Special feature article

Railways and Energy

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1 Introduction

I was constantly involved in one way or another with energy and other environmental issues since joining the former Japanese National Railways (JNR). The universal and temporary matters of energy issues come into view if one takes a long-term view. The following covers my current thoughts on energy conservation and on utilization of energy storage technologies that stand out in means of transport and on information & communication technologies (ICT).

Profile

1972 Department of Electrical Engineering, Faculty of Engineering, The University of Tokyo
1972 Entered Japanese National Railways (JNR)
1977 Assistant to Chief Engineer for Levitated Railways, JNR Rolling Stock Design Office
1981 Assistant, Supplies Section, Materials Bureau, JNR
1983 Assistant, Rolling Stock Management Office, Morioka Railway Management Bureau, JNR
1986 Chief Researcher, Rolling Stock Control Laboratory, Railway Technical Research Institute (RTRI)
1994 Director, Electric Vehicle Research Laboratory, RTRI
2000 Senior Researcher, Rolling Stock Control Technology Research Dept., RTRI
2004 Manager in Charge, Information & International Affairs Division, RTRI, Minister of Economy, Received Trade and Industry Award (Industrial Standardization Awards)
2007 Received IEC 1906 Award
2010 Senior Expert, Railway Technical Research Institute International Standards Center
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2 Energy Conservation Standing out in Railways

The 18th century industrial revolution was supported by coal in terms of energy used. The Stockton and Darlington Railway started operations as the first public railway in 1825 with steam locomotives, and it subsequently switched from horse-drawn railways to use steam locomotives exclusively. The London Underground, which opened in 1863, initially operated using steam locomotives. It is hard to imagine how tough it was for crews and passengers then with the smoke and soot from those. Electric railways spread from the 1880s, and the London Underground was electrified in 1890.

Petroleum replaced whale oil as lamp fuel from the mid 19th century, and the gasoline engine was invented in 1876 followed by the automobile in 1886. Mass production of automobiles stared in the 20th century, with that eventually thriving in terms of its share of land transport where it holds the majority share today. In the chemical industry as well, coal chemistry was supplanted by petroleum chemistry, which still holds the lead today.

Negative aspects also came about with large-scale consumption of petroleum on a global scale. Air pollution occurred with the advance of the chemical industry and popularization of automobiles, with photochemical smog reaching a peak in the Japan in the 1970s. Emissions restrictions were later placed on factories and automobiles to achieve the situation we are in today. The air in Tokyo becoming cleaner during the New Year's holidays demonstrates the fact that factory and automobile emissions still pollute the air to some extent.

Air pollution in China has reached epic proportions in recent years.[1] Measurements of particulate matter (PM 2.5) noted in local newspapers are of a level more than 10 times the standard for Japan. It is common in Chengdu, located in a basin, for takeoff and landing of airplanes to be delayed for hours due to poor visibility, and sometimes on the roads the car ahead cannot be seen. Some places in Europe and China restrict vehicles use by day of the week and license plate number to combat air polution.[2] Cities such as Strasbourg in France have prohibited ordinary vehicles from the city center and instead rely on trams.[3]

Energy consumption by transport in fiscal 2009 made up 23.6% of Japan's domestic energy consumption, and 62.4% of that was for passenger travel, with 85.9% of passenger travel consumption for automobiles and 3.3% for railways (Fig. 1).[4] In

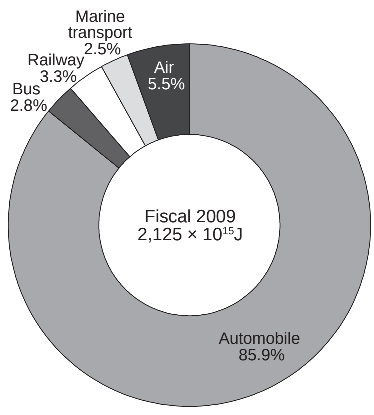

Fig. 1 Energy Consumption in the Railway Sector

terms of transport volume, energy conservation aspects of railways stand out considering the transport share of 62% of passenger kilometers for automobiles and 28% of passenger kilometers for railways in Japan.[5] Moreover, the energy consumption rate by mode of transport in Japan is 402.8 KJ/person-km for railways and 2,586.3 KJ/person-km for automobiles, putting automobiles at 6.4 times the energy consumption rate of railways. From these domestic macro statistics, we can say that, "automobiles make up approx. 90% of the energy consumption of all modes of transport, and if the automobile transport is replaced with the railway transport, 80% of that energy consumption could be eliminated." This fact needs to be better promoted in Japan.

Automobile use is increasing at a tremendous pace worldwide, especially in Asia. It is only natural that people want added convenience, but many automobiles that emit large volumes of pollutants are still in use across Asia today. China seems to be moving toward greater regulation,[7] but it probably should implement emissions standards on the level of Japan and other developed nations to protect the global environment. Moreover, Japan and other developed nations should probably provide more information on ways to prevent pollution.

Asia is home to many metropolises with populations in excess of 10 million people, such as in China (Beijing, Shanghai, Chengdu, etc.), India (New Delhi, etc.), and Thailand (Bangkok). Railways can simultaneously solve the problems of transport, energy, and air pollution in those metropolises. Developing societies and cultures where railways are used as a means of transport instead of automobiles will result in energy saving, and it is the best way to prevent air pollution and protect the environment.

3 Railways and Energy Saving

3.1 From Chopper EMUs to Inverter EMUs

Energy saving has always been demanded for railways, even though the intensity of that demand may fluctuate over time. My first job at the JNR Rolling Stock Design Office was to narrow down to a single method the for chopper control EMU circuit methods proposed by various companies, which achieve power regeneration in DC EMUs. Series 6000 chopper control EMUs were already in service on the Chiyoda Line of Teito Rapid Transit Authority (Today's Tokyo Metro). JNR was set on regenerative braking at much faster speeds (110 km/h) than those of subways (maximum speed 70 km/h), but it had not managed to succeed in that. A regenerative breaking method had to be decided on in a mood where failure would not be allowed. By making various considerations based on the characteristics of DC traction motors, we narrowed down the choices to a method proposed by Hitachi where resistance is inserted at high speeds, taking into consideration the output rating of reverse conducting thyristors, which were the most advanced semiconductors for power at the time. This came to be used for the mass-produced series 201 commuter EMUs (Fig. 2). Readers who have spent time in Tokyo in the past may remember these as the orange body EMUs of the Chuo Line. The method of inserting resistance adopted may at first glace seem to be opposite of energy conservation, but it works as a medium exceeding the performance limitations of semiconductors of the time, increasing the speed range of regeneration and regenerative energy.

The person at Hitachi who proposed this method (Kiichi Kimura) passed away long ago, but I continue to admire his work[8]. The principals of motors and chopper circuits I learned from him then formed the basis for my knowledge of electric motor cars.

Fig. 2 Series 201 Chopper Control EMU

The reduction in energy needed to operate trains by more than 30% with the chopper method was revolutionary. However, chopper circuits were large due to the technical limitations of the time, and obstacles of cost and equipping them to EMUs were probably tremendous. I also remember that it was difficult to make up for the increase in costs with chopper circuits by amount saved in electoral power. Even today, it costs money to achieve energy saving. The space under the floor of trains was filled up with chopper devices and their accessories, but using today's semiconductor IGBTs, chopper circuits can be achieved with a single semiconductor switch.

It was universally accepted at the JNR Rolling Stock Design Office in the mid 1970s that inverters were the ultimate traction circuit. With inverters, six semiconductor switches are necessary. In terms of technology, chopper development was the platform on which inverters were created. If railways had not introduced chopper control EMUs for economic reasons calculated for the short term, introduction of today's inverter control EMUs would probably have been greatly delayed, leading to a technological gap with European manufacturers. While difficult to do in a competitive environment, it is very important to continuously develop technologies looking ahead that will help the future of the industry as a whole.

Inverter control EMUs appeared in Japan in the mid 1980s, and new EMUs have almost all employed inverter control since the early 1990s. Regenerative breaking has become commonplace, and commuter trains have achieved tremendous results in reduction of energy required for running, reaching less than half that of previous resistance control EMUs thanks to that and lighter bodies. Even for Shinkansen EMUs, the same tremendous energy saving is achieved when compared at the same speeds. (With Shinkansen EMUs, the effect of aerodynamics on reducing running resistance is large too).

3.2 Environmental Performance of Shinkansen EMUs

In 1981, quite a bit of time after the start of the Shinkansen in 1964, France's TGV entered commercial services at a maximum speed of 260 km/h. Spurred by this success, France opened the TGV Atlantique Line in 1989 with a maximum speed of 300 km/h. Comparing Japanese and French high-speed railways using documentation on running resistance of the TGV's Atlantique

Line, running a high-speed train with Japan's Shinkansen at the Atlantique Line's maximum speed and acceleration performance would be possible at output of just 6,000 kW, opposed to the 8,800 kW of the TGV. Japan's Shinkansen EMUs of the time such as the Series 500 and Star21 had running resistance greatly reduced from that of the first Series 0 Shinkansen EMUs and were thus much more energy conserving. This was a result of noise reduction measures from aerodynamics research to reduce outside noise in effect greatly helping reduce aerodynamic drag, as I wrote in RTRI Report.[9] When I visited France, somebody at Alstom brought up this report. For the development personnel at TGV, it was without a doubt a frustrating fact. Many people may think that a vehicle with high output is good, but describing that in the terms of making a car with the looks and performance of a sports car using a compact car engine would probably make the difficulty of the job easier to understand. The Shinkansen would maintain that advantage until about 2010.

However, the difference in running resistance of CRH2 and CRH3 high-speed railway vehicles in China, which incorporate originally Japanese and German designs, came to light by running those many times between Beijing and Tianjin and comparing various test data.[10] The Chinese conducted their own wind tunnel tests and aerodynamic simulations to develop the CRH380A high-speed railway vehicle optimized over the CRH2 (based on the JR East E2) from 20 nose shape models as well as the CRH380B likewise optimized from analysis of air resistance test on the CRH3 (based on the German ICE3). [11] [12] [13] [14] From that development, the predominance of Japan's Shinkansen in running resistance became less significant. It should be noted that while those high-speed railway vehicles were developed in China, the knowhow from was picked up by Siemens and others.

4 Grasping the Chaos of an Outpouring of New Technologies

4.1 Innovation in Energy Storage Technologies

From experiences being directly or indirectly involved with development of storage batteries for linear motor cars from the 1970s, I came to feel that progress in storage batteries was proceeding at a turtle's pace. Charging and discharging tests to confirm performance would take a year or two. The situation, which had become the accepted norm, took a major turn in around 2000. With the release of hybrid cars (Toyota Prius) and electric cars (Mitsubishi i-MieV), Japan's industry and universities began to put much monetary investment and effort into development of storage batteries and their materials. New methods came to be used in development, such as implementation of nanotechnology.[15] The reverse thinking of multiple combinations of general use compact storage batteries in series and parallel which Tesla Motors introduced also came about.[16] Japan's top financial newspaper, The Nikkei, also came to print almost every month articles related to storage batteries, such as those on batteries with new principles and electrodematerials.[17] In specifications for lithium-ion batteries too, electrode materials and electrolytic solutions have came to be selected based on their purpose, such as to raise safety, achieve longer lifespans, or gain more power.[17] Storage battery manufacturers even came to say that the cost of lithium-ion batteries could be reduced to half the current price if they are mass produced. Cars that travel more than 300 km with a single charge will probably be available for less than 2 million yen (approx. US$17,000) within the next 10 years.[19] For railways as well, the price will drop even further in the future if standardized mass-produced items can be introduced. In that way, the cost effectiveness of battery-powered vehicles compatible with non-electrified sections and battery posts will become very attractive and the main type of train for non-electrified sections will probably be those equipped with storage batteries for economic reasons as well. The domestic demand in Japan for vehicles compatible with non-electrified sections is miniscule in terms of demand for EMUs for inter- and intra-city travel, but there are railways across the world that are not electrified. If vehicles equipped with storage batteries can be introduced there, it would create an enormous railway rolling stock market.

Even though it may not pay off now, there is no need to give up on battery-powered vehicles. What is important now is to look to the future advancement energy storage technologies, continue to promote the future needs of railways for those, and to develop even more attractive and innovative battery-powered vehicles by open innovation, introducing technologies of other companies as well.

4.2 Smart Grids and Smart Cities

Up to here I have covered various forms of energy-conserving operation. Standardized methods of operation are becoming desirable for the most part from a perspective of energy conservation. The energy to run trains has become quite complex taking into account regenerative braking capacity and onboard and wayside power storage capacity in addition to the issue of conventional limits of overhead contact line voltage fluctuation.

In past studies, online information exchange between rolling stock and the wayside had not been considered much. Advances in today's sensor and transmission technologies have enabled automatic information exchange without incurring a large amount of costs. Internet of Things (IoT) also is gaining a lot of attention now, and the foundations for adopting devices incorporating IoT have been put in place. [20] The facilities and rolling stock of railway operators can be managed by those operators, so it should be easier for them to manage energy by means such as smart meters and smart grids. Various things can be considered, such the effects of installing voltage sensors every kilometer or so along overhead contact lines, jointly managing electrical power for operating trains and for operating stations and other facilities, and the possibility of coordinating with users other than railways.

A higher level of energy use will probably possible if there are external loads that can absorb the fluctuation of electrical power when running trains. In fact, new business has emerged in industry where companies that have turned off electrical power are paid an incentive and power is traded between companies.[21]

4.3 Standardization for Complex Railways Networks

New innovations with direct energy conserving effects, such as introduction of rolling stock with regenerative brakes, are not often seen today, so combining train operation and wayside equipment to bring about energy conservation has come to be demanded. Up to now, individual subsystems could be utilized unrelated to others, but individual subsystems of the future will rely more and more on each other, with that relationship being more important than ever. The key to that will lie in subsystems viewing each other beyond the limits of authority and responsibility. For that reason, standardization of subsystems is of crucial importance.

In all fields, not just railways, it becomes impossible to gain the whole picture without standardization as systems become large-scale. This systemization of complex and large systems seems to be something Japanese are never good at, and we seem to overlook the importance of standardization that involves much effort, putting priority on other things such as optimizing individual systems. Conversely, the more specific the individual issue is, the easier it is for Japanese to deal with.

Looking at the example of Japanese semiconductor manufacturers, they used to boast a competitive advantage over Intel. Forced into a corner, Intel made the major decision to pull out of the memory business to concentrate on CPU business.[22] Memory business passed to Taiwanese manufacturers so as to compete with Japanese manufacturers, and those Japanese companies subsequently lost their robust constitutions. Moreover, the standardization of systematic semiconductor manufacturing led by the USA and the appearance of rivals (Korean and Taiwanese manufacturers) put Japanese firms on poor footing as memory gradually became larger. That and Japanese firms being unable to immediately introduce the latest manufacturing equipment that came about as a result of standardization of manufacturing processes meant they could not compete with Korean and Taiwanese firms in terms of performance and cost, and they suffered a major defeat.[23]

I believe a track record could be made in Japan for standardization of complex networks with railways, which employ closed systems not reliant out outside entities, and that benefits of those enjoyed with railways, as that is an industry where the work could be done within the industry. Just as Japan's railways got a head start in online information processing with trains seat reservation systems, I believe industry innovation could still be brought about from railways.[24] To do that, an "innovative mechanism" will be needed like how a development setup was made where manufacturers and railway operators worked as one in seat reservation systems.

5 Making Better Use of Railways in Society

Japan's railways developed with an edge in terms of energy conservation and the like. If railways could be used as an alternative to automobiles, we will be able to reduce almost that amount of energy consumption. In macro-level statistics, this applies to freight transport as well as passenger transport. And in terms of air pollution, railways are also far more environmentally friendly than automobiles.

Thousands of people die in automobile accidents in Japan every year, but the number of railway accident deaths is far fewer. Greater use of railways would thus be beneficial in terms of safety of society as well.

On the other hand, railways cannot be used for door-to-door transportation. In order for railways to be used more than they are today, we need even more contrivances to encourage people to ride them. Making travel comfortable is a given; and in addition to that, railways need to be made more closely tied to the community by means such as improving access to stations and increasing the number of train runs.

Railways themselves can work to further that edge, and at the same time, using that edge to increase railways' share of transport and encouraging society to go in that direction will directly contribute to energy saving and environmental protection worldwide.

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