System Design for Energy Management in Railways

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1 Introduction

The Environmental Engineering Research Laboratory at JR East continuously works on R&D with an aim of achieving railway systems that have smaller environmental burden. The individual themes in that R&D are covered in their respective papers in this edition of JR East Technical Review. Here, I would like to provide an overlook of design in energy management we should aim for.

I will start with describing what load is and what optimization involves.

Energy consumption has, as shown in Fig. 1, a structure whereby first there are services that must be provided, then rolling stock systems and facility equipment capacity are required to provide the services, and finally that capacity demands energy consumption. Energy consumption alone cannot be reduced without reducing demand (load). Energy conservation can thus be achieved by the approach of measuring and assessing to know the load, making changes to reduce load, and building optimal systems that meet the load.

The basis of optimization is to set equipment capacity that meets the load. However, the actual load fluctuates over time, so the issue of optimal operation remains in addition to physical optimization. Also, if different load patterns exist in a single area, the issue emerges of optimizing the entire area by means such as leveling the load according to the situation or having loads complement each other. This is the basic concept for systemization of energy management.

Specific system design is covered from the next chapter, separated into train operation systems and building systems.

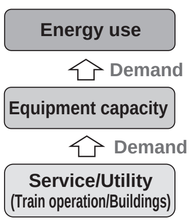

Fig. 1 Explanation of Load

2 Energy Conservation in Train Operation Systems

2.1 Making Traction Circuits More Efficient

Energy for train operation is consumed by drive systems in rolling stock systems (for EMUs, that is drive motors and controllers) and auxiliary equipment systems for cooling, lighting, and the like. In energy conservation, higher efficiency is expected for drive systems and auxiliary equipment systems. Let's take a look at trends in technical innovation for raising efficiency on drive systems, which have a larger weight on energy consumption.

In this field, it can be said that after power electronics technology was introduced, the advancement of power devices propelled technical innovation in traction circuit systems.

Table 1 shows the advancement of power devices and the relationship of that with application to EMUs. Rectifiers came to have control functions, and chopper control and VVVF control made their appearance. Next, ICBTs came about where transistor systems bore the main role for traction circuit devices. MOSFETs using silicon carbide (SiC) are expected to be next step in traction circuit devices. The issue we have to tackle is how to utilize advancements in semiconductor technologies for EMU systems.

Table 1 Advancement of Power Devices and Relationship with Application to EMUs

	Advancement of power devices		
Rectifier system	SCR (Series 201)	→	GTO (Series 207, Series 209)
Transistor system	IGBT (Si) (Series 231, Series 233)	→	MOSFET (SiC) (Series 235)

The impediments of manufacturing technologies and cost seem to have been high up to now for using SiC in EMUs, but its use is at last catching on. The order in which that occurs seems to from articles with low withstand voltage to those with high withstand voltage. By component, the order is from application to diodes to fully switching to SiC including transistors (MOSFET). To find out the possibilities for application to EMUs, an actual prototype traction circuit system was made in 2013. The NE-Train test platform for catenary and batterypowered hybrid railcars was equipped with a 600V VVVF traction circuit, so the prototype traction circuit was equipped to that train and evaluated. The power devices were of a hybrid type where only diodes were made to be SiC and controlling elements were IGBTs.

In the first step, a prototype VVVF alone was made, and in the second step, a prototype motor was also made and the control software changed along with that. As you can see in Fig. 2, simply changing the element did not result in large effects; but by using the strength of ability to have higher switching frequency and designing a dedicated motor and changing the control software to operate that efficiently, we were able to confirm energy conservation effects for the traction circuit as a whole.

The results of this evaluation were put to use in Series E235 EMUs, which came into commercial operation in 2015. Table 2 shows a comparison of traction circuit control between the Series 235 and Series E231 EMUs.

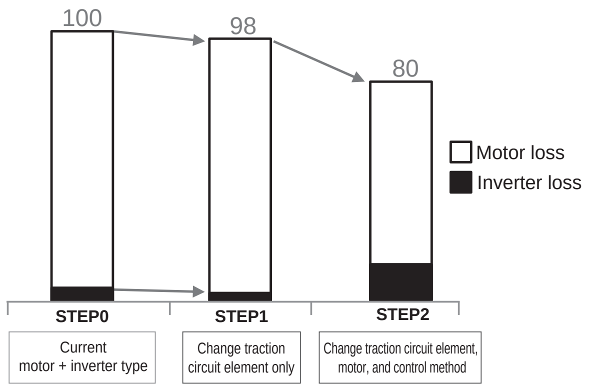

Fig. 2 SiC Traction Circuit System Evaluation

Table 2 Traction Circuit Control of Series 235 EMUs

		E231series	E235series
VVVF	Power device	IGBT	MOSFET(SiC)
	Carrier frequency	Asynchronous 156 Hz → Synchronous 3 P → 1 P	Asynchronous 1200 Hz → 1800 Hz → Synchronous 27 P
	V/F	1100 V/60 Hz	1050 V/77 Hz
MOTOR	Slip	2.0 %	0.7 %
	Efficiency	92.5 %	94.5 %

2.2 Energy-conserving Train Operation

In order to conserve energy for trains, good driving practices are an important issue in addition to making individual rolling stock equipment to be highly efficient. In order to quantify this, we conducted driving energy measurements on Series E231 EMUs on the Yamanote Line in 2013. Energy data was stored on memory set up temporarily on the lead car using train information management devices onboard, and that data was read when the trains entered the depot. Fig. 3 and 4 show the results of comparison of maximum and minimum driving energy from data sets of the same section and driving time.

It is surprising that driving energy was so different with the same hardware and schedule. Comparing the train performance

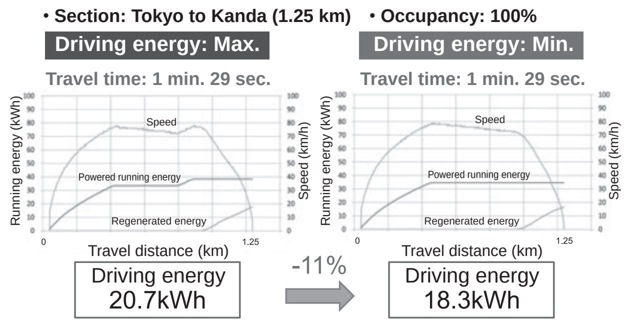

Fig. 3 Comparison of Consumed Energy by Train Performance Curves

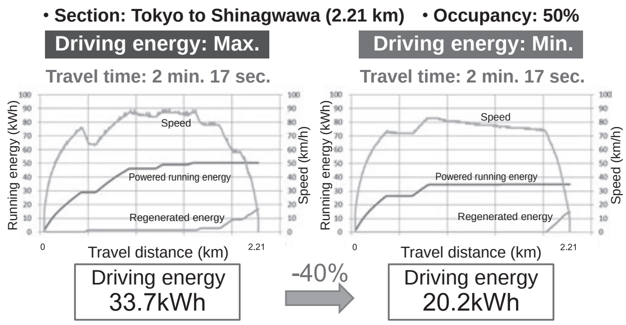

Fig. 4 Comparison of Consumed Energy by Train Performance Curves (2)

curves, driving that makes good use of coasting and minimizes powered running time results in energy conservation. If the section has a speed limit as in Fig. 3, taking that into consideration in advance and avoiding wasteful driving operations leads to energy conservation. Even when there is a long continuous gradient, driving to obtain a train performance curve where that effect is taken into consideration is probably effective in conserving energy.

Making good use of coasting has long been known to be effective in conserving energy, and driving models of economic driving have been proposed. Information technologies are used for train control with the latest VVVF control, so smart energy-conserving driving that does not rely on the skill of the driver is sought after. Next, I will introduce that approach to achieving that.

The traction circuit system supplies the torque required to run the train, but torque demand differs by location and speed, so the motor operating point also moves rapidly. If an induction motor efficiency map is overlaid on the speed and torque space, motor efficiency would rapidly move all over the map. If train set control to fit system supply capacity according to train operation torque demand were possible, motor efficiency on the efficiency map would be maintained well.

Fig. 5 proposes system design for such energy-conserving train operation. When load is light, operation of some units can be suspended to heighten efficiency of the train as a whole, but that can be said to reassemble long-used energy-conserving operation in that energy loss is managed by suspending equipment well.

Highly functional train set control is imperative for this, and the aforementioned Series E235 EMUs have a highly functional

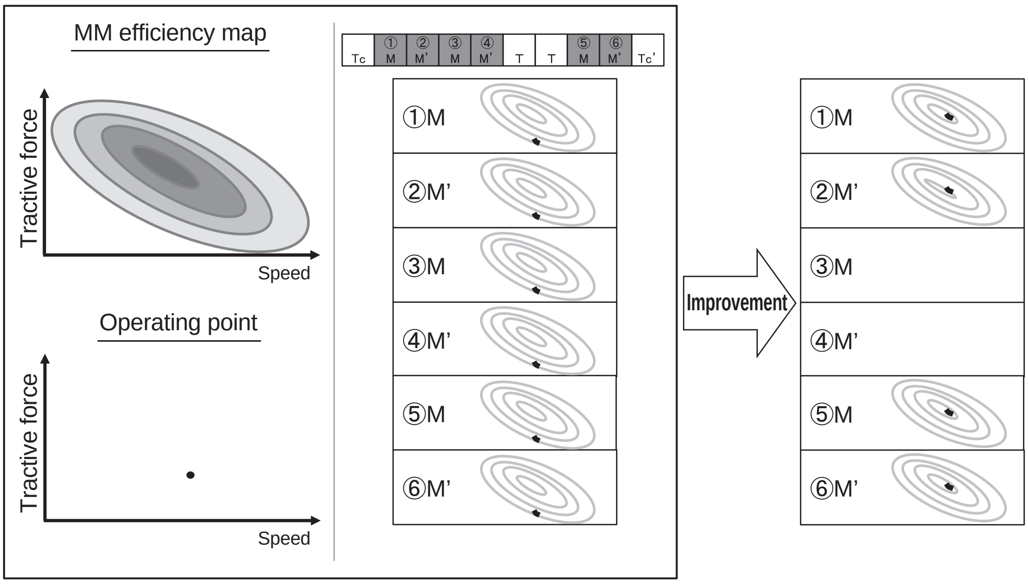

Fig. 5 System Design for Energy-conserving Train Operation

train communication network (TCN) that uses Ethernet. We will create prototype energy-conserving operation software, first installing that on test vehicles for verification, and we would like to then reflect the results of that in operating trains in the future.

3 Energy Conservation in Building Systems

3.1 Optimization of Station Underground Air Conditioning

The following describes energy conservation for air conditioning of large underground stations as building system loads in railways. The Environmental Engineering Research Laboratory has been measuring and evaluating load of air conditioning at Tokyo Station and researching system optimization since the laboratory's inception in 2009. We have been doing that because we believe railway technology should lead to a solution to the issue of air conditioning in spaces having the conditions of tunnels and platforms. Another reason is that much room for improvement can be expected because current equipment capacity is extremely large.

This research has brought about two results. First is proposal of optimal design in platform level air conditioning, which has been put to use in improving energy conservation for Tokyo Station Sobu underground platform air conditioning from 2013 to 2015. Second is the proposal of a more accurate simulation method in underground station air conditioning load evaluation. That is expected to result in major energy saving effects if applied to excessively dilapidated equipment at Omiya and Sendai stations.

One other area where energy consumption is large and where solutions in railway technologies are expected is Shinkansen snow melting equipment. Issues in that have been clarified by studies up to now, so we would like to develop a highly efficient system and energy-conserving methods of driving.

3.2 Area Management of Energy

Connecting multiple buildings in an energy network and optimizing energy supply and consumption by the area as a whole is a theme society is aspiring to achieve. This section introduces the development approach for that.

Fig. 6 was produced by the Environmental Engineering Research Laboratory in fiscal 2009. This illustrates managing energy in total while leveling the loads of stations where load is large in the morning rush, shopping centers where load is large in the afternoon, and hotels where load is large at night and using distributed power sources and heat storage technology.

Actually achieving this is no easy task. Each individual building differs in owner, age, vendors that built its system, and other aspects. In order to overcome that and achieve such management requires some sort of convention within the area regarding system design and plan design.

Even within Tokyo Station, facilities with different owners, age, and vendors are intermingled due to the large size of the space and a history of expanding and developing individual functions. In order to manage those as a single station, system and organization backing are demanded. Fig. 7 shows the vision for improving Tokyo Station as a whole that was drawn up in

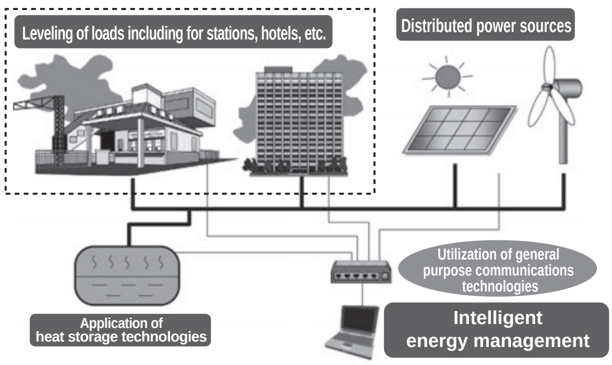

Fig. 6 Optimization for Area as Whole

2006. It is a vision for achieving area management using Internet technologies in the top level system while allowing vendor technology in field control.

As the scale of construction in the aforementioned improvement of air conditioning at Tokyo Station Sobu underground platform was massive, we considered this a once in a lifetime chance and proceeded with improvements to make the monitoring network be open. The facilities monitoring center realized from that is shown in Fig. 8. And if we spread that to the area surrounding the station, the design will probably be as shown in Fig. 9.

To conserve energy with building systems, optimized design of system capacity that fits the load as well as advancements in design technologies for that optimization are needed.

Furthermore, a system and organization for that must be built to achieve overall optimization through area management. However, standardization of communications procedures and merger of management duties are prerequisites for that. You probably noticed that this approach is very similar to with train systems.

We would like to meet our development issues for the time being one by one so as make system design an actuality and to promote from JR East a form of energy management that will be a model for society.

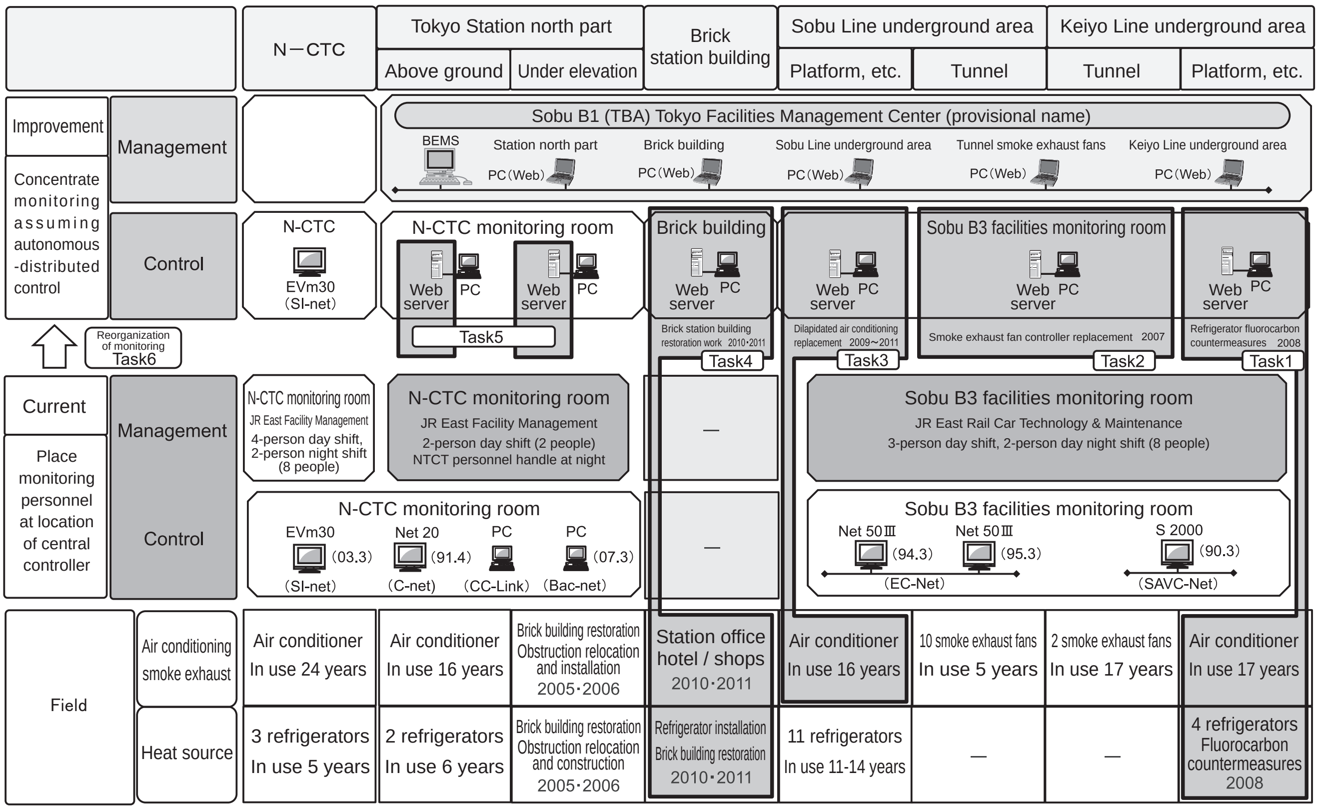

Fig. 7 Plan for Improving Facilities Monitoring Network at Tokyo Station


Fig. 8 Tokyo Station Facilities Monitoring Center

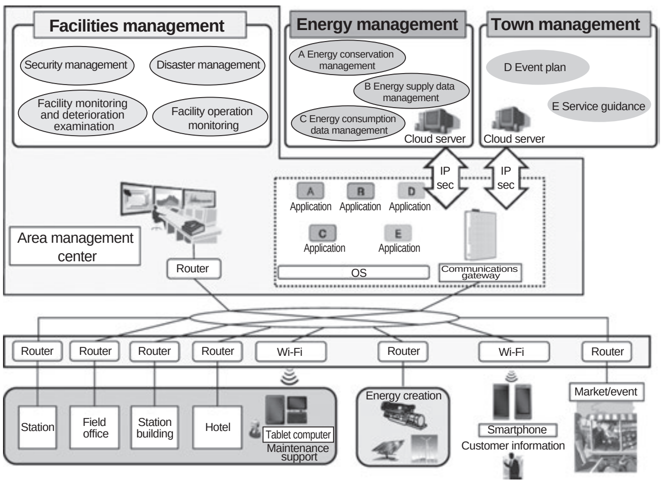

Fig. 9 Area Management Vision