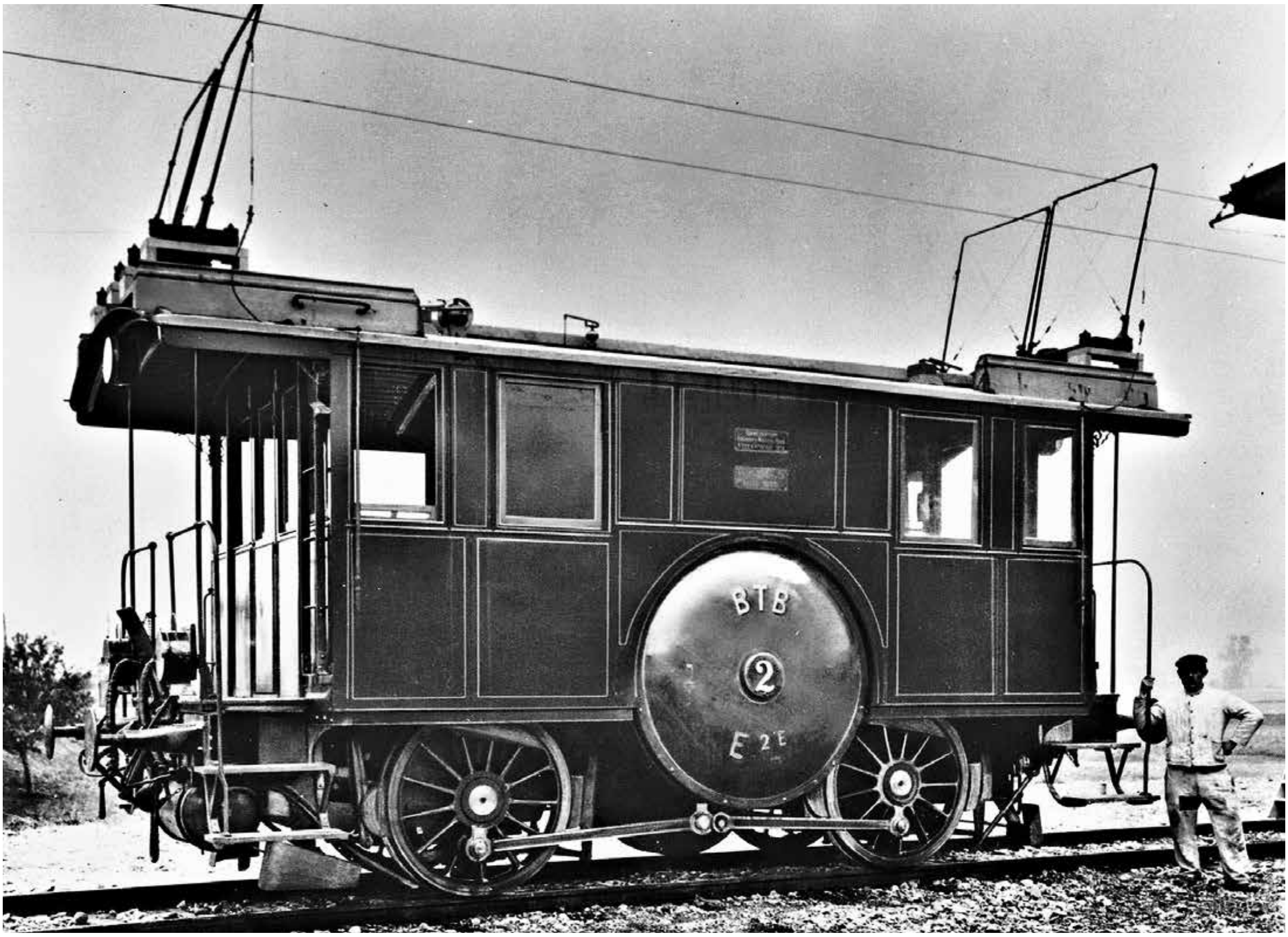


Historical perspective

Electrifying history

A long tradition in electric railway engineering

NORBERT LANG – It may come as a surprise that long before the emergence of globalization technical developments in different countries of the western world occurred largely in parallel, despite differences in conditions and mentalities. This is definitely true for the development of railway electrification and vehicles. Depending on whether a country had rich coal deposits or huge hydropower resources, the reasons to electrify railways would have differed. Even so, many notable innovations occurred simultaneously yet independently.

For most manufacturers, the development of electrification technology started with tramways. In 1890, a predecessor of ABB's business in Sécheron, Switzerland, supplied France's first electric tramcars to Clermont-Ferrand ➔ 1. These were soon followed by the world's first electrically operated mountain rack railways. In 1898 another ABB predecessor, BBC, equipped several mountain railways, including the world-famous Jungfraubahn climbing to the 3,500 m-high Jungfraujoch, using a 40 Hz (later 50 Hz) three-phase system.

Although local transport systems and mountain railways have also undergone huge technical developments since the early years, this article will focus on developments on standard-gauge mainline railways.

Electrification with different power systems

It is a little-known fact that it was Charles Brown Sr. (1827–1905), whose name lives on as one of the B's in ABB, who founded SLM ➔ 2 in 1871. The company produced steam and mountain railway locomotives and for many decades was to supply the mechanical part (ie, body, frame and running gear) of practically all Swiss electric locomotives. Brown's two sons, Charles E. L. and Sidney Brown also worked on equipment for electric locomotives (It was Charles Brown who later cofounded BBC.) Together the two sons designed the first mainline electric locomotive for the 40 km Burgdorf–Thun railway ➔ title picture. This was a freight locomotive with two fixed speeds (17.5 and 35 km/h) powered by 40 Hz three-phase AC. The transmission used straight-cut gears and had to be shifted during standstill. Two large induction motors drove the two axles via a jackshaft and coupling rods. The overhead line voltage was limited to a maximum of 750 V by law.

In 1903, ABB Sécheron's predecessor company CIEM (Compagnie de l'Industrie Electrique et Mécanique) electrified the narrow-gauge railway from St-Georges-de-Commiers to La Mure in France using direct current at an exceptionally high voltage (for the time) of 2,400 V using a double overhead contact wire system. Almost simultaneously yet independently, Maschinenfabrik Oerlikon (MFO) and BBC each initiated a landmark electrification project on the Swiss Federal Railway (SBB) network.

MFO: Single-phase alternating current

Between 1905 and 1909, MFO tested a single-phase 15 kV/15 Hz electrification on a section of the former Swiss "Nationalbahn" railway between Zurich-Seebach and Wettingen (now part of the Zurich suburban network). The first locomotive used was equipped with a rotary converter and DC traction motors ➔ 3. In 1905, a second locomotive was added ➔ 4. This used the same axle arrangement (B'B'), but the bogies both had a 180 kW single-phase series-wound motor fed directly from the transformer's tap changer. (Tap-changer control was in later years to become the standard control method for AC locomotives and was not to be displaced until the advent of power electronics.) The axles were driven via a speed-reduction gear, jackshaft and coupling rods. The maximum speed was 60 km/h. The motors used salient stator poles and phase-shifted field commutation. This locomotive performed so well that the earlier locomotive was adapted accordingly. Between December 1907 and 1909 all regular trains on this line were electrically hauled. Because overhead contact wires centered above the track could not be approved due to the high voltage, the contact wire was carried laterally on wooden poles. As agreed before the commencement of the trial, the electrification was removed after completion of the trial and the line reverted to steam operation (it was finally electrified in 1942). However, experiences gained were to have far-reaching consequences.

Title picture
The first mainline electric locomotive for the 40 km Burgdorf–Thunrailway (1899).

1 Early milestones

- 1890: A predecessor company of ABB Sécheron in Geneva supplies the first electric tramcars in France to the city of Clermont-Ferrand.
- 1892: The world's first electric rack railway is installed at the Mont-Salève near Geneva, using 500 V DC.
- 1894: Maschinenfabrik Oerlikon (MFO) supplies the first electric tramcars to Zurich.
- 1896: BBC builds electric tramcars for the Swiss city of Lugano. The Swedish ABB predecessor company ASEA, founded in 1883, starts its electric traction business with tramcars.
- 1898: BBC equips the Stansstaad–Engelberg and Zermatt–Gornergrat mountain railways as well as the Jungfraubahn to the summit of the Jungfraujoch at 3,500 m above sea level.
- 1901: ASEA supplies electrified tramcars to the city of Stockholm.

> The electric traction vehicle in particular, in a way the most harmonic and most beautiful means of electrical and mechanical engineering, consistently presents new and very interesting design problems to be solved.
>
> Karl Sachs

3 MFO experimental locomotive no. 1 with rotary converter and DC traction motors

4 MFO experimental locomotive no. 2 with single-phase traction motors

Walter Boveri objected to the operation of utility and railway grids at different frequencies. Among others, his intervention led to the compromise of using 16 ⅔ Hz for railways.

2 Abbreviations of railway and manufacturing companies

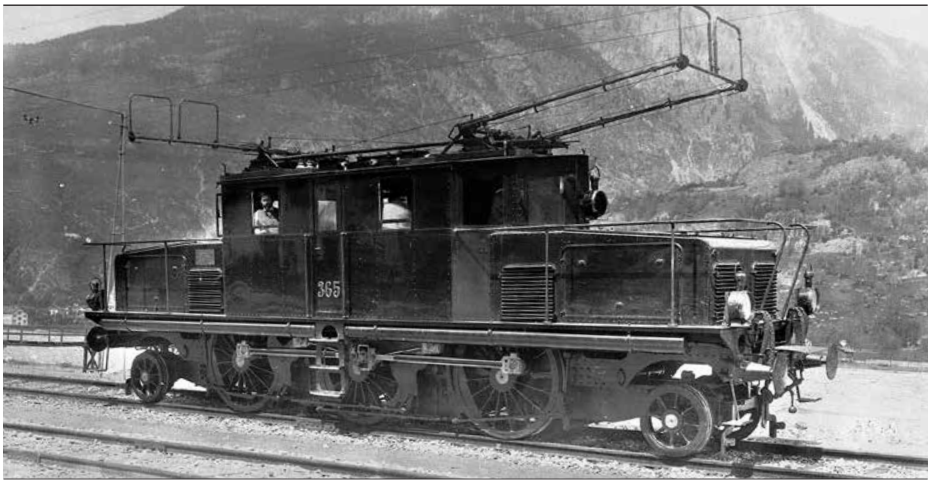
ASEA	Allmänna Svenska Elektriska Aktiebolaget, Västeras, Sweden (1983–1987). In 1988, ASEA merged with BBC to form ABB.
BBC	Brown, Boveri & Cie. AG, Baden, Switzerland (1891–1987)
BLS	Bern-Lötschberg-Simplon Railway, Spiez, Switzerland
CIEM	Compagnie de l'Industrie Electrique et Mecanique
DB	Deutsche Bahn AG (German Railways)
MFO	Maschinenfabrik Oerlikon AG (1876–1967). Acquired by BBC.
ÖBB	Österreichische Bundesbahnen (Austrian Federal Railways)
SAAS	Société Anonyme des Ateliers de Sécheron, Geneva, Switzerland (1918–1969). Acquired by BBC.
SBB	Schweizerische Bundesbahnen (Swiss Federal Railways)
SLM	Schweizerische Lokomotiv- und Maschinenfabrik, Winterthur, Switzerland (Swiss Locomotive and Machine Works, est. 1871). Acquired by Adtranz in 1998.
SJ	Statens Järnvägar (Swedish State Railways, became a public limited company in 2001)

BBC: Electric power for the Simplon tunnel

In late 1905, BBC decided to electrify (at its own cost and risk) the 20 km single-track Simplon tunnel under the Alps between Brig (Switzerland) and Iselle (Italy), which was then approaching completion. An important argument for electrification was the risk that carbon monoxide from steam locomotives could present to passengers should a train break down in the long tunnel. However, only six months remained until the tunnel's inauguration. Electrification was carried out using a three-phase supply at 16 ⅔ Hz / 3 kV fed from two dedicated power stations located at either end of the tunnel. The same power system was also adopted on the Valtelina railway in Northern Italy, the Brenner and the Giovi lines as well as the line along the Italian Riviera. The initial fleet comprised two locomotives of type Ae 3/5 (1'C 1') → 5 and two Ae 4/4 (0-D-0), all using induction motors. Speed was controlled using switchable stator poles. The low-mounted low-speed motors drove the axles via multi-part coupling rods. The locomotives had an hourly rating of 780 kW and 1,200 kW respectively and a top speed of 75 km/h. Until all locomotives were completed, three locomotives of a similar design were rented from the Valtelina railway.

At the time it was already realized that asynchronous AC motors offered several advantages for traction applications, including robustness and simpler maintenance due to the absence of a commutator. Disadvantages, however, included the coarse speed graduation resulting from pole switching and the double-wire overhead line of the three-phase supply, which added to the complexity of turnouts. Three-phase motors were thus to remain relatively rare in traction applications until recent times when power electronic converters were able to alleviate

5 BBC three-phase AC locomotive of the Simplon tunnel line, 1906



6 Determining the optimal electrification system

In 1904 the "Schweizerische Studienkommission für den elektrischen Bahnbetrieb" (Swiss Study Commission for Electric Railway Operation) was formed to "study and clarify the technical and financial prerequisites for the introduction of an electric service on Swiss railway lines." Different railway electrification systems were investigated in detailed studies, taking into account recent experience. Results and findings were published on a regular basis. In 1912, the commission concluded that a single-phase current system using an overhead line with 15 kV and approximately 15 Hz was the preferable system for the electrification of Swiss main lines.

their shortcomings without compromising their strengths.

In 1908, the SBB took over the installation. In 1919 two further locomotives were added and the electrification extended to Sion. A second tunnel bore was completed in 1921. The three-phase era on the Simplon ended in 1930 when the line was converted to the standard single-phase 15 kV / 16 ⅔ Hz → 6.

Electrification of the Lötschberg railway

With gradients of 2.2 to 2.7 percent and curve radii of 300 m, the railway from Thun via Spiez to Brig operated by BLS and completed in 1913 has a distinct mountain railway character. From an early stage, it was intended to operate the twin-track Lötschberg tunnel electrically. As early as 1910, BLS decided in favor of the 15 kV / 15 Hz system of the Seebach–Wettingen trial. The frequency was later increased to 16 ⅔ Hz. The BLS thus paved the way not only for the later electrification of the Gotthard railway but also for the electrification of railways in Germany, Austria and Sweden, all of which adopted this system.

AC motors offered several advantages for traction applications, including robustness and simpler maintenance due to the absence of a commutator.

In 1910, MFO and SLM jointly supplied a 1,250 kW prototype locomotive to BLS with a C-C axle arrangement → 7. Following successful trials, BLS ordered several Be 5/7 (1'E1') 1,800 kW locomotives, the first of which was delivered in 1913. In 1930, SAAS supplied the first of six Ae 6/8 (1'Co)(Co1') locomotives using the proven single-axle quill drive to BLS. These pulled heavy passenger and goods trains until well after the second world war.

Electric operation on the Gotthard line

In view of the shortage of coal during the first world war, in 1916 SBB decided to electrify the Gotthard railway using the power system that had already proven itself on the Lötschberg line. SBB asked the Swiss machine and electrical industry to provide prototype locomotives with a view to of later winning orders. To ensure the line's power supply, the construction of three high-pressure hydrostorage power plants (Amsteg, Ritom and Barberine) was commenced immediately.

BBC's cofounder Walter Boveri vehemently objected to the operation of national utility and railway grids at different frequencies. Among others, his intervention led to the compromise of using 16 ⅔ Hz (= 50 Hz → 3) for railways.

Boveri also suggested equipping locomotives with mercury-arc rectifiers, a technology that had already proven itself in industrial applications. However, the time was not yet ripe for converter technology on railway vehicles as the voluminous mercury containers would hardly have been able to withstand the tough operating conditions.

The electrification of the Gotthard line progressed so rapidly that there was virtually no time to adequately test the trial locomotives. Orders had to be placed quickly. BBC/SLM supplied 40 passenger train locomotives (1'B)(B1'), and MFO/SLM supplied 50 freight locomotives (1'C)(C1'). Both types were equipped with four frame-mounted motors driving the axles via a jackshaft and coupling rods. With an hourly rating of 1,500 and 1,800 kW and top speeds of 75 and 65 km/h respectively, these locomotives were able to fulfill expectations and handle traffic for a long time to come. In fact, these Gotthard locomotives became iconic among Swiss trains. This is particularly true for the 20 m long freight version with articulated frames, the so-called Crocodiles → 8, which continued in service for nearly 60 years. This type has been copied in various forms in different countries, and even today it is still a "must" on every presentable model railway.

Contributions by Sécheron

In 1921/22 ABB's predecessor company, Sécheron, supplied six Be 4/7 locomotives (1'Bo 1') (Bo') for the Gotthard railway. They were equipped with four individually driven axles with Westinghouse quill drives → 9. Despite their good run-

Electrification of the Swedish state railways started before the first world war.

7 Trial locomotive for the Lötschberg railway, 1910

ning characteristics, no further units were ordered as SBB was initially wary of the single-axle drive. For its less mountainous routes, SBB ordered 26 Ae 3/5 (1'Co 1') passenger locomotives with an identical quill drive and a top speed of 90 km/h. Weighing 81 t, these machines were considerably lighter than other types. Ten similar units with a 2'Co 1' wheel arrangement (Ae 3/6 III) followed later. These three types were generally referred to as Sécheron machines and were mainly used in western Switzerland. The last were still in operation in the early 1980s when they were mostly to be found on the car transporter trains of the Gotthard and Lötschberg tunnels.

ASEA's activities in the railway sector

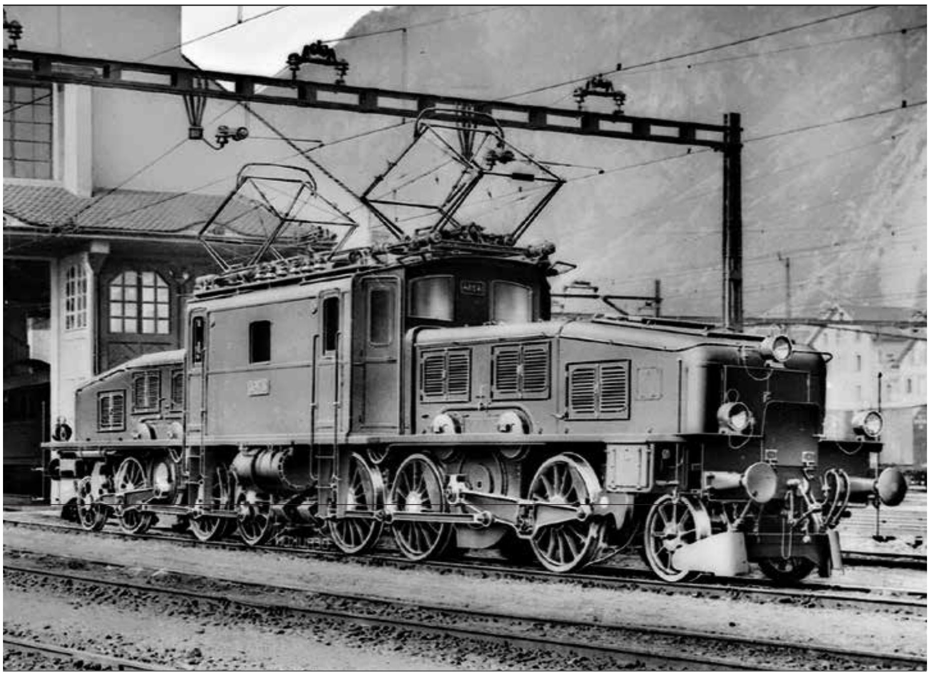
Similarly to Switzerland, electrification of the Swedish state railways started before the first world war. From 1911 until 1914, the 120 km long so-called Malmbanan or "ore line" was electrified. Its main purpose was to transport magnetite ore from mines in Kiruna to the port of Narvik (Norway), a port that remains ice-free all year due to the Gulf Stream. Sweden has huge hydropower resources. The Porjus hydropower plant supplies the power for this railway, which is operated with single-phase 15 kV at 16 ⅔ Hz (initially 15 Hz). By 1920, the electrification had been extended via Gellivare to Lulea on the Gulf of Bothnia. The Norwegian section of the line was electrified in 1923. The mountains traversed are of medium height, and the gradients of 1.0 to 1.2 percent are considerably lower than those on Swiss mountain railways. However, the heavy ore trains placed high demands on the locomotives. ASEA supplied the electrical equipment for 12 1,200 kW articulated locomotives (1'C)(C1') with side-rod drive, as well as for two similar 600 kW express locomotives (2'B 2'). 10,650 kW four-axle locomotives for express goods services were later added and mainly operated in pairs. In 1925 the 460 km SJ mainline between Stockholm and Gothenburg was electrified, with ASEA supplying the 1,200 kW 1'C1'locomotives.

Successful single-axle drive

After commissioning the electric service on the Gotthard line, SBB extended its railway electrification onto the plains and into the Jura mountains. By 1927, continuous electric operation was possible from Lake Constance in the east to Lake

The so-called Crocodile locomotives became iconic among Swiss trains.

8 SBB Crocodile Ce 6/8 built by MFO for goods transport on the Gotthard line



From a design perspective, a single-phase AC motor is largely identical to a DC motor. However, speed or power control is simpler with DC.

Geneva in the west. BBC/SLM developed the Ae 3/6 II (2'Co1') passenger locomotives, which incorporated a new single-axle drive. This drive concept, named after its inventor Buchli, consisted of a double-lever universal-joint arrangement in a single plane that acted between the frame-mounted motor and the sprung driving axle → 10. 114 locomotives of this type entered service on SBB. The design proved so satisfactory that the initial speed limit of 90 km/h could be raised to 110 km/h. The type was a huge success for Swiss industry and led to export orders and license agreements for similar locomotives for Germany, Czechoslovakia, France, Spain and Japan. In total, some 1,000 rail vehicles with Buchli drives must have been built.

Longer and heavier international trains on the Gotthard and Simplon lines soon demanded more powerful locomotives. Developed from the type described above and using the same BBC Buchli drive, 127 Ae 4/7 (2'Do1') locomotives were built between 1927 and 1934. Despite a well-known Swiss design critic claiming that these machines had a "monkey face," they remained a characteristic feature on SBB lines for several decades. Some continued in service until the 1990s.

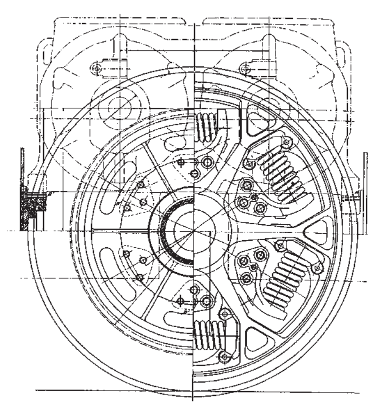
Post-war trends: bogie locomotives

Most locomotives described so far had combinations of carrying axles and powered axles, a feature inherited from steam locomotive design. In 1944, however, BBC/SLM broke with this tradition and supplied BLS with the first Ae 4/4 (Bo'Bo') high-performance bogie locomotives with all axles powered. These 3,000 kW machines could reach a top speed of 120 km/h. From then, on, virtually all railway companies opted for bogie locomotives. In 1946, SBB received the first of 32 Re 4/4 I light express locomotives, followed by 174 of the much more powerful Re 4/4 II for express trains. The latter are still in operation today. With a weight of 81 t and a rating of 4,000 kW they can reach 140 km/h.

ASEA also turned to the development of bogie locomotives. The first Bo'Bo' type Ra was introduced in 1955 → 11. With its beaded side panels, the "porthole" windows and its round "baby face" the machine reflected American design trends. Like its Swiss counterparts, it was equipped with two traction motors per bogie. Weighing only 60 t, it was capable of a top speed of 150 km/h. These locomotives proved highly satisfactory and remained in service until the 1980s. In 1962, the first type Rb rectifier locomotives were introduced, followed by the type Rc thyristor locomotives in 1967. The latter were also supplied to Austria (type 1043) and the United States (type AEM-7, built under license by General Motors).

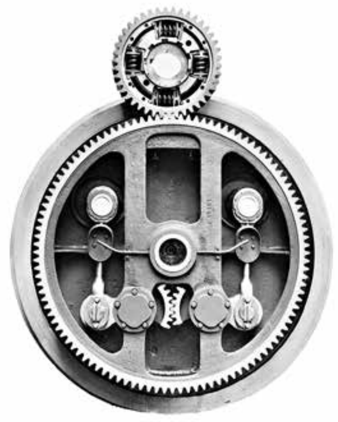
Today, ABB has strategic agreements with several major players in the rolling stock market and supplies state-of the-art components for a wide range of uses.

9 Sécheron type single-axle quill drive (Sécheron)



The springing helped decouple the movement of the axle from that of the motor, reducing track wear.

10 Buchli single-axle drive manufactured by BBC (BBC 12395)



The motor shaft attached to the upper cog and the axle to the lower.

From rectifier to converter technology

From a design perspective, a single-phase AC motor is largely identical to a DC motor. However, speed or power control is simpler with DC. While some countries chose to electrify their mainline networks with DC using a voltage of 1,500 or 3,000 V, others sought to acquire locomotives with onboard rectifiers converting the AC supply to DC. One of the downsides of DC electrification is that the line voltage must be relatively low as transformers cannot be used. This leads to higher conduction losses requiring more frequent substations. Manufacturers thus long sought ways of combining DC traction with AC electrification (see also MFO's first Seebach-Wettingen locomotive described above). It was not until vacuum-based singe-anode mercury tubes (so-called ignitrons or excitrons) were developed that rectifier locomotives were built in large numbers (mostly in the United States and some Eastern Bloc countries).

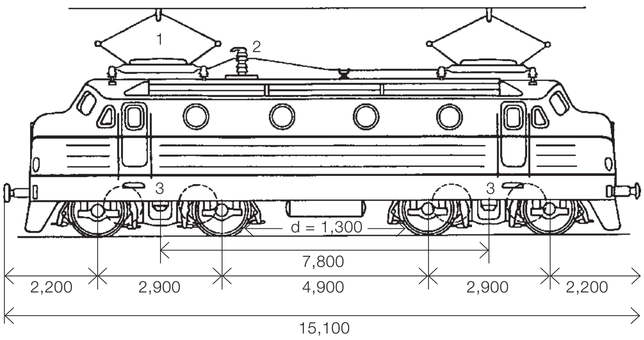
The semiconductor revolution in electronics was to change this, and solid-state components soon found their way into locomotives. Between 1965 and 1983, BLS purchased 35 Re 4/4, series 161 locomotives → 12. Instead of using single-phase AC, the traction motors were fed with half-wave rectified and reactor-smoothed DC. The oil-cooled solid-state diode rectifier was fed from the transformer tap changer. These locomotives had two traction motors per bogie, connected in parallel to reduce the risk of slippage on steep inclines. The locomotives have an hourly rating of nearly 5 MW and have proven themselves extremely well. One machine was modified with thyristor-based converters and successfully tested on the Austrian Semmering line. As a result, ÖBB ordered 216 locomotives of a similar design (type 1044) from ABB in Vienna.

The combination of frequency converters and asynchronous motors proved to be particularly advantageous. It allowed a largely uniform drive concept to be realized that was essentially independent of the type of power supplied by the contact wire. This enabled some standardization and also made it easier to build locomotives able to work under different voltages and frequencies for international trains. Furthermore, the use of robust three-phase induction motors saved on maintenance due to the absence of commutators while also offering a higher power density, meaning motors could either be made smaller or more powerful. Examples of BBC and ABB locomotives using this arrangement are the E120 of DB, the Re 4/4 of Bodensee-Toggenburg and the Sihltal railways (Switzerland), the Re 450 and Re 460 of SBB and the Re 465 of BLS.

High-speed trains

Between 1989 and 1992, German railways (DB) commissioned 60 ICE (Intercity Express) trains, which were based on the technology of the E120. ABB was involved in their development. The trains consisted of two power cars with converter-controlled three-phase induction

11 ASEA type Ra bogie locomotive of the Swedish State Railways



12 Re 4/4, series 161 rectifier locomotive of BLS, 1965

motors and 11 to 14 intermediate passenger cars. During a trial run on the newly completed high-speed line between Hamburg and Frankfurt, one of these trains reached a speed of 280 km/h.

In 1990, ABB supplied the first of 20 X2000 tilting high-speed trains to SJ for the express service between Stockholm and Gothenburg. They use GTO converters and induction motors and can reach 200 km/h. The type is now also used on other lines in Sweden, enabling reductions in journey times of up to 30 percent.

Streamlining the railway business

Arguably, no other products of the machine or electrical industry were considered as prestigious by the general public as railway vehicles, and although exports did occur, administrations generally preferred to buy from domestic suppliers. However, this paradigm began to change in the late 1980s and 1990s. Notably, the prefabrication of parts allowed considerable reductions of lead times. Furthermore, such prefabricated subassemblies permit final assembly to be carried out virtually anywhere. For the industry, this shift – combined with market liberalization – resulted in a transition from complete manufacturing for a local market to component delivery for a global market.

The ABB railway business today

Following the merger of ASEA and BBC to form ABB, the respective transportation system businesses were formed into an independent company within the ABB Group. In 1996, ABB and Daimler Benz merged their railway activities under the name ABB Daimler-Benz Transportation (Adtranz). Adtranz also acquired the Swiss companies SLM and Schindler Waggon in 1998. In 1999, ABB sold its stake in Adtranz to DaimlerChrysler which later sold its railway sector to Bombardier. Thus today, ABB no longer builds complete locomotives, but continues to supply different high-performance components for demanding traction applications.

Since 2002 ABB has maintained a close strategic cooperation with Stadler Rail. Stadler is an internationally operating rolling stock manufacturer that emerged from a small Swiss company, which originally produced diesel and battery-electric tractors for works railways and industrial lines. The company is now an important international supplier of multiple unit passenger trains for both intercity and commuter service. The company also supplies trams, metros and other types of trains to customers across the world. In recent years ABB has developed new components for different overhead line voltages and frequencies as well as for diesel-electric traction applications. ABB supplies the transformers, traction converters, onboard power supply systems and battery chargers used on Stadler trains.

Today, ABB also has strategic agreements with several other global players in the rolling stock market and supplies state-of-the-art components for a wide range of uses, fulfilling the most stringent demands. In the spirit of the company's founders, ABB remains at the forefront of developing innovative solutions for an ever-developing market.

This article originally appeared in ABB Review 2/2010 and was brought up to date by ABB Review staff for the present anniversary.

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