In 2019, developed a 44kW wireless charging system for buses (charging during stops)	Developing next-generation high-speed trains (HST) and regional trains (LINK) with applied wireless power supply technology. Wireless power supply and catenary hybrid operation are possible	In 2017, developed a 1MW wireless power supply AMP system for electric sightseeing boats in Norway

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

- **Korea**

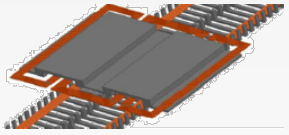
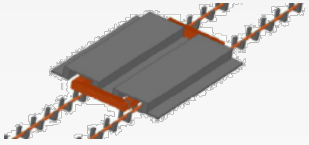
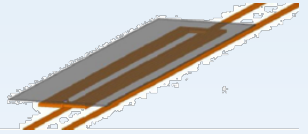
(KRRI, 2020) Test operation of Gyeongsan LRT Test Line, 1MW class

(WiPowerOne, 2021) Test operation of Daejeon Daedeok Circulation Line, 150kW class

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

▪ Development of WPT for Railways

Items	Future Green Railway Project Phase 1 (2013)	Future Green Railway Project Phase 2 (2013)	WPT for Light Rail Transit (2020)
Inverter	200 kW-class	1 MW-class	1.2 MW-class practical model
Pickup	60kW module * 3	300 kW module * 3	250kW lightweight module * 4
Efficiency	86%	83%	90%
Transmitter Line	15m E-core, one location 	128m U-core, one location 	200m Coreless, four locations 
Applied vehicles	Wireless tram (demo) 	HEMU-430X (demo) 	K-AGT Light Rail Transit (Test) 
Reliability test	None	None	40,000 km test driving

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

▪ WPT Technology (KRRI) – Tram

- Joint research conducted by Korea Railroad Research Institute and KAIST (2012~2013)
- Feb 25, 2013, 60kHz high-capacity wireless power supply core technology demonstration
- June 3, 2013, demonstration of wireless power supply technology for catenary-free trams

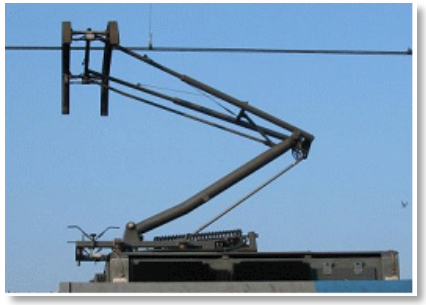
Development of 60 kHz/200 kW-class non-contact power supply system for catenary-free trams

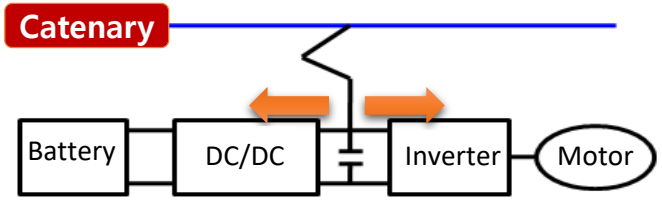
Introduction to WPT for Railways and development

- **WPT Technology (KRRI) – Tram**

Existing catenary-free trams and power supply methods

Conventional





Contact wire + Battery

Non-contact

Power supply to onboard charging and propulsion devices

Non-contact

60kHz high-frequency power

Introduction to WPT for Railways and development

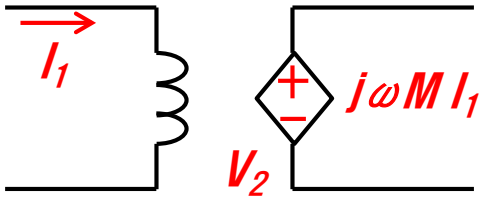
▪ WPT Technology (KRRI) – Tram

Existing catenary-free trams and power supply methods

(20 kHz ➔ 60 kHz)

- Effects of increasing resonant frequency
  - Res. Freq. increased by 3 times ➔ Induced Volt.(pickup) : Increased by 3 times

$V_2 = j\omega M I_1$



Pickup coil turns: 1/3 times
Reduction in pickup size/weight

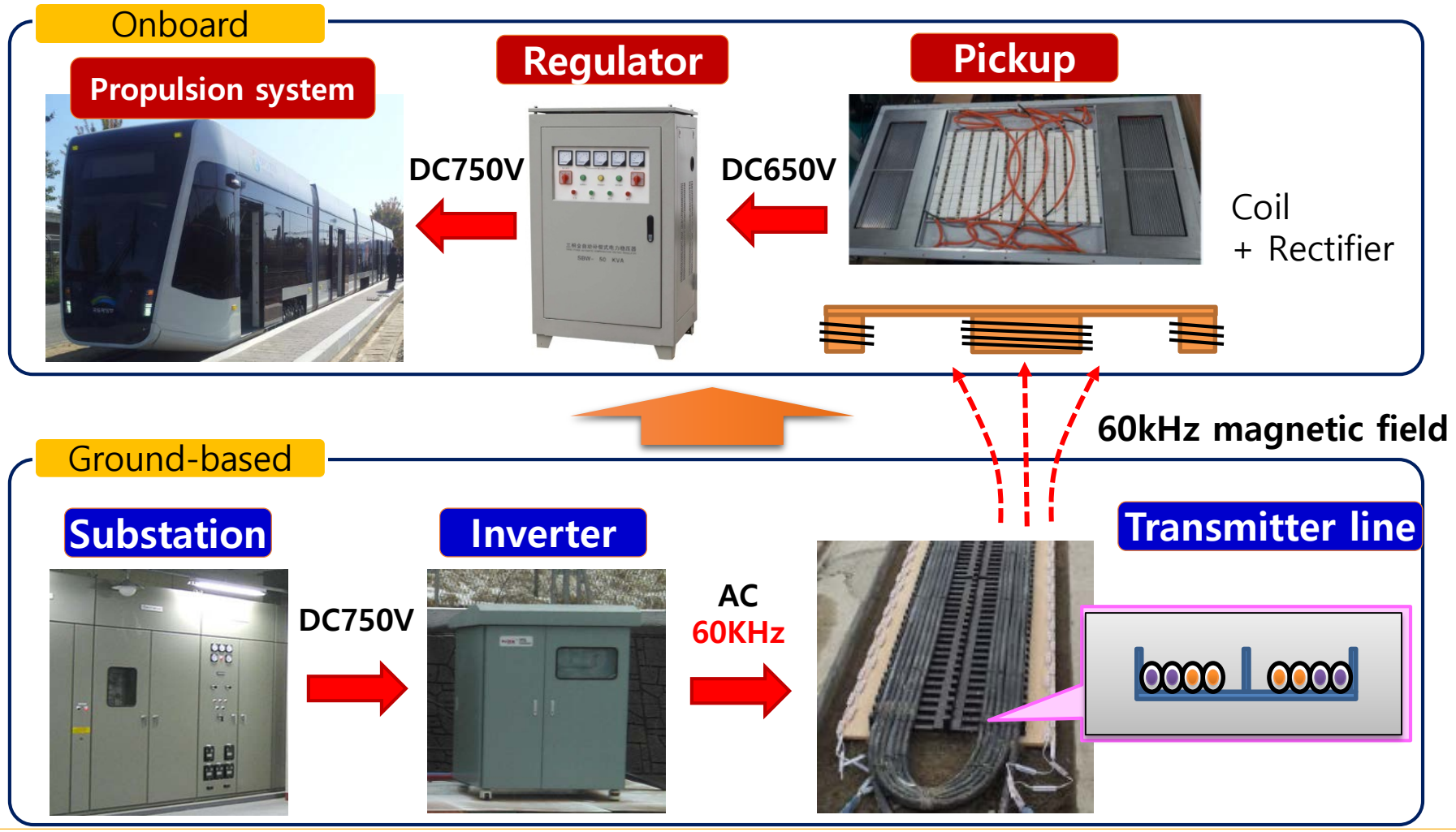
Supply current : 1/3times
Cable thickness/cost reduction

Commercialization of high-power WPT for railway

Securing the reliability of various power components

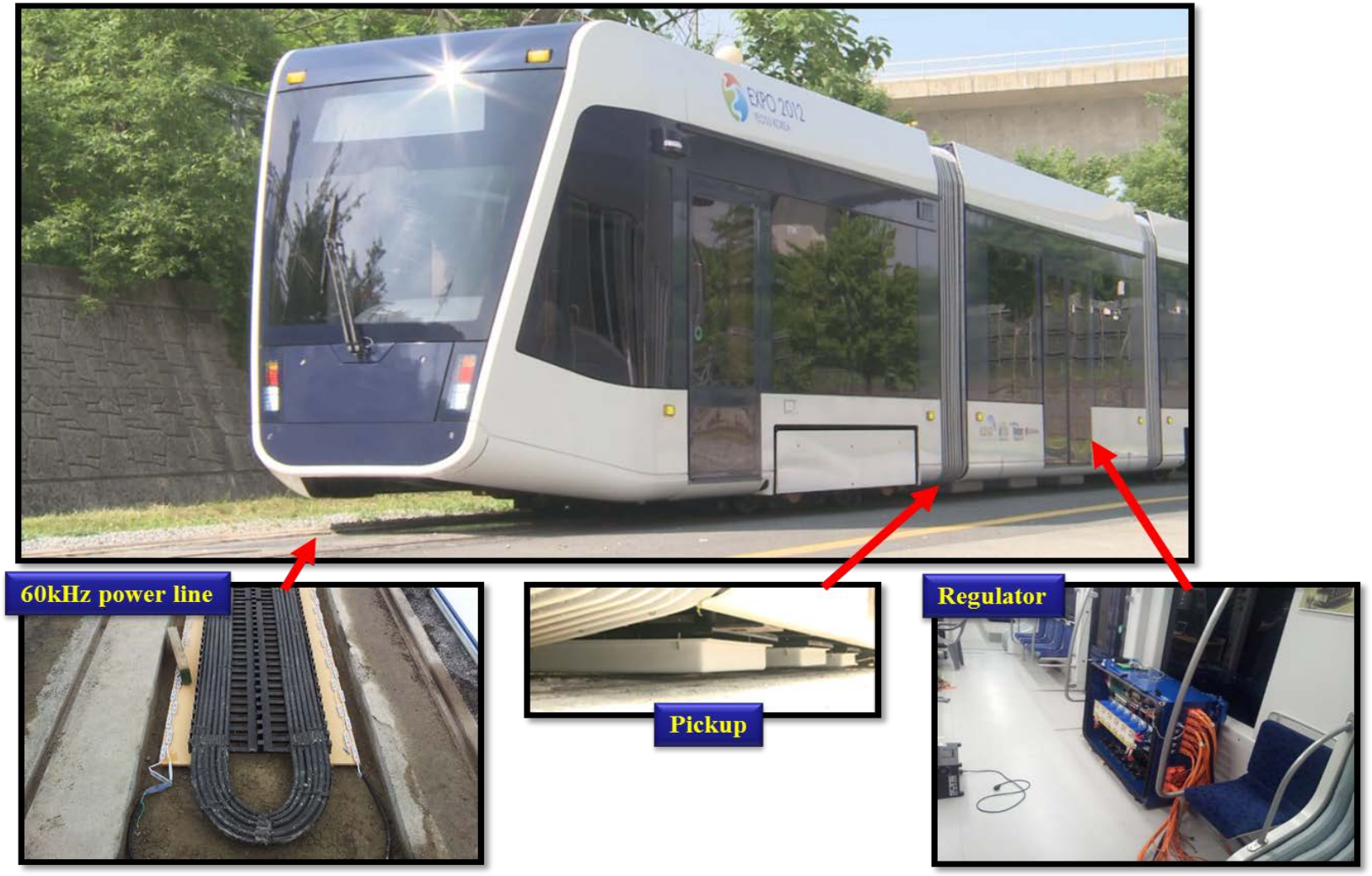
Introduction to WPT for Railways and development

▪ WPT Technology (KRRI) – Tram



Introduction to WPT for Railways and development

- **WPT Technology (KRRI) – Tram**



Introduction to WPT for Railways and development

Trends in WPT technology for Railways

- **WPT Technology (KRRI) – Tram**
  - Demonstration (2013. 6)

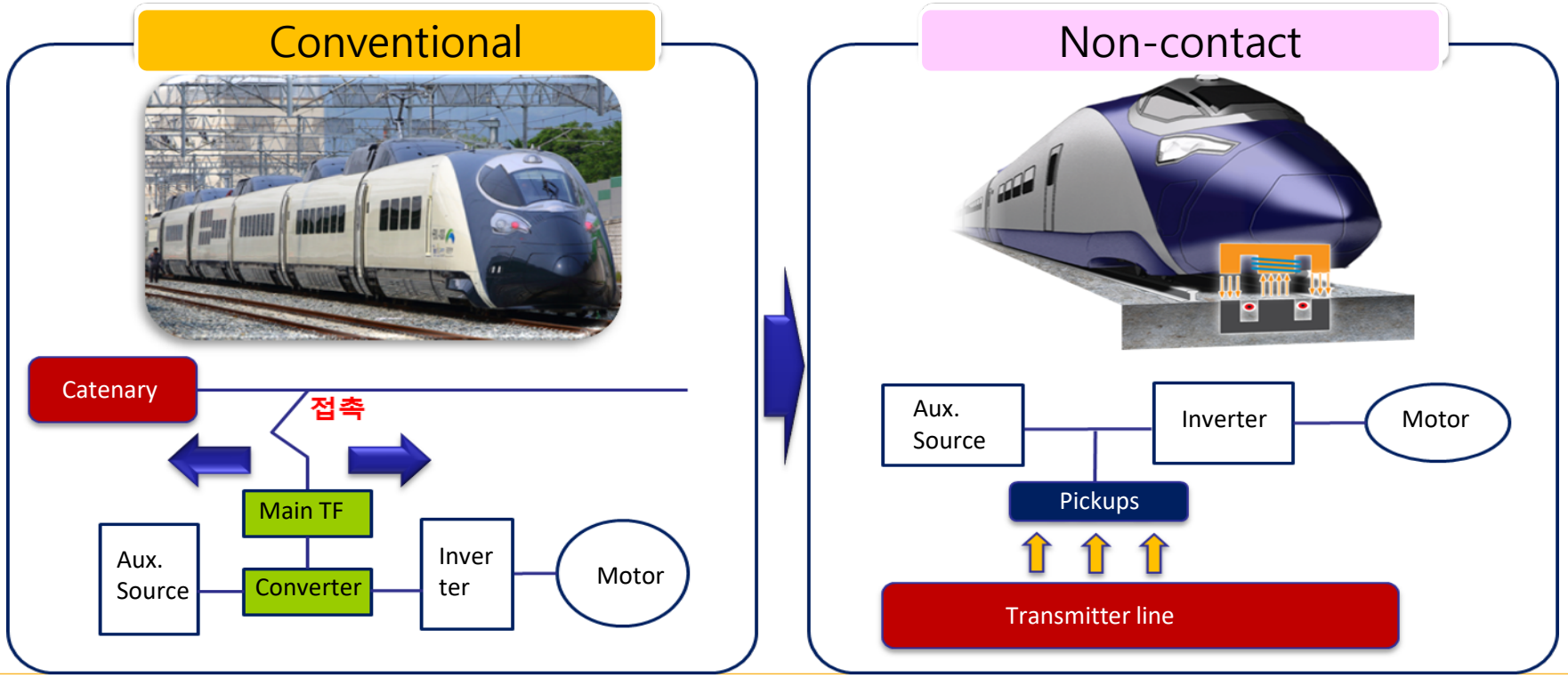
Introduction to WPT for Railways and development

Trends in WPT technology for Railways

- **WPT Technology (KRRI) – High-speed train (HEMU-430X)**

  - Joint research conducted by Korea Railroad Research Institute and KAIST (2013~2014)
  - May 20, 2014, 60kHz/1MW-class high-speed train WPT technology demonstration

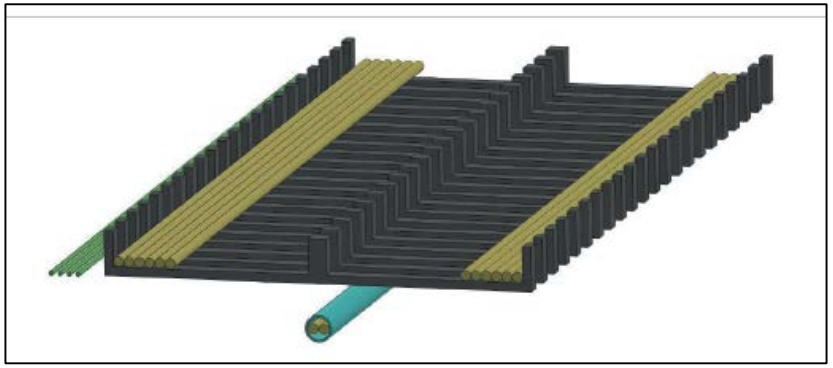
Development of 60kHz/1MW-class non-contact power supply system for high-speed trains

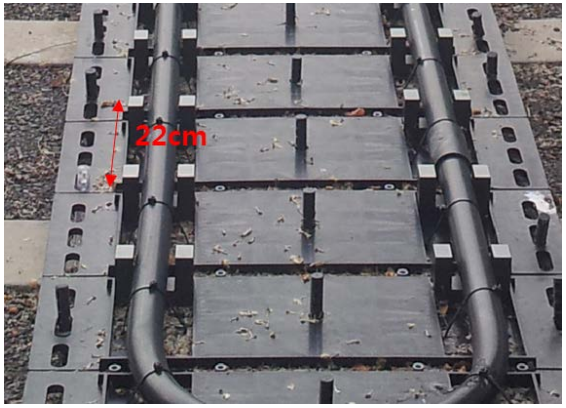


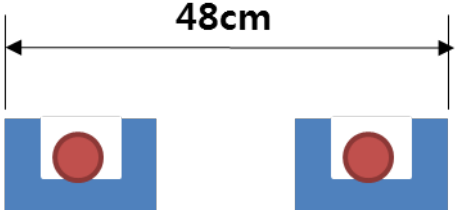
Introduction to WPT for Railways and development

▪ WPT Technology (KRRI) – High-speed train (HEMU-430X)

- Development of low-cost transmitter line structure (U-core application)



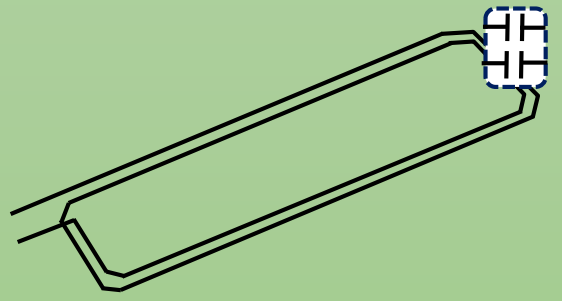
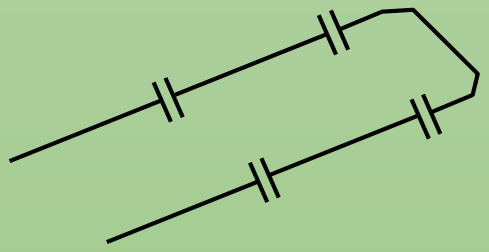




Introduction to WPT for Railways and development

▪ WPT Technology (KRRI) – High-speed train (HEMU-430X)

- Development of high-voltage/high-capacity technology for ground transmitter line

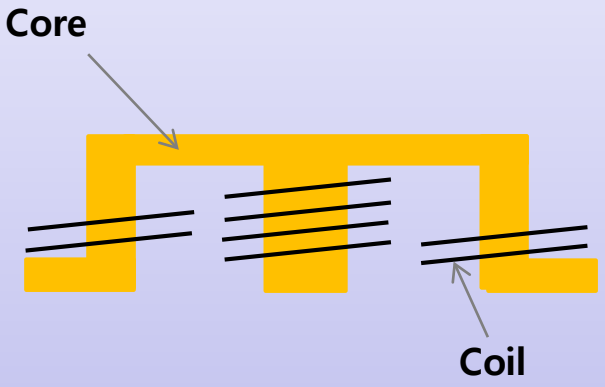
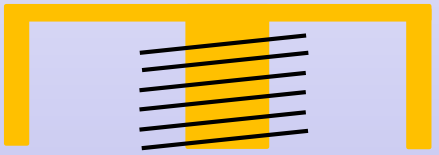
Item	Conventional (Tram ver.)	Proposed
Voltage	750V (180kW)	2800V (1MW)
Transmitter	Length: 15m	Length: 128m
	Capacitor Box  **Integrated structure**	**Capacitor**  **Distributed structure (High voltage, high power)**
	-	Heat generation and insulation reinforcement

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

▪ WPT Technology (KRRI) – High-speed train (HEMU-430X)

- Development of lightweight technology for onboard pickup modules

Item	Conventional (Tram ver.)	Proposed (HEMU)
Structure		
Power capacity	60kW / 1ea	300kW / 1ea
Weight	200kg	300kg
Weight-to-capacity ratio	100%	30%

Introduction to WPT for Railways and development

- **WPT Technology (KRRI) – High-speed train (HEMU-430X)**

Onboard

High-speed train

2800Vdc

Inverter

Pickup

Coil + Rectifier

60kHz magnetic field

Ground-based

Switchboard

AC440V

Inverter

60kHz

Transmitter

Introduction to WPT for Railways and development

Trends in WPT technology for Railways

- **WPT Technology (KRRI) – High-speed train (HEMU-430X)**

Application Strategies for WPT for LRT

Research objectives

"World's first 1.2MW-class wireless power transfer system for light rail"

Construction and operation technology development for Test-Bed

- · Lightweight/modular inverters, TX lines, and pickup
- · Over 85% efficiency
- · A 1.2MW-class Test-Bed with 100m sections, totaling over 1km
- · Ensuring reliability of coreless WPT application and test driving on light rail

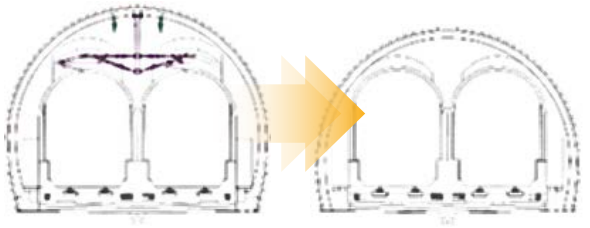
Application Strategies for WPT for LRT

Advantages of WPT system

New paradigm of power supply system using WPT

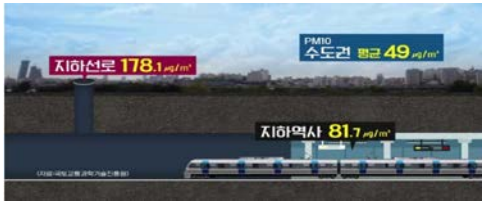
Economy

- Construction and installation cost reduction (trolley wires, tunnels)
- Maintenance cost reduction



Environment

- Elimination of the cause of fine dust in subways
- Contributing to national carbon emission reduction
- Realizing green transportation through energy regeneration utilization



Technology

- The world's largest capacity WPT system
- Reduced capacity and increased lifespan for battery-operated vehicles
- Overcoming speed limits due to the removal of trolley wires

[무선전력전송 기술 적용을 통한 관련설비 제거]

Society

- Achieving future image transportation means
- Reduction of accidents such as electric shock
- Improved urban aesthetics due to the removal of trolley wires

Application Strategies for WPT for LRT

Semi-dynamic WPT

1. Wireless power supply instead of wireless charging?!

- Wireless charging: Wirelessly charging the battery

- Wireless power supply: Supplying the power needed for vehicle operation

2. Applied to Busan Line 4 Light Rail

- Domestically developed light rail vehicle, K-AGT

- 6-car configuration, the heaviest light rail (passengers about 300 people)

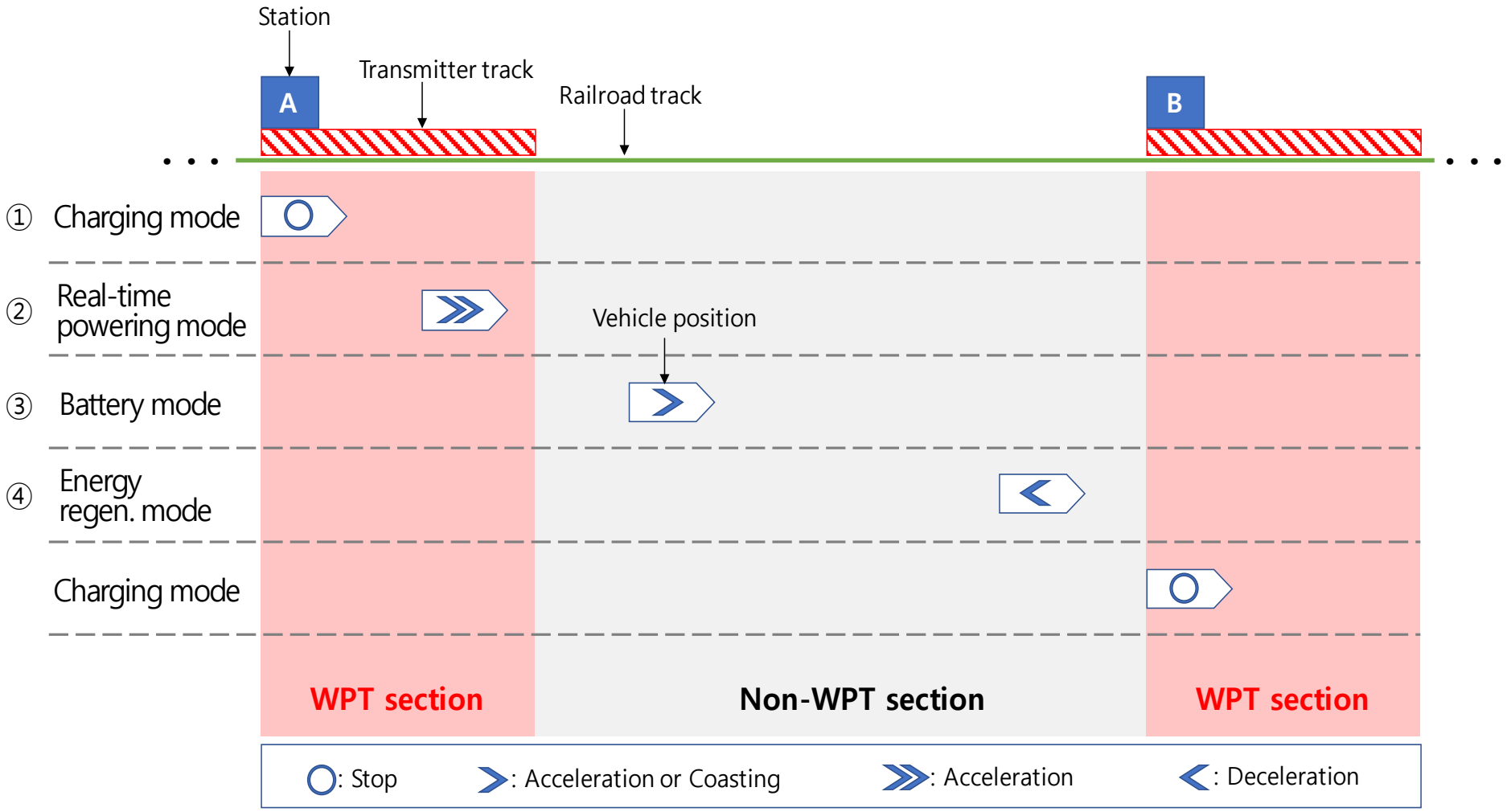
3. Economical construction cost

Semi-dynamic wireless power transfer system

Application Strategies for WPT for LRT

Semi-dynamic WPT

Semi dynamic WPT operation method

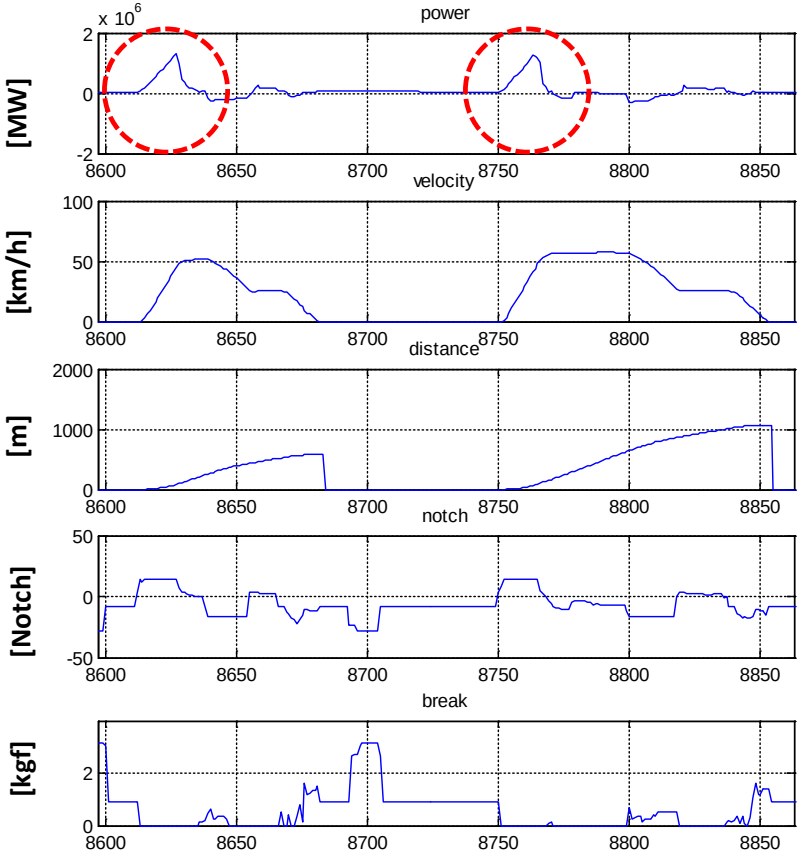


Application Strategies for WPT for LRT

Operation Scenario

Analysis of Busan Line 4 route operation data

- Analysis of daily driving data of 3 trains on Busan Line 4 on July 30th and 31st, 2014 (summer peak period) and January 24th and 28th, 2015 (winter peak period)



July 30, 2014, summer peak load data

Parameter	Measurement
Instantaneous Maximum Power	1.4 MW
Cumulative Power Consumption between Stations	13 kWh
Regenerative Power	Avg. 0.85 kWh (Max. 3.6 kWh)
Acceleration Time	Avg. 19 s
Distance Covered during Acceleration	Avg. 156 m (Max. 260 m)

- **Semi-dynamic WPT technology application**
- **Charging available time: about 50 seconds (30 seconds stop, acceleration 19 seconds)**
- **Rated power: 13000 / (50/3600) = 936 kW (wireless power supply)**
- **For a maximum power of 1.4 MW,**
- **1 MW wireless power supply and 400 kW battery output required**

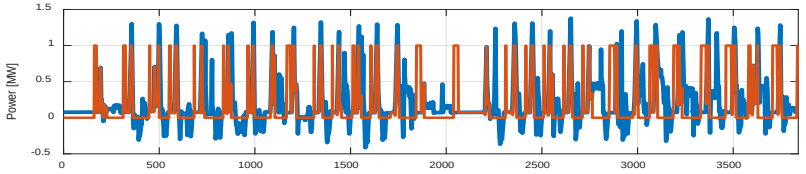
Application Strategies for WPT for LRT

Semi-dynamic WPT

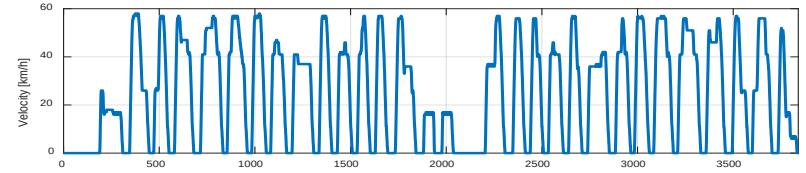
Busan Line 4 route operation power simulation data (round-trip data for all sections)

- WPT transmitter line: 200m Power stabilization device: 50kWh
- **DoD(Depth of Discharge) < 20%**

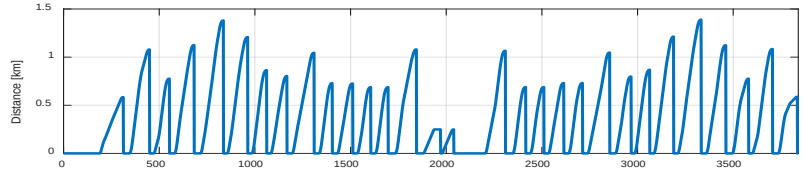
Power (WPT)



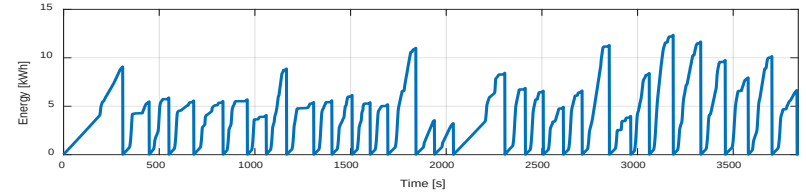
Speed

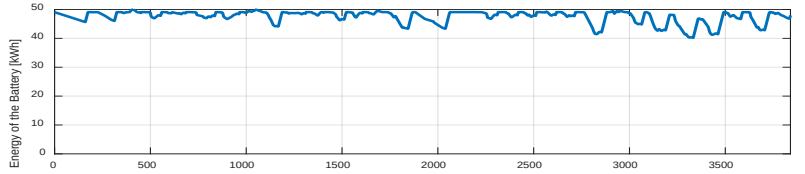


Distance

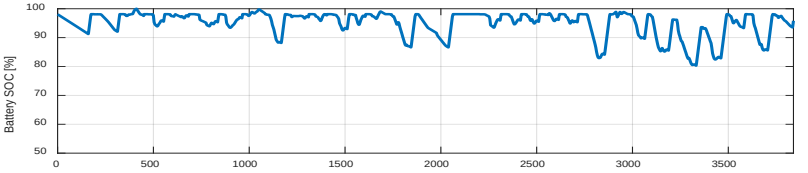


Energy

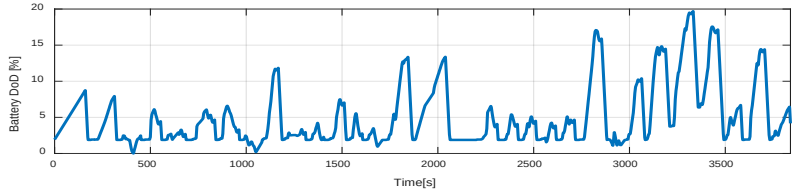


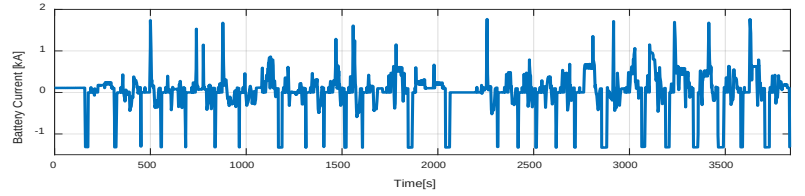


SoC



DoD





Application Strategies for WPT for LRT

Component design and testbed construction

Ground

Inverter

- ✓ SiC advanced material semiconductor (high efficiency)
- ✓ 60 kHz resonant inverter technology (high efficiency)
- ✓ EMI reduction cable application (electromagnetic safety)

Onboard

Pickup

- ✓ Lightweight pickup coil application
- ✓ Compact package structure implementing EMI reduction

Application Strategies for WPT for LRT

Component design and testbed construction

Ground

Inverter

Transmitter line

Onboard

Pickup

DCDC converter

- ✓ Distributed resonant capacitor application (length extension)
- ✓ Modular coreless technology (weight reduction, cost savings)
- ✓ Variability of extension length from 10m up to 250m

- ✓ 3-phase interleaved converter method application (miniaturization)
- ✓ Real-time wireless power supply-battery-propulsion device linkage technology
- ✓ Versatile energy flow control and SoC management of Battery

Application Strategies for WPT for LRT

Component design and testbed construction

Ground

Inverter

Transmitter line

Resonant capacitor

- ✓ New dielectric membrane configuration technology
- ✓ Minimization of bonding resistance through the application of microfabrication
- ✓ Localization of advanced overseas technology

Onboard

Pickup

DCDC converter

Battery pack

- ✓ **50 kWh LTO battery application**
- ✓ **Fast charge and discharge configuration**

Application Strategies for WPT for LRT

Component design and testbed construction

Ground

Inverter

Transmitter line

Resonant capacitor

Onboard

Pickup

DCDC converter

Battery pack

Testbed

WPT test track construction

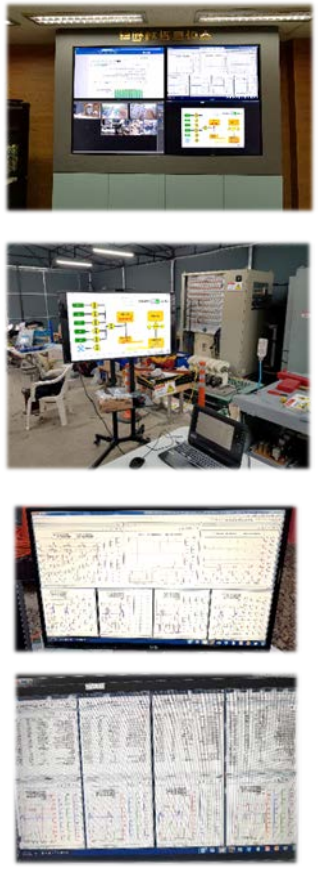
Operation system setup

Application Strategies for WPT for LRT

Component design and testbed construction

Static Test

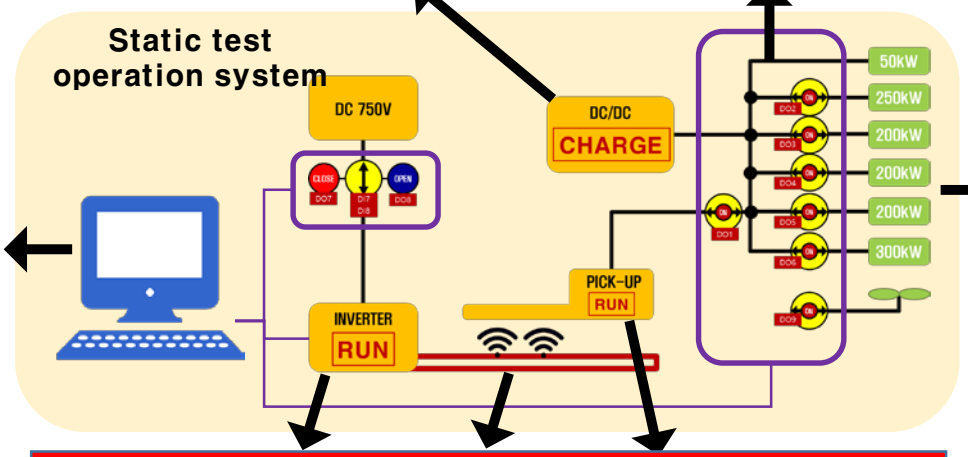
Control room



Stabilization device

Simulated load controller

Static test operation system



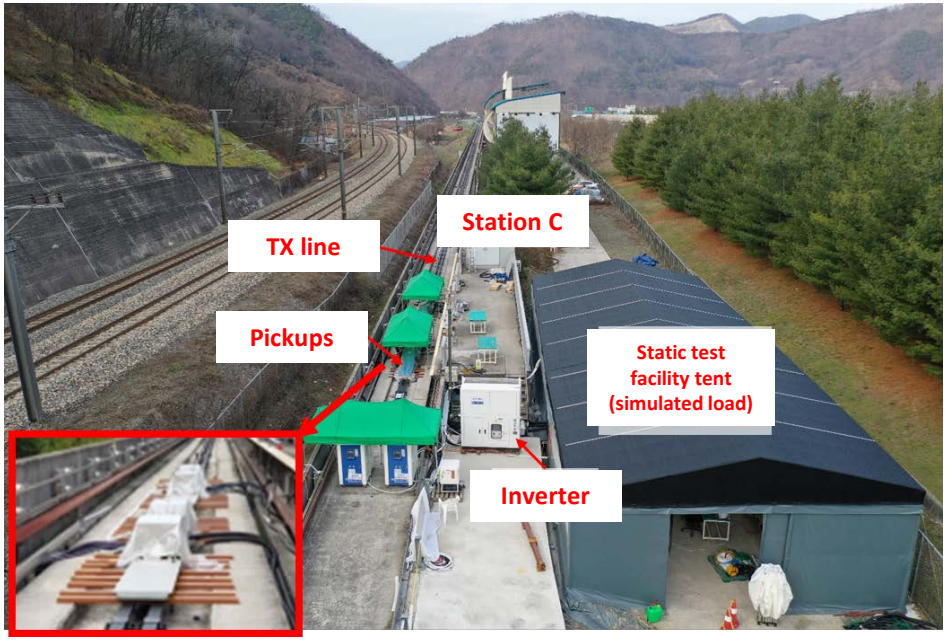
Simulated load device

Inverter, transmitter line, pickup

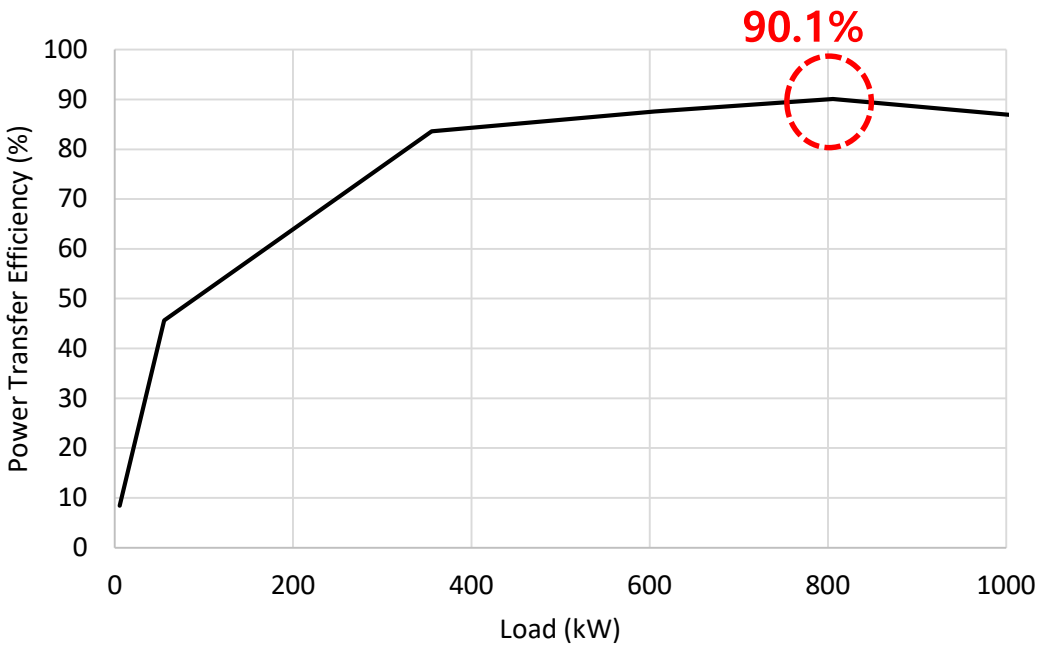
Application Strategies for WPT for LRT

Component design and testbed construction

Static test using resistive load



Static test environment



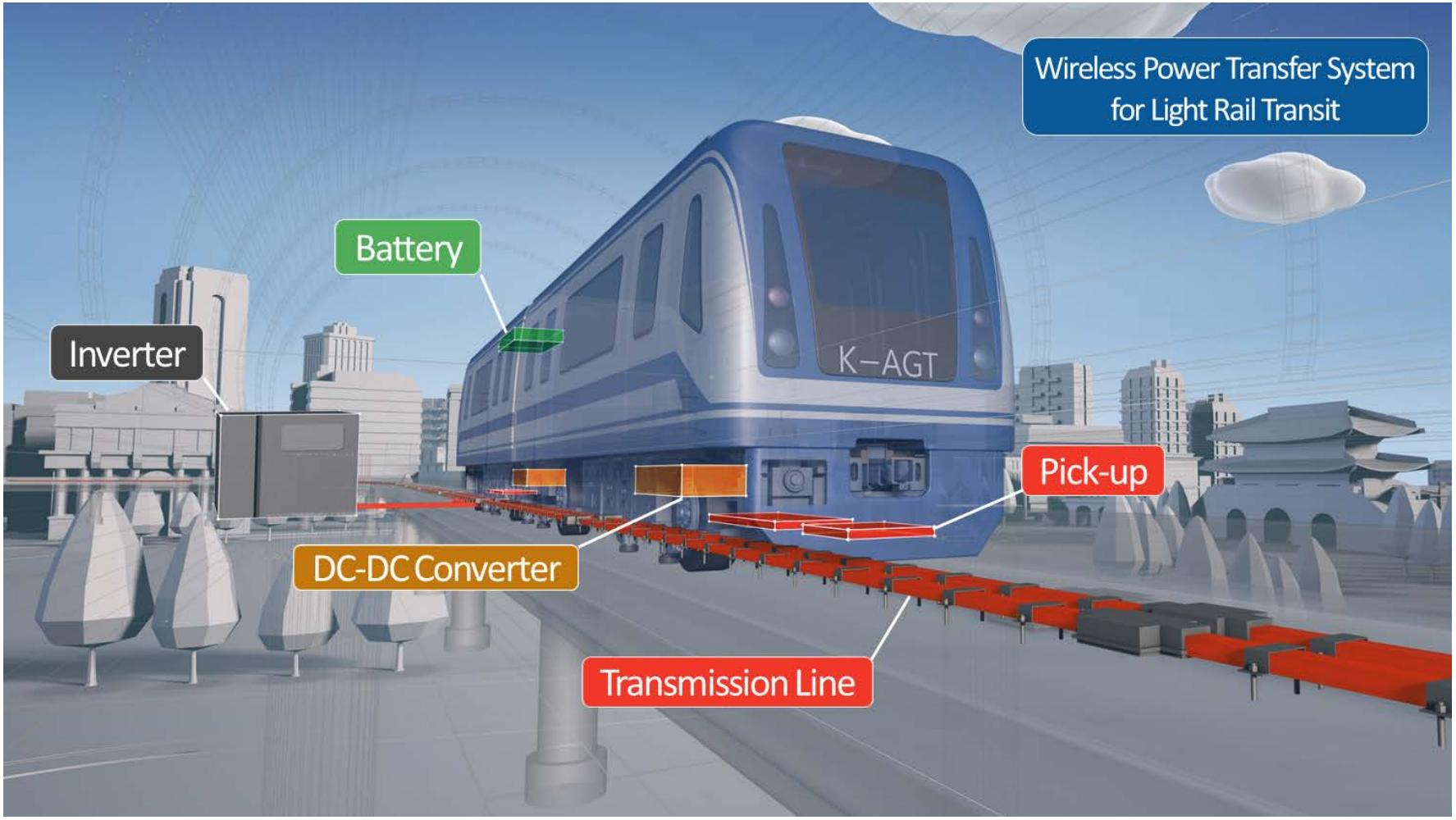
- Maximum power pickup: Over 1MW
- Maximum efficiency: 90.1%*

Overall wireless power transfer system efficiency result (KTL, 18-037625-01-2, 2018. 12.)

Application Strategies for WPT for LRT

Component design and testbed construction

Testbed construction



Application Strategies for WPT for LRT

Component design and testbed construction

Installations of onboard equipment (light rail vehicle)

Vehicle relocation for modification
(Gyeongsan test track)

Battery pack installation

DC-DC converter installation

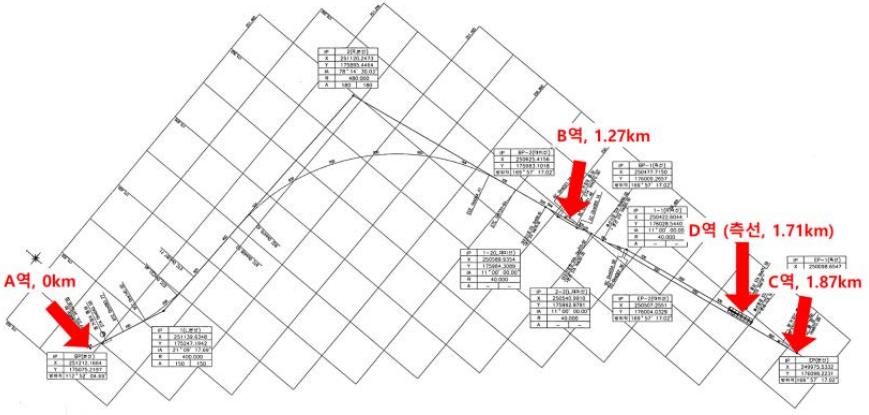
Pickup device installation

Application Strategies for WPT for LRT

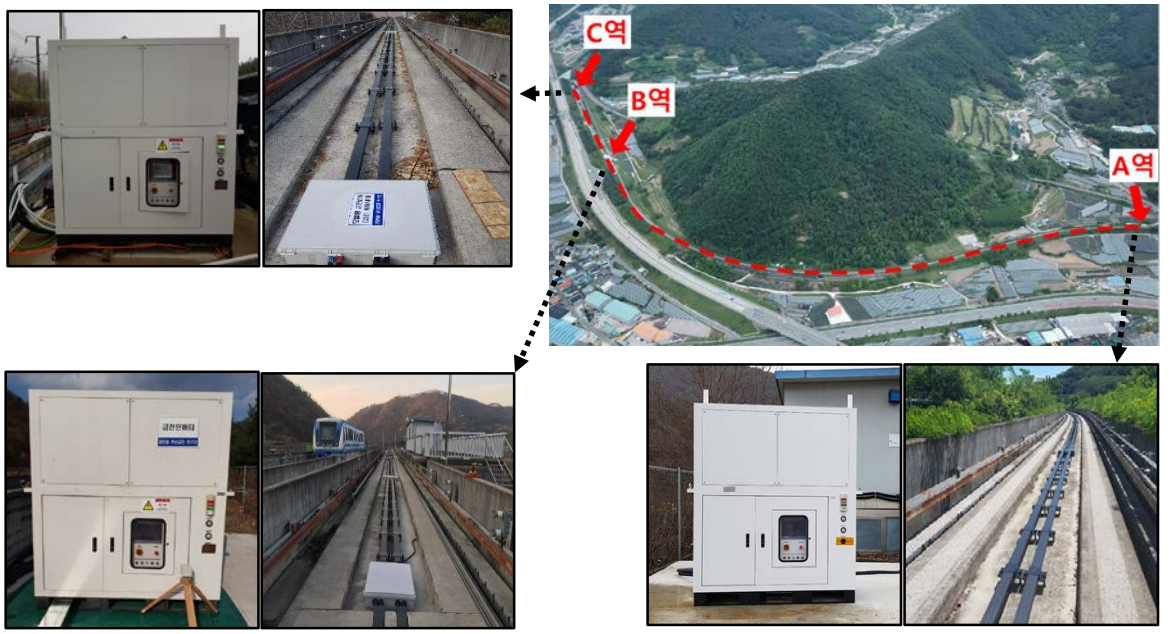
Component design and testbed construction

WPT test track construction (fixed installation of ground side)

Building exterior of WPT test track



- Transmitter line



- **Construction location: KRRI Light Rail Test Track (Gyeongsan, Gyeongbuk)**
- **Mainline length: 1.87km**
- **Constructed stations: Station A (250m), Station B (stopping section 30m, acceleration section 200m), Station C (200m)**
- **Vehicle type: Rubber-tired AGT system (2 cars, 1 trainset)**

Application Strategies for WPT for LRT

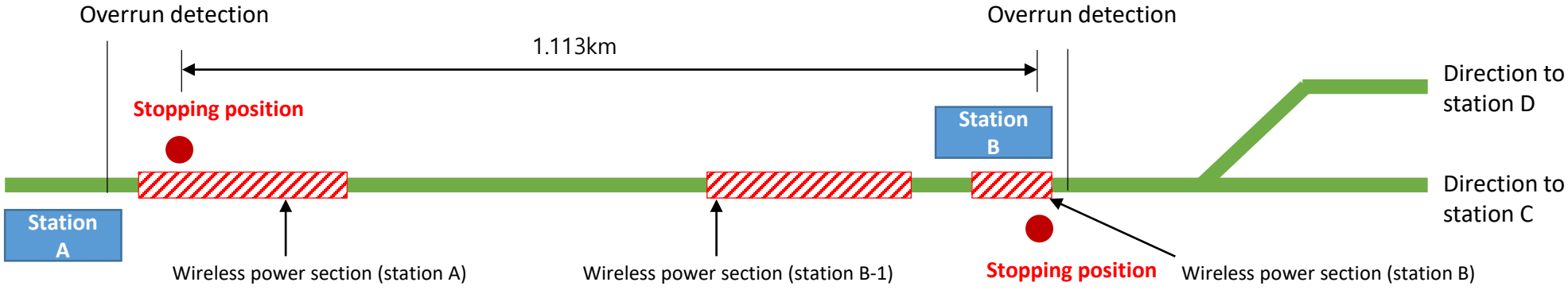
Component design and testbed construction

WPT test track construction

Application Strategies for WPT for LRT

Dynamic test plan

- Round trip between A and B stations (unmanned operation)



Station A (250m)

Station B-1 (200m)

Station B (40m)

Operating Results of WPT Test Track

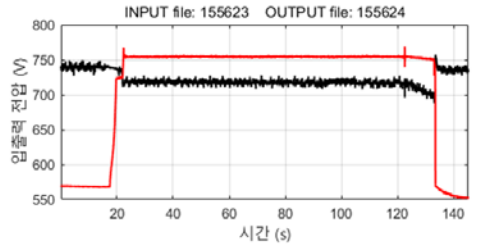
WPT light rail dynamic test

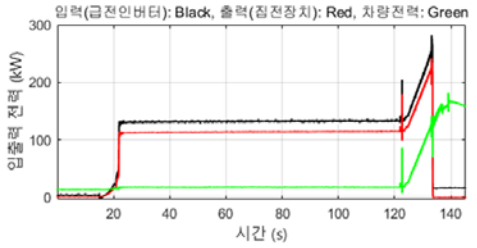
Efficiency in real vehicle application

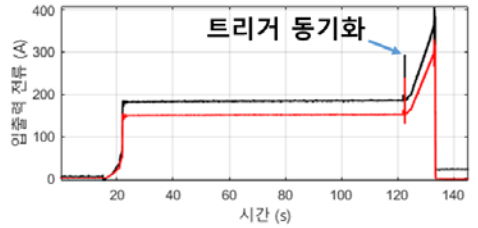
- Departure from Station B

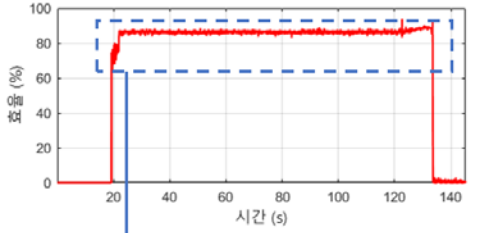
Input voltage/current

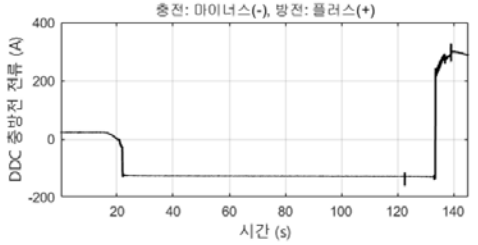
Output voltage/current, battery current, vehicle speed

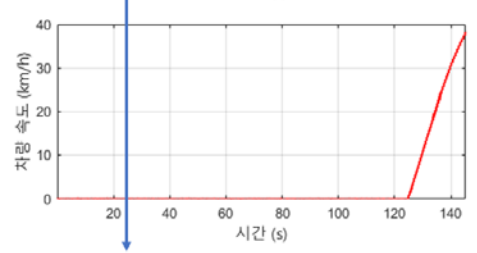




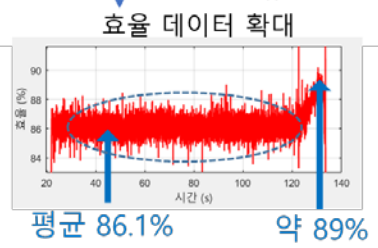








- Efficiency achieved 86~89% (53mm gap)

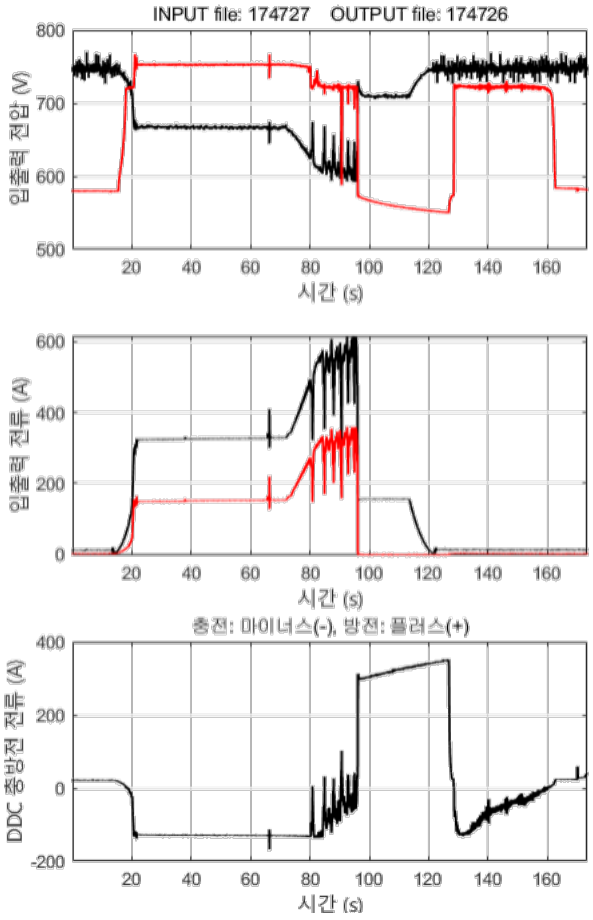


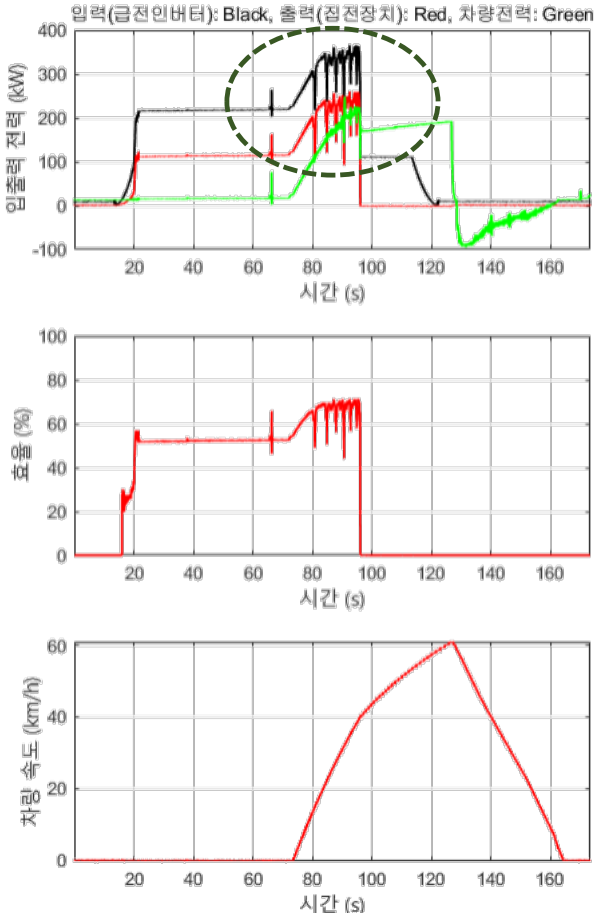
Operating Results of WPT Test Track

WPT light rail dynamic test

Efficiency in real vehicle application

- Departure from Station A





- Maximum collected power: about 250kW
- Efficiency: 72%
- Dead zone (capacitor box)

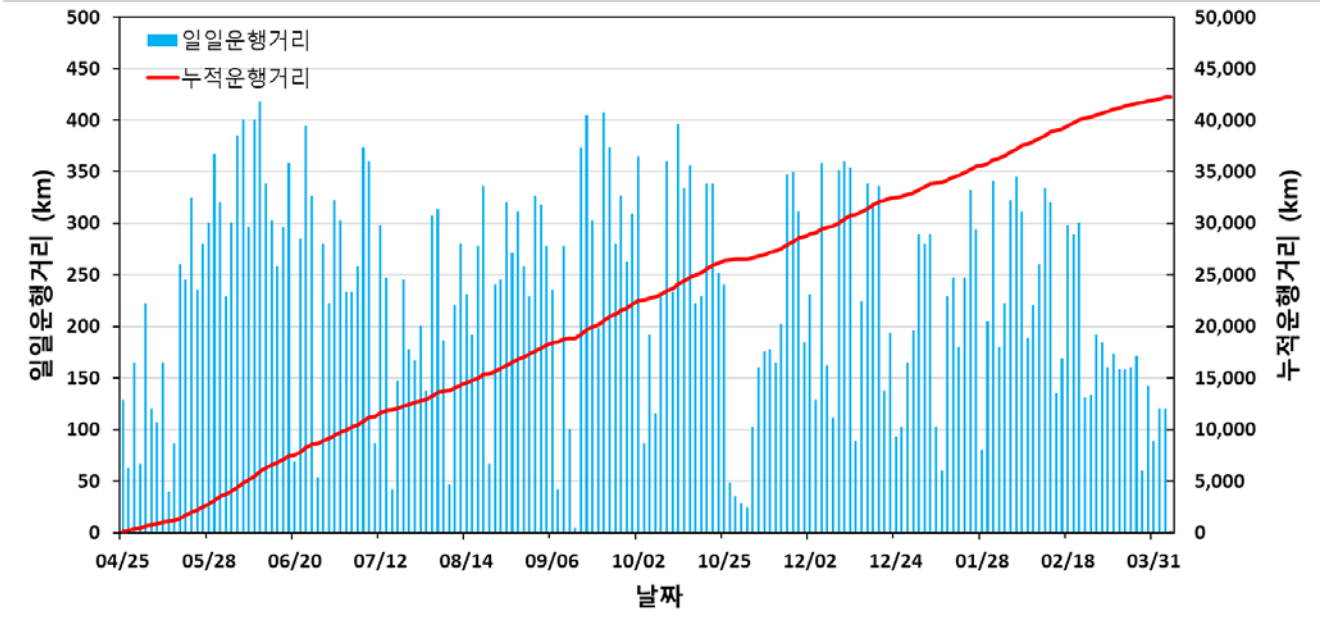
- Efficiency decreases caused by operation of light load (less than half of the designed rated output, 1MW)

Operating Results of WPT Test Track

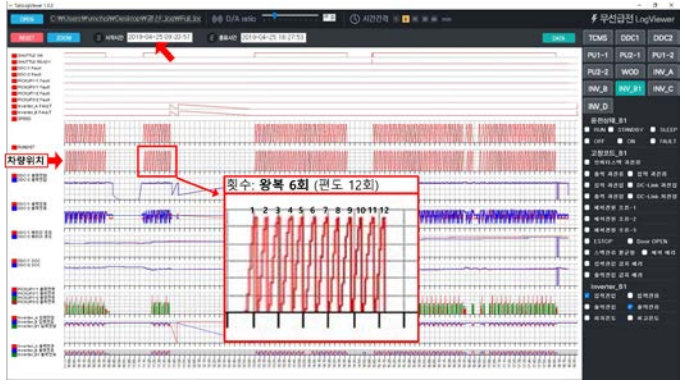
WPT light rail dynamic test

Test drive (shuttle operation)

Test period	Total round trip	Total accumulated distance* (Round trips*2.226km)
2019.04.25 ~ 2020.04.21	18,959	**42,203**



Driving distance statistics

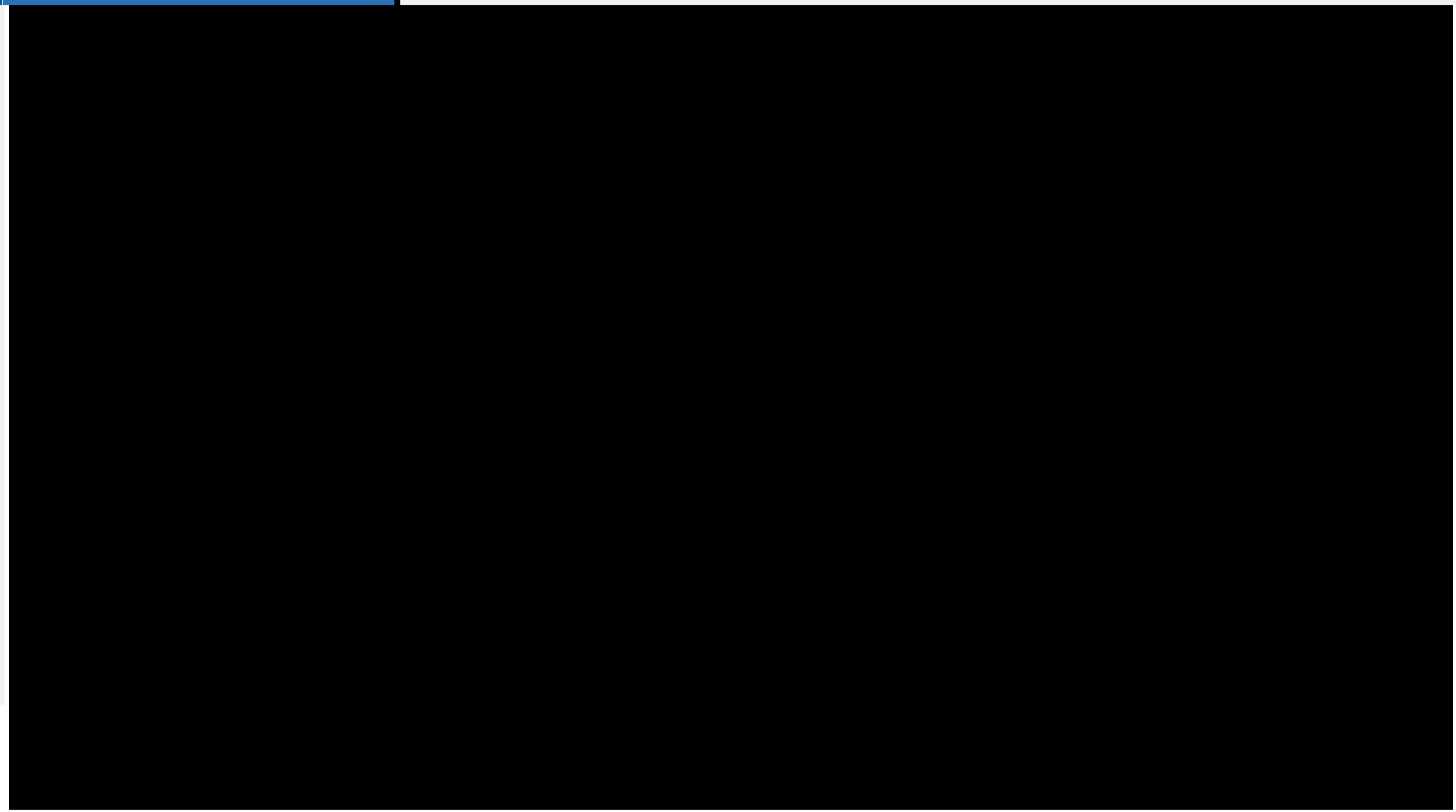


Log record analysis

*Wireless power supply system test drive results (KTL, 20-031895-01-1, 2020.06.)

Operating Results of WPT Test Track

WPT light rail dynamic test



Operating Results of WPT Test Track

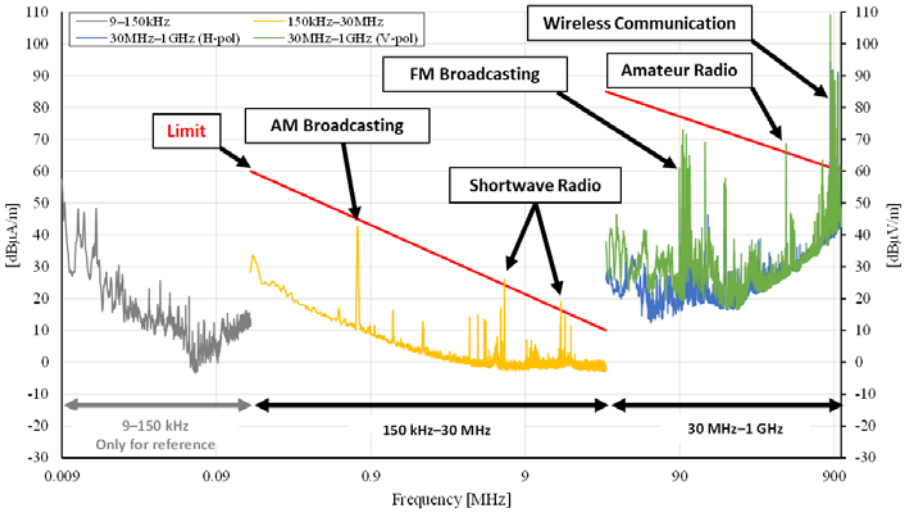
WPT light rail dynamic test

EMI Measurement

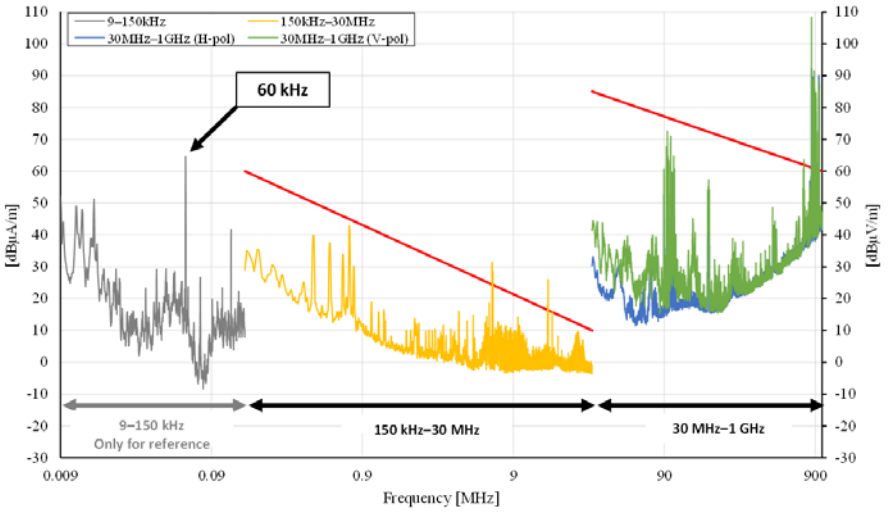
- Radiation standard for railway vehicles: IEC 62236-2
- Measurement taken 10m away from the center of the track

Operating Results of WPT Test Track

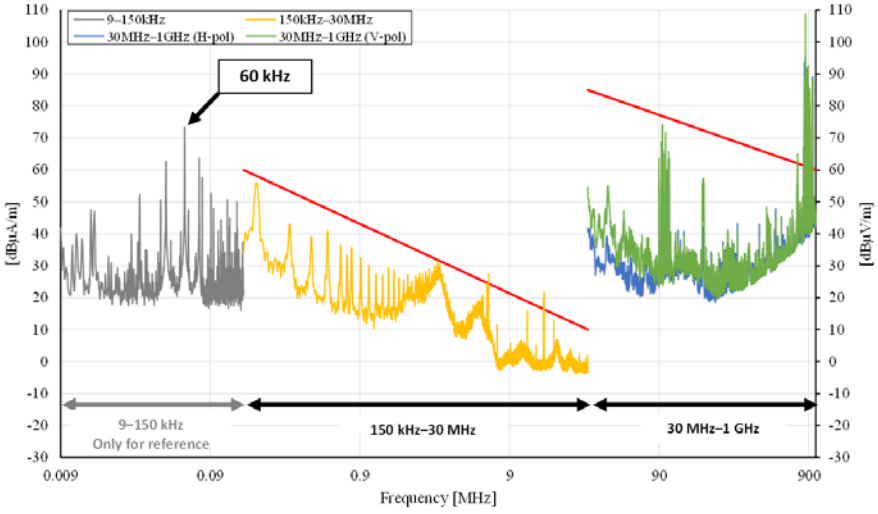
WPT light rail dynamic test



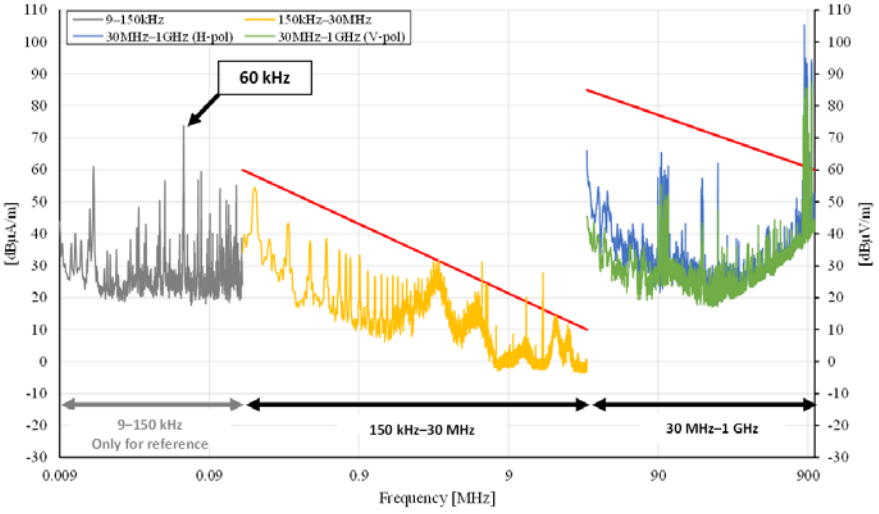
Background noise



Charging during stop



Low-speed operation



High-speed operation

Conclusion

- Proposing a commercialization of a wireless power supply system for domestic light rail
- Applying 1MW output and 50kWh battery to semi-dynamic wireless power transfer method
- Fabrication and verification of developed equipment and combined system (maximum efficiency 90.1%)
- Completed 40,000km of four-season running test using a light rail WPT test line built in Gyeongsan
- EMI measurements also meet the standard

Thank you

한국철도기술연구원
Korea Railroad Research Institute