PT.9: 15kV 16.6Hz AC IN NORTHERN EUROPE

THE EVOLUTION OF ELECTRIC RAILWAYS

Following the success of the Swiss with their BLS railway, Northern European countries such as Sweden and Norway began to follow suit. One notable undertaking was the electrification of the Lappland Railway.

By BRYAN MAHER

The Lappland line was built originally in 1885-1902, specifically to haul iron ore to the ice-free Norwegian port Narvik, and to the Swedish harbour at Luea on the Gulf of Bothnia. It became the communication lifeline for all people to the far north of both countries. Even today, this single-track line carries 67% of all Norwegian freight rail traffic.

With snow-bound mountainous terrain and the need to transport coal for steam locomotives over long distances, the line presented real problems in operation. Thus, the numerous high rivers (for possible hydroelectric power generation) turned the engineers' minds towards electrification.

Noting the BLS Railway's success, the Norwegians and Swedes chose to electrify the whole Lappland Line, from Lulea on the Gulf of Bothnia in Sweden to Narvik in Norway, where the Atlantic Ocean confronts the Arctic Ocean. Though geographically mostly in Sweden, this line had always been a joint effort by both countries, a shining example of peaceful cooperation.

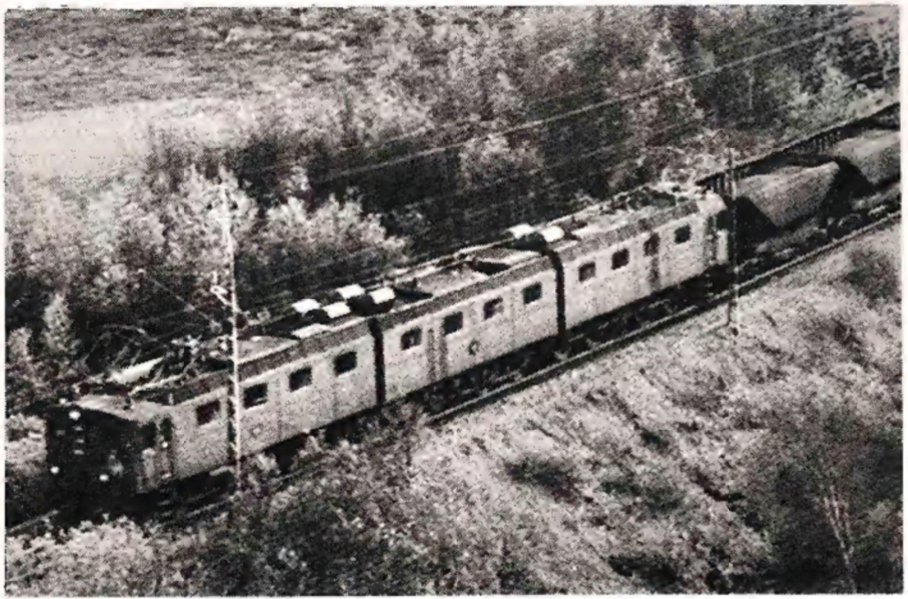

Fig.1: the Swedish Dm3 class triple-unit rod-drive electric locomotive is one of the most powerful electric locos in Europe. These locos operate from a 15kV 16.6Hz supply, are rated at 7.2MW and have 24 driving wheels. (Photo SJ).

AC 15Hz system

It was decided to electrify the line using a 15kV 15Hz system initially, derived from low-speed water-turbine driven alternators installed specifically for traction power.

Traction was provided by series AC motors operating on convenient medium voltages between 200 and 1000 volts, provided by the high-power secondary winding of an onboard transformer. The transformer's 15kV primary was fed by the insulated pantograph atop the locomotive, with the circuit return path being via the running wheels and rails.

As with later German systems, auxiliaries and electric lamps on the train were run from separate low-power secondary windings. Such lamps operate best on very low voltage, so that high current filaments may be used. The large thermal inertia of the heavy filament minimises the annoying, very visible flicker caused by the low-frequency supply. An alternative was to supply lighting from low voltage batteries charged by an onboard AC/DC motor-generator set.

Rod-drive locomotives

The locomotives used today on the Luea to Narvik line are the rod-drive type illustrated last month. The Dm class are rated at 4.8MW (6434HP) and 20 of these locos were built between 1953 and 1971.

The Dm3 class, of which 19 were built between 1960 and 1970, are

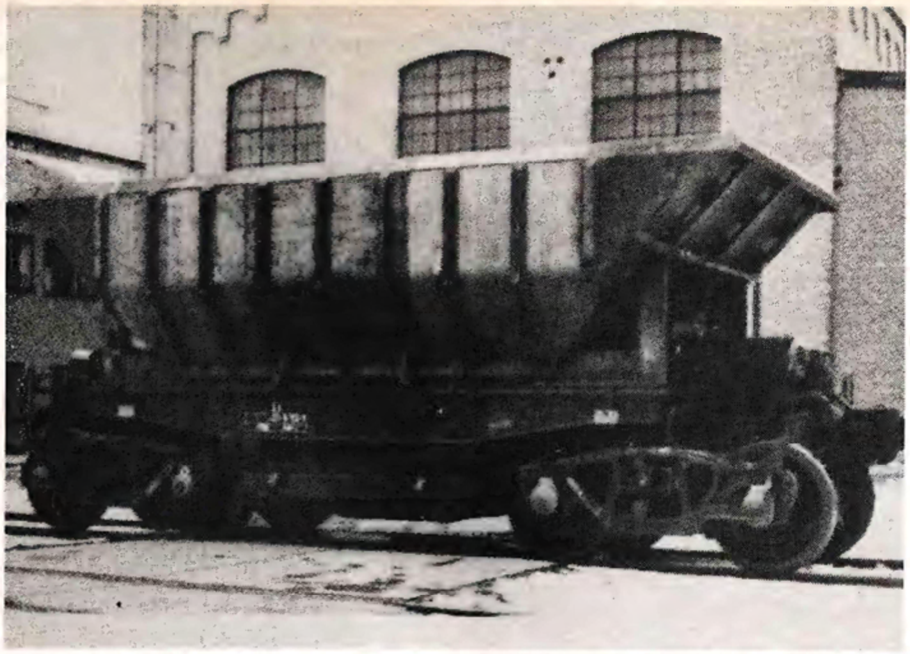

Fig.2: these 81-tonne capacity iron-ore wagons are used in regular 5280-tonne trains hauled by the Dm3 class locos on the Lulea to Narvik line. (Photo SJ).

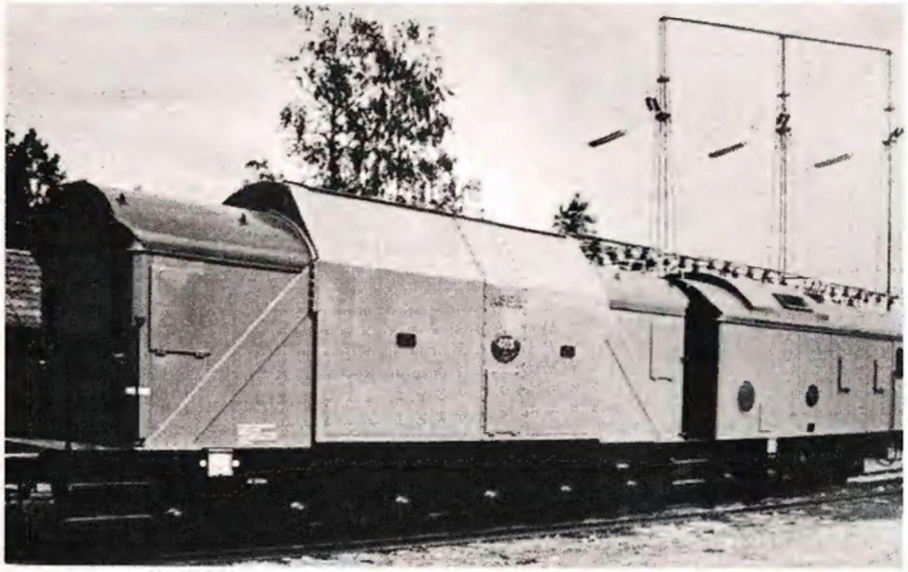

Fig.3: a mobile rotary frequency converter used by the Swedish Railways. It converts a 6kV 50Hz input to provide a 15kV 16.6Hz 10MVA output. The 198-tonne converter wagon is at left while the equipment wagon is at right. (Photo SJ).

rated at 7.2MW (9652HP). These rod-drive locos are limited in speed to 75km/h but are capable of considerable tractive effort. The triple-unit Dm3 class, illustrated in Fig.1, haul 5280 tonne trains on a regular basis, although the line gradients are limited to 1 in 100 (ie, 1%).

Centralised traffic control is used over the whole 660km length. The eight wheel wagons used (Fig.2) carry 81 tonnes of iron ore. These high efficiency trains use only 24.6 watt-hours per kilometre for each tonne of train weight, a truly remarkable performance.

Being so impressed with the performance of their far northern electric railway, the Swedish Government Railways, SJ, began electrifying their complete railway system. In 1926 the Stockholm-Goteborg line electrification was completed, dramatically reducing the original 1862 steam-hauled running time of 14 hours.

Today, passenger demand has increased in response to the fast electric train schedules to the point where hourly express trains run right across the country from Stockholm to Goteborg and also to Malmo, a journey of 619 kilometres.

Early passenger electric locomotives were of the rod-drive type, such as the standard electric 1-3-1 (ie, one leading axle, three driven axles, one trailing bogie) which have quite high power efficiency. But because of their basic "single-chassis and single-axle leading bogie" design, they too are limited in speed.

Bogie locomotives

The ASEA company of Sweden, which had been in the forefront since the beginning of electrification in Sweden and Norway, ultimately produced bogie-type electric locomotives. These were capable of higher speeds because of the shorter fixed wheelbase of the bogies compared to the long wheelbase of a rod-drive locos.

Synchronous frequency changers

Not wishing to install special low frequency power stations all over the country (as originally provided in the far north to generate the 15Hz traction supply), the SJ used the normal 3-phase 50Hz national supply to drive synchronous motor-alternator frequency conversion sets.

These consist of a 3-phase 50Hz 6kV synchronous motor direct coupled to a single phase 15kV 16.6Hz alternator. The motor has three times as many poles as the alternator, so giving the frequency ratio of 3:1.

Such motor-alternator units were installed at trackside substations, between two and five units per substation. The units range from 3.1MVA to 5.8MVA to 10MVA each. Substations are at varying intervals depending on traffic density. Eventually the same "50Hz motor — 16.6Hz alternator" substation scheme replaced the original 15Hz Porjus power station in the Arctic.

As SJ extended the electrification of the main lines, maintenance of motor-alternator sets and replacement of faulty units in rare

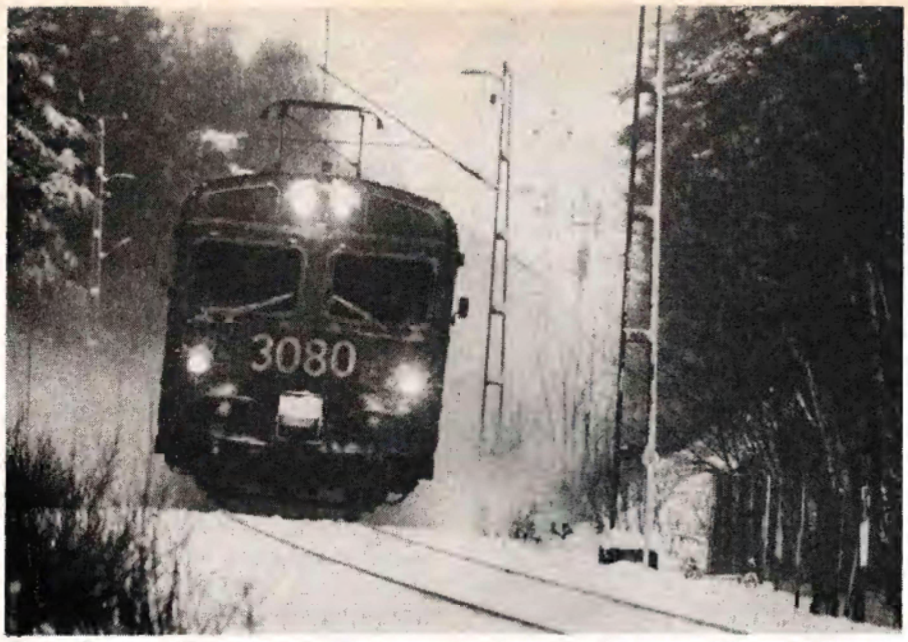

Fig.4: the Swedish electric BoBo locomotives operate in very cold conditions. Wet snow on the high-voltage (15kV) insulators is a constant problem for the engineers. (Photo SJ).

Fig.5: a diesel-powered snowplow at work on the Swedish Railways. (Photo SJ).

emergencies prompted the idea of mobile motor-alternator sets. Accordingly a number of units were constructed, each consisting of a 12-wheel wagon carrying one 10MVA motor-alternator unit.

This wagon, complete with motor-alternator and DC exciter generator, weighs 198 tonnes. Direct coupled to this wagon is an 8-wheel equipment wagon containing a single phase transformer, high voltage switchgear and control equipment. An example of one of these 10MVA mobile frequency converters is shown in Fig.3.

The first bogie electric locomotives were of the Co-Co wheel arrangement, meaning three driving axles in each of the two bogies. Thus each locomotive was propelled by six traction motors.

Designers today realize that this basic Co-Co design, (popular though it eventually became worldwide), is heavier, more expensive and involves more friction between wheel-flanges and rail (on curved track) than does a similarly powered locomotive of the "Bo-Bo" design.

Bo-Bo electric locomotives

A Bo-Bo electric locomotive uses two traction motors and two driven axles in each of two bogies. The original problem with trying to make four pairs of driving wheels produce as much tractive effort as that produced by six pairs of driving wheels boiled down to the wheel-slip limitations of steel wheels on steel rails. How that problem was solved is a story we will leave to a later episode in this series.

In the mid 1950s, ASEA produced the Swedish class Rb2 Bo-Bo type, 8-wheel electric locomotive, propelled by four 825kW single phase AC series traction motors, running on the 16.6Hz supply. Rated at an armature speed of 96 to 1320 revolutions per minute and geared to a driving axle, each motor was 1.154 metres in diameter and weighed four tonnes. The total locomotive power was 3.3MW (4424HP).

A similar locomotive was the Ra class of 2.64MW (3540HP), designed for express passenger service with a top speed of 150 km/hour. Ten of this class were built between 1955 and 1961. As such, they proved to be excellent for express train haulage but were too high-geared for freight service.

Later SJ locomotives built by ASEA have been designed to be powerful enough for freight work but fast enough for express passenger trains.

As Figs.4 and 5 show, railways and their electrical equipment in such cold countries must withstand snow, blizzards, rain and ice. At night-time it can be so cold that the track points freeze solid and refuse to move when power is applied.

To prevent this, many track points have heaters installed to maintain a reliable working temperature. Altogether, throughout the SJ railway system, a total of 25MW of heating power is used to keep some 5000 track points operational.

SJ system electrical figures are impressive: total electricity con-

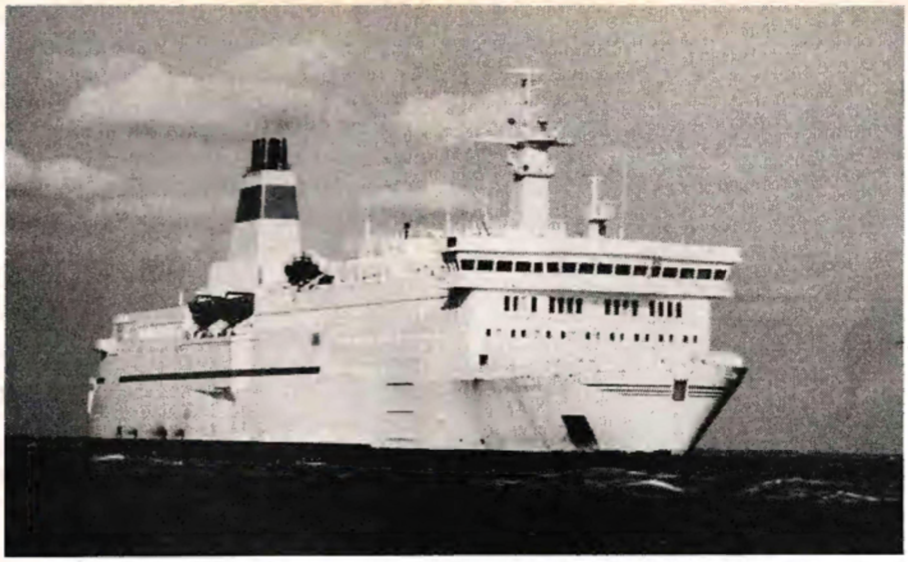

Fig.6: a train-carrying ship en-route in the Baltic Sea between Malmo in Sweden and continental Europe. These ships have five rail tracks for passenger and freight trains and can carry up to 700 metres of train length. (Photo SJ).

sumption for the whole SJ system amounts to 1,530,000 MW-hours for the year, used by the 754 electric locomotives and 186 rail car sets, running over the 7063km of electrified mainlines.

A total of 58 frequency converting trackside substations are in use and the system has 47 remotely-controlled frequency converting substations.

High efficiency rod-drive locos

An interesting figure is the SJ railway average W.h (watt-hours) of energy used for every kilometre travelled and every tonne carried. For the whole system the average used is 32.5 watt-hours of energy per tonne per kilometre.

Compare that with the Arctic iron-ore carrying section of the railway, with the huge 72MW (9650HP) rod-drive locomotives, which use only 24.7 watt-hours of energy per tonne per kilometre.

Norway electrifies

Being close to the Swedish nation culturally, geographically and technically, the people of Norway also commenced electrification of their railways quite early this century. Completing electrification of the Norwegian section of the Lappland line in the Arctic between 1919 and 1923, they originally used the same 15kV 15Hz supply from the Swedish hydro-electric power station.

Very large iron ore trains ran from the mines in Sweden, westwards up and over the coastal Kongsbakkind mountain range at Riksgransen on an elevation of 550 metres above sea level, before dropping to sea level in a distance of 39 kilometres. Today, centralised track control (CTC) of signals and points allow maximum usage of this long, high, snowy mountain railway.

Fig.7: through rain and hail and snow and ice — a Swedish electric Bo-Bo class locomotive in near blizzard conditions. (Photo SJ).

Long mountain tunnels

The Norwegian Government followed the electrification of their Lappland section with a program to electrify all main lines. This work commenced in a westerly direction from Oslo, with electrification of all main lines completed by 1970 except for the northernmost section to Bodo inside the Arctic Circle.

Some very high track exists on the western line from Oslo to Bergen, and some of the tunnels reach heights of 1282 metres, comparable to the height of the Swiss Lotschberg tunnel. Other electrified tunnels, though lower in elevation, total 10.72km, close to the length of famous Swiss tunnels.

Let us pause to make a comparison of AC versus DC traction, under the conditions existing between 1900 and 1930:

- AC can be transformed from high voltages down to lower voltages, while DC cannot.
- AC single phase high voltage low frequency supply for the overhead contact wire can be taken either straight from low frequency power station alternators or derived via transformers from still higher voltage transmission lines.
- The use of high voltages on the overhead contact wire means lower current (for the same power) and thus lower voltage drop problems.
- Trackside substations for high voltage AC are simple and comparatively inexpensive, consisting only of switching, protection and possibly transformers. Furthermore, these need little maintenance, occupy only small space and require no buildings or operating staff.
- The engineers can select the system voltage, for optimum design of the traction motors.

These points contrast with DC overhead supply railway systems (at that time) as follows:

- As DC cannot be transformed, the full overhead supply voltage is used for the motors. This can be awkward as around 750 to 1500 volts appears to be optimum for motor operation.

Sometimes, as in the NSW-SRA 46 class 1500V DC locomotives, pairs of traction motors are per-

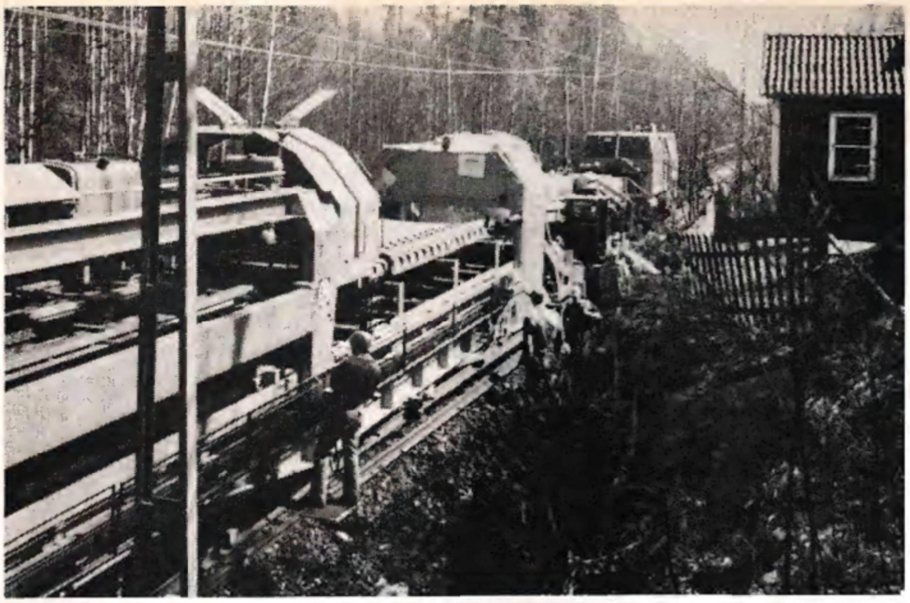

Fig.8: track maintainance on the Swedish Railways is highly mechanised to cope with the heavy workload imposed by a harsh climate. (Photo SJ).

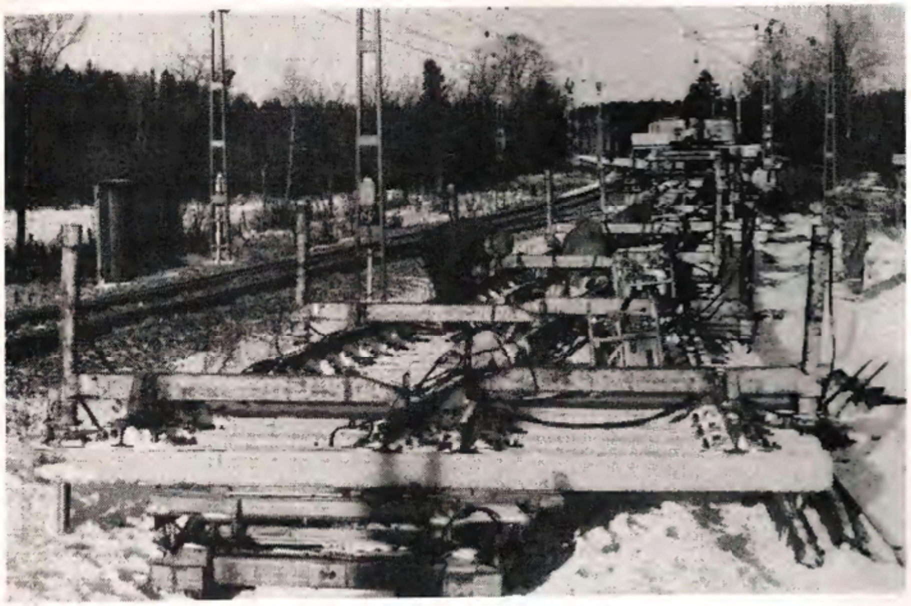

Fig.9: despite electrical heating, track points require frequent maintainence in the snowy conditions. Over 5000 track points are heated to keep the system operational in cold weather. (Photo SJ).

manently wired in series and controlled as one motor. By this means, the critical voltage across one motor commutator is kept down to half the overhead line voltage, though armature slot insulation for the full voltage must be provided.

- As all large power stations are AC, trackside substations for DC electric railways are required to convert the AC to DC. Though comparatively easy in 1988 using large banks of silicon rectifiers, in the 1900-1930 period the only AC-DC conversion means available were rotary converters, motor converters or motor generators, each requiring costly buildings and operating and/or maintenance staff.

Rotary-converters, though the most efficient of these three, require a low frequency supply, either 25Hz or 16.6Hz.

Therefore, in the 1910-1930 period, the choice of either AC or DC traction demanded the provision of special low frequency alternators at the power station. (Thus Sydney and Newcastle Railway power stations generated more 25Hz power than 50Hz power).

- Feasible DC traction systems are limited to 1500 or 3000 volts, resulting in higher currents in the overhead contact wire (for the same power) than high voltage systems.

For example, a Swiss 6.7MW (9000HP) loco on a 15kV system takes 450 amps running and 900 amps starting current, compared to a NSW-SRA triple-header 46-class of comparable power taking 4500 amps running and 9000 amps starting in the mountains.

Therefore, DC systems require trackside substations at frequent intervals to avoid excessive voltage drop in the overhead wire.

- Because of the rotary machinery used in 1910-1930, trackside substations for DC railways were expensive. Furthermore, in order to limit the voltage between brush sets around a commutator, some 1.5kV and 3kV rotary converters used the device of running pairs of rotary converters in series within the substation. So two 1.5kV machines could run in series to generate 3kV.

In Argyle Substation (on the south end of Sydney Harbour bridge), two 750 volt rotary converters were used, running in series to generate 1.5kV for the electric trains. Naturally both machines had to be insulated for the full DC contact wire voltage. (These have now been replaced by large banks of silicon diodes).

Two series rotary converters are more expensive and less efficient that one machine of equivalent total power.

- Apart from the "pairs-of-motors" technique mentioned above, the motor designer had to prepare the motors for the full overhead contact wire voltage.

Next month we'll look at high voltage single phase railway systems in Central Europe.

Acknowledgements

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