Breakthrough

Breakthrough of Japanese Railway 1

Progress of Electric Railways in Japan

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Current State of Electric Railways in Japan

In 2001, railways in Japan carried 21.79 billion passengers (25.1% of all passenger transport) or 384.5 billion passenger-km (27% of all passenger transport). Rail freight totalled 59 million tonnes (1.0% of all freight transport) or 22.2 billion tonne-km (3.8% of total), clearly indicating that Japanese railway operators are almost exclusively passenger companies. Following the 1987 privatization and division of Japanese National Railways (JNR), railways in Japan are now composed of the six passenger operators and JR Freight in the JR group plus as other public and private railway operators.

Table 1 to 4 show that Japanese railways are principally passenger railways and the majority of lines use EMUs, with companies in the JR group using both DC and AC electrification methods and other private railway companies using DC electrification only.

Today's operations by the JRs started with transport in the large cities and then progressed to electrification of main lines between major cities and the opening of shinkansen high-speed railway links; the other private and public railway companies handle transport in and around the larger cities. Moreover, the low numbers of locomotives is due to the better suitability of EMUs for passenger and high-density operations in the major cities. Electrification technologies in Japan started with tramway operations and then developed into DC electrification of city operations. The major changeover point occurred in 1955 on the JNR Senzan Line when it was converted to single-phase AC using the commercial electricity supply. Subsequent main-line electrification saw widespread adoption of AC, which was also adopted at the 1964 opening of the Tokaido Shinkansen. This article describes the development of electrification technology in Japan from the dawn of railways to today's shinkansen high-speed railways and the progress in power technologies required for successful electric operations.

Start of Railway Electrification in Japan

Railways in Japan started with the 1872 opening of the 29-km line built by under the guidance of British engineers between Tokyo and Yokohama—the gateway port to Japan in those days. Early railway construction and operations were the responsibility of the Railway Bureau of the Ministry of Public Works. Railway construction started throughout the nation but a large number of new lines were being built by private investors. In 1893, the Railway Bureau became the Railway Agency and the 589-km line between Tokyo and Kobe was opened in 1899 as the nation's main rail artery. Other main lines were being built in rapid succession by private companies and the length of private lines was soon three times that of government lines; many private lines were also offering better speeds and services than the government railways. In 1895, the year before railway nationalization, the government railways covered 2413 km while the private railways reached 5231 km.

After the Russo–Japanese War (1904–05), the railways were soon making a major contribution to Japanese politics and the economy but there were increasing calls, especially from the military, for railway nationalization. The passage of the Railway Nationalization Law in 1906 saw the start of railway nationalization when the government purchased 4800 km of lines belonging to the 17 private railway companies transferring 48,000 employees and 25,000 pieces of rolling stock to the publicly owned government railways.

Japan's first electric railway was opened in May 1890 when Tokyo Electric Light Company built a 400-m track (1372-mm gauge) at the Third Industrial Exposition in Ueno Park, Tokyo where they operated two tramcars imported from J. G. Brill & Co. of the USA. The first genuinely commercial operations started in 1895 when Kyoto Electric Railway started operating four tramcars using a 500-V trolley pole system in Kyoto City with hydroelectric power generated by water

Table 1 Electrified Operation-km of JR Group Companies in March 2003

	Operation-km	DC km	AC km	Electrification
Conventional lines	17,857	6280	3,662	55%
Shinkansen	2,249	–	2,249	100%

Table 2 Electric Rolling Stock of JR Group Companies

	Electric locomotives	EMUs	Total
Conventional lines	780	21,719	22,499
Shinkansen	–	3,731	3,731

Table 3 Operation-km and DC Electrified Operations of Private Railways

	Operation-km	DC Electrified km	Electrification
Railways	7,108	5,088	71%
Tramways	482	475	99%

Table 4 Electric Rolling Stock of Private Railways

	Electric locomotives	EMUs	Totals
Railways	119	25,649	25,768

JNR-designated Railway Memorial *Nade* 6141 electric railcar (two trolley poles)
(JR East Oi Workshop)

Rotary transformers
(*Tokyo–Yokohama Electric Plant Memorial Photograph Album* by Railway Bureau)

carried by canal from Lake Biwa. A few years later, electric operations started over a 2.3-km line in Nagoya City using power supplied by a coal-fired power station. Tram ordinances promoted electrification of city tramway operations and the first steam railway to be electrified was the 10.9-km line operated by Kobu Railway between Iidamachi and Nakano in 1904. This section was purchased by the Ministry of Railways as part of the 1906 nationalization to become the first electrified section of the government railways.

Single and multiple overhead lines

The early electric operations used cars with either one or two trolley poles. In modern electric railways, the negative current (return) flows back to the power substation via the rails but at that time, the return current was returned to the substation via the overhead line. Since communications lines in those days used a single wire, this overhead return was used to prevent railway earth leaks interfering with communications and also to prevent electrolytic corrosion of underground structures caused by leakage current. In 1899, a special working group decided on future use of multiple overhead lines for any suburban electric railway and the start of Kobu Railway tram operations used two trolley poles. However, the multiple overhead line method had a complex structure and made it difficult to achieve faster operations speeds so the single overhead line method was investigated and by 1911, electric carriages were running using this method.

Power supplies and overhead line voltages

Today, Japan's national power grid uses two frequencies; 60 Hz in the east and 50 Hz in the west, with the border at the River Fuji near Mt Fuji on the main island of Honshu. The historic reason is because generation equipment was imported separately from Europe and the USA. Unlike today, in the early days of electric railway operations, commercial power from the national grid was not used and the railway companies built their own power stations and the generated power was then transformed to the 600-V supply used by railcars. Some generation stations used hydroelectric power but most were thermal stations generating power from coal. The power transformation from AC to DC was done using rotary converters but since the technology of the day made rectification of commercial frequencies difficult, a 25-Hz rotary converter was used and the railway power stations supplied power at a frequency of 25 Hz. As a consequence, dedicated hydroelectric power stations generating power at 25 Hz were built to supply power to tram lines and railways in Tokyo.

Railway Nationalization and Railway Agency

Railway Agency Working Committee

Following the 1906 nationalization, in 1908, responsibility for administration of railways was transferred from the Ministry of Communications to the Railway Agency, which was part of the cabinet, and this administration system continued until 1987 when JNR was privatized and divided. The first Director-General of the Railway Agency was Shimpei Goto (1857–1929) who had been appointed the first President of the South Manchuria Railway in 1906.

In 1910, Goto established the Railway Agency Working Committee to deal with the enormous expansion in the government railways caused by purchases resulting from the Railway Nationalization Law. This committee had 17 sub-committees. The avowed purpose of nationalization was to streamline railway management and operations; increase transportation capacity; promulgate the ascendancy of manufacturing; plan railway infrastructure; cut administrative costs; and reduce transportation charges. The second sub-committee of the committee was responsible for matters related to track gauge; until then tracks had been laid to the narrow-gauge standard (1067 mm) and this sub-committee examined whether or not to recommend a change to standard gauge (1435 mm). The opening of the Tokaido and the San'yo main lines had already seen discussion about the advisability of changing to standard gauge and in 1911, the government established the so-called 'Standard Gauge Railway Upgrade Committee' to compare the standard and narrow gauges, and examine the economic effects of standard gauge and whether it should be adopted for the national railways network. However, due to the massive costs of reconstructing the existing narrow-gauge network to standard gauge, it was decided to put priority on new constructions, a situation that remained unchanged until 1964 when the Tokaido Shinkansen was opened running on standard gauge. In addition, sub-committee 13—the motive power sub-committee—was responsible for discussing plans for railway electrification, electrification methods and hydroelectric power generation and the results saw the planning and start of electric operations on Tokyo's Yamanote Line.

Usui Pass (*Electrification Works on Shin'etsu Main Line (1912)* by Railway Bureau)

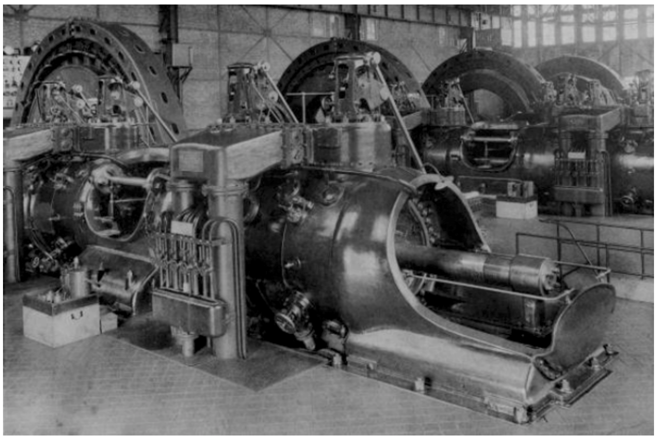
Shin'etsu Line and Usui Pass

The Shin'etsu Line links Tokyo with Niigata, the gateway port to Japan on the Sea-of-Japan coast. It was an important line for transporting agricultural produce, fish, and petroleum from Niigata to the Tokyo metropolitan region. However, the 11.2-km section between Yokogawa and Karuizawa stations crosses the Usui Pass with a steep grade of 66.7 per mill (1:15) rising and falling 553 m over 26 steeply inclined sections. Steam operations using an Abt rack-and-pinion system started in 1893 but the speed of 7.5 km/h meant that 75 minutes were required to cross the pass and this section was seen as a candidate for urgent electrification. The start of electric operations in 1912 saw the journey time drop 75 minutes to 43 minutes. To supply the required electric power, a coal-fired power station with three generators each supplying 1000 kVA was built along with 6.6-kV power lines and two substations to transform the power to 650 Vdc using rotary transformers. A third rail supplied the electric locomotives. Interestingly, there were storage batteries (total of 1332 Ah) at the substations that were used to compensate the output of the rotary transformers when trains were climbing the grade and to store power produced by regenerative braking when trains were running downgrade. At that time, use of storage batteries in substations was quite normal and could still be a very good technology for confronting energy problems today.

The generators, generation equipment and electric locomotives were all imported from Europe and the USA. However, the subsequent construction of a gravity-fed oil pipeline parallel to the tracks between Karuizawa and Yokogawa making use of the difference in elevation saw the line struggle economically due to decreasing freight levels and the section was finally closed in 1997 to become part of an Important Cultural Property after the opening of the Hokuriku (Nagano) Shinkansen.

Tokyo (Central) Station

The 1906 railway nationalization presented the opportunity to move the terminus at Shimbashi Station in Shiodome to the new Tokyo (Central) Station completed in 1914. The new station had four platforms serving 8 lines; two platforms and four lines served Tokyo's urban lines and the Tokyo–Yokohama line, while the other platforms served the Tokaido main line. At the time of the station opening, the 22-km section between Shinagawa and Yokohama had been electrified but the overhead double line system used previously had been changed to the overhead single line system electrified at 1200 Vdc. The Tokyo–Shinagawa section used the German 60-m compound catenary method of Siemens while the Shinagawa–Yokohama section used the American 45-m simple catenary method of Ohio Bryce. The electrifications works were completed in December 1914 and electric operations started from 20 December. However, due to poor work and lack of experience with the new technologies, operations were switched back to steam from 26 December and electric operations were delayed for a further 6 months. The first pantographs used the roller method but soon changed to the slip-plate method still used today. Electricity (DC) was purchased from Tokyo Railway operating electric tramways in inner Tokyo and also from electric utilities but there were problems of price and since the frequency of the utility power was 50 Hz, the government railways built their own power station at Yaguchi on the Rokugo



Generators powered by gas engines at Yaguchi Power Station
(*Tokyo–Yokohama Electric Plant Memorial Photograph Album* by Railway Bureau)

Hydroelectric power station on River Shinano (JR East)

River using engines powered by city gas to generate 6000 kW at 25 Hz, as well as transformer substations next to the tracks. This marked the start of genuine electric railway operations in Tokyo.

Securing Power Supplies

Electrification Investigation Committee and power company

Following the end of WWI, railway electrification became the subject of intense debate as a means of securing the nation's rapidly growing transport needs. The Electrification Investigation Committee established in 1919 recommended electrification of 4100 km of lines and securing sufficient generation capacity for transport became an important issue in developing the plans. It was decided, 'In principle and irrespective of whether power is purchased from power utilities or obtained from a government railways' power company, it must be both inexpensive and high quality. Moreover, consideration will have to be given to the performance of private power utilities as well as to development of government railways' own power companies.' In concrete terms, this meant examining plans to build a hydroelectric power station to save coal, the main fuel at that time.

At a cabinet meeting in July 1919, it was decided to economize on the usage of coals for government railways' operations and a plan was proposed to secure power for the railway operations in Tokyo by building a hydroelectric power station utilizing the flow of the River Shinano. The plan called for construction of a station producing 11,700 kW at Ojiya where the main river drops 100 m in a short stretch. In the following year, the Government Railways Power Company Law was proposed to establish a public–private power generation company but although the proposal was passed by the House of Representatives of the Japanese Diet, discussion was shelved by the House of Peers. The first aim of the plan was to secure power for the government railways' electrification by building a public–private power company that would supply any surplus power to other railways and businesses. The existing private power utilities were worried about this competition from a new business and petitioned the government to reject the idea of selling any surplus, leading to the plan's abandonment. The plan for the hydroelectric power station called for construction to start in October 1920 but the financial impact of the 1923 Great Kanto Earthquake on the public purse caused a temporary delay and in 1925 it was decided to split the construction into four phases to permit economies in construction costs and time for raising funds. Phases 1 and 2 called for construction of a power station at Senju followed by the second stage of construction at Ojiya during phases 3 and 4. The Senju power station finally started operations in 1939.

On the other hand, demand for electric power was increasing rapidly following the 1923 electrification of 77 km on the Tokaido main line between Tokyo and Kozu, and the 1931 electrification of 81 km on the Chuo main line between Hachioji and Kofu. As a result, coal-fired power stations were built in 1923 in Akabane and in 1930 in Kawasaki to strengthen the electricity supply system. Furthermore, the Tenryu River was examined as a source of power for the electrification of the Shizuoka–Nagoya section of the Tokaido main line in the Tokai and Chubu regions and responsibility for development of power supplies was shifted in 1952 to the Electric Power Development Company Ltd. Electrification in the Kansai region started with examination of the Totsu River but hopes for developing it as a hydroelectric source were abandoned in 1954. Subsequently, generation capacity was strengthened at the hydro plant on the River Shinano and the coal-fired plant in Kawasaki with the former able to generate 450,000 kW and the latter 550,000 kW. Currently, the power stations belonging to JR East supply about 60% of its annual electricity needs.

Progress with electrification

When the cabinet decided in July 1919 to economize on coal consumption, the Railway Electrification Investigation Committee had planned to electrify 4100 km of lines, starting with 83 km on the Tokaido main line between Tokyo and Odawara, 26 km on the Yokosuka Line, and 87 km on the Chuo main line between Hachioji and Kofu. Electrification started, but in terms of results, only part of the network, such as city suburbs and graded sections was being electrified. As part of the WWII controls to strengthen military transport capacity, some sections of private electric railways were purchased by the government railways between 1943 and 1944, giving a total of 19,620 operation-km of which 1315 km (6.6%) were electrified lines. Of these 1315 km, 690 km were government railways' lines and 625 km were purchased private electric railways.

Private and Public Railways

Electric railways

With the spread of electric trams services from the main cities into regional cities, not only tram services but also small and medium size electric railways started appearing to link urban railways with tourist regions. In the 1930s, there were 3800 km of regional lines and 2060 km of tramway lines forming the private railway network. Subsequently, the April 1938 publication of the National Mobilization Law and the Land Transport Business Coordination Law resulted in takeovers and transfers of the many various private companies to form the basis of the nine major private railway operators that exist today. Furthermore, the birth of the publicly owned Teito Rapid Transit Authority in 1941 marked the start integrated subway services in Tokyo now operating as the Tokyo Metro.

Electric lighting business

Electric railways need electricity to produce motive power and the early railways operated their own power stations using coal or water to generate electricity. Naturally this was supplied to their railway operations but they inevitably saw a business opportunity for supplying lighting to trackside areas too. In addition to lighting, they also loaned industrial electric motors to factories. Companies that started out getting the bulk of their income from electric railway operations soon became relatively large electric lighting and supply utilities. Conversely, electric power utilities also entered the electric railway business.

However, the small generation capacity of the railway companies in the huge electricity supply business meant that they could not compete with the power companies and their electric lighting business was soon consolidated with that of the larger power utilities, leaving five powerful national companies at that time. The 1938 National Mobilization Law and the National Electricity Regulations of April 1942 saw management of the electric railways' power generation business (70 operators) pass to nine power distribution companies. Ever since then, the electricity business has been independently managed by the nine regionally divided power companies but recent approval for liberalization of the generation market seems likely to lead to the entry of new players.

Postwar Electrification

Following WWII, private railways were the mainstay of electric operations while the government railways had still only managed to electrify a few difficult sections and regions in and around the major cities. The government lines were experiencing great difficulties with steam operations due to the poor-quality postwar coals. The need for electrification had to be negotiated with MacArthur's GHQ and was commenced slowly during postwar shortages of food and materials.

By 1947, 106.5 km of the Joetsu Line had been electrified between Takasaki and Minakami (41.5 km) and between Ishiuchi and Nagaoka (65 km). A further 40 km were added by 1949 on the Ou Line between Fukushima and Yonezawa, followed by 130 km in 1951 on the Tokaido main line between Numazu and Hamamatsu.

However, the urgently desired plan for full electrification of the Tokaido main line all the way between Tokyo and Kobe was opposed by the Civil Transportation Section (CTS) of GHQ and work was not started until the signing of the 1951 San Francisco Peace Treaty. It was completed 10 years later in 1961, taking 46 years since electrification was first proposed and 35 years since the first work started.

During this early postwar period, the government railways established the Railway Electrification Committee in September 1947 that drew up a plan to electrify a total of 1849 km of main lines.

AC Electrification

Reports about the postwar success of the French National Railways (SNCF) in electrification using commercial single-phase AC power were soon heard and the JNR President Sonosuke Nagasaki visited France in 1953 to study the potential of AC electrification, resulting in the formation of the AC Electrification Inspection Committee on his return to Japan (see *JRTR* 27. pp. 32–39). This was the start of AC electrification technology in Japan, which would be subsequently adopted for the Tokaido Shinkansen opened in 1964. Compared to DC electrification, the voltages used in AC electrification are an order of magnitude higher, so the distances between trackside transformer equipment can be much longer, which might be expected to reduce the number of ground facilities. However, for rolling stock using DC motors, a rectifier is needed to transform the AC to DC. Similarly, for rolling stock using AC motors, a voltage–frequency controller is required.

In 1951, SNCF engineers successfully completed development tests on a section of the Annecy Savoie Line, which they reported at an international meeting in 1952. This 'Nancy Report' led to the establishment of the AC Electrification Investigation Committee in 1953.

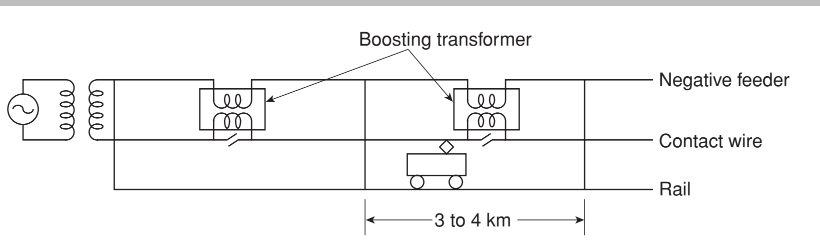
The committee minutes concluded that, 'Since it will be difficult to immediately start building AC electric locomotives in Japan, it would be advisable to conduct test runs using imported locomotives on the Senzan Line and to start test production of main equipment with a view to building a base for future manufacturing. Furthermore, prototyping of domestically manufactured AC electric motors and mercury rectifiers for replacement of DC motors must be started along with simultaneous trial production of transformers and controllers, etc., and preparation of two test cars. Two units of one class of the most difficult to domestically manufacture electric locomotives for which manufacturing licenses can be obtained will be imported. We have confidence in domestic manufacture of mercury rectifiers for rolling stock so mercury-rectifier locomotives will be trial manufactured in Japan.... If there is no hope of importing AC electric locomotives, there seems little chance of importing test locos unless we can guarantee an order of 10 to 15 units. But if there is a chance, we have given an intermediary *carte blanc* to purchase one unit each of an AC electric locomotive and a mercury rectified locomotive from French National Railways.'

In 1955, SNCF successfully completed the first genuine AC electrification over a 363-km section between Valencienne and Thionville in northern France and reported the results to the AC Electrification International Conference held in Lille that year. Japan sent five delegates and when the conference finished, they unsuccessfully attempted to negotiate the purchase of two electric locomotives.

At the same time, tests were being conducted over a 23.9-km section between Kitasendai and Sakunami on the Senzan Line; four types of locomotives were built and tested using both mercury rectifiers to convert AC to DC to drive DC motors and direct AC motor drives. The results demonstrated the excellence of using mercury rectifiers and formed the basis of new electric carriages to be used with subsequent AC electrification. Testing started in September 1954 and ran until March 1956.

AC Electrification of Senzan Line using ED44 Electric Inspection Car (*JNR Centennial Photo History*)

Figure 1 BT Feeding System

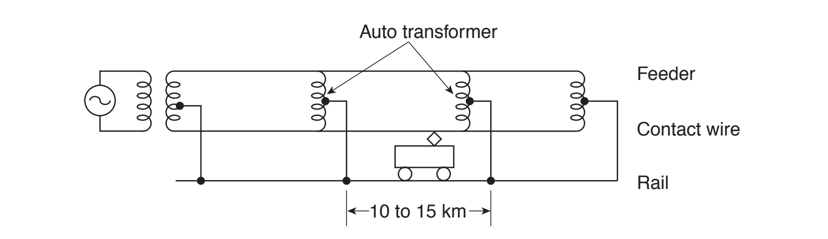


Japan's first AC electric operations started a year later in 1957 over a 46-km section of the Hokuriku main line between Maibara and Tsuruga.

A feature of AC electrification is that since high voltages of 20–25 kV are supplied to the trolley wire (compared to 1500 V for DC), large cost savings can be achieved due to the fewer on-ground substations at wider intervals compared to DC installations. Moreover, since there is less wheel slip when starting, the traction force is higher so lighter smaller locomotives can haul heavier loads. In addition, since the pantograph collection current is smaller, high-speed operations are more easily achieved. As a consequence, AC electrification became the favoured method for the Tokaido Shinkansen when it opened in 1964.

This early electrification work formed the basis for all subsequent railway electrification in Japan. In concrete terms, AC electrification is achieved by using a Scott transformer to adjust voltage imbalances in the three-phase power from the power utility to provide a single-phase load. Boosting transformers (BT) with a winding ratio of 1:1 are installed every 3 to 4 km along the trackside to reduce inductive interference in communication lines caused by earth leakage current by absorbing return current (Fig. 1).

Figure 2 AT Feeding System



Tokaido Shinkansen

The Tokaido Shinkansen was opened in October 1964. Prior to that time, Japanese electric operations had been predominantly DC on narrow-gauge tracks so the Tokaido Shinkansen heralded a new era of high-speed operations on AC-electrified standard-gauge tracks.

To achieve high operations speeds, one shinkansen train set requires about 10,000 kW of power, which meant developing various new technologies for pickup currents in excess of 1000 A.

First, for the pantograph to collect sufficient current from the catenary, six pantographs were installed on one train set and a compound catenary composed of contact wire, auxiliary catenary and messenger wire was used. To prevent wire vibration due to the action of the pantograph, many hangers with a damper effect were inserted close to the overhead wire supports. However, this method experienced a large number of faults due to wire vibrations caused by increases in the number of shinkansen running at very short headway. The present overhead wire structure uses a contact wire with a thicker cross section and a higher wire tension. In addition, use of a high-voltage bus running between pantographs has permitted the latest 16-car shinkansen train sets to collect sufficient power through just two pantographs.

Second, although the old BT AC electrification of conventional lines could be used at 25 kV, since a single shinkansen train set has a current load of 1000 A, some new technology was required. Using BT at 3-km intervals to suppress induced interference in communications lines resulted in a great amount of arcing at pick-up slip plates; this was controlled by inserting serial capacitors in the negative feeder. However, such a complex overhead structure resulted in a number of overhead wire accidents and the problem was finally solved by development of the auto transformer (AT) feeding method, which does not require boosting transformers.

Third, to prevent shorts between sections using different power supplies resulting from feeds from different substations, on conventional lines, the driver sets the handle notch to off and back on again. Since the driver of a high-speed shinkansen could never do this, trackside power supply auto-switching was developed to automatically switch power supplies when passing between sections. These technologies were developed as part of the 1950 AC electrification tests on the Senzan Line and subsequent experience of full-scale commercial AC operations on the Hokuriku main line before being perfected as the shinkansen electrification system.

Since the Tokaido Shinkansen runs between Tokyo in the 50-Hz region and Osaka in the 60-Hz region and 60-Hz in-carriage electrical equipment was adopted to lighten weight, two frequency conversion stations were built in the 50-Hz shinkansen operations region. Conventional AC electrified lines use 20 kV because that was the voltage supplied by the power companies at that time but the shinkansen catenary is energized at 25 kV.

Latest Shinkansen

Following the 1964 opening of the Tokaido Shinkansen, transport demand grew rapidly and the first 12-car train sets were quickly increased to 16 cars with about 10 services running every hour. However, the pressure on the infrastructure resulting from running 8-pantograph train sets at a headway of 6 minutes caused a number of problems due to wire vibration. At the time, the easiest solution was to suppress wire vibration by changing to a heavy compound catenary design using thicker wire at a higher mechanical tension. Since this made the catenary structure extremely complex in sections containing a BT, there were more wire accidents, resulting in the urgent need for an upgrade solution. The solution was development of the AT feeding method instead of the BT. The AT method was already in use at 11 kV and 25 Hz on the New Haven Line in Connecticut, USA, but had not been tested using commercial power frequencies. In the AT method, the feeder line and contact wire are linked by a single-winding transformer, and the neutral point is connected to the rail. Since the substation feed voltage is twice the overhead wire voltage, the interval between substations is much longer than the BT feeding system and the ground infrastructure can be simplified. However, there is a problem with voltage drops due to the insertion of the AT single-winding transformer but the great merits of the simple structure and the elimination of sections containing BTs made adoption of the AT method very attractive. Simulation of AT feeding circuits was started in 1964 and after proof-of-technology tests on some narrow-gauge lines, it was adopted commercially over the 259-km section between Yatsushiro and Nishi Kagoshima (now Kagoshima Chuo) on the Kagoshima main line in October 1970. Subsequently, this method became the standard AC

Simple Catenary on Nagano Shinkansen (RTRI)

electrification technology in Japan where it was adopted for both conventional and shinkansen lines—it also became the standard method of AC electrification overseas. Due to increases in demand and aging infrastructure on the Tokaido Shinkansen, the old BT feeding method was replaced by reconstruction to the AT method and as soon as all the old BT sections were eliminated, operations speeds were increased to 270 km/h from the original 210 km/h (Fig. 2).

In addition, although the thick, high-tensile strength contact wire of the compound catenary developed in Japan continues in use, a new contact wire design was adopted on the 117-km section of the Nagano Shinkansen between Takasaki and Nagano opened in 1997, on the 96-km extension of the Tohoku Shinkansen between Morioka and Hachinohe opened in 2002, and on the 137-km first southern section of the Kyushu Shinkansen between Shin Yatsushiro and Kagoshima Chuo opened in 2004. This new contact wire has a copper-clad steel core, providing a high wave propagation velocity and permitting construction of a simple catenary structure with high-tensile strength; R&D into new catenary structures is still continuing.

The move to increased operations speeds depends on the section in question but the maximum is about 300 km/h. Some test sets have recorded speeds of 430 km/h.

The Japanese shinkansen have all been constructed to standard gauge but to improve access to the conventional lines of regional cities, tests were made on operating shinkansen through services by upgrading narrow-gauge lines to standard gauge. This resulted in the recent opening of the 148-km Yamagata mini-shinkansen (1993) linking Shinjo with Fukushima Station on the Tohoku Shinkansen, and the 127-km Akita mini-shinkansen (1997) linking Akita with Morioka also on the Tohoku Shinkansen.

Summary

Looking at the history of railway electrification in Japan, most technology in the Meiji period (1868–1912) was imported and copied but then the trend soon moved towards electric operations using domestic technology. Private railways took the lead over government railways in introducing urban electric rail services and during this period, electricity for operations was supplied from the railway companies' own generating stations with surplus capacity sold to trackside housing and factories. However, the railway companies' electricity supply business disappeared due to severe cost competition with the larger power utilities and because wartime government regulations forced transfer of generation capacity to the utilities. Electric rail operations continued growing and the early postwar period saw promotion of main-line electrification by the newly formed JNR due to severe postwar coal shortages hampering steam operations. The major turning point came with SNCF's success in using commercial single-phase AC power for rail operations while Japanese electric railway companies were still using DC electrification. On hearing about SNCF's success, JNR pushed ahead with AC electrification of the Senzan Line using its own technical developments and, as a result of this experience, was able to introduce AC electrification on the new Tokaido Shinkansen when it opened in 1964.

In the early days, the BT feeding method using trackside boosting transformers was adopted but was subsequently replaced by the AT feeding method using low-cost single-winding auto transformers, which became the standard AC feeder system for railways around the world, including high-speed lines. ■

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