DC Microgrid Technology toward Green E-Transportation

Yanbo Wang
Department of Energy Technology, Aalborg University
ywa@et.aau.dk

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Background

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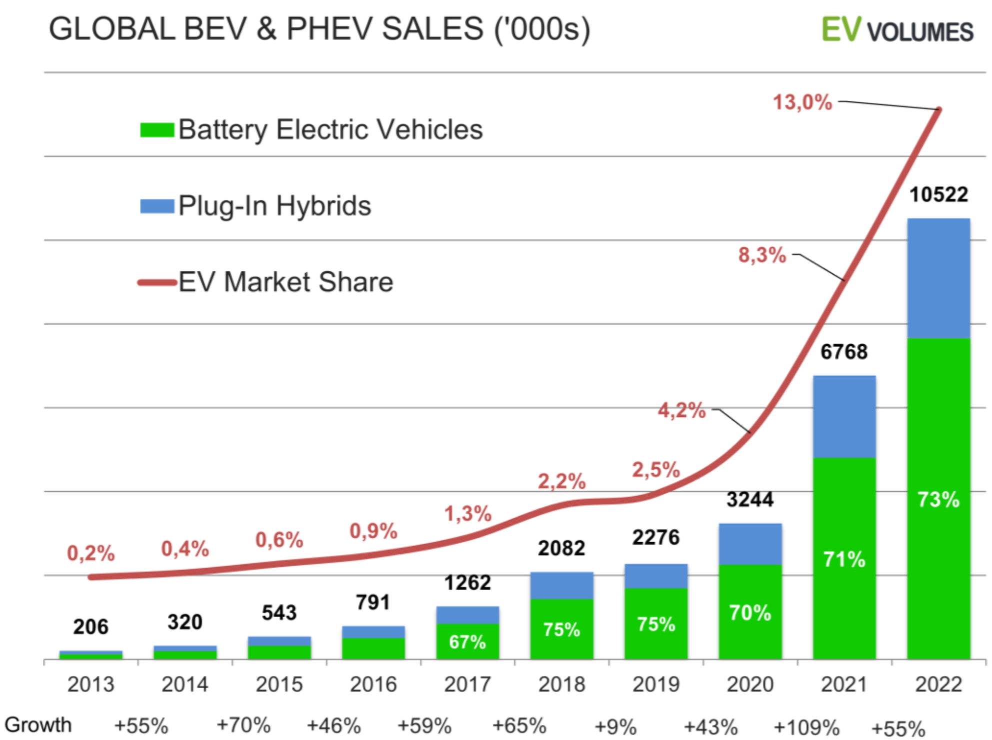

Battery Electric Vehicle

Hybrid Vehicle

- 10.5 million new EVs were delivered during 2022, an increase of 55% compared to 2021.
- It is estimated that there is 14.3 million EVs sales in 2023, a growth of 36% over 2022.

Fuel cell Electric Vehicle

Source: Electric vehicle world sales database.

Green Transition in Transportation in Denmark

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In Aalborg, the city bus system will be **100%** electrified until the end of 2023.

Battery-powered bus

Electric ferry

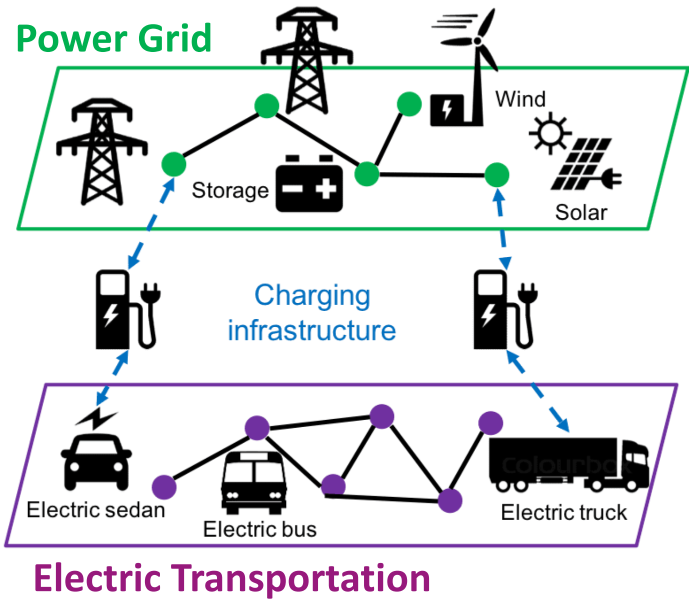
Supercap-powered bus

Charging station

Methonal truck

E-transportation toward 100% is pending!

New Opportunities and Challenges



The increasing penetration of ***Electric Transportation*** promotes the revolution of modern power system.

- ✓ Carbon emission reduction
- ✓ High energy efficiency
- ✓ Government support for tax breaks

The rapid development of ***Electric Transportation*** poses new technical challenges.

- Challenges in security and stability of power grid
- Complicated load characteristics of Electric loads (Power converter-interfaced loads)
- Electric fuleling station and charging infrastructures
- Electricity services for E-transportation
- Business model of E-transportation value chain

What are roles of Microgrids in future Green E-transportation?

https://skliotsc.um.edu.mo/power-and-transportation-nexus-transportation-electrification-and-autonomous-driving/

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Microgrid-based Solution for Green E-Transportation

- DC Microgrid-based Vehicle-to-Grid (V2G) solution
- DC Microgrid-based metro traction power system
- DC Microgrid-based hybrid metro traction power system

DC Microgrid-based framework for Green E-Transportation

- DC Microgrid-based Vehicle-to-Grid (V2G) solution
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1. DC Microgrid-based V2G solution

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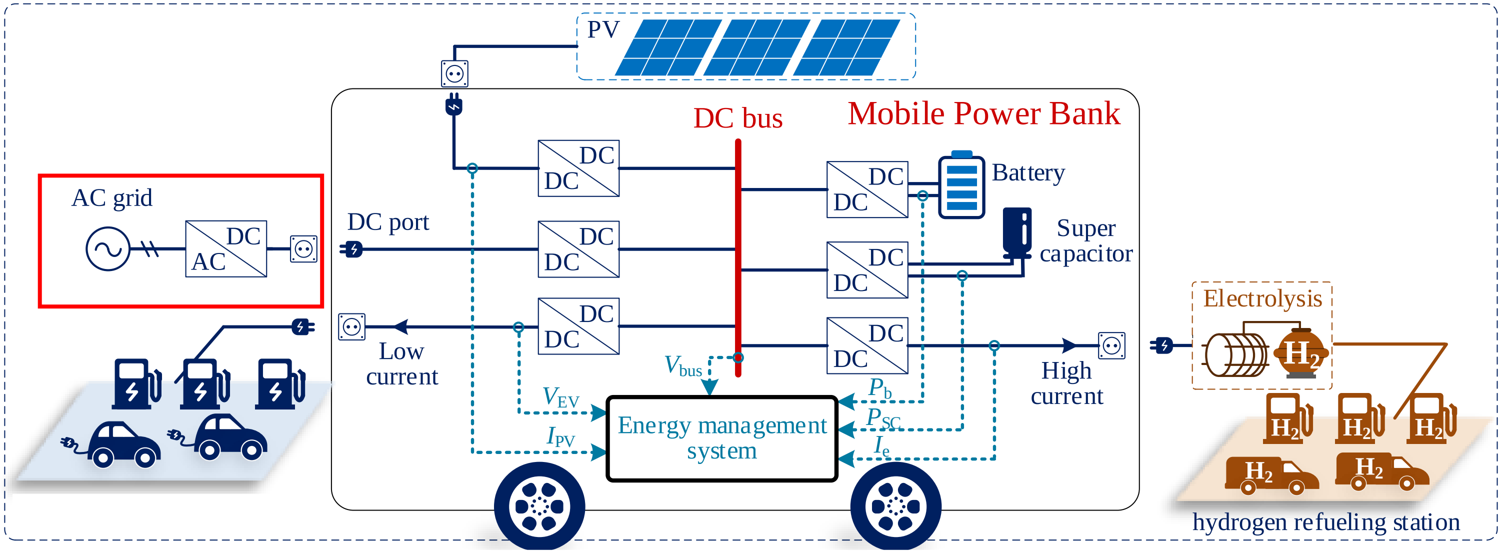
A compact and mobile power bank based on DC microgrid



- DC microgrid-based V2G solution (Grid-connected/Islanded)
- Hybrid energy storage system (HESS): adjust peak-to-valley difference and smooth power peak
- Electricity service for E-transportation such as road assistance

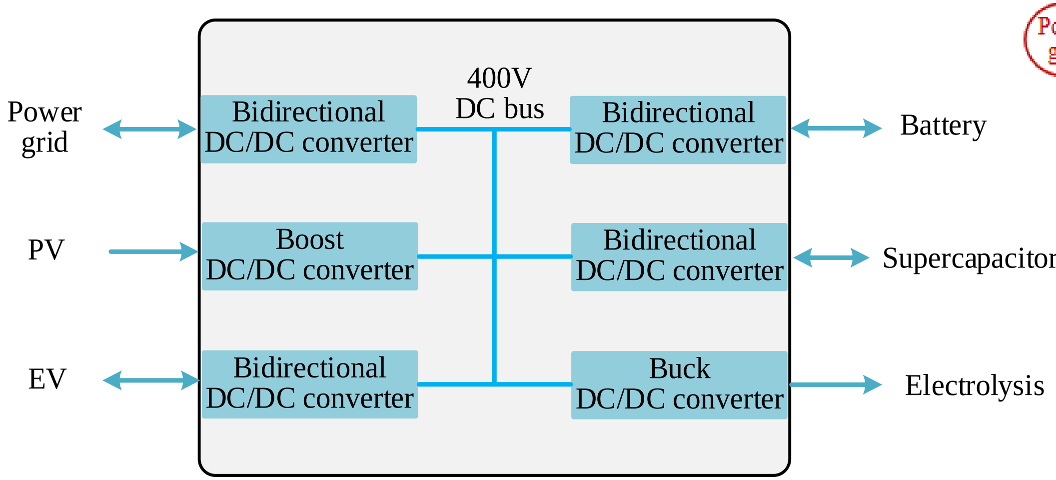
Grid-connected operation

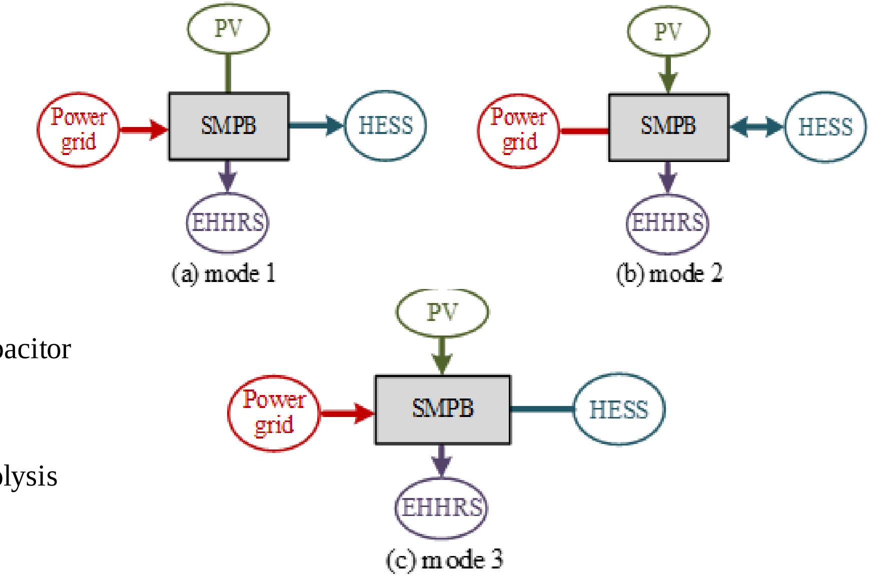
- Electricity price-dependent power management and economic benefits
- Energy storage system control
- Peak-to-valley power balance

Islanded operation

- Mobile charging
- Emergency resuce
- Road assistance

The operation modes of SMPB





Mode 1: Grid supplying mode

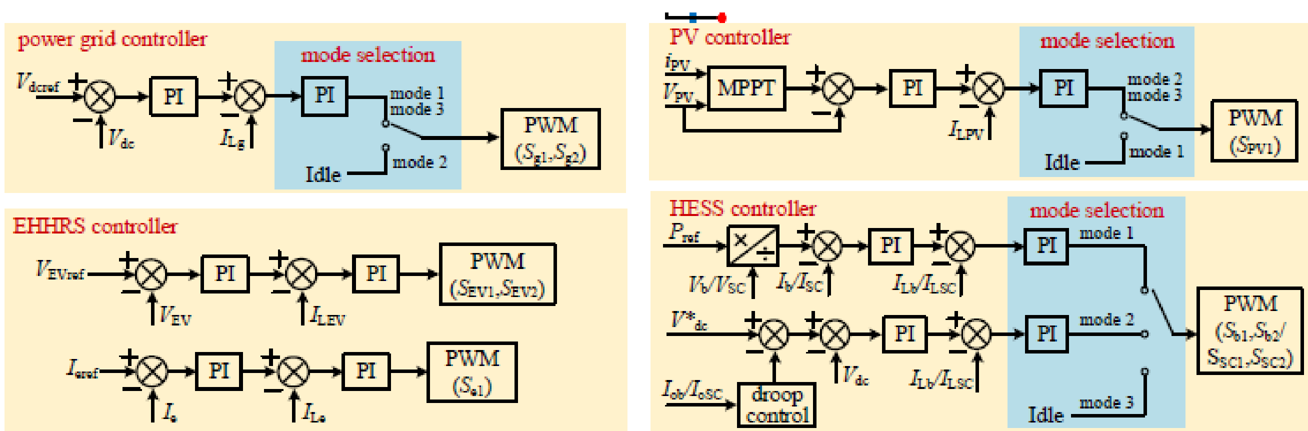
- PV is out of operation during the nighttime
- Power grid provides the power supply for EVs and ES under a low electricity price

Mode 2: Independent operating mode

- The power of PV and the SOC of HESS is sufficient during the daytime

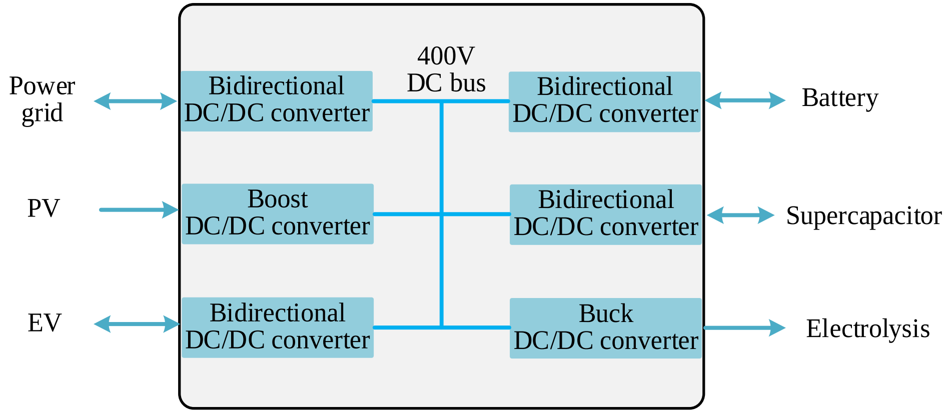
Mode 3: Hybrid supplying mode

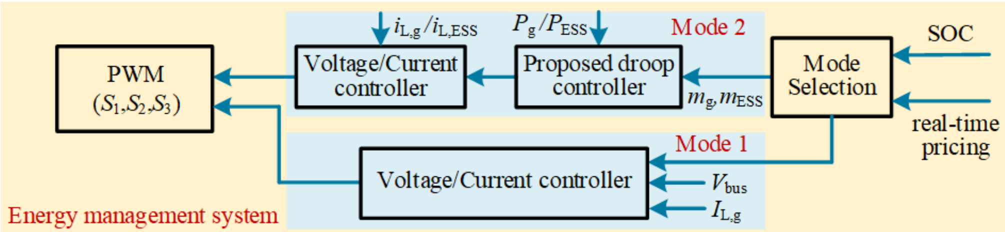
- The power of PV is insufficient and the SOC of HESS is less than 20% during the daytime.

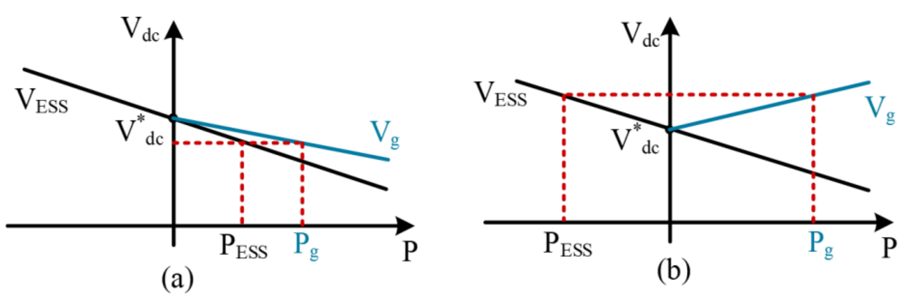


Control Strategy

Electricity Price-prioritized Droop Control Strategy



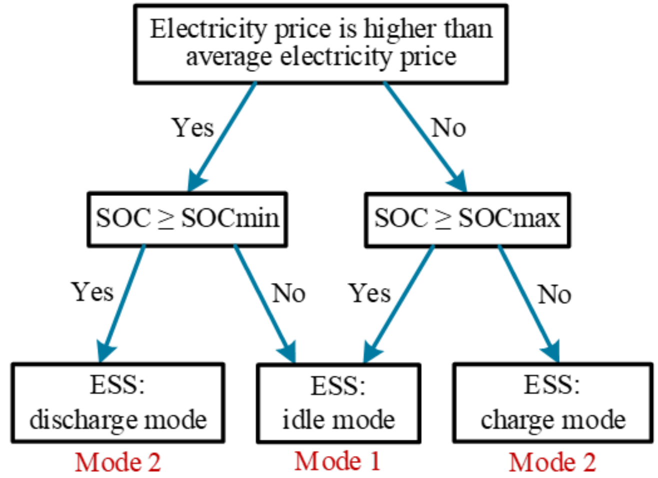




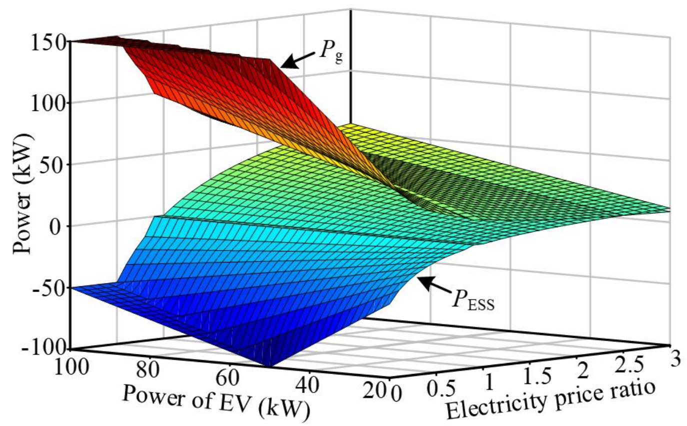
The V-P droop curve of the proposed power controller. (a) ESS: discharge mode. (b) ESS: charge mode.

$$V_{ESS}^{ref} = V_{dc}^{*} - m_{ESS} P_{ESS}, m_{ESS} = \frac{V_{max} - V_{min}}{P_{ESS,max}}$$

$$V_{g}^{ref} = V_{dc}^{*} - m_{g} P_{g}, m_{g} = \frac{\lambda_e (V_{max} - V_{min})}{P_{g,max}}$$

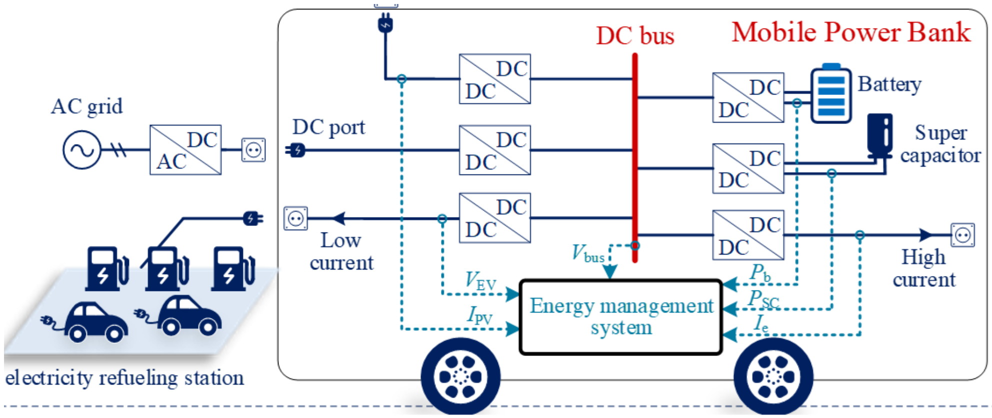


Operation modes



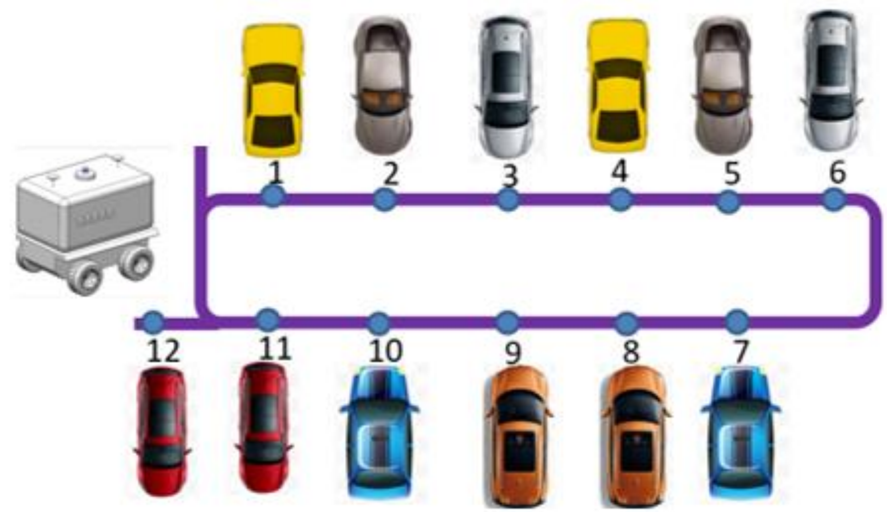
The electricity price coefficient λ_e is introduced into droop coefficient m_g to form the proposed droop control equation.

Demonstration with the proposed solution



- ESS
- Multi-port design
- App terminal
- Blue tooth

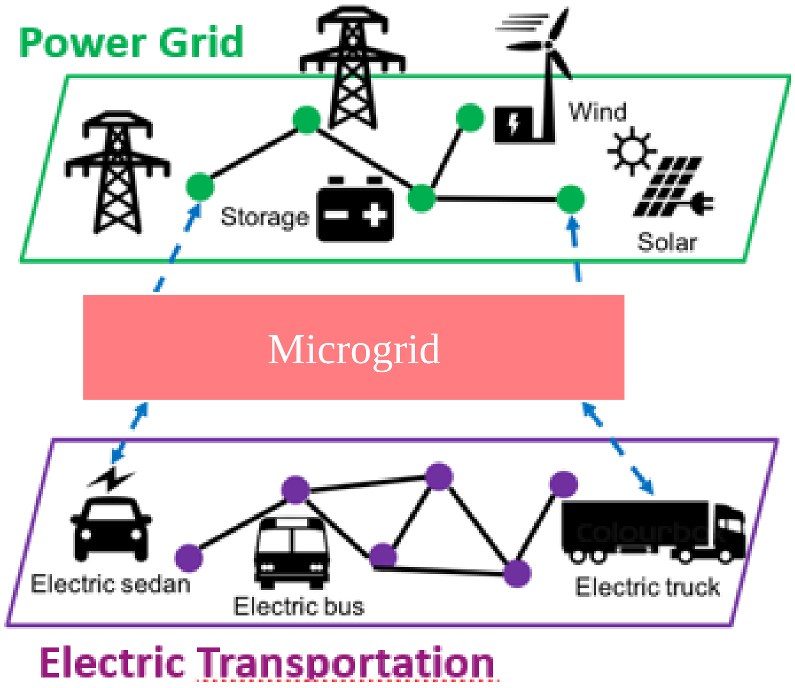
Demo Project with the proposed solution



Application in Parking Lot

DC microgrid-based V2G solution

DC Microgrid can contribute to green E-transportation system, which likes an "electric spring" to bridge power grid and E-transportation.



Grid-connected operation

- Regulate peak-to-valley difference
- Improve security and reliability
- Electrity price-dependent energy business

Islanded operation

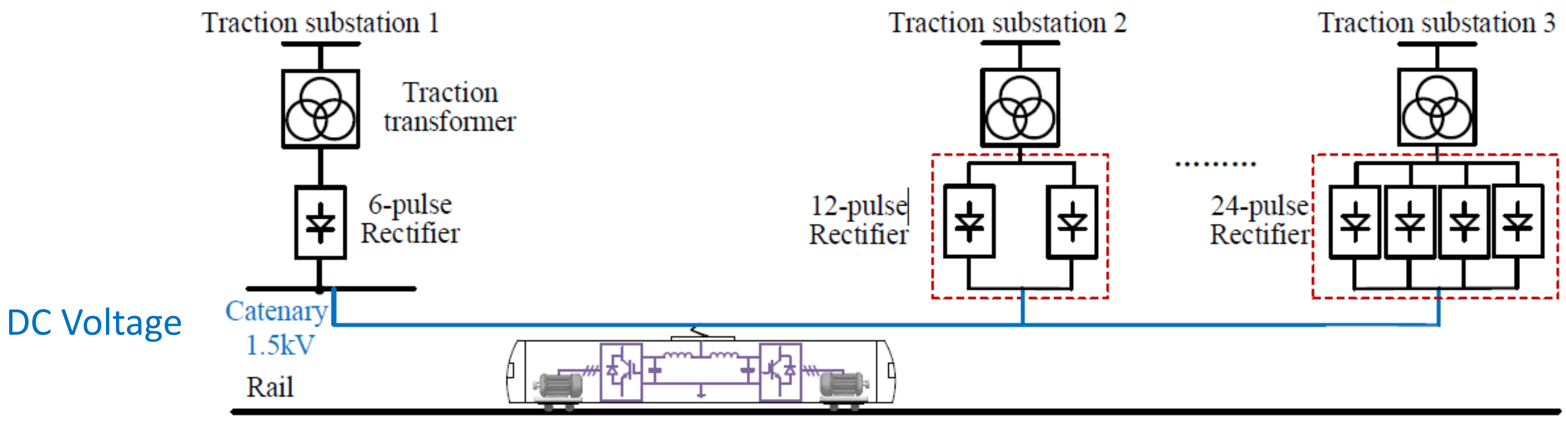
- Emergency resuce
- Offline electricity service such as road assistance
- Improvement of charging efficiency in parking lots

DC Microgrid-based framework for Green E-Transportation

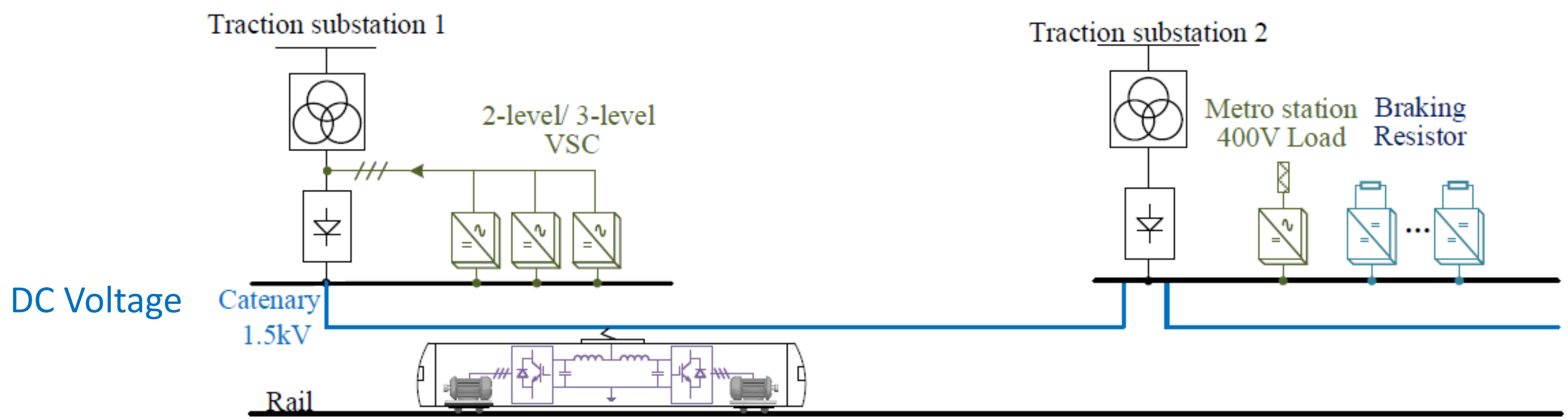
- DC Microgrid-based Vehicle-to-Grid (V2G) solution
- DC Microgrid-based metro traction power system
- DC Microgrid-based hybrid metro traction power system

Metro Traction Power Supply System

Metro transit system is an important public utility in metropolitan areas.

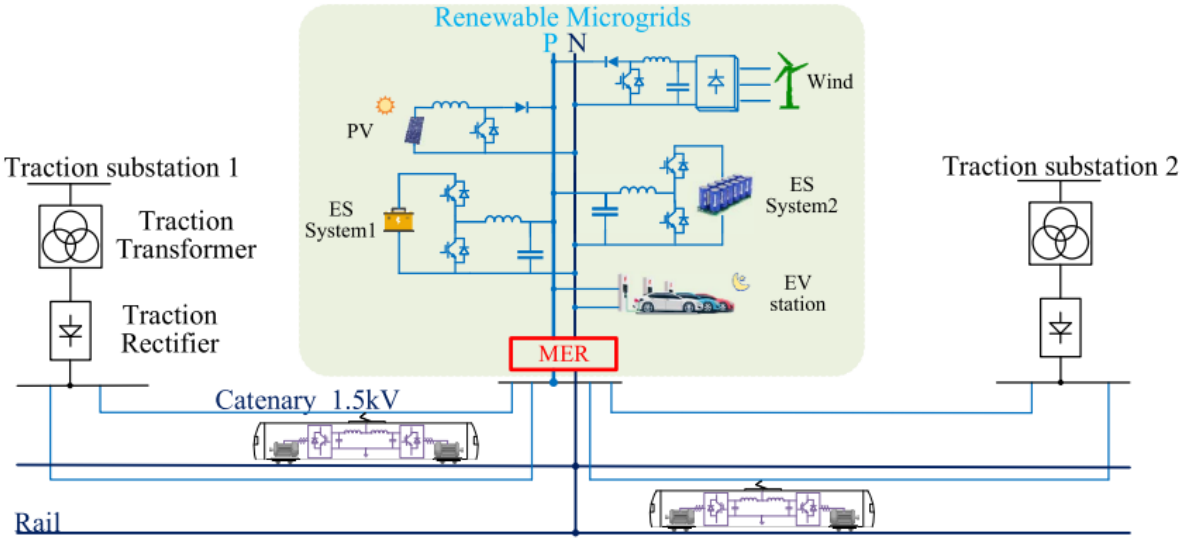


The diagram of conventional metro traction power system



The diagram of metro traction power system with ***regenerative braking appliacation.***

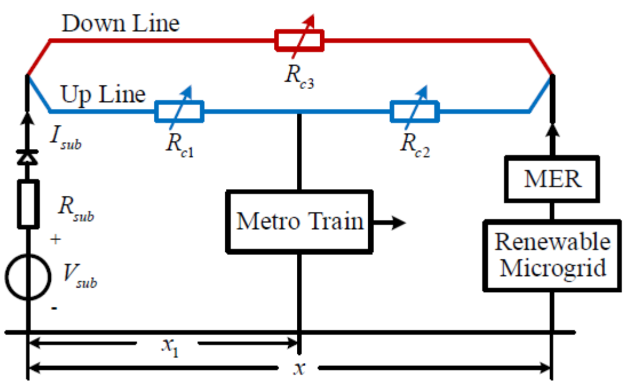
DC Microgrid-based Metro Power System



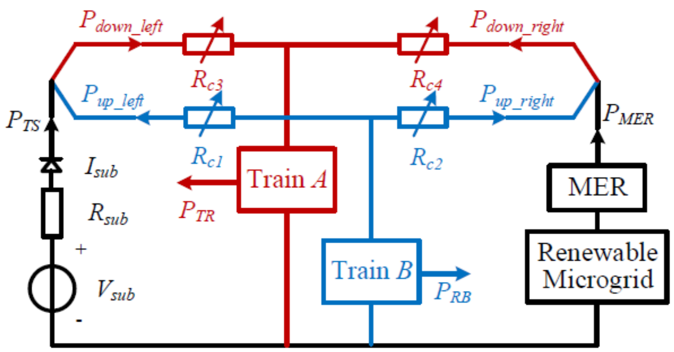
The proposed microgrid-based metro power supply system

The microgrid is operated as a dynamic regulator.

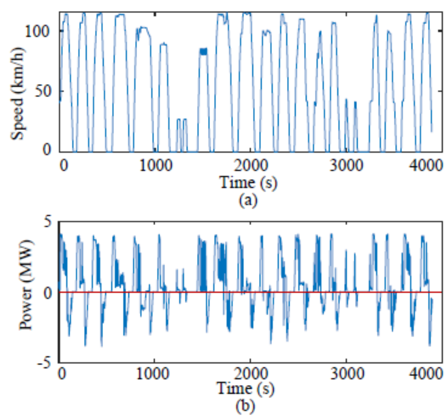
- Integrate renewable energies
- Reduce energy consumption
- Improve security and reliability of power supply
- Improve power supply capability and extend distance between substations



Model of traction network with single train

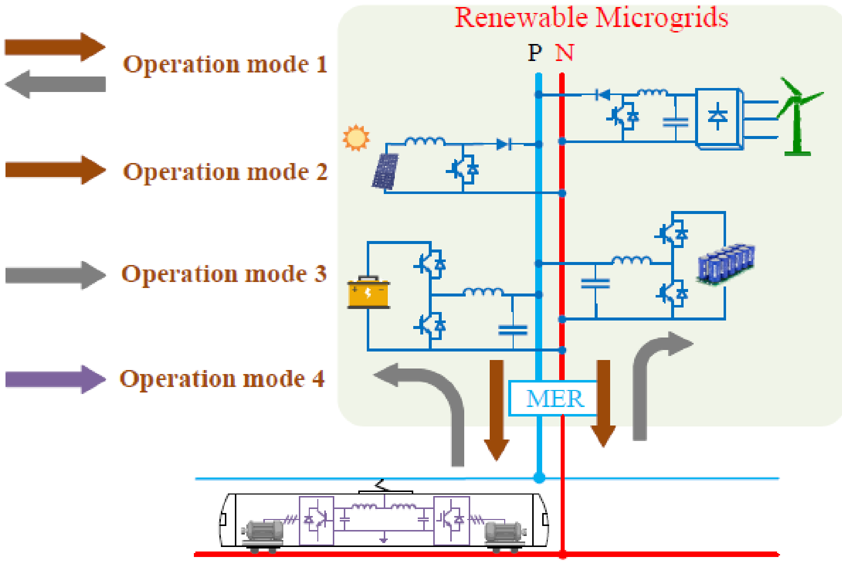


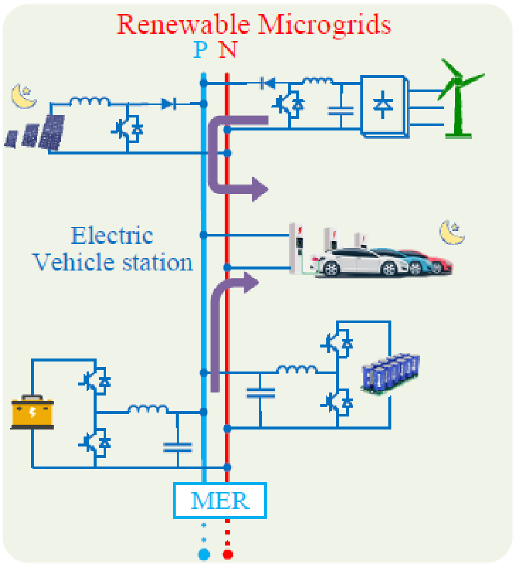
Model of traction network with multiple trains

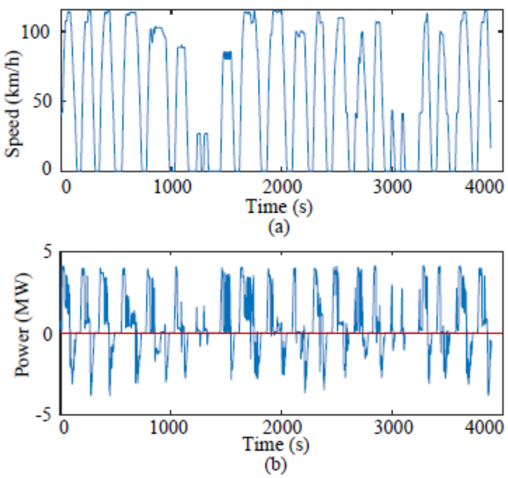


Practical load profile

Operation Mode







Practical metro load profile

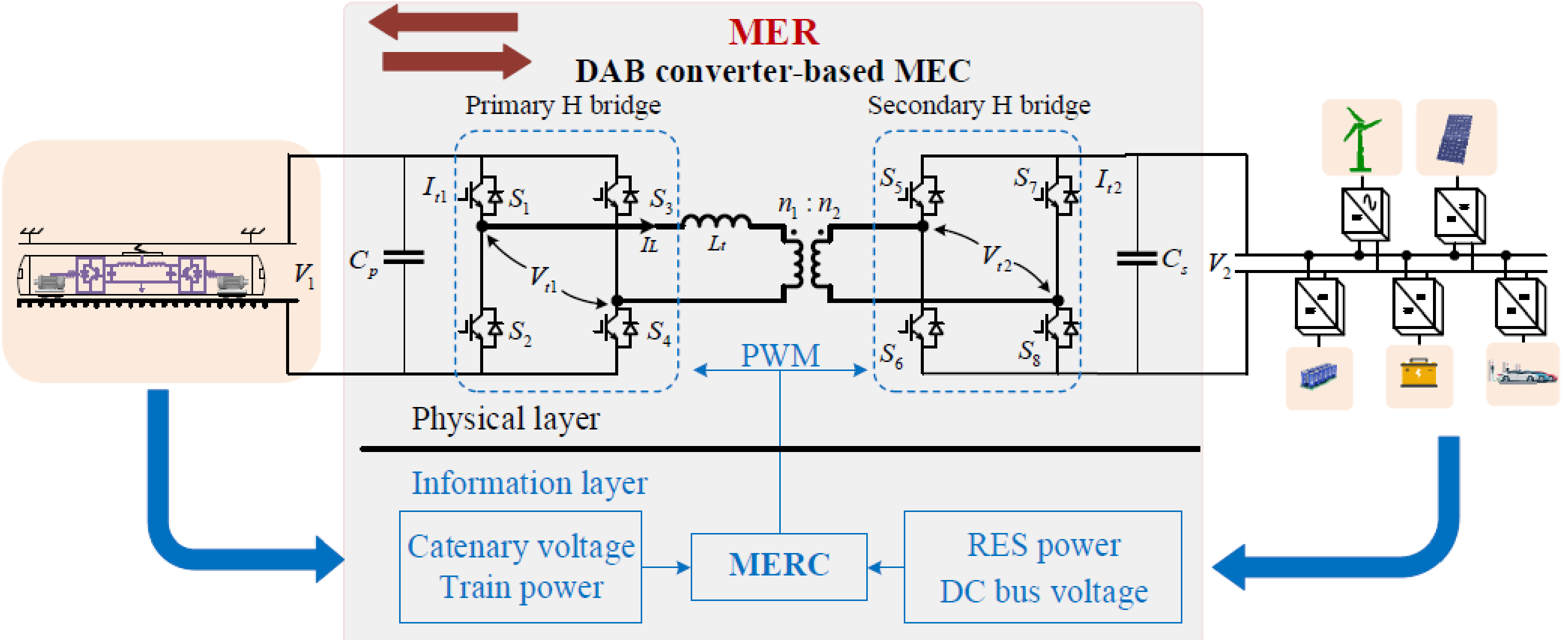
Grid-connected operation

- **Mode 1 (Voltage control)**: Catenary voltage regulation for multiple trains operation
- **Mode 2 (Power control)**: : Power control to reduce energy consumption from traction substation and enhance dependence of metro system on power system.
- **Mode 3**: **Regenerative braking support mode** (RB energy recycle)

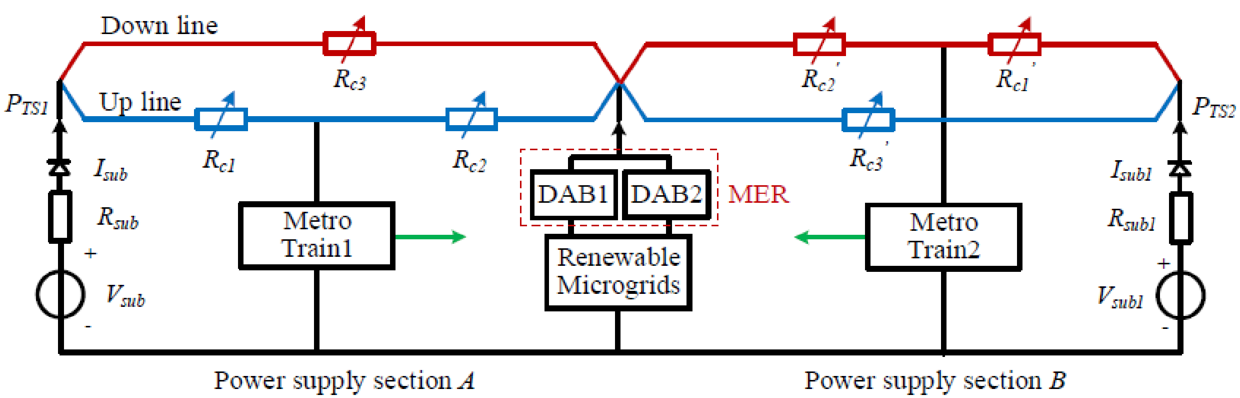
Islanded Operation (Nighttime)

- **Mode 4 :** The stored RB energy is sold to obtain economic benefits.

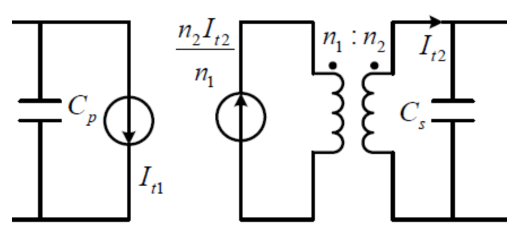
The Proposed Energy Management Strategy



The diagram of the proposed system



Model of multiple power supply sections with microgrids

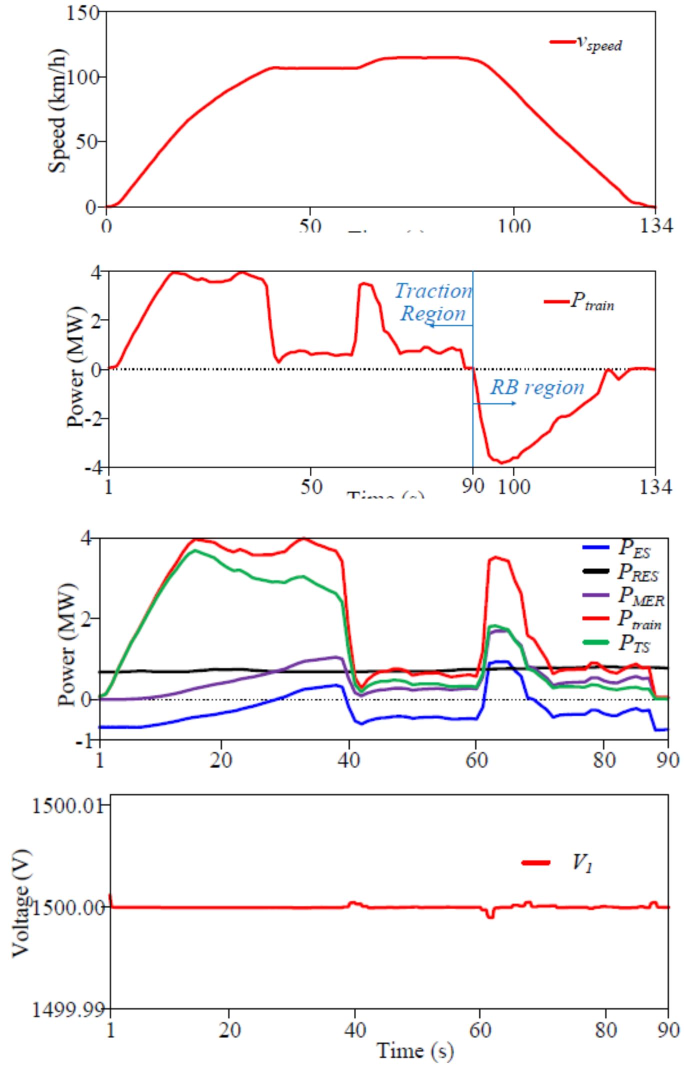


$$P = \frac{(n_1 / n_2) V_1 V_2}{2 f_s L_t} d(1 - |d|)$$

Power relationship

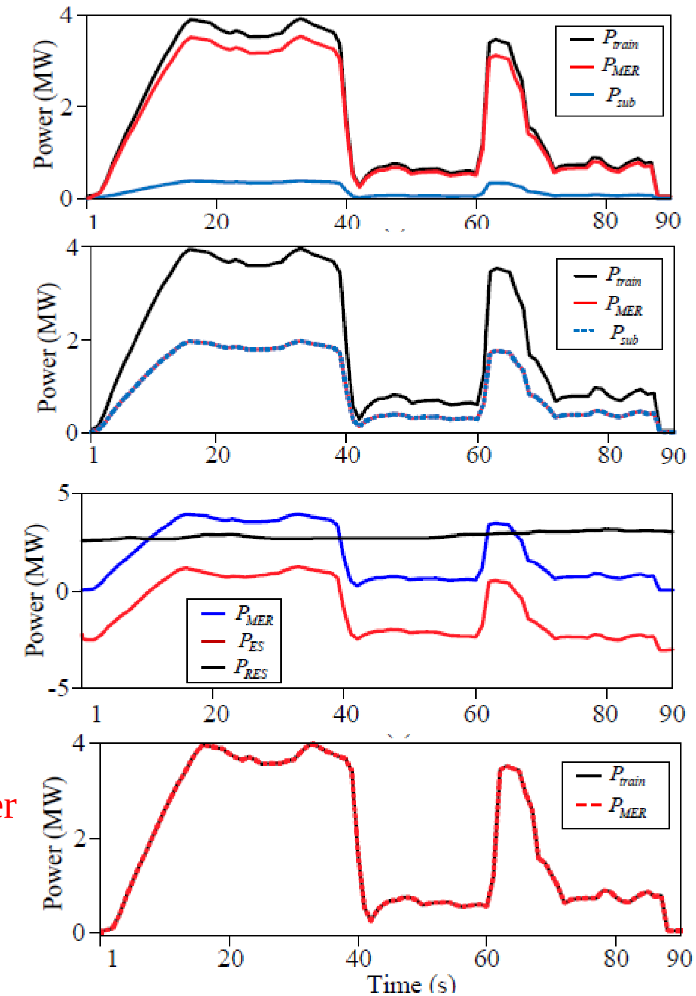
Practical Measured data-based HIL Verification Result

Mode 1: Voltage Control



- Catanary voltage is stabilized at 1500V.
- RES and ES are well balanced.

Mode 2: Power Control



100% power supply by microgrid

- Microgrid is flexibly operated to regulate output power for metro power supply.
- Microgrid independently supplies MTPS in presence of failure of metro power supply.

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DC Microgrid-based framework for Green E-Transportation

- DC Microgrid-based Vehicle-to-Grid (V2G) solution
- DC Microgrid-based metro traction power system
- DC Microgrid-based hybrid metro traction power system

3. Electricity-Hydrogen-Integrated Metro Power System

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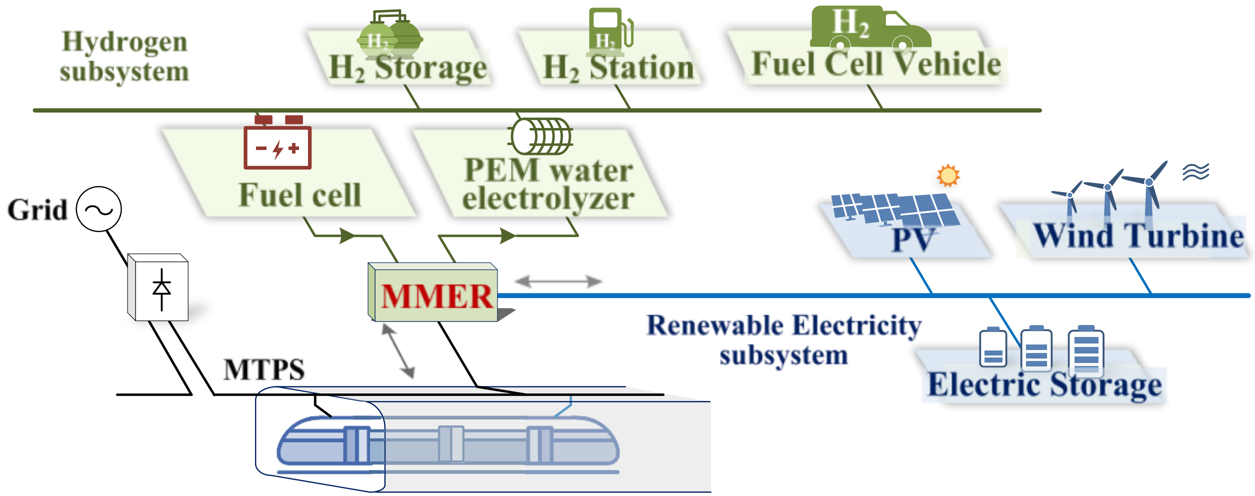
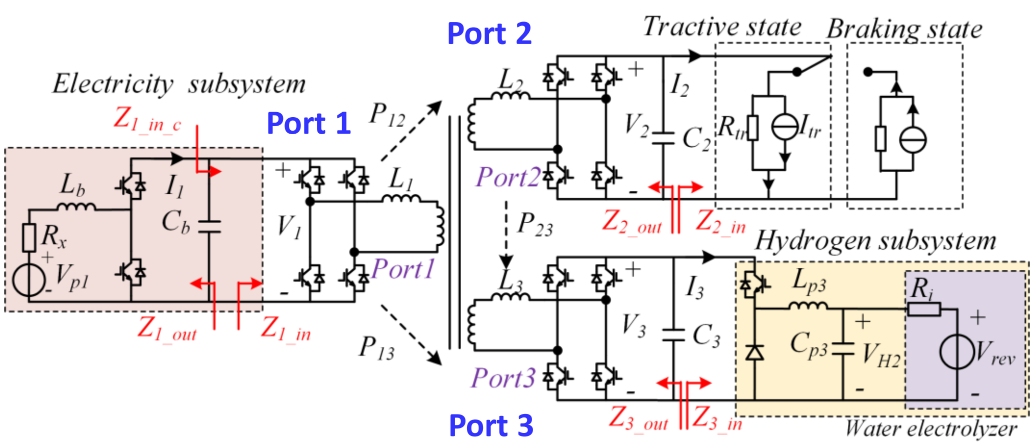
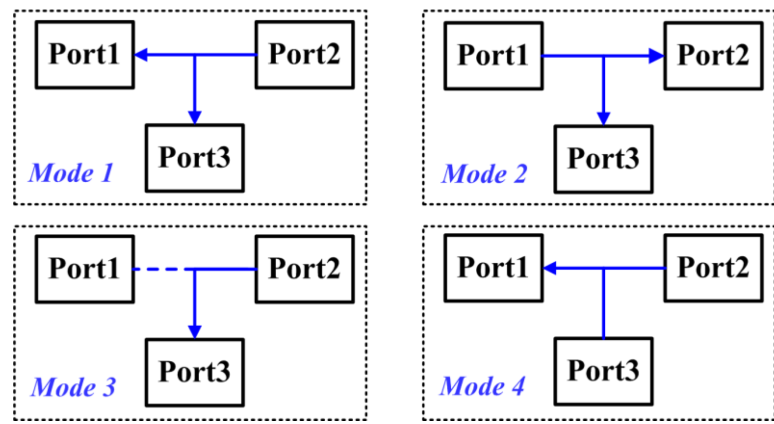


Integrated DC microgrid (Electricity/Hydrogen)

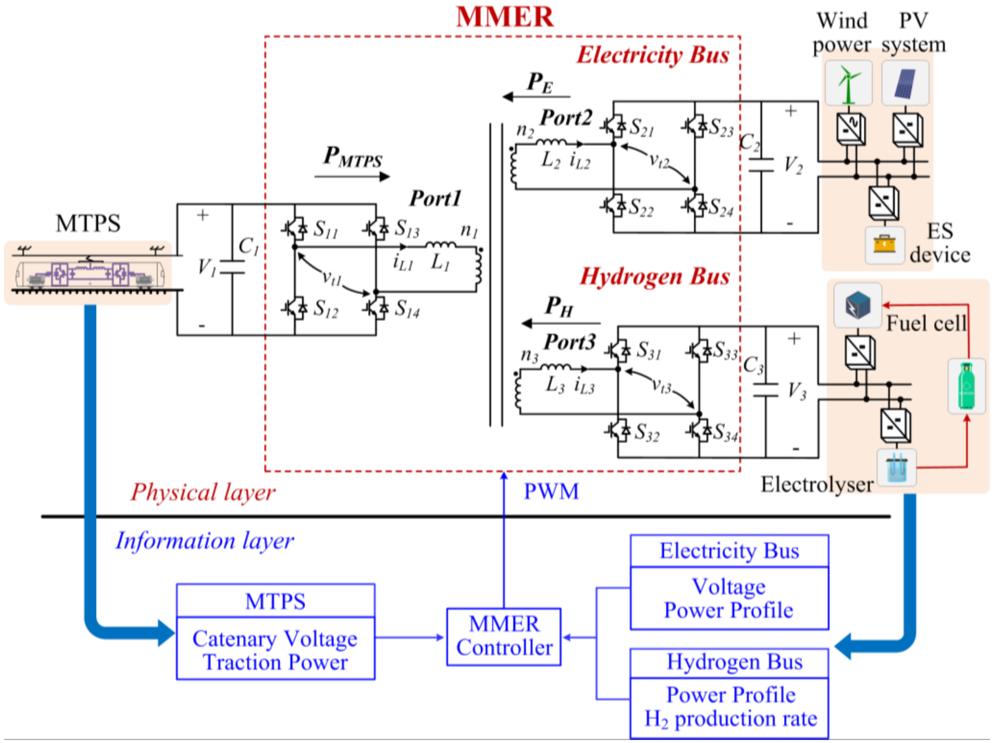


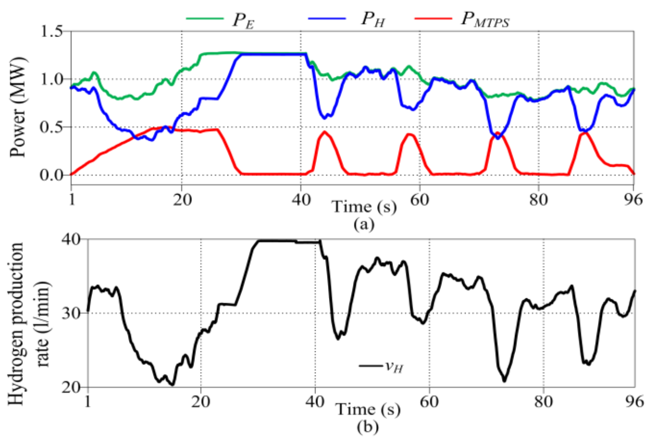
System modelling considering metro power system and integrated DC microgrid



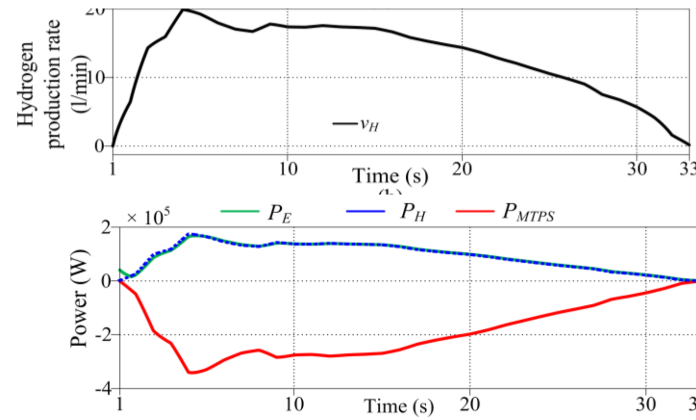
Operation mode

Control Strategy

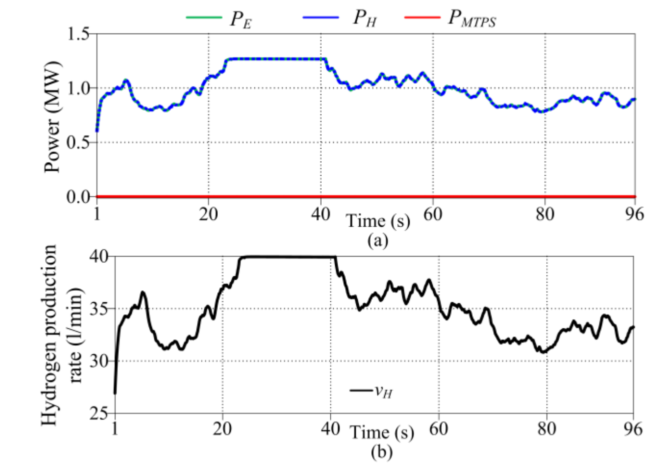




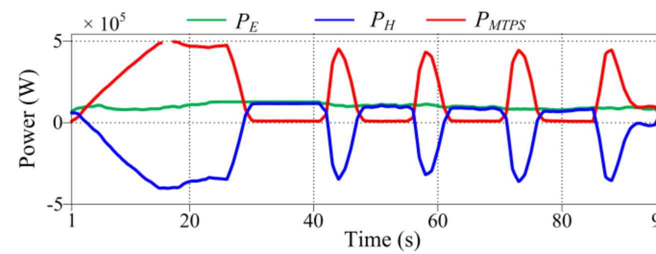
Metro system and hydrogen production by electricity subsystem



Regenerative braking energy utilization

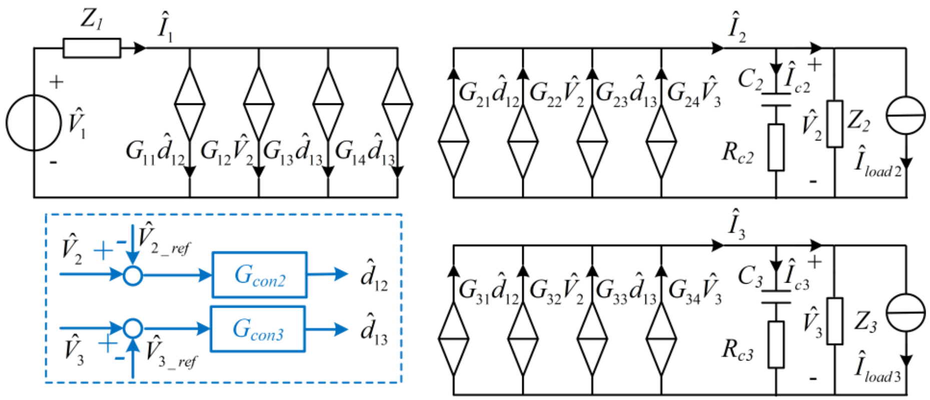


Renewable energy for hydrogen production

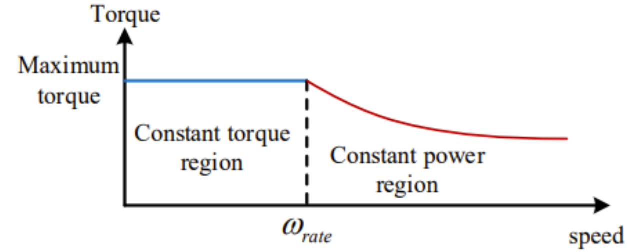


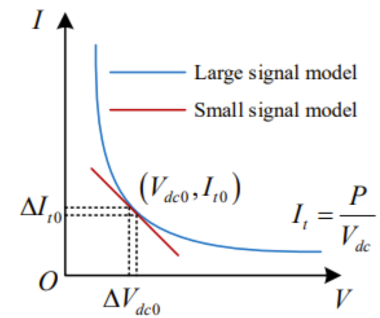
Power supply by hydrogen subsystem

Stability Analysis

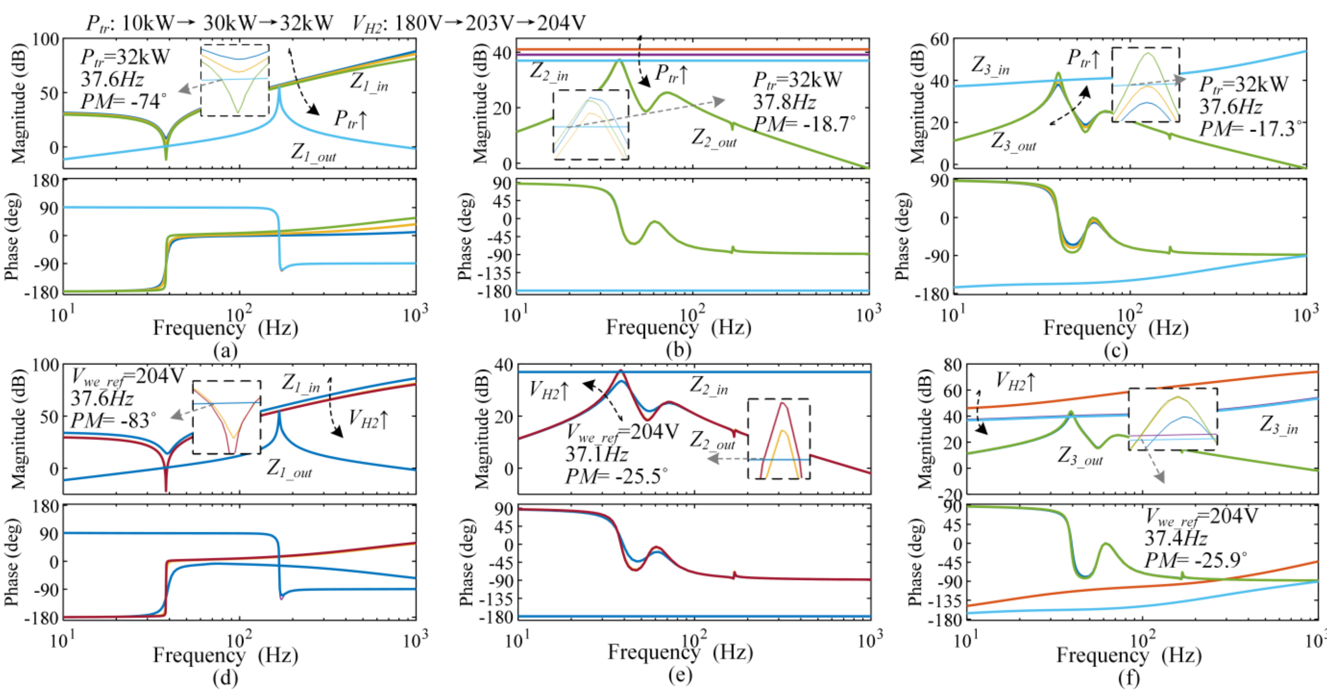


Impedance Modelling





Constant power characteristic

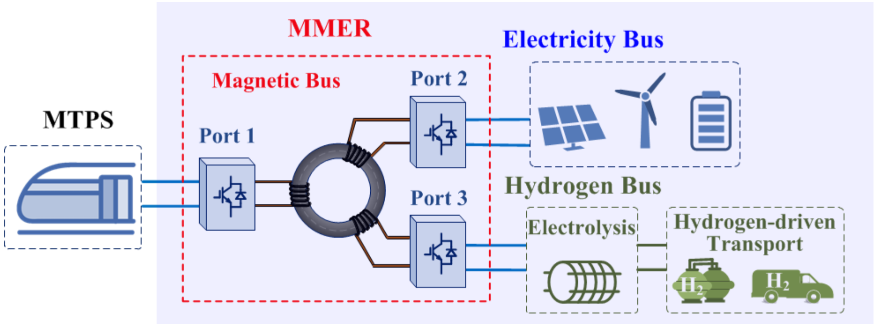


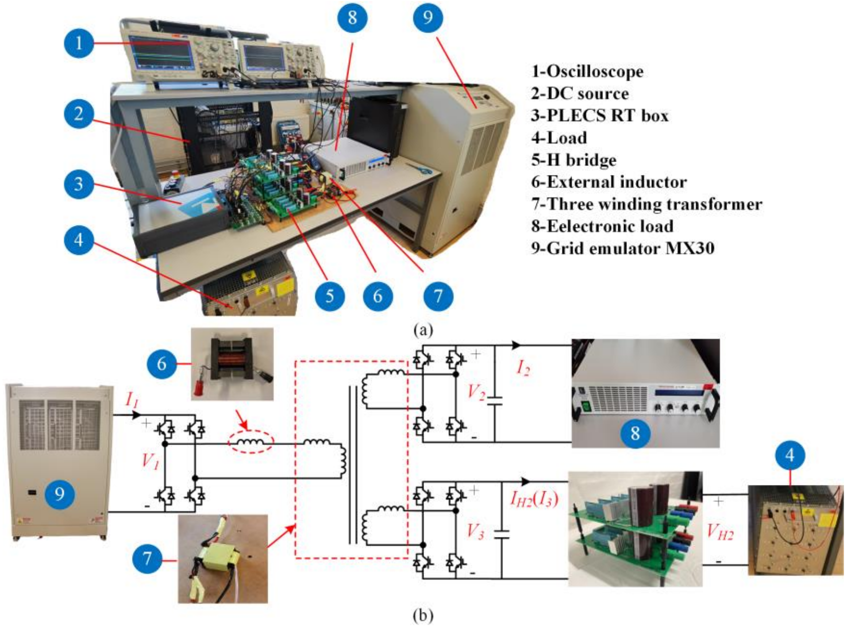
Impedance stability analysis at different terminals

1) Oscillation phenomenon can be caused and propagated to different ports as increase of tractive power.
2) The reverse power flow at one port can mitigate the instability phenomenon at the rest of ports.

Laboratory Setup and Verification Result

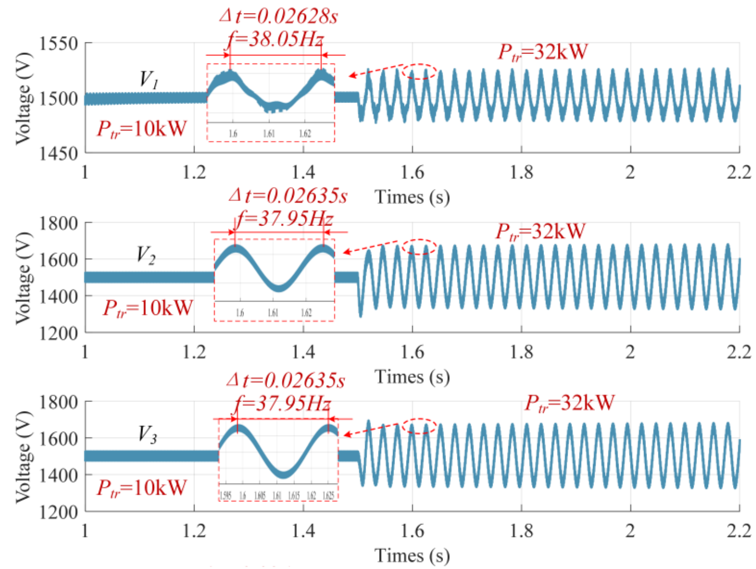
Electricity-hydrogen-integrated microgrid



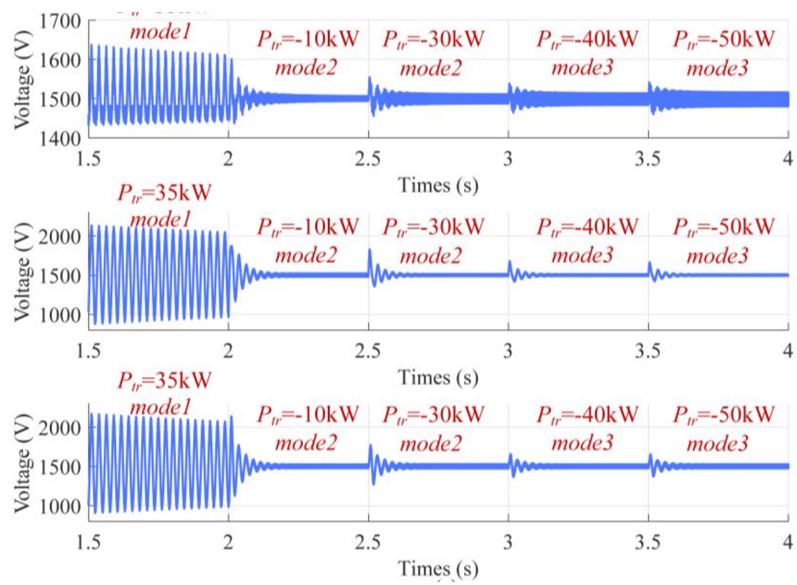


Laboratory setup

Experimental verification



Mode 1 when tractive power increases



Mode 2 and Mode 3

Conclusion

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DC microgrid-based traction power supply system

- Integrate renewable energies by DC microgrid to reduce carbon emission
- Reduce energy consumption
- Improve security and reliability of power supply
- Improve power supply capability and extend distance between substations
- Impedance-based stability is proposed to analyze stability issue.
- The demonstration and HIL verification shows that the microgrid-based solution is a promising solution for E-transportation.

Microgrid technology will play a more and more important role in green E-transportation system.

Selected Publication

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[1] H. Yu, Y. Wang and Z. Chen, "A Novel Renewable Microgrid-Enabled Metro Traction Power System—Concepts, Framework, and Operation Strategy," *IEEE Trans. Transportation Electrification,* vol. 7, no. 3, pp. 1733-1749, Sept. 2021.

[2] H. Yu, Y. Wang, H. Zhang and Z. Chen, "Impedance Modeling and Stability Analysis of Triple Active Bridge Converter-Based Renewable-Electricity-Hydrogen-Integrated Metro DC Traction Power System," *IEEE Trans. Industrial Electron.*, vol. 70, no. 12, pp. 12340-12353, Dec. 2023.

[3] H. Yu, Y. Wang and Z. Chen, "A Renewable Electricity-Hydrogen-Integrated Hybrid DC Traction Power System," in *Proc. SPEC*, 2021, Rwanda.

[4] H. Yu, Y. Wang and Z. Chen, "Impedance-based Stability Analysis of Metro Traction Power System Considering Regenerative Braking," in *Proc. ECCE Asia*, 2020, China.

[5] H. Yu, Y. Wang and Z. Chen, "A Novel DC Microgrid-enabled Metro Traction Power System," in *Proc. PEDG, 2020, Romania*.

[6] Y. Wan, Y. Wang and Z. Chen, Electricity price-prioritized droop control strategy of grid-friendly vehicle-to-grid integrated microgrid. *2023 IEEE PEDG*.

[7] Y. Wan, Y. Wang and Z. Chen, A novel grid-friendly vehicle-to-grid solution for power grid with large-scale renewable fuel vehicles. *2022 IEEE SPEC*.

[8] H. Zhang, Y. Wang, H. Yu and Z. Chen, A black start strategy based on multiport linterlinking converters for DC microgrids. *2022 IEEE SPEC*.