7 Electric traction vehicles for mainline service

The examples will be treated in the same sequence as the technologies, which have been basically dealt with in the chapters 4, 5 and 6.

7.1 Electric traction vehicles with DC traction motors

7.1.1 DC-chopper control

Fig. 7.1 gives (left) side and top elevation and (right) the main schematic circuit diagram of the universal locomotive Class E 632 of FS Italia for DC 3 kV, P = 4,700 kW, v_{max} = 160 kph and Z_A = 231 kN (TIBB 1985 [203]). The locomotive features three motor bogies with 1570-kW DC Monomoteurs (cf. Fig. 3.18) of U_{Amax} = 2000 V, fed by three-pulse DC choppers. Separate excitation is provided by an inverter in square-wave modulation from the 3-kV mains, transformer, rectifier and a controlling DC chopper [204] [205].

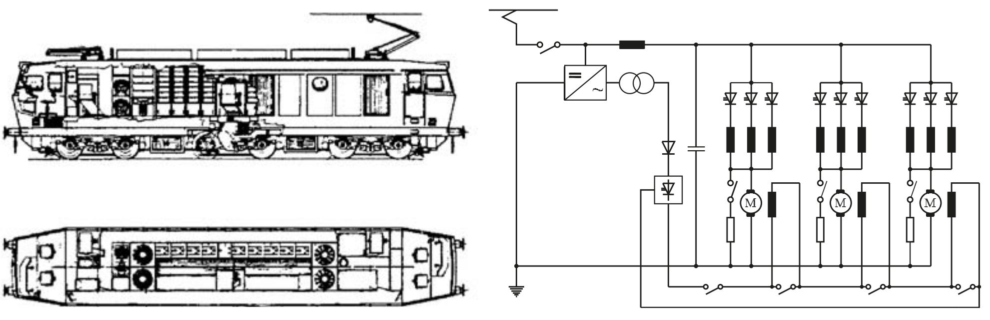


Fig. 7.1: *Sketch of locomotive E 632 of FS Italia and main schematic circuit diagram*

7.1.2 Thyristor phase-angle control

The locomotive Rc2...3 of the Swedish States Railway (SJ), built by ASEA, for AC 15 kV/ $16^2/_3$ Hz, was one of the pioneers of thyristor phase-angle control in the 1970s (Fig. 7.2); P_N = 3,600 kW, v_{max} = 130/160 kph and Z_A = 155/140 kN (goods train/express train variant) [206].

Fig. 7.3 displays the main schematic circuit diagram, slightly simplified: Four times two two-pulse bridges in half-controllable connection of pairs of arms with sequential phase control (B2HZ) feed four traction motors separately. The field windings of the separately excited traction motors are fed by two mid-point double-way rectifiers in anti-parallel connection.

This locomotive type was very popular with several European railways (Austria, former Yugoslavia, Romania and Norway).

Fig. 7.2: *Locomotive Rc2 of SJ, with thyristor phase-angle control*

1 Pantograph 1
2 Disconnector
3 Main breaker (type ASEA)
4 Valve bypass
5 Roof entrance with current transducer
6 Earthing switch
7 Main transformer
7a Train heating winding 1000 V
7b Winding for auxiliary rotary converter 220V
7c-7d Windings for thyristor bridges
8_1 Half-controllable thyristor bridge 1
8_2 Half-controllable thyristor bridge 2
9 Traction motor disconnector
10 Smoothing reactor
11 Traction motor, rotor
12 Traction motor, excitation winding
13 Thyristor converter for excitation
14 Earthing transformer
15 Earthing brush
16–18 Current transformer
19–20 Shunt resistors
21 Measuring transductor
22 Switching plate
23 Earth-current resistor & relais
24 Harmonic filter

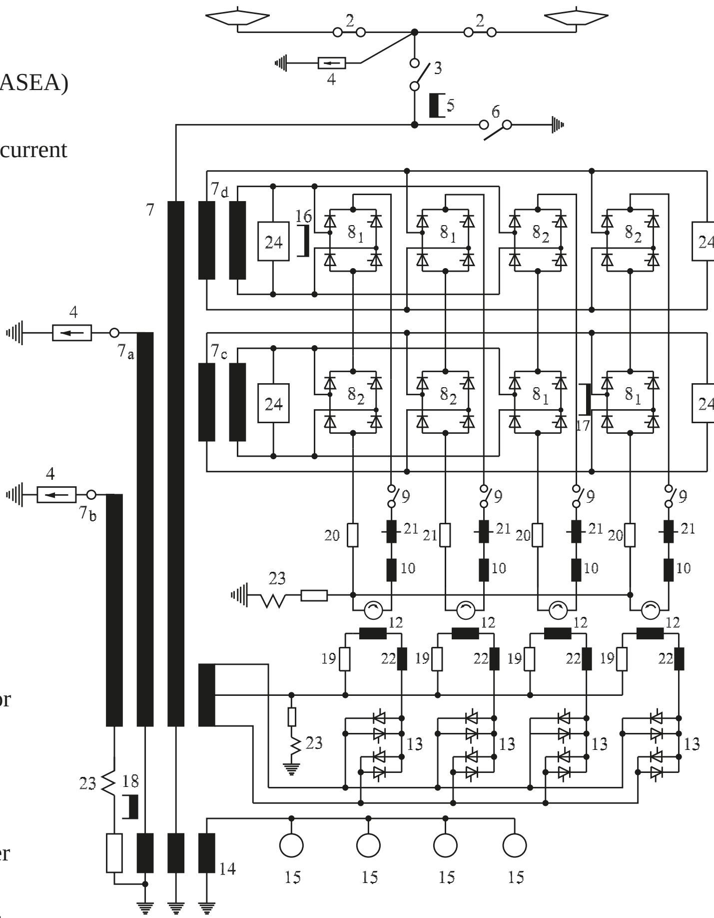


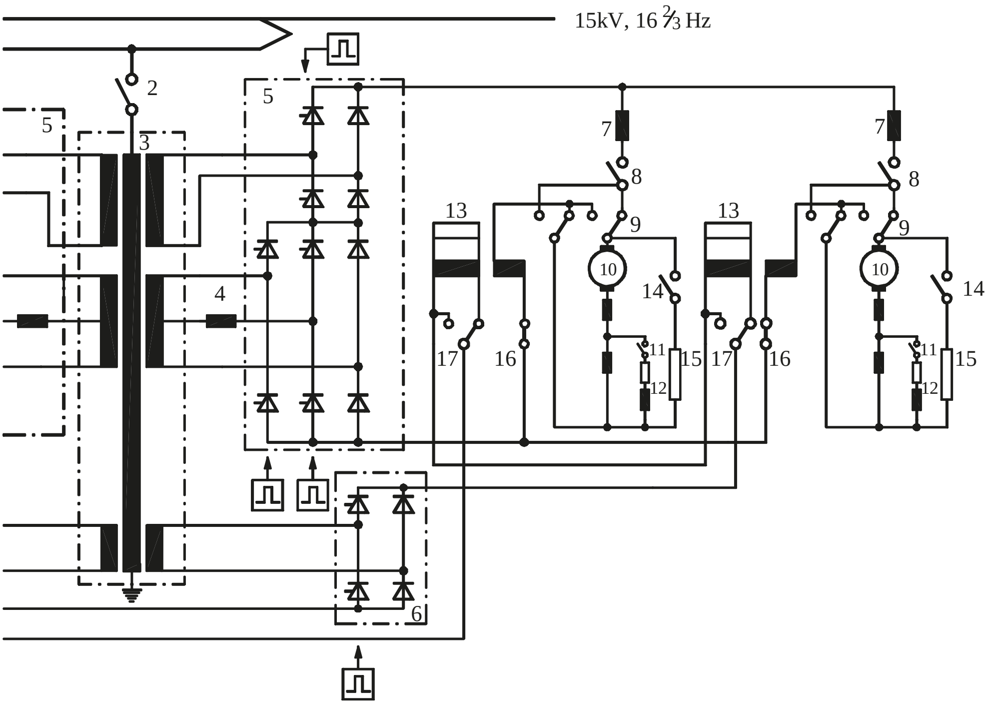
Fig. 7.3: *Simplified schematic circuit diagram of locomotive SJ Rc2/3 (acc. to [206])*

A descendant to be mentioned especially is the AEM-7 locomotive delivered by EMD and ASEA in 1979 to AMTRAK, USA, for the North-East Corridor service Boston–New York–Harrisburg, Pa.. It operates on the 25 kV & 12.5 kV/60 Hz and the 12.5 kV/25 Hz systems as well and reaches a maximum speed of 200 kph (125 mph).

Fig. 7.4 shows the high-power locomotive Class 1044 of ÖBB (BBC [42] [207] [208]), which was, in effect, the last – continental – development stage of the “thyristor locomotive” before the transition to three-phase drive technology; Fig. 7.5 gives the schematic circuit diagram. Here the converter feeds two traction motors in parallel; the lower bridge is extended by an additional pair of arms, connected via a commutation reactor to a tap of the secondary:

Fig. 7.4: ÖBB Class 1044

"AC-sided sequential control", [71] [65]. This allows to reduce the line interference at low output voltage, as the phase-delay angle is smaller and the current rise slower (cf. section 14.3.2). The traction motors are equipped with mixed series-separate excitation ("simulated series motor"), typical for the German/Austrian/Swiss area. The one-hour power rating is 5,400 kW; v_{max} = 160 kph and Z_{Amax} = 337 kN – a "universal" characteristic (cf. Fig. 2.16 and Exercise 17.5!)



1	Pantograph	8	Disconnector	13	Shunt for separate field
2	Main breaker	9	Reversing switch	14	Brake contactor
3	Transformer	10	Traction motor	15	Brake resistor
4	Commutation choke	11	Commutation pole switch: Closed at v > 90 kph	16	Armature disconnector
5	Armature converter	12	Commutation pole shunt	17	Bypass contactor for separate field
6	Excitation converter				
7	Smoothing choke				

Fig. 7.5: Schematic circuit diagram ÖBB Class 1044

7.2 Electric traction vehicles with AC commutator traction motors

The express-train locomotives for mountainous regions Class Ae 4/4 Nr. 251–254 of the Bern-Lötschberg-Simplon Railway (BLS) of 1944 are considered the first high-speed high-power locomotives without idling wheelsets (P_N = 2,944 kW, v_{max} = 125 kph, Z_A = 236 kN; Fig. 7.6). They feature deep-draft force attack in the bogies and an electro-pneumatic wheelset balance with steel ropes, to compensate for load transfer, as shown in Fig. 2.16. In the right part of the figure, the transformer and the high-voltage tap-changer control is displayed (BBC, acc. to [39]).

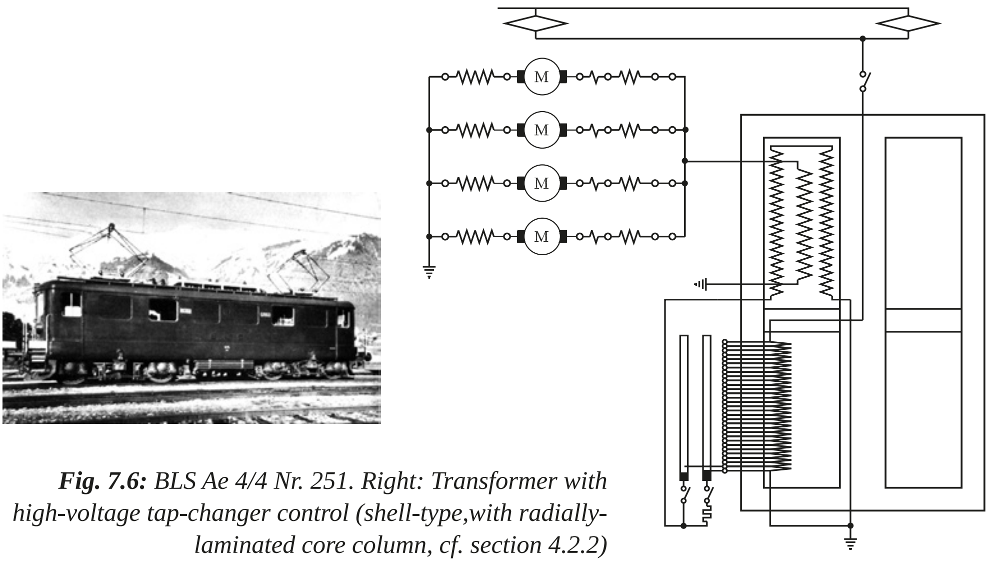
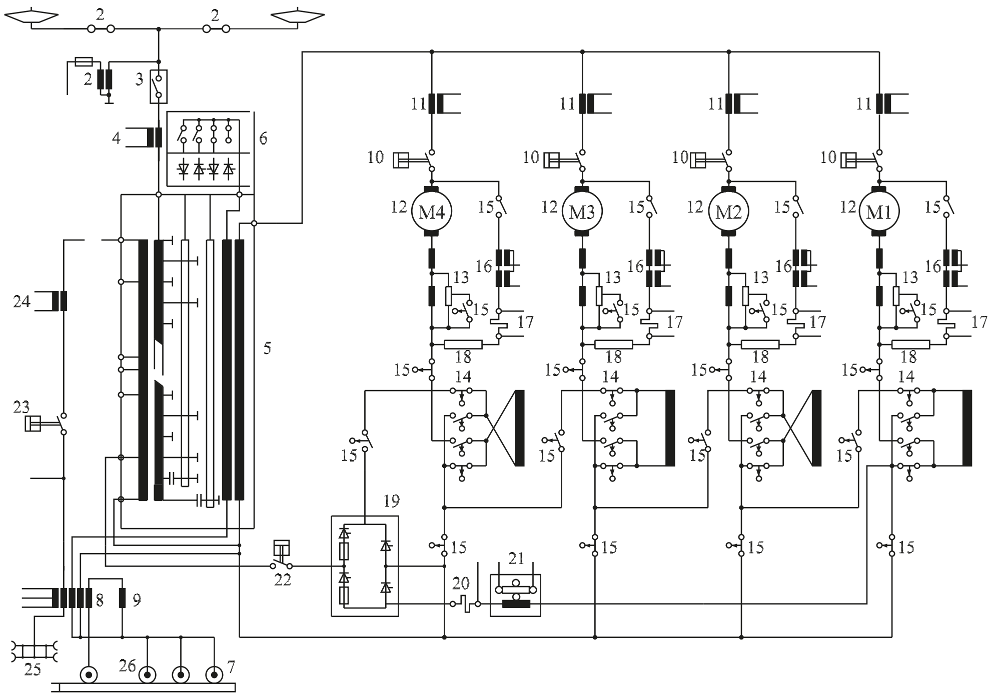


Fig. 7.6: *BLS Ae 4/4 Nr. 251. Right: Transformer with high-voltage tap-changer control (shell-type,with radially-laminated core column, cf. section 4.2.2)*

Fig. 7.7 represents the last locomotive with AC commutator motors put into operation by DB, Class 111 (apart from the locomotives taken over from DR and delivered subsequently until 1992, of Classes 112, 143 and 156 with LEW tap-changer control and thyristor controller, Fig. 4.25). It has been developed from the standard locomotives Class 110/140 from the mid-fifties: P_N = 3,720 kW, v_{max} = 150 kph.

The permanent power rating of the brake resistors has been raised to 2 MW, with the traction motors excited by a thyristor converter from the main transformer. Each motor has its own brake resistor; by this measure the tendency to slide is considerably reduced [209]. Schematic circuit diagram Fig. 7.8. Additional information in [208].

Fig. 7.7: *Class 111 of DB AG (Bombardier Transportation)*



1	Pantograph	14	Reverser
2	Primary voltage instrument transformer	15	Traction-braking reverser
3	Main breaker	16	DC transducer
4	Primary current instrument transformer	17	Brake-current shunt
5	Main transformer	18	Brake resistor
6	High-voltage tap-changer switch gear	19	Excitation converter for electric brake
7	Earth contact for traction current	20	Brake-excitation current shunt
8	Compensated earth-current transducer	21	Brake torque calculation
9	Earthing reactor	22	Brake excitation switch
10	Traction motor disconnectors	23	Train heating switch
11	Traction motor current instrument transf.	24	Train heating current instrument transform.
12	Traction motor	25	Train heating coupling
13	Commutation pole shunt	26	Earth contact locomotive body

Fig. 7.8: *Circuit diagram Class 111 DB*

7.3 Electric traction vehicles with induction traction motors

Three-phase drive technology with induction motors and voltage-source inverters allows to a degree not known before the standardisation of vehicle drive technology, as Fig. 7.9 shall make clear: The drives differ only in the supply circuits for the DC links [90] [87] [93]. This will be elucidated in subchapter 8.2, treating the multi-system traction vehicles.

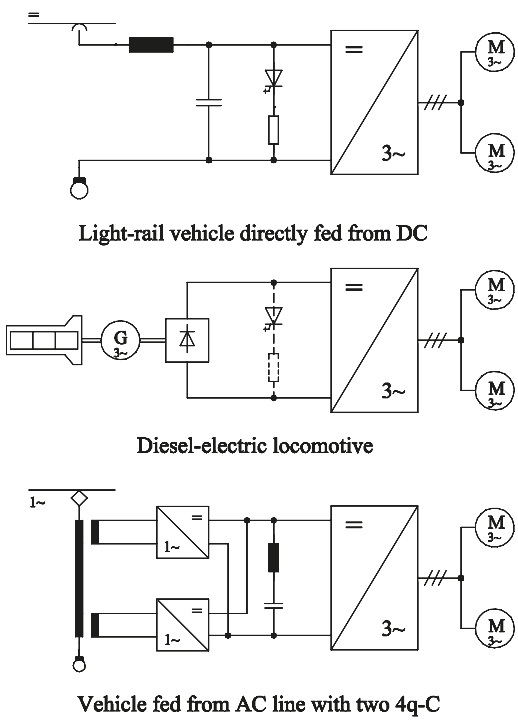


Fig. 7.9: *Schematic diagram of electric traction vehicles with three-phase drive technology*

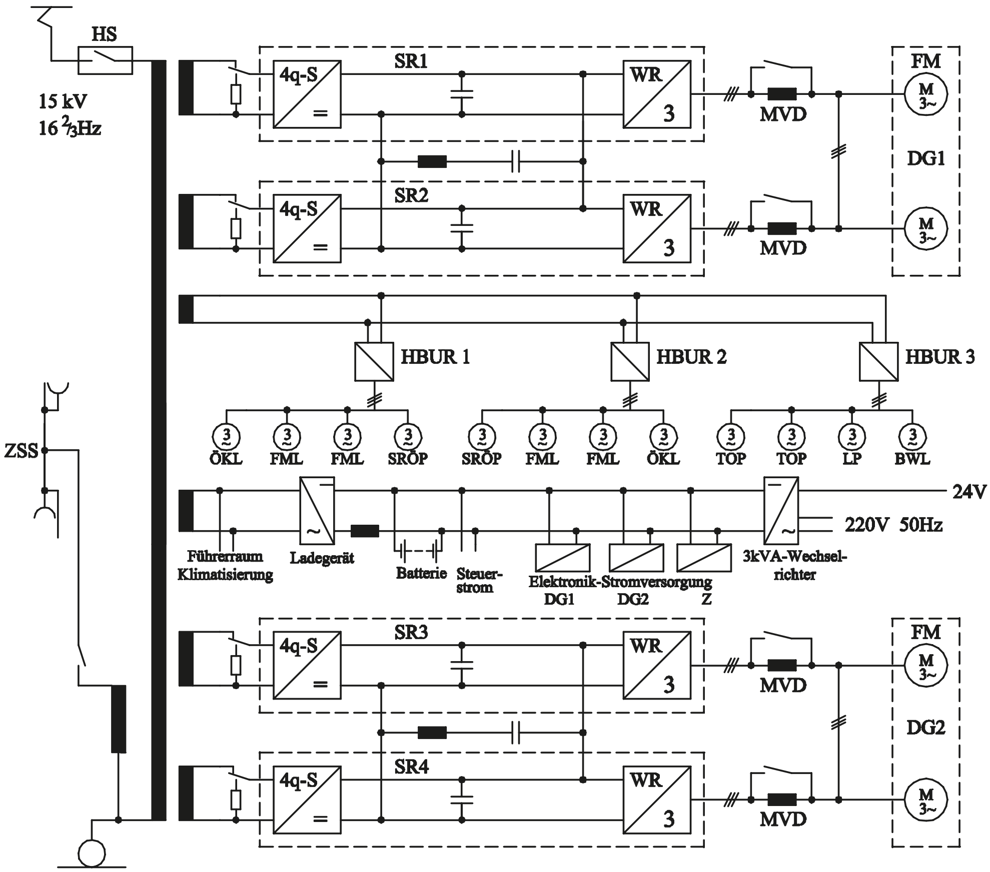
Vehicles fed from the DC line need a brake resistor/chopper, as – due to the diode rectifiers in the substations – the capability of the grid to take up the brake energy cannot be taken for granted.

This section shall present samples of locomotives and motor coaches with three-phase drives, the main components of which have already been treated in previous chapters.

7.3.1 Locomotives

Fig. 1.9 has already presented the exterior view of locomotive Class 120, Fig. 2.7 the bogie construction, Fig. 3.12 and 3.13 the BBC cardan hollow-shaft drive with rubber-jointed coupling rods, Fig. 5.3 and 5.4 the traction motor (with the control characteristics given in Fig. 5.17) and Figs. 5.38 and 5.39 the phase building block and the converter; now Fig. 7.12 displays the main schematic diagram [167]. The two converters feeding the motors of one bogie are connected in parallel at the DC links and controlled by one controller; the resonant-tank circuit is common. To limit the harmonic motor currents, reactors (MVD) with some 50 % of the motor leakage inductance L_σ are connected in series. These reactors are short-circuited at high stator frequency ($> 0.6\, f_{smax}$), when the motors have to produce full break-down torque at maximum frequency; then the current harmonics are of reduced amplitude already and can be tolerated.

Initially brake resistors had been provided, which were controlled by the four-quadrant converter (4q-C) as a single-phase inverter: After short time they were removed, as it could be shown that the probability of the AC railway supply grid to fail is considerably lower than that of the brake contactors [210]. So now only the regenerative brake – together with the direct air brake and the train brake (subchapter 11.1) – is used. In the free space a 15-kV line filter to reduce the line



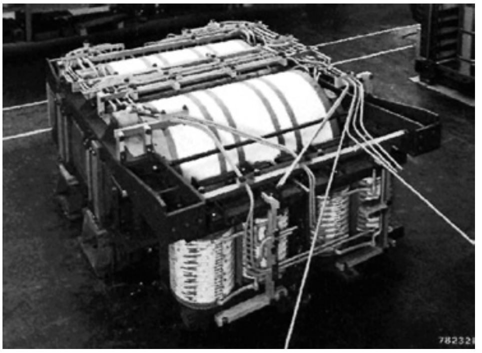
BWL	Brake-resistor blower	LP	Compressor	SRÖP	Converter oil pump
FML	Traction-motor blower	MVD	Motor series reactor	TÖP	Transformer oil pump
HBUR	Auxiliary converter	ÖKL	Oil-cooler blower	ZSS	Train line
HS	Main circuit breaker	SR	Converter		

Fig. 7.10: *Main circuit diagram Class 120 DB*

interference (section 14.3.4) could be housed. The auxiliary converters (HBUR) 1 and 2 are controlled dependent upon demand with variable frequency, HBUR3 with fixed frequency.

The main transformer (Fig. 7.11) is built as a core-type transformer with four totally separated secondary windings and – concentrically arranged around them – the four primary windings, connected in series. The short-circuit voltage is $u_K \approx 33$ % (cf. subchapter 5.5). The “stranded” conductors of the secondary windings are made from a multitude of flat, insulated partial conductors running in a screw line through all heights of the layer (Roebel-type winding), to minimise eddy-current losses. Outmost the train-heating and auxiliary windings are situated [167]. The transformer is mounted beneath the vehicle bridge, as with all vehicles with three-phase traction.

Fig. 7.11: *Transformer of Class 120 15000 V / 4·1513 V / 860 A (in front the resonant-tank reactors are to be seen) M_{ges} = 11.2 t, forced oil cooling*



A descendant with only half the power-electronic equipment (one converter per bogie) is the Norwegian Class EL 17 (P_N = 3,000 kW) [211]. Class EA 3000 of DSB is a 50-Hz variant of Class 120 (P_N = 4,000 kW), with two seven-phase converter units as Fig. 7.9, bottom.

Fig. 7.12 shows the high-power locomotive Class 101 of DB AG, the successor of Class 120 for express trains (IC, nevertheless an universal locomotive layout), Fig. 7.13 the main circuit diagram (P_N = 6,400 kW, v_{max} = 220 kph, Z_A = 300 kN [169] [212] [213]. The GTO-thyristor converters (Figs. 5.44, 5.45) are again connected in parallel at their DC links, but the inverters are now controlled separately (using DSC, subchapter 5.3 and section 15.1.5), to be able to exploit adhesion maximally (bogies with Integrated Aggregate Drive, Fig. 3.14). Regrouping of the resonant-tank circuit allows to maintain operation with 75% of rated power, if one inverter (or motor) fails. The line filter is connected to a 1000-V tertiary winding of the main transformer, for optimised lay out (cf. section 14.3.4). A derivate of this locomotive has been delivered to New Jersey Transit, USA as Type ALP 46, for the 25 kV & 12.5 kV/60 Hz and the 12.5 kV/25 Hz systems [214].

Fig. 7.12: *Locomotive Class 101 of DB AG (Bombardier Transportation)*

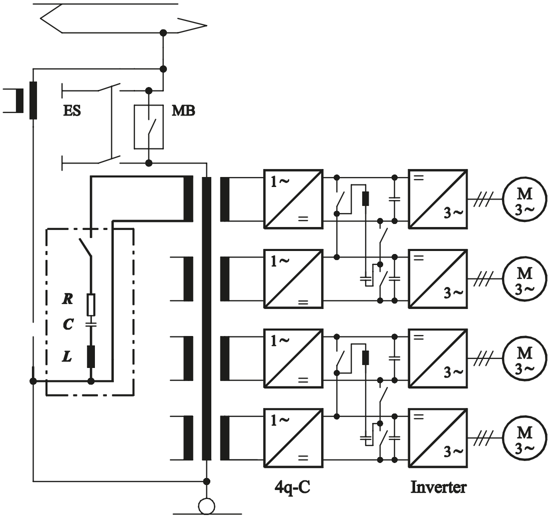
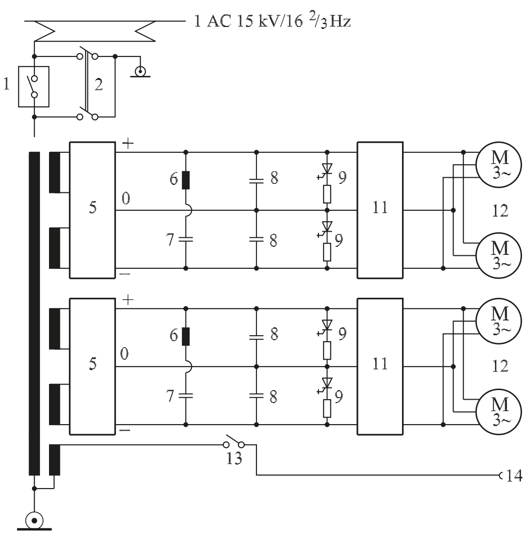


Fig. 7.13: *Main circuit diagram of Class 101*

The locomotives of Class 460 of SBB (Fig. 7.14) are equipped with three-level GTO-thyristor converters [33]; Fig. 7.15 gives the schematic circuit diagram. The nominal DC-link voltage is 3,500 V, the rated power of one converter, equipped with standard 4.5-kV, 3-kA GTO devices, reaches 3,500 kW, so that only group supply of the two motors in each bogie was economically reasonable.

Fig. 7.14: *SBB Class 460 "Loco 2000" (Bombardier Transportation)*



1 Main breaker AC
2 Grounding disconnector
5 Three-level NPC GTO four-quadrant converter
6 Resonant reactor
7 Resonant capacitor
8 DC-link capacitor
9 Instantaneous voltage limiter
11 3-level NPC GTO VSI
12 Traction motors
13 Train-line switch
14 Train-line connector

Fig. 7.15: *Schematic circuit diagram SBB Class 460 with three-level NPC GTO inverter*

The changes in the European railway landscape, mentioned in subchapter 1.1, such as liberalisation and deregulation, made the former "national" railways – now divided in transport and infrastructure entities – dispense with the former multitude of individual varieties of locomotive types and turn to more general specifications. This development was supported by the upcoming of "independent" transport companies, often within bigger logistics groups, leasing their traction material from specialised enterprises and having maintained them from railway industry, as described in subchapter 1.5.

Highly standardised and modularised "platform" traction vehicles evolved from this, allowing an optimisation in technical and economical regard not possible before, known from the automotive and aviation industry, even including crash tests. An outstanding example is the TRAXX platform of Bombardier Transportation, built in more than 2000 locomotives for DB AG, SBB or several leasing houses. They exploit the standardisation potential offered by the three-phase drive technology (cf. Fig. 7.9) to an utmost degree [215] [216]. A power of 5.6 MW is delivered by two "seven-phase" traction blocks, three pairs of arms (phases) for the motor inverter and four for two four-quadrant converters, after 2005 equipped with IGBT modules, in two-level technology.

Fig. 7.16 shows the side elevation of DB AG Class 185.2 (TRAXX F140 AC2), the multi-purpose, two-frequency (15 kV/16$^2/_3$ Hz and 25 kV/50 Hz) variant with v_{max} = 140 kph and Z_A = 300 kN, Fig. 7.17 a photo of the equivalent MRCE type; please see subchapter 8.2, Figs. 8.12 and 8.14, too. Due to the relatively low maximum speed, the drive is of the axle-hung type (sub-chapter 3.2), but the corresponding express type is equipped with a bogie-mounted cardanic drive. As for diesel-electric versions, see subchapter 9.2, Figs. 9.23 – 9.26, and subchapter 9.4, Fig. 9.32.

On the same basis, but somewhat being out of the ordinary, are the huge IORE double locomotives with the wheel arrangement C_0' C_0'+ C_0' C_0' for the Swedish mining company Luossavara Kirunavaara Aktiebolaget (LKAB), dragging iron-ore trains of 8,600 t with 60 kph to the North Sea harbour Narvik. The rated power is 2 x 5,400 kW, the mass 2 x 180 t (with ballast); 17 couples have been delivered between 2000 and 2014 [217].

The same platform strategy can be found with the competing groups from Table 1.5; the PRIMA platform locomotive of ALSTOM Transports [218] is under delivery for SNCF (Class 437) and e.g. the French leasing enterprise Akiem (Class E37.5, Fig. 7.18). The Siemens TAURUS locomotives ES64U2…4 using the HAB quill drive (Fig. 3.15) have been delivered to ÖBB (Class 1016, 1116, 1216 [62]), DB AG (Class 182), the Slovenian SZ (Class 541) and e.g. Dispolok, for the full range of power supply systems (Fig. 1.11). A diesel-electric variant with reduced power and only minor differences in the mechanical construction (EURORUNNER) followed. Fig. 7.19 shows locomotive ÖBB 1216.050 after its record trial, at which 357 kph were reached. The TAURUS is recently going to be detached by the new platform VECTRON [219] [64], featuring the simpler axle-riding cardanic drive of Fig. 3.17.

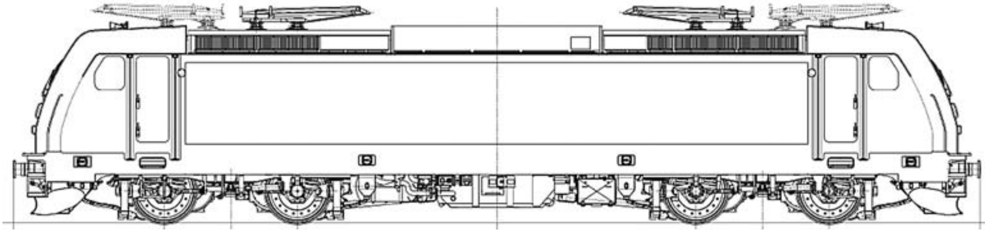


***Fig. 7.16:** Side elevation of locomotive Class 185.2 DBAG /TRAXX F140 AC2*

Fig. 7.17: *TRAXX F140AC2 MRCE 185 546 (equivalent to DB AG Class 185.2)*
P_N = 5.6 MW, v_{max} = 140 kph
Signalling package for German and France (Bombardier Transportation)

Fig. 7.18: *Class E37.5 AKIEM three-system locomotive of the Alstom PRIMA family (type 3U15)*
P_N = 4.2 MW, v_{max} = 140 kph
As Cl. 437 of SNCF delivered with P_N = 5.6 MW, v_{max} = 160 kph

Fig. 7.19: *ÖBB Class 1216 ("TAURUS") three-system locomotive*
P_N = 6.4 MW, v_{max} = 230 kph
(Siemens AG)

7.3.2 High-speed trains

Since the introduction of scheduled high-speed Intercity connections in the 1930s (in D, F, GB, I, USA) the two concepts “locomotive-hauled train” and “high-speed EMU” (cf. section 3.1.1) have been rivalling.

For the high-speed EMU, individual self-propelled units with multiple-unit control, the following *technical arguments* speak in favour:

- The necessary very high specific drive power ($P \sim v_{max}^3$) of about 20 kW/t is distributed to many driving wheelsets. Thus it is feasible to keep wheelset loads under the value of 16...17 t, which is regarded necessary for reasons of running stability and wheel-tyre wear for v_{max} = 250...270 kph/155...170 mph. Wheelset loads of only 13...14 t necessary for v_{max} = 330 kph/205 mph are only possible with motor coaches with at minimum 50 % driven wheelsets.
- Shorter trains, exploiting the limited station length better.
- Homogenous construction, thus lower train (air) resistance, lower total mass, especially if one bogie per each two car-ends is used (articulation, Jakobs’ bogies [23]).

Against high-speed EMUs and pro locomotive-hauled trains the following mainly *economic and operational reasons* are important:

- Only for small capacities the high-speed EMU is cheaper than the locomotive-hauled train. In former times it occurred nearly regularly that high-speed EMUs/DMUs had to be replaced with locomotive-hauled trains, when the transportation demand increased, due to the great attractiveness of these high-speed connections.
- The whole electric equipment of high power rating and thus volume has to be accommodated underneath the floor, which is technically more demanding (e.g. noise issue).
- The capacity can only be adapted in rather rough steps (one or two EMUs) to the effective demand.
- Individual trailers can be taken more easily out of the train compound, if repair becomes necessary; with multiple units that is only possible in the shops.
- Motor coaches need much more protection from noise and vibration.

Japan made its decision in favour of the EMU concept when introducing its Tokaido Line Shin-Kansen high-speed service in 1964 (cf. Fig. 1.6; [149] [220]). The European railway authorities chose uniformly a compromise solution, the high-speed train with special streamlined trailer coaches and power headcars (cf. Fig. 7.20, top; [221]), e.g. in case of the French TGV (cf. Fig. 7.27 [222]), the German Intercity Express ICE 1/2 or the Italian Elettrotreno Rapido (ETR) 500.

The power headcar of the first series of ICE (Class 401, 1990, Fig. 7.21, [63] [223]) corresponds to locomotive Class 120 of DB in its drive technology. The first 30 trains (with two headcars – cf. Fig. 7.20 top – each and 12...14 trailers) were still equipped with thyristor converters (as in Fig. 5.39, schematic diagram similar to Fig. 7.10) Starting with headcar 61 (... 120), the evaporative-cooled GTO converter (Fig. 5.41) with seven phase modules was employed [173]. The drive is the BBC cardan hollow-shaft drive with rubber-jointed coupling rods (acc. to Fig. 3.12); but the motor is totally fixed in the vehicle’s bridge, to reduce the masses coupled to the bogie. Initially, the possibility to fix the drive to the bogie at low speed to ease the negotiation of sharp curves was provided; but this did not prove necessary and was abandoned.

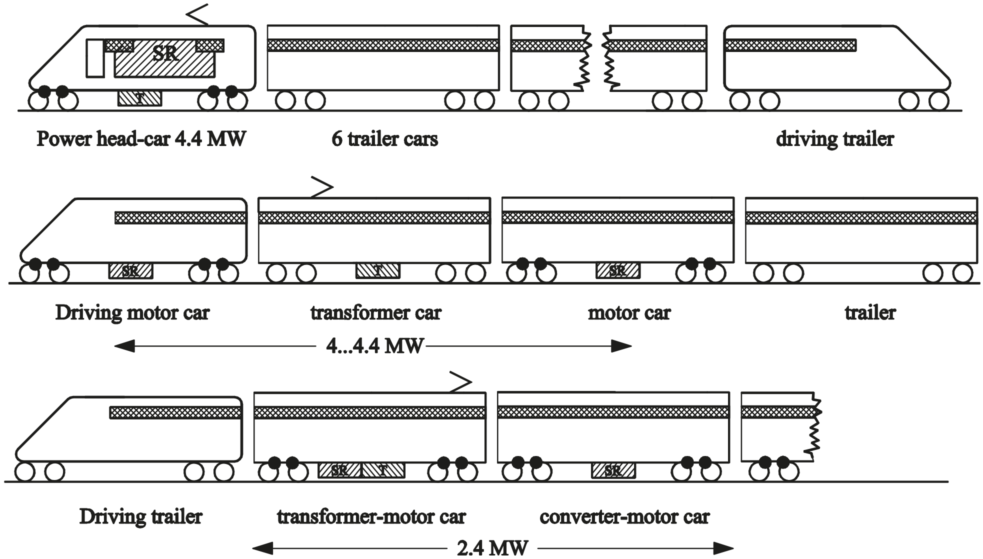


Fig. 7.20: Different concepts of High-Speed Trains

The prototype train Class 410 of ICE reached a speed of 407 kph in 1988. The second series, ICE 2 (Class 402, 44 trains) features only one power headcar, six trailers and one control trailer. It enables the so-called "wing-train concept" which is especially suited for the German polycentric structure: The HSTs running unitedly on the high-speed line can be easily split for two final targets, e.g. from Berlin to Düsseldorf via Essen or to Cologne via Wuppertal, with separation in Hamm.

As the ICE 1 trains with roughly one eighth of driven wheelsets are not able to start on ramps of more than 25 % gradient safely if one power headcar fails, it soon became clear that this concept was not suited for the newly planned High-Speed Line Cologne–Frankfurt (Fig. 7.24) with gradients of s_{max} = 40‰.

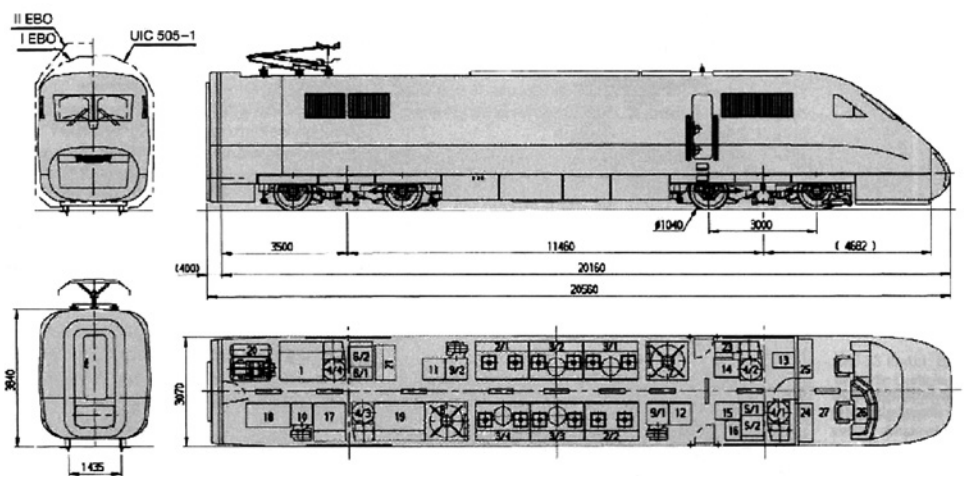


Fig. 7.21: Power Headcar of ICE 1, 2 (P_N = 4.8 MW)

Fig. 7.22: *High-speed line Cologne–Frankfurt*

In addition, the planned scheduled maximum speed of 330 kph was not compatible with the wheelset load of 20 t of the Class 401 power headcars, either. Therefore a new multiple-unit high-speed train ICE 3 (Class 403, or 406 as multi-system vehicle for traffic to Benelux and France, cf. subchapter 8.2) with 50 % driven wheelsets and a wheelset load of only 16 t was developed (see Fig. 7.20, centre, only a half-train sketched); P_N = 2 x 4 MW. A photo of the train has been given in Fig. 1.10, the traction drive is as Fig. 3.16; the underfloor converters (cf. Fig. 7.23) with water-cooled GTO-thyristor modules as in Fig. 5.42, are housed in the first and the third coach, the transformer (M = 9.1 t) in the second coach.

From the ICE 3, Siemens developed the international "platform" HST Velaro [224] [225], delivered to RENFE (at standard gauge!), RZD and the railways of Chinese People's Republic (KZD). The successor trains Class 407 for DB AG with multi-system equipment are based on the Velaro platform with IGBT converters.

In the 400-m 16-part HST "Velaro e320" (Cl. 374) for the railway transport enterprise Eurostar International Ltd., London, the drives are distributed to eight autonomous two-car groups, on behalf of the very strict redundancy requirements of Channel Tunnel operation. The train is equipped for the three railway power systems of the adjacent countries AC 25 kV/50 Hz and DC 1.5 and 3 kV.

A distributed drive concept is underlying the ICE T, the high-speed train with curvature-dependant body-tilting equipment (section 2.1.5; see Fig. 7.24; [226]). With only v_{max} = 230 kph it serves Enhancement Lines ("Ausbaustrecken") in mountainous areas, not the high-speed lines

Fig. 7.23: *Underfloor converter cubicle 2.2 MW for ICE 3, Class 403 (Siemens AG)*

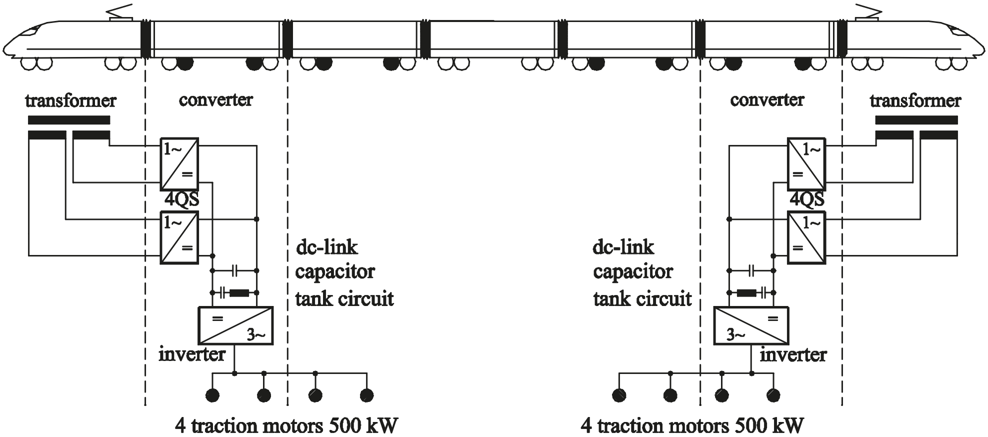


Fig. 7.24: *General arrangement of traction equipment in ICE T (Cl. 415, acc. to [226])*

themselves. It uses the Italian "Pendolino" technology, with two traction motors of 500 kW mounted longitudinally in the motor coaches, driving the inner wheelset of each bogie via cardan shafts and bevel gears. Here 6/20 = 30% of the wheelsets of the five-piece Class 411 (P_N = 3 MW) or 8/28 = 28.6% of the seven-piece Class 415 (P_N = 4 MW) are driven. The transformers are housed in the headcars, so the wheelset load is rather uniformly some 14 t. This is necessary, to prevent the headcars being lifted by sidewinds, as this was a problem with the relatively light control trailer of ICE 2, when leading. Fig. 7.25 gives a view of the ICE T train.

Fig. 7.20 has depicted (at the bottom line) the configuration of the E2-HST of Japan East RR. With IGBT-inverter-fed motors it features 75 % driven bogies. But it was necessary to give each headcar not motored a special "duck-bill profile", which compensates – like a spoiler – the lessening wheelset load of the first bogie at high speed [149]. A similar solution had been chosen with the new TALGO power headcars for Spain (v_{max} = 350 kph) by Krauss-Maffei/ Bombardier (Fig. 7.26).

Recently, DB AG ordered 130 new trains-sets of the ICx type at Siemens AG, with Bombardier as subcontractor with a share of 35%; there is an option for a maximum of 300 trains until 2030.

Fig. 7.25: *View of ICE T Class 411 DB AG*

Fig. 7.26: *Power headcar RENFE S. 102 with duck-bill profile*

Here the unit drive equipment of 1.65 MW is housed in a motor coach of 27.9 m length. The order splits up in 45 seven-car trains with 456 seats and three four-system motor coaches per train, v_{max} = 230 kph, and 85 twelve-car trains with 830 seats and six AC 15 kV/16$^2/_3$ Hz motor coaches for v_{max} = 249 kph. It is possible to form trains with five to 14 cars, with v_{max} = 230 or 249 kph. The limitation to 249 kph allows to stay at a wheelset load of 17 t and avoids the additional equipment prescribed by the TSI for HSTs; the trains are not provided for the Cologne–Frankfurt HSL [227].

A special problem arises with HSTs from current collection: The first pantograph excites long-wave oscillations of the catenary (subchapter 13.4), which disturb the contact of the second one. Many HSTs use only one pantograph in service and feed the motor units via a HV connection cable in the roof (e.g. ICE 3, ICE T). The ICE 1 does not have such a connection line, for cost reasons; but this is admissible as the pantographs of both power headcars have a distance of about 400 m, in which the disturbing oscillations have died away already. The same holds for the French TGV.

In Japan, high-speed traffic cuts through densely populated areas, much more than in Europe; so special attention had to be directed to the problem of aerodynamic noise of the pantographs. At first by shielding, then by the use of a telescopic boom; now a single-arm solution is preferred [220], with additional deflectors at the sides.

7.4 Electric traction vehicles with synchronous traction motors

Fig. 7.27 displays the high-speed train TGV-A (Train a Grand Vitesse-Atlantique) of SNCF, using the converter circuit according to Fig. 6.4. It is driven by two power head-cars. In Fig. 7.28 the faces of the evaporative-cooled converter vessels [180] [222] are to be seen, containing a thyristor bridge each or a GTO chopper module.

Descendants are the KTX HST for Korean National Railways (50 Hz) and the ACELA trains for AMTRAK (12.5 kV/25 Hz and 25 kV/60 Hz). The similar Thalys HST for Paris–Brussels–Amsterdam and Cologne (1996) are equipped for 15 kV/16$^2/_3$ Hz, too, at distinctly lower power (only 3,680 kW instead of 8,800 kW for 25 kV/50 Hz operation, due to transformer and smoothing-reactor rating).

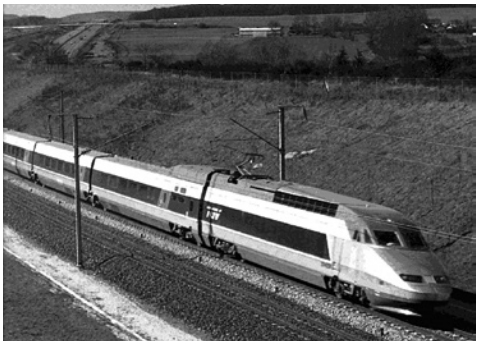


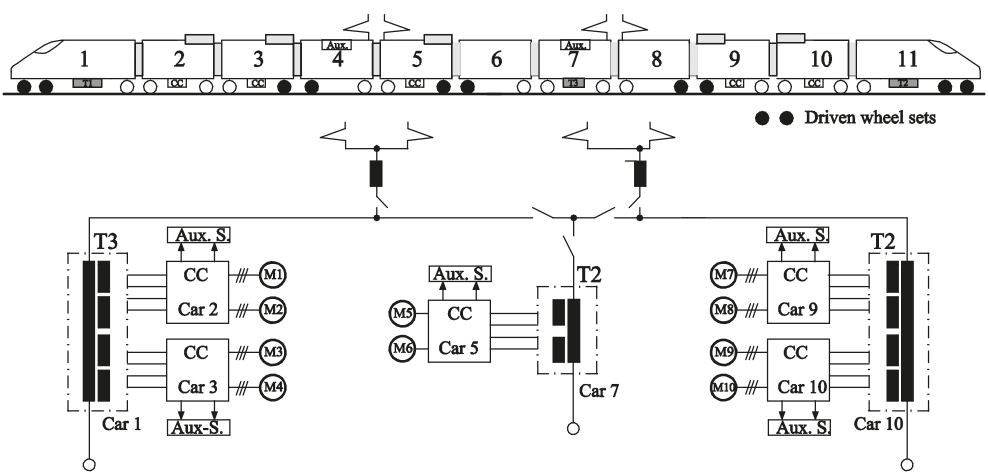
Fig. 7.27: *High-speed train TGV-A of SNCF (Alstom Transports)*

Fig. 7.28: *Evaporative-cooled thyristor converters of TGV-A (Alstom Transports)*

From 1995 onwards, the TGV family included double-deck (Duplex) trains; in 2006, the much-discussed changeover to asynchronous motors and IGBT inverter technology (PWM inverter and 4q-S; cf. subchapter 6.2) was finally implemented. In 2010, the double-deck TGV 2N2 (2 niveaux, 2ème génération, as dual- and three-system trains) commenced trial operations. On April 3, 2007, one of the new TGV-POS[23] trains, supported by an additional motor unit equipped with converter-fed permanent-magnet synchronous motors attained a maximum speed of 574.8 kph. Following this event, ALSTOM Transports unveiled its new high-speed motor coach train AGV ("Automotrice à Grande Vitesse") in February 2008, which featured permanent-magnet synchronous drive motors [228] [229]. In contrast to the TGV, it does no longer use power head-cars but rather features an articulated layout based on Jakobs' bogies and a variable number (7–14, depending on the desired layout and capabilities) of modules. It achieves a traction power of 6–12 MW, depending on the number of motored coaches, and a maximum speed between 300 and 360 kph.

Fig. 7.29 depicts the drive train configuration of the 11-coach variant, featuring five motor bogies. Two drive groups contain four four-quadrant converters and four IGBT inverters each, which feed four PMSMs; one drive group only uses two 4q-S and one twin inverter for two motors. The inverters have an hourly rating of 1050 kW; the line converters are equipped for all four power-supply systems, with a nominal DC-link voltage of 3000 V. If operating in a DC 1.5-kV system, the grid voltage is stepped up by using the 4q-C units as a boost converter (cf. subchapter 8.2, Fig. 8.12 bottom); a rheostatic brake is provided. The transformers are placed in the leading cars; in case of higher power requirement (more than 8 coaches), additional transformers are provided in special transformer wagons. The 11-coach train, which has a TSI-compatible length of 200 m, has a structural mass of merely 380 t.

[23] POS: Paris – Eastern France – Southern Germany



T: Transformer C-C: Converter Container Aux-SV: Auxiliary energy supply Aux: Auxiliaries

Fig. 7.29: *Configuration of traction equipment of AGV 11-5 ".italo" (acc. to data from ALSTOM)*

Fig. 7.30 illustrates the rotor and its surface-mounted magnets; Fig. 7.31 shows the external view of the fully encapsulated, self-ventilating motor unit [230]. This pattern was chosen for the considerable danger a winding short-circuit poses to a PMSM – a fire must not, under any circumstances, spread into the coach superstructure. To ensure this, isolating disconnectors and short-circuit switches have been included in the assembly (cf. subchapter 6.3). The rated power is 900 kW, the nominal efficiency is listed as 97% at a mass of 775 kg (excluding the transmission gear). Compared to the 0.6 kW/kg induction motor found in the E 120 (Fig. 5.3) thirty years ago, the power-to-mass ratio has been almost doubled to 1.16 kW/kg, while increasing efficiency by 2 percentage points! In contrast to Fig. 2.8, the motor features a simple axle-riding gear drive and is mounted again in the bogie [229].

Fig. 7.30: *Rotor with surface-mounted permanent magnets (Alstom Transports)*

Fig. 7.31: *PMSM of AGV; P_N = 900 kW (Alstom Transports)*

The Italian railway transport company Nuovo Trasporto Viaggiatori (NTV), which was founded in 2006, has ordered 25 train sets ETR 575 in the 11-coach configuration, which have been delivered from 2011 onwards [231]. They are scheduled to operate on the Italian high-speed network between Torino and Salerno, using the 25 kV/50 Hz and DC 3 kV systems (the latter on the old *Direttissima* high-speed line between Florence and Rome). Due to the maximum speed of 300 and 250 kph, respectively, traction power is 7.5 MW on AC lines and 6 MW at DC supply. Fig. 7.32 shows the aerodynamically shaped train head.

Fig. 7.32: *HST motor-car train-set AGV .italo. (Alstom Transports)*

In Sweden, Bombardier Transportation trialled the MITRAC-PM technology using a two-part REGINA motor-coach train as part of the "Gröna Taget[24]" research project. The motor has a power-to-mass ratio of slightly over 1.2 kW/kg, while achieving 97% efficiency [232]. In 2010, SBB placed an order with Bombardier Transportation for 59 double-deck high-speed trains of the TwinDEXX Express type (50 eight-car IR200, 9 four-car IR100; Fig. 7.33 shows a design concept study), which will feature a water-cooled PMSM and a tilt compensation system (WAKO, section 2.1.5). Its maximum speed is 200 kph [233]. Delivery is not to be expected before 2015. Future planning includes the use of medium-frequency AC-link line converters (cf. section 5.6.6) to optimise payload and efficiency.

Similar trains have been ordered by DB AG as fast regional trains (TwinDEXX Vario) which operate at a maximum speed of 160 km/h (five trains have been initially ordered, with outline agreements for 135 trains.

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[24] Green Train

Fig. 7.33:
Double-deck train-set TwinDEXX Express SBB IR200 (Bombardier Transportation)