Energy and Environmentally-friendly Solutions for Railway Systems of the Mitsubishi Electric (MELCO)

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1. Introduction

Mitsubishi Electric Corporation, MELCO, is the leading electrical manufacture of the railway vehicle equipment and systems in Japan and global market. MELCO has been manufacturing electrical equipment for railway vehicles since 1922, and currently holds 50% share of the Japanese market for the Shinkansen, conventional and subway EMUs, LRVs, and locomotives. In Japan, railway operators evaluate MELCO products' reliability, durability, energy-saving performance, ability to meet diverse user needs, and flexibility of engineering design, as well as advanced functions and operating performance including low LCC and environmentally friendliness for sustainable future.

MELCO possesses advanced technologies in diverse areas including power electronics, information and communications, and control instruments, and also the technological expertise to cover the requirements for an entire railway system. MELCO supplies the onboard electrical equipment including propulsion systems, train control and monitoring systems, auxiliary power supply systems, brake systems, passenger information systems, and air conditioning systems. MELCO also provides linkage systems between onboard and wayside and wireless train control systems, CBTC, as well as vehicle maintenance support services.

MELCO has also been active in overseas railway business. After delivering electrical equipment for Indian Railways' electric locomotives in 1960, the business has continued to expand globally, with shipments now being made to 30 countries including India, Spain, Australia, Mexico, and the United States. In response to the expansion of overseas business, we have set up new overseas bases. Since 2014, we have opened new manufacturing plants in India and Italy. Fig.1 shows current status of MELCO's overseas bases.

The overseas railway market is expanding, particularly in developing countries. To help resolve urban environmental issues such as traffic congestion and air pollution, new railway lines are being built, and plans are underway for high-speed railways for intercity mass transportation. Therefore, Energy and Environmentally-friendly solution is the key issue for all railway operators and the future sustainable railway systems

This paper outlines the latest concepts, technologies and railway applications of Energy and Environmentally-friendly solutions for Railway Systems like Energy Management Systems, EMSs, which is proposed by MELCO.

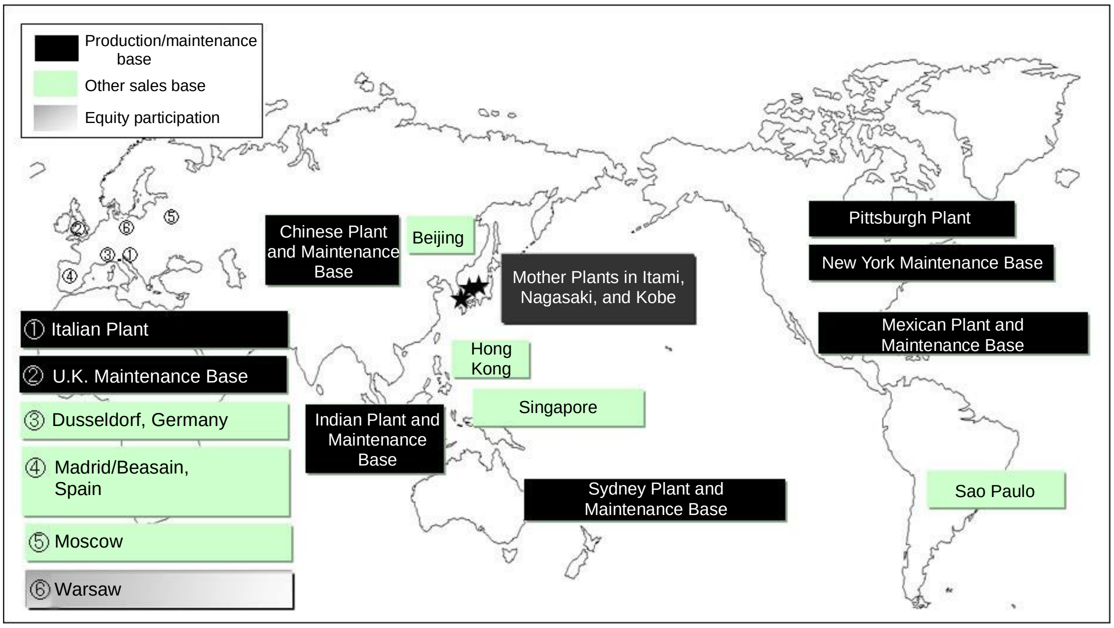


Fig. 1 Mitsubishi Electric's overseas bases

2. Concept of Energy Management Systems (EMSs) for railway applications

The Paris Agreement was adopted to mitigate global warming after the COP21 held in Paris in 2015. Countries are required to further reduce the burden on the global environment, starting in 2020. In response, MELCO is working on railway energy and environmentally-friendly solutions aimed at conserving energy for an entire railway system achieved by Energy Management Systems (EMSs) in the following four areas (Fig. 2).

(1) Train energy management (TEMS)

Pursues energy conservation in units of a train involving improvement of the efficiency and functions of electric equipment for trains brought by our industry-leading SiC power modules, and improvement of energy efficiency through coordinated control of battery-powered trains and multiple devices, etc.

(2) Railway line energy management (REMS)

Pursues effective maximization of regenerative energy use throughout the entire railway line including trains and wayside facilities, using a Station Energy saving Inverter (S-EIV), Feeder Voltage Optimization System, and other equipment.

(3) Station energy management (SEMS)

Pursues energy conservation by reducing the increasing use of electric power for station auxiliary facilities through visualization of energy, demand control, etc.

(4) Factory energy management (FEMS)

Manages the energy used throughout the train depot facilities including inspection equipment and repair lines.

MELCO has contributed to the energy conservation of railway vehicles by improving the efficiency of train equipment, which constitutes our flagship products, and sophisticating their control functions, upgrading regenerative braking systems, and developing train

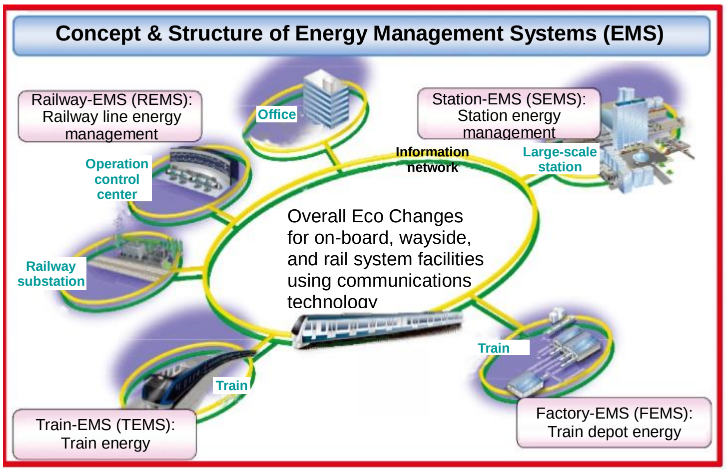


Fig. 2 Energy Management System (EMS) of MELCO

Fig. 3 SiC applied VVVF inverter unit for DC1500V commuter EMU

Fig. 4 Power converter for battery-powered EMU

control and monitoring systems (TCMSs) for all-inclusive control. We have also developed a regeneration inverter that allows wayside facilities to absorb surplus regenerative electric power for effective use of regenerative power and improved energy utilization.

The goal of these new solutions is to optimize energy demand and supply throughout the entire railway system, as with the case of a smart grid in an electric power supply system.

We seek energy conservation for an entire railway system using real-time information on the fluctuating supply-demand relationship and the four EMSs working together by making the best use of information and communication technology (ICT), also called the Internet of Things (IoT) and Machine-to-Machine (M2M) technology, which has recently made rapid progress.

3. Initiatives for Energy Management Systems

3.1 Train energy management system (TEMS)

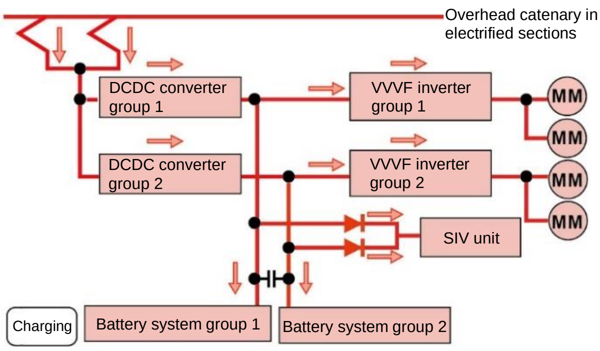
A TEMS performs energy optimization for a railway vehicle.

We work on TEMS development in two main directions: energy efficiency improvement by improving the efficiency and functionality of electric equipment; and energy efficiency improvement through the coordinated control of multiple devices.

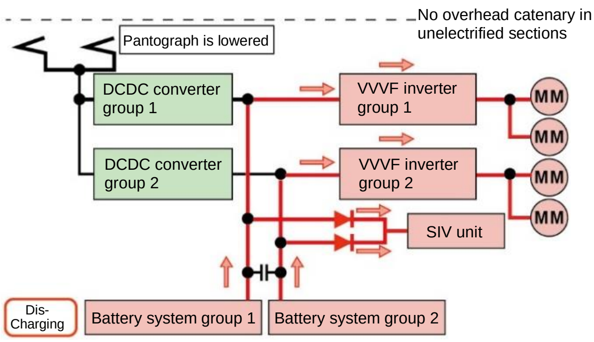
For the improvement of electric equipment efficiency and functionality, we have applied two systems that each use different devices to railway vehicles operating on existing lines. One is the traction system that combines propulsion control equipment using a silicon carbide (SiC) power module with a highly efficient, fully enclosed induction motor. The other system includes a power storage device and aim to increase the use of regenerated electric power, reduce noise in unelectrified sections, and attain zero emissions.

As the first application, the high-efficient traction system is installed in the commuter EMUs for 1500V DC supply conventional line. MELCO's variable-voltage variable-frequency (VVVF) inverter unit comes with a SiC power module was adopted for the commuter EMUs as shown in Fig.3. Service with the VVVF inverter unit was launched in January 2015, marking the world's first adoption of a railway inverter rated at 3.3 kV/1,500 A with a high-capacity SiC power module. With its low-loss characteristics, the VVVF inverter unit has reduced train electric power consumption by approx. 40% compared to a conventional train, and is also approx. 80% smaller and lighter than the former VVVF inverter unit.

The second application of the traction system with a power storage device is for battery-powered vehicle.



(a) When traveling in an electrified section



(b) When traveling in an unelectrified section

Fig. 5 Traction system operation when a train is moving

Fig.4 shows the power converter used for the battery-powered vehicle.

Service of the battery-powered vehicle was launched in March 2014, and has since brought the following benefits.

(1) As shown in Fig.5, power is supplied from the overhead catenary when a train is traveling in an electrified section, while power is supplied from batteries when traveling in an unelectrified section. This allows for direct service, which is more convenient for passengers.

(2) The same performance as that of an electric train can be obtained even in an unelectrified section and improves the acceleration compared with that of a conventional diesel train.

(3) Even in an unelectrified section, the recovery and reuse of energy for regeneration, noise reduction, and exhaust gas elimination are achieved.

Furthermore, in pursuit of improvement through coordinated control of multiple devices, we are working on the visualization of energy in a railway vehicle. This involves collecting vehicle electric power data by train car composition using ground-to-train networks (wireless communication), in addition to providing blended brake control for each car composition using the TCMS and energy-saving equipment control by optimizing the equipment operation timing control.

3.2 Railway energy management system (REMS)

An REMS performs energy optimization for the entire rail line. Regenerated energy in a railway vehicle is increasing every year with the adoption of VVVF vehicles and increasing use of SiC power modules in train inverters. This also increases the energy that fails to be flexibly used in response to the needs of accelerating trains via DC electric-car lines and thus is wasted. The challenge to achieving further energy conservation throughout the entire rail line is to effectively utilize the redundant energy that trains cannot conventionally accommodate. In this section, we describe representative equipment and systems that are used for minimizing/optimizing the energy in the feeder system.

3.2.1 S-EIV Station Energy saving Inverter

The Station Energy saving Inverter (S-EIV) is an energy conservation device that converts the regenerated energy that becomes redundant when a train comes to a stop at a station to AC power to be supplied to the electric facilities of the station building. Fig.6 shows the redundant energy recovery flow by an S-EIV. Table 1 shows the product specifications. The S-EIV is installed at the nearest location to the station building where train drivers brake their train and generate recoverable regenerated energy. The energy is recovered, converted to AC electric power and utilized as power for the station building. This mechanism reduces transmission losses and enables efficient local production and consumption of redundant regenerated energy. Table 2 shows the commercialization history of the S-EIV. From August to December 2012, we conducted field verification tests using prototypes during the development. We used the findings of the tests to improve the product and verified its functions and energy-saving effect. In June 2014, the first model was delivered to commercial use, and an energy-saving effect of approx. 600 kWh per day was confirmed.

Table 1 S-EIV specifications

Rated capacity	200 kW; 30s to charge, 2min and 30s to stop
Input voltage	1,500 V DC, 750 V DC, 600 V DC
Output voltage	210 V AC, three-phase, 50/60 Hz
Cooling method	Natural air-cooling

Table 2 Commercialization history of the S-EIV

Period	Main event
August to December 2012	Field verification testing using prototypes
June 2014	Delivery of the first model
February 2016	Delivery of a downsized, high-functionality model

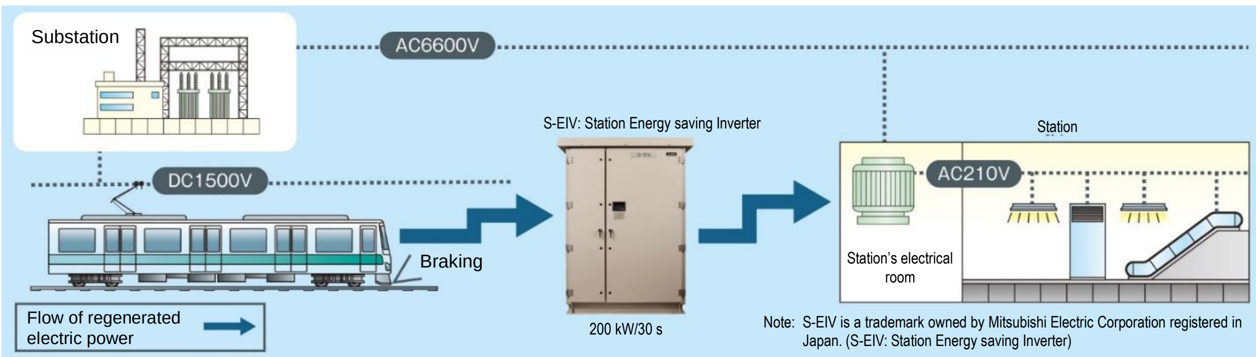


Fig. 6 Recovery flow of redundant regenerated energy by S-EIV

We subsequently delivered the product to accumulate data, and continued developing the product. In February 2016, we delivered a downsized, high-functionality model with a 40% smaller footprint than conventional equipment, which also offers reinforced features such as a ground fault detection circuit. In the future, we will continue to expand the product lineup, while promoting the S-EIV to railway operators both in Japan and overseas to help reduce the burden on the global environment.

3.2.2 Feeder Voltage Optimization System

The Feeder Voltage Optimization System currently under development is intended to reduce overhead line energy losses and efficiently use regenerated energy through real-time control of substation output voltage in accordance with the position and operation conditions of a train, to reduce train line loss. Fig.7 shows a schematic view of the Feeder Voltage Optimization System. Information regarding the current position on the route and the power demand/supply (amount of required power or of recoverable power for regeneration) is transmitted from a TCMS to the Feeder Voltage Optimization System via communications networks. The Feeder Voltage Optimization System controls the voltage control substations such that the maximum amount of regenerated power is flexibly fed to trains in order to optimize the output voltage and reduce the substation power supply. We simulated this power feeding mechanism using a railway line model in a section with a tight train schedule in a metropolitan area. The results showed that the amount of power conventionally discarded as heat as a result of limited regeneration due to the absence of a feeding destination could be reduced by up to 80%, and that the power supply from substations could be reduced by up to 5%. In the future, we will continue developing technologies for the Feeder Voltage Optimization System and related equipment in coordination with vehicle technological development using ICT, with the aim of further energy conservation throughout the entire rail line.

3.3 Station energy management system (SEMS)

An SEMS optimizes energy in a train station. The incidental facility power consumption of stations is increasing due to the increase in commercial station facilities, subway air-conditioning systems, etc., so it is important to reduce the power used for such incidental facilities in order to conserve energy. We have delivered a station facility management system that optimally controls individual station facilities to balance comfortable services and energy conservation, in addition to refurbishing air conditioning, lighting, and other facilities by replacing them with leading-edge energy-saving facilities (high-efficiency air conditioners, LED lights, etc.). Furthermore, to stably and effectively use power generated from photovoltaic systems that would be introduced in accordance with the size and local conditions of existing stations, we are working on the application of smart grid technologies including power storage to SEMSs for further energy optimization.

We are also focusing on an approach, based on our energy-saving systems for individual stations, involving saving energy for each station group by monitoring and coordinating the demand levels of multiple stations.

3.4 Factory energy management system (FEMS)

An FEMS optimizes energy in a train depot (including a vehicle maintenance factory and other facilities). Equipment and facilities operating at a train depot are managed in a sophisticated manner using a programmable logic controller (PLC) and networks to also allow management of maintenance work progress,

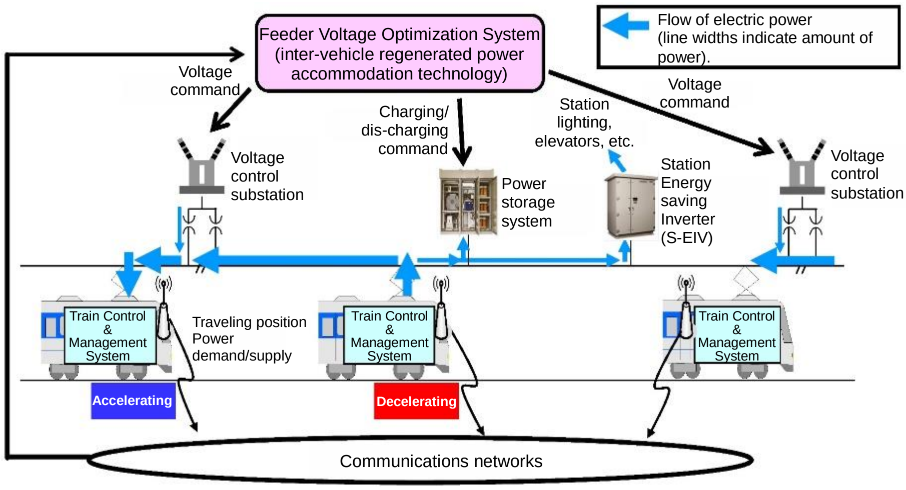


Fig.7 Feeder Voltage Optimization System

energy consumption, etc., thereby conserving energy of the entire train depot. The FEMS introduces a specific energy consumption management approach using a database of collected information on the operation status of individual equipment and facilities, progress in inspection/repair work, energy consumption, etc., with the aim of improving inspection and repair work.

4. Conclusion

Global warming and urban environmental problems are important issues for all over the world, then the innovative railway technologies and solutions can contribute to solve these issues. In this paper, MELCO introduced proposal and example of our railway energy and environmentally-friendly solutions like four Energy Management Systems, EMSs, in pursuit of energy optimization for an entire railway system.

With the growing international effort to mitigate global warming and improve the energy supply conditions, it is becoming increasingly important to bring about a low-carbon society. Using a wide range of accumulated technologies, MELCO will continue developing solutions that improve railway systems, together with railway operators, passengers, government, and stakeholders, which are vital low-carbon infrastructure for the sustainable society in the future.