

Modernization of Electric Railways

Part 2: Energy-efficient & Alternative fuel Vehicle Drive Systems for Urban, Regional and High Speed Train

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1. Introduction

- **Improving the energy efficiency of vehicle drive systems is an important issue for railway operators from various aspects, e.g. reducing operating costs and vehicle weight.**
- **The modern society aims to enhance the network of environmentally friendly rail transportation, especially in urban areas to expand the mobility and promote the modal shift. The transportation for the last one mile is also needed in this context.**
- **These goals are being steadily realized by new technologies such as SiC power devices, lithium-ion batteries, fuel cells and I.o.T.**



2. Urban transportation

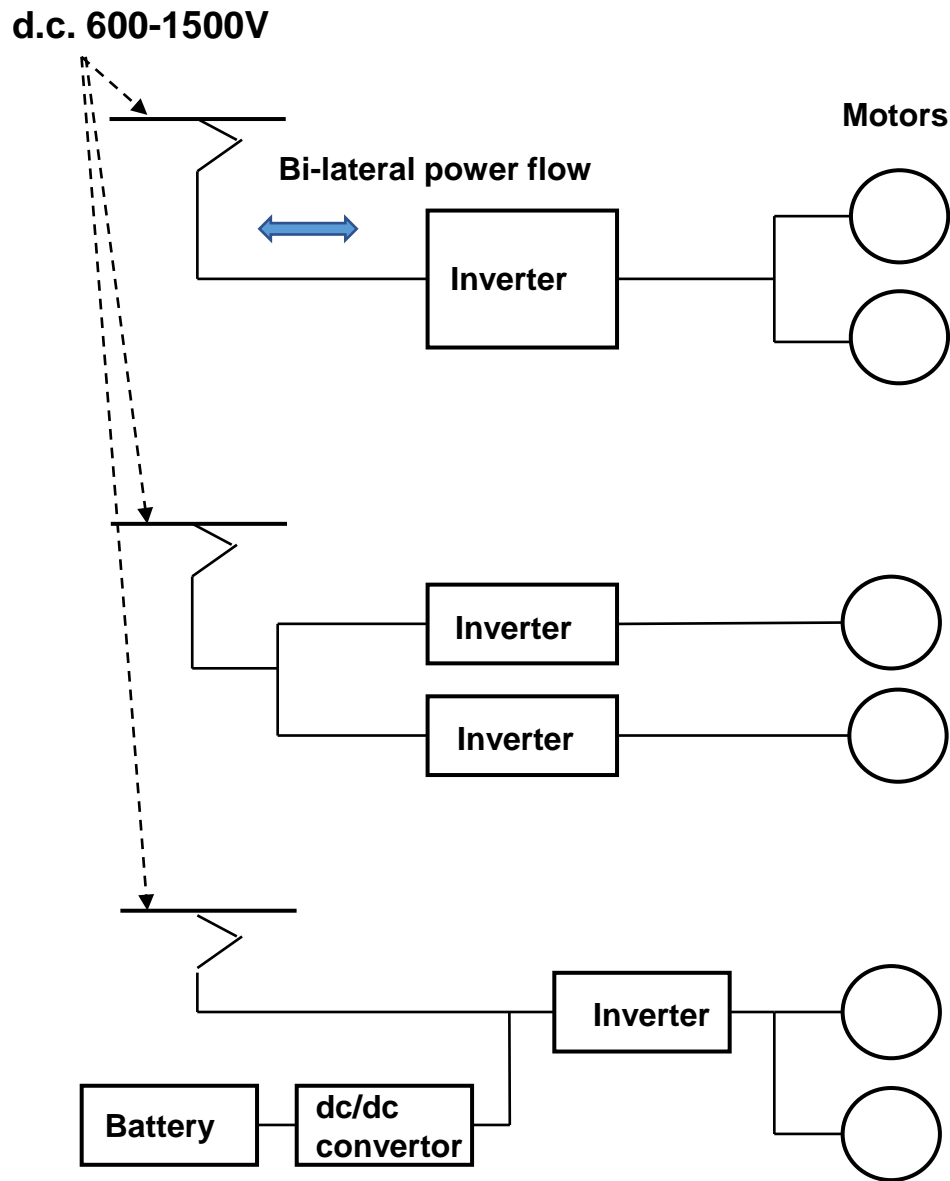
- **Energy recovery by regenerative braking is widely utilized for highly frequent operation.**
- **The battery assisted drive can sustain train operation at power outage at the natural disaster.**
- **For the underground system, the cross-sectional area of tunnel should be as small as possible to reduce construction costs.**
- **The energy used by the air conditioning facilities of vehicles also should be considered.**



Inverter Drive System & Energy Recovery

- The bi-lateral d.c./a.c. power conversion recovers roughly 30% of motoring energy through regenerative braking. The synchronous motor with permanent magnets can improve energy efficiency further.
- The inverter with SiC power devices improves the recovery rate up to 10% higher with lower switching losses, higher operating frequency and temperature.
- The direct drive system with linear induction motor reduces the height of bogie truck and realizes the smaller cross section tunnel.





Modern Drive Systems For Urban Transportation

Asynchronous Motor Drive

Synchronous Motor Drive

Battery Assisted Drive



Features of Three Types of Drives

- **Asynchronous Motor Drives:**

Replacing D.C. motor drives, most widely utilized in urban systems. An inverter for multiple motors. Regenerative braking with bilateral power flow of inverter.

- **Synchronous Motor Drives:**

Improved energy efficiency with field permanent magnets. One to one inverter-motor composition for synchronization.

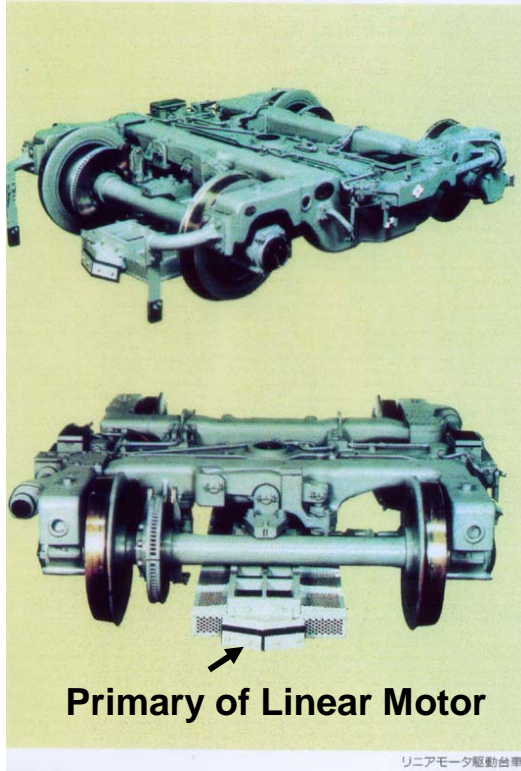
- **Battery Assisted Drives:**

Operation in un-electrified line sections. Limited power conditioning of regenerative braking. Sustainable operation against power outage.



Linear Metro: Direct drive with linear induction motors on board for urban underground transportation

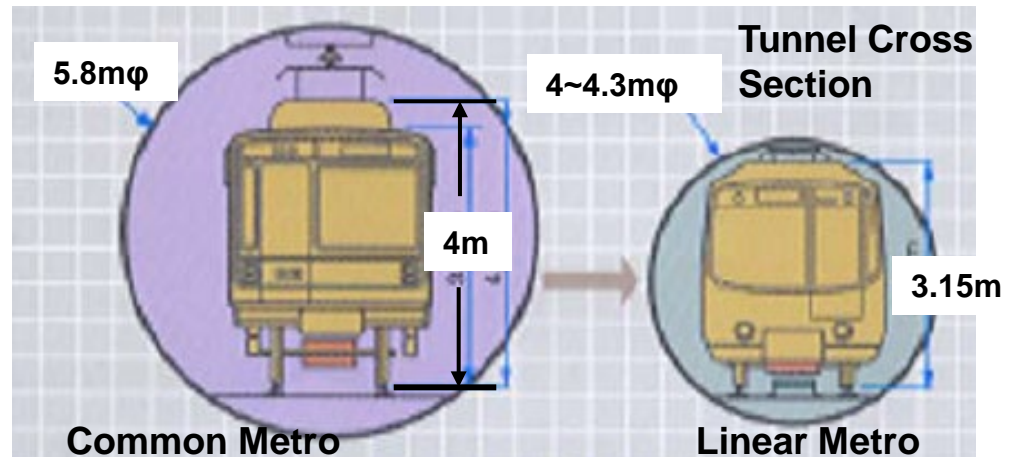
Bogie Structure



Photographs are copied from a brochure of Japan Underground Railway Association.



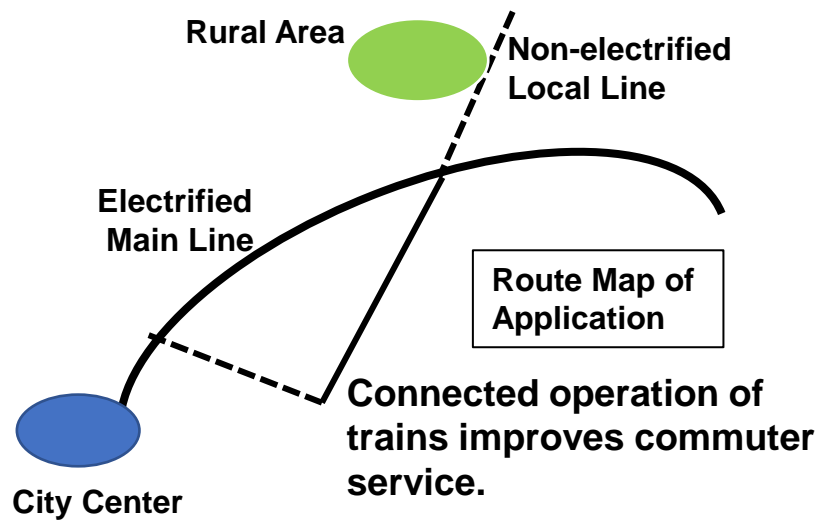
Train of Fukuoka Municipal Subway



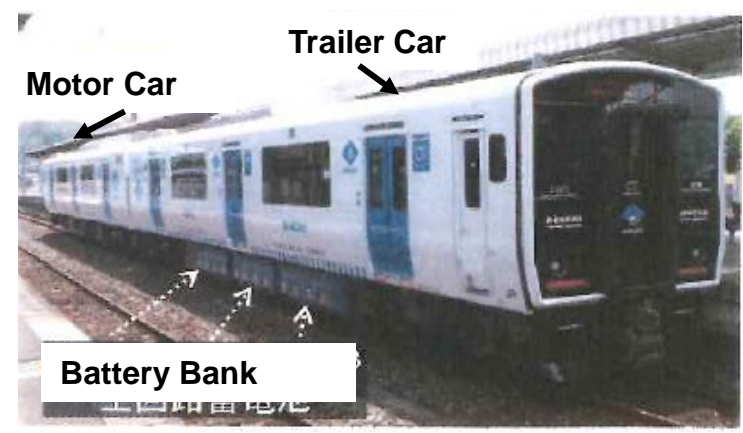
2. Regional Railway System

- **Main lines are electrified with the single phase a.c. system of 15~20kV. Due to the low frequency of trains, recovery of regenerative braking energy by ground facilities is limited.**
- **The train with a storage battery on the vehicle can efficiently cope with this problem.**
- **For un-electrified lines, the Diesel hybrid drives have been introduced for vehicles and locomotives especially for luxury train.**
- **The hydrogen fuel cell-powered train has been developed and is about to enter commercial operation due to excellent environmental integrity in spite of restriction on the supply of alternative fuels.**

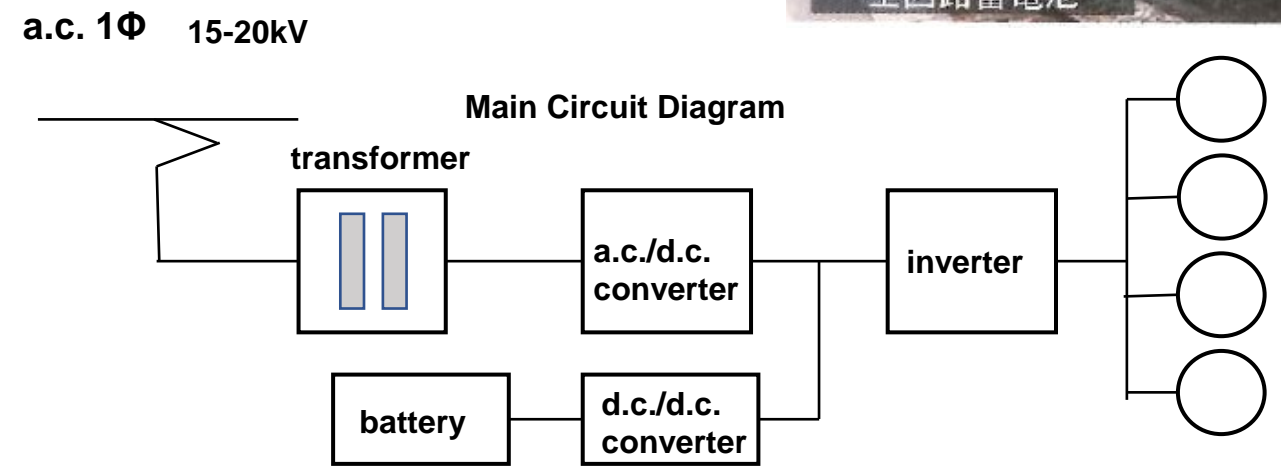




Application of Battery Assisted Train in Suburban Transportation

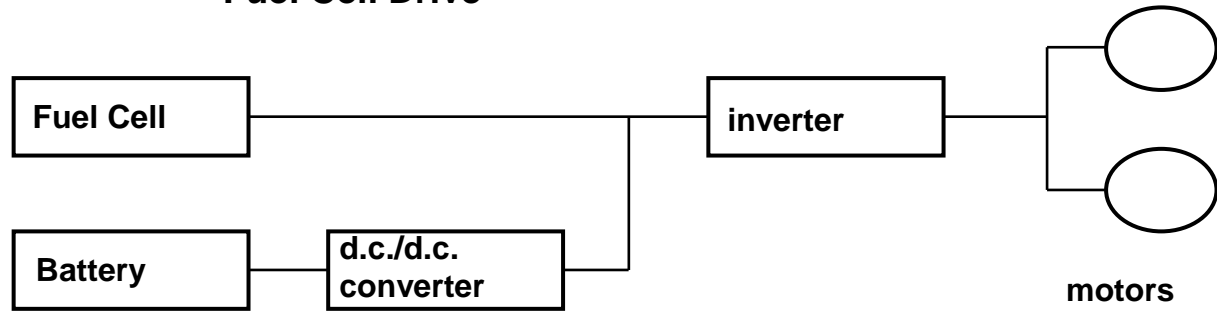


Train Overview

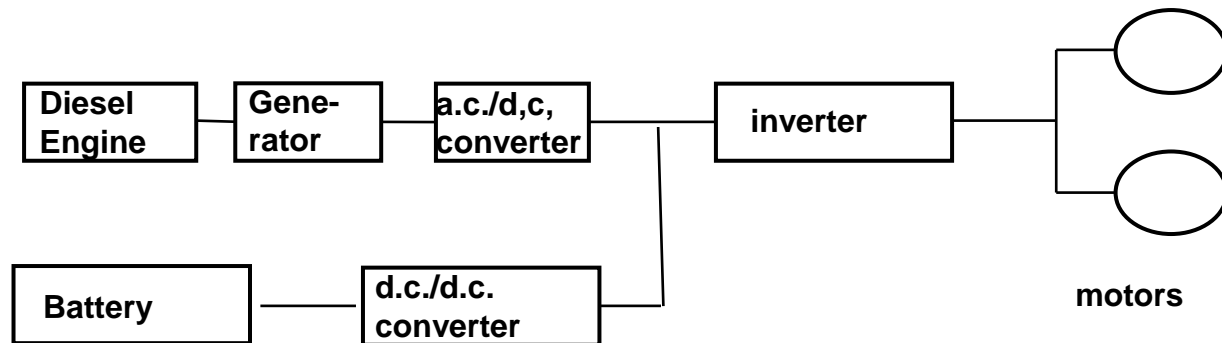


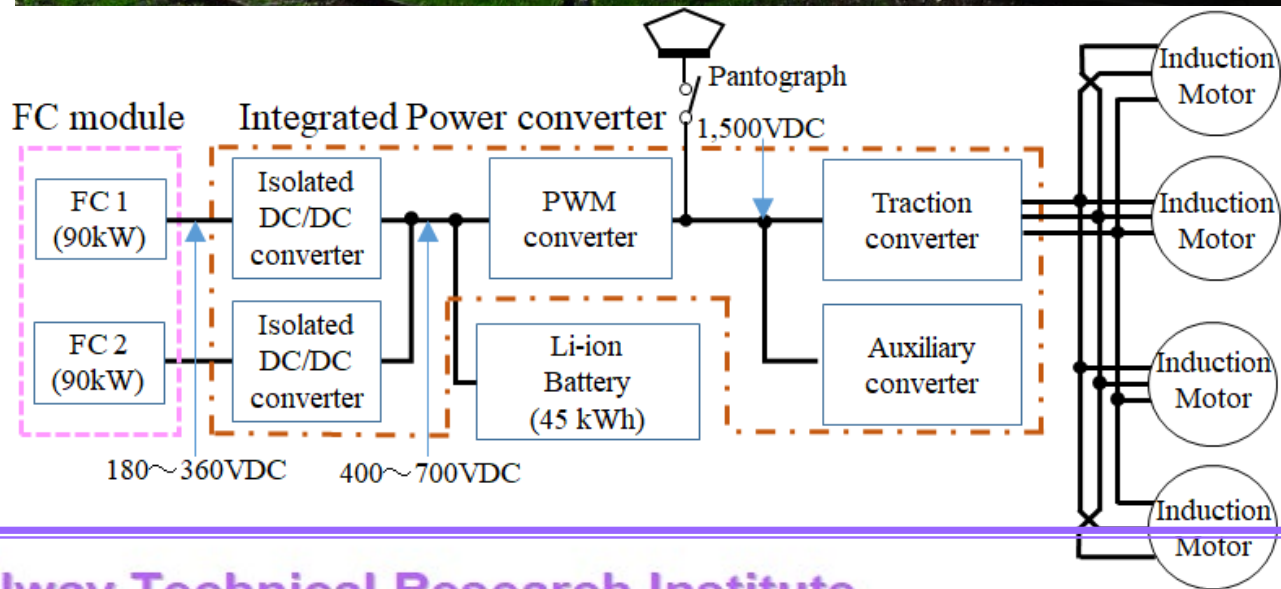
Alternative Fuel Train for Regional Transportation

Fuel Cell Drive



Diesel Hybrid Drive

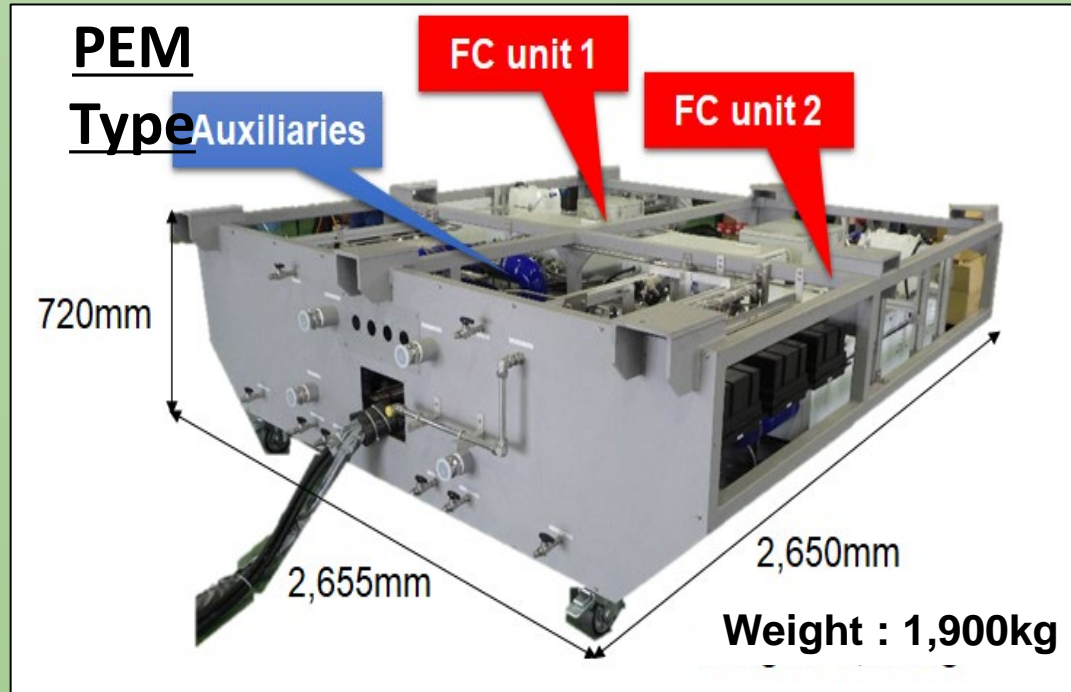




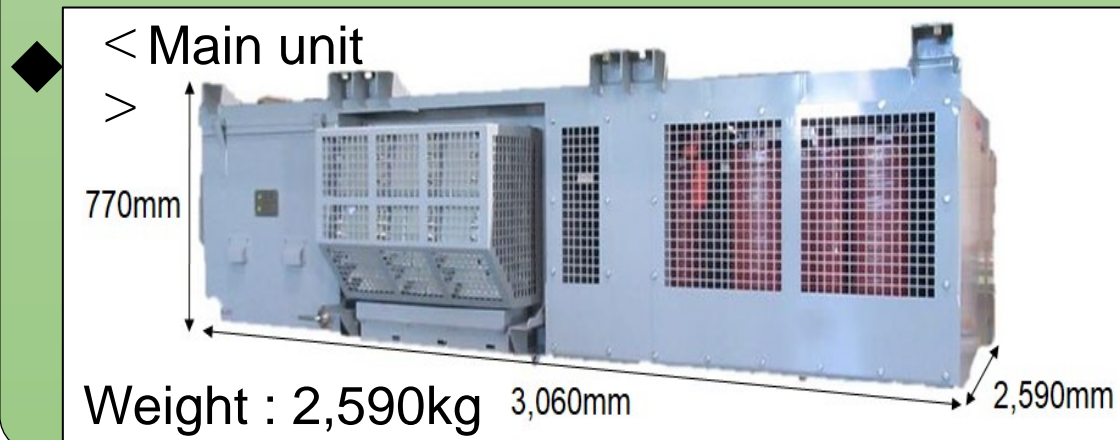
Composition	Motor car (Mc)	Trailer car (Tc)
Acceleration	2.5 [km/h/s] (at startup)	
Deceleration	3.1 [km/h/s] (Max. regeneration)	
Weight	36,400[kg]	31,000[kg]



◆ FC module



- **High-power density** FC stacks ($30\text{kW} \times 3\text{series} \times 2\text{units} = \underline{180\text{kW}}$)
- **Decentralizing** downsized auxiliaries (Air blower etc.)
- **Commoditizing** auxiliaries' power supply with vehicle auxiliaries' one of 440VAC
- Compact cooling system for **primary system only**



- **Integration** of multi power converters (Main unit = Traction + BAT + Auxiliaries)
- FC converter is **low-voltage type (750VDC)**, which makes it possible to use SiC and the **small-sized circuit breaker**.

Comparison between three types of systems

- **Battery Assisted Drives:**

Interoperability in different electric systems as well as in unelectrified line section. Absorbing regenerative braking power in regional systems.

- **Diesel Hybrid Drives:**

Simple modification of Diesel drives. Saving fuels. Improved performance of drive. Customer satisfaction against fumes.

- **Fuel Cell Drives:**

Carbon free operation with hydrogen fuel. Considerable battery capacity required. Limited supply of fuel cells. Pressurized storage tank on board. Supply infrastructure needed.



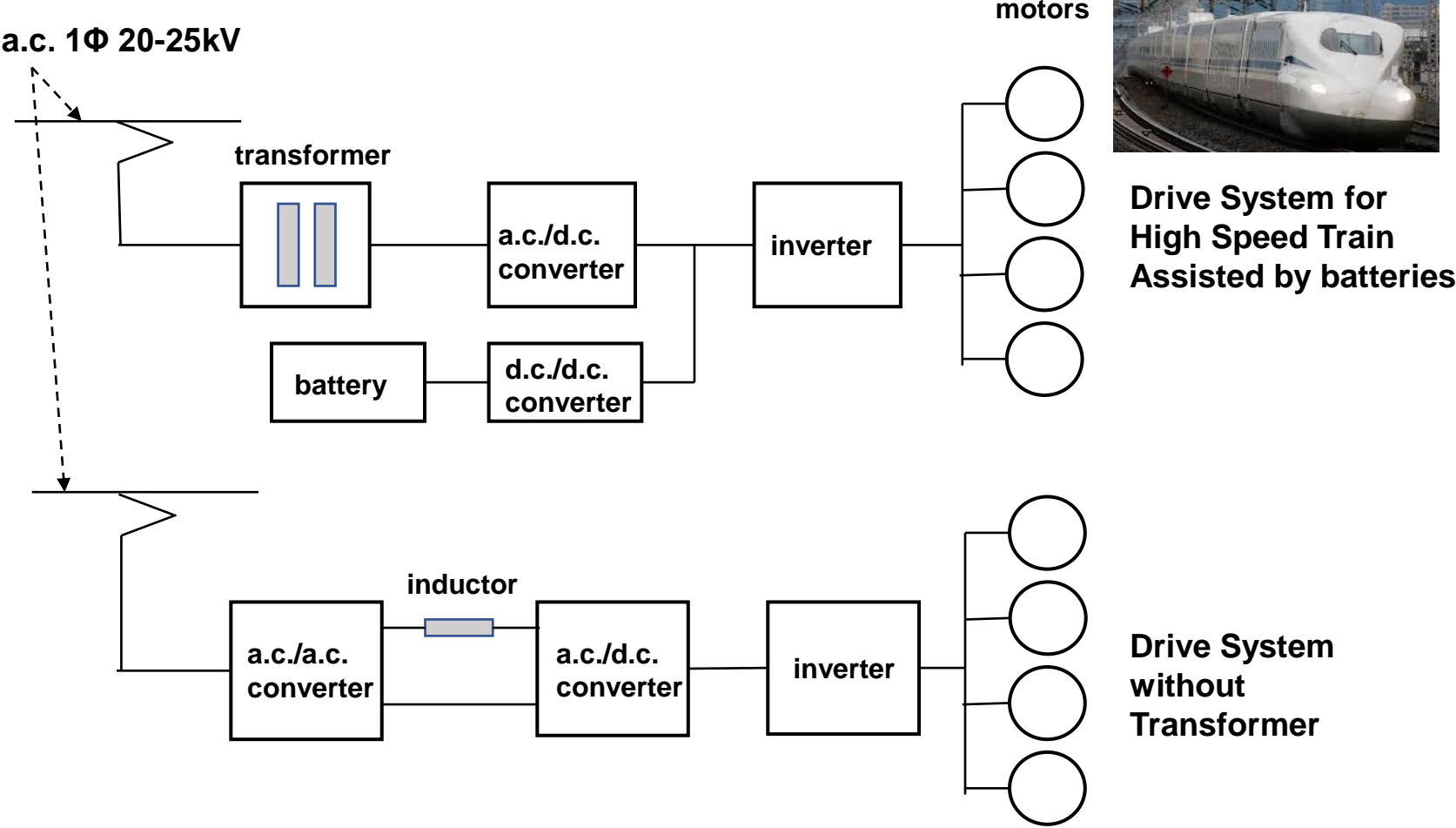
3. Drive systems for high speed train

- With SiC power devices, the converter is reduced in size and weight, as well as transformers and motors and the cooling device can work only with running wind.**
- The battery drive has also been introduced to eliminate the suffering of passengers trapped in the vehicle due to prolonged power outages.**
- Replacement of on-board transformers with SiC a.c./a.c. converter is under study.**
- Emergency braking for trains operating with velocity higher than 350km/h, the application of linear induction motor brake is proposed and studied.**



Innovative Drive Systems for High Speed Train

N700S JR Central



Examples of Trains with SiC Drives supplied in 2016-2017

totally 724 motor cars

operator	Series	use	line	SiC type	Motor	Number of Motor Cars
JR East	E235	Urban	Yamate	Full 2 level	Asynchronous	162
JR West	323	Urban	Osaka-Circle	Full 2 level	Asynchronous	96
JR kyushu	811	Regional	Kagoshima	IGBT hybrid	Asynchronous	12 (a.c. supply)
Tokyo Metro	9000	Commuter	South-North	Full 2 level	Asynchronous	30
Tokyo Metro	1000	Metro	Ginza	Hybrid 2 level	Synchronous	12
Keihin Kyukou	1000	Commuter	Main Line	Full 2 level	Asynchronous	40
Keiou	5000	Commuter	Main Line	Hybrid 2 level	Asynchronous	50 (Battery on board)
Tokyo Kyukou	2020	Commuter	Denen Toshi	Full 2 level	Asynchronous	50



Summary of Part 2

- **With application of high power and fast operating power devices, a.c. motor drives have been widely introduced and contributed to global environment.**
- **The progress of Li-ion batteries has promoted their application to train drives for higher energy efficiency and better service quality.**
- **Fuel cell drive is going to be introduced into trains for practical operation with consolidation of fuel supply infrastructure.**
- **High speed train technology requires furthermore sophisticated drive systems.**



Conclusion

- **Due to the demand for low-carbon society and the convenience of passengers, improvements in new energy supply and drive systems are constantly being introduced and applied.**
- **From an industrial point of view, railway equipment are not so large in capacity but utilized with rather large quantity. Then railways also play a leading role in the application of new technologies supported by high level of public interest.**
- **Introduction of autonomous system management is expected to increase further the total energy efficiency on the platform of information network technology (NIT).**

