The Elmer A. Sperry Award

1982

for advancing the art of transportation

The Elmer A. Sperry Medal

The Elmer A. Sperry Award

☐ The Elmer A. Sperry Award shall be given in recognition of a distinguished engineering contribution which, through application, proved in actual service, has advanced the art of transportation whether by land, sea or air.

In the words of Edmondo Quattrocchi, the sculptor of the Elmer A. Sperry Medal:

"This Sperry medal symbolizes the struggle of man's mind against the forces of nature. The horse represents the primitive state of uncontrolled power. This, as suggested by the clouds and celestial fragments, is essentially the same in all the elements. The Gyroscope, superimposed on these, represents the bringing of this power under control for man's purposes."

Presentation of

THE ELMER A. SPERRY AWARD FOR 1982

to

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EHRHARD FUTTERLIEB
JOACHIM KÖRBER
EDMUND MÜLLER
G. REINER NILL
MANFRED SCHULZ
HERBERT STEMMLER
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by

The Board of Award under the sponsorship of

The American Society of Mechanical Engineers
Institute of Electrical and Electronics Engineers
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At the IEEE Luncheon during the ASME/IEEE Joint Railroad Conference

Wednesday, April 27, 1983 □ Baltimore Hilton Hotel, Baltimore, Maryland

Elmer Ambrose Sperry 1860–1930

Founding of the Award

☐ The Elmer A. Sperry Award commemorates the life and achievements of Dr. Elmer A. Sperry (1860–1930) by seeking to encourage progress in the engineering of transportation. Much of the great scope of the inventiveness of Dr. Sperry contributed either directly or indirectly to advancement of the art of transportation. His contributions have been factors of improvement of movement of men and goods by land, sea and air.

The award was established in 1955 by Dr. Sperry's daughter, Mrs. Robert Brooke Lea, and his son, Elmer A. Sperry, Jr.

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Award Citation

☐ To Jörg Brenneisen, Ehrhard Futterlieb, Joachim Körber, Edmund Müller, G. Reiner Nill, Manfred Schulz, Herbert Stemmler and Werner Teich for their contributions to the development and application of solid state adjustable frequency induction motor transmission to diesel and electric motor locomotives in heavy freight and passenger service.

Previous developments

It was in 1879 that Werner v. Siemens presented the first operational electric locomotive at the Industrial Exhibition (Gewerbeausstellung) in Berlin. In 1889 M.v. Dolivo-Dobrowolski invented the three-phase asynchronous motor. Very soon railway engineers realized the advantages offered by the asynchronous motor in comparison with a commutator motor and they tried to apply it as a traction motor in numerous projects.

In 1899 the first locomotive applying three-phase traction motors was put into service between Burgdorf and Thun (Switzerland); in 1902 a motor-coach equipped with three-phase motors attained on the Berlin-Marienfeld-Zossen a speed of in those times hardly believable, 210 km/h (Fig. 1); and in 1906 the Simplon line (Switzerland) was electrified with a three-phase overhead line and operated with three-phase locomotives.

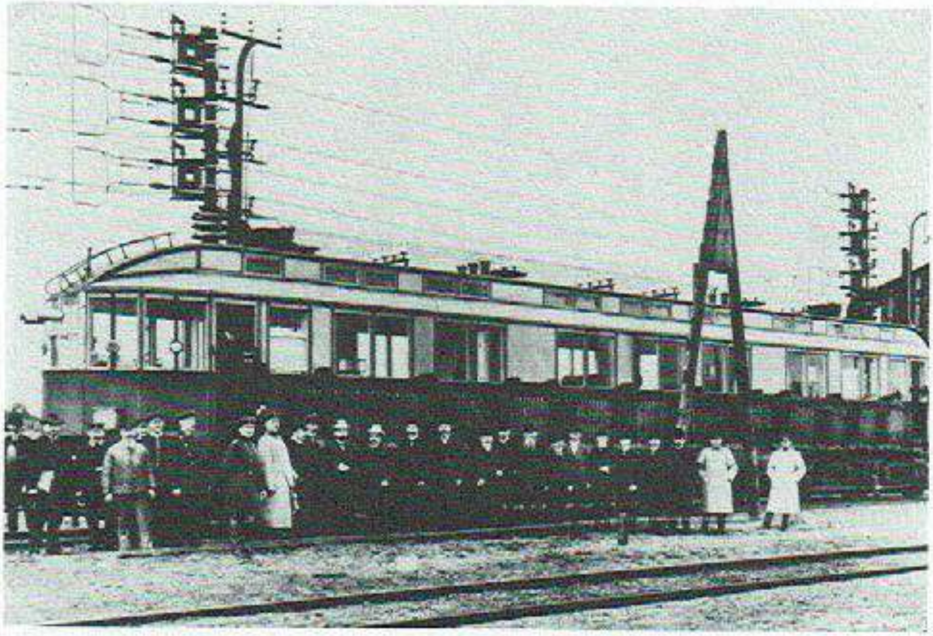

Fig. 1: *High-speed motor coach with three-phase induction motors.*

Despite these and other projects, drive systems applying three-phase asynchronous motors could not succeed in a final break-through.

How can this be explained?

The three-phase asynchronous motor is the most simple electrical machine and offers in comparison to a commutator-motor numerous advantages making it most preferable for the very demanding railway service.

It has a simple mechanical layout and therefore is very rugged and inexpensive to build. Besides the bearings there are not parts subject to wear or requiring maintenance. It permits higher rotating speed thus reducing dimensions and weight at constant power. These features are most important for a bogie-mounted motor as they permit lowering of the unsprung mass. This again influences the traction charactertics positively and reduces rail wear and tear.

The three-phase drive is "friendly" to the track. The steep torque-speed-characteristic itself resists slippage of individual axles.

Unfortunately these advantages are counteracted by an essential disadvantage: the speed of a three-phase asynchronous motor—especially in its most simple version as a squirrel-cage-motor—cannot be varied in such a simple way as is the case with the commutator motor. Speed variation requires a power supply with which frequency and amplitude of the supply voltage can be varied independently over a wide range (Fig. 2).

Despite the large inertia of a locomotive, this power source has to offer a fast dyna-

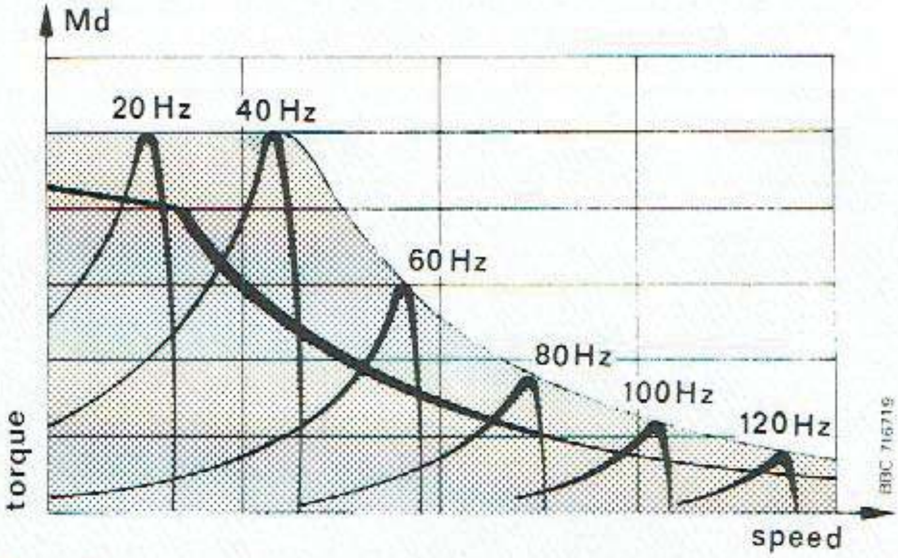

Fig. 2: *Torque-speed diagram for an asynchronous motor for operation with variable frequency. Desired traction curve superimposed.*

mic response to make wheel slipping and skidding under extreme adhesion and load conditions controllable.

In earlier times technology was not far enough advanced to build such equipment.

A New Start

Modern semi-conductor technology provided the base for building such power conversion equipment at reasonable technical and economic expense. Thyristors (1957) permitted economical power conversion and transistors (1948) had already laid the basis for the required control equipment.

Static converter technology has a long tradition in the BBC Group. Therefore, BBC applied its resource from the very beginning to the application of this new device which replaced mercury arc rectifiers. In the early sixties a reasonable number of proven electric circuits and control methods for forced-commutated inverters had been developed, e.g. for the supply of variable speed industrial drives (rolling mill motors, synthetic fiber spinning) and for battery-balanced uninterruptible power supplies for computers.

The performance results were encouraging enough to reconsider the idea of applying asynchronous motors for railway traction. First investigations were carried out in the BBC Group since 1963 followed by a period of intensive studies starting 1965. Technical feasibility, economic aspects and marketability were investigated. Evidently assumptions had to be made for development trends, e.g. in the field of power semi-conductors. Furthermore, it had to be considered that this new technique was about to compete with a well established technique matured during decades. Hence technical and economical aspects were interwoven with psychological aspects: the power of innovation had to be assisted by the power of persuasion.

The first diesel electric locomotive with three-phase traction drive

As a result of the BBC investigations, the German BBC in Mannheim decided to develop a completely new diesel electric locomotive rated 2500 hp. From the very beginning the objectives included that the mechanical design should also profit from the benefits offered by the new drive system. Therefore a cooperation with the locomotive builder, Rheinstahl-Henschel (now Thyssen-Henschel) was initiated and the new locomotive was named HENSCHEL-BBC-2500.

Already on June 18, 1969, in the laboratory of the Central Development Department

Fig. 3: *Presentation of prototype components for the diesel-electric locomotive DE 2500.*

of BBC in Mannheim, the prototype components were presented to a large group of important decision makers within the management of the German Federal Railway (DB). During this presentation, the operation of two traction motors, i.e. about half the power of the locomotive was shown between standstill and maximum speed. "Driving" was performed in a mock-up of the driver's cabin (Fig. 3).

Then and later on other occasions, one of the outstanding advantages of the new drive was demonstrated in a rather impressive way by the experiment "blocked rotor." In this experiment, the rotor of the asynchronous motor was brought to complete standstill with the aid of a torque balance. The inverter was then controlled to produce the maximum motor torque, which could be read on a scale. This standstill could last for a prolonged time, while the project-leader gave his explanations. This was most impressive for experienced railway engineers knowing and fearing the deadly effect of maximum current on the commutator bars during standstill.

What was the new technique like? Fig. 4 shows that structure of the power-transmission system. The diesel engine 1 drives a three-phase generator 2, its output voltage

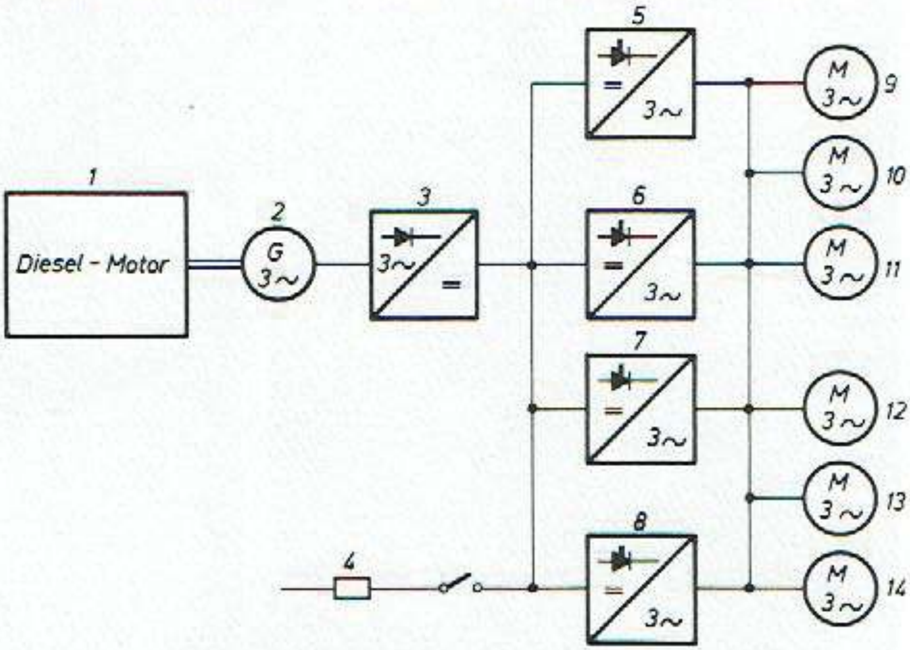

Fig. 4: *Power transmission system of diesel-electric locomotive DE 2500. 1) Diesel engine; 2) Three-phase generator; 3) Diode rectifier; 4) Resistor for electrical braking; 5-8) Inverter units; 9-14) Traction motors (squirrel cage).*

being rectified in a simple bridge 3. The heart of the power transmission and the really new part are the forced-commutated inverters 5-8. They change the dc voltage into a three-phase voltage system with variable amplitude and frequency. They supply and control the traction motors (squirrel cage motors). To obtain the required power ratings, four equal inverters are operating in parallel. All motors are connected to the common three-phase bus-bar. In the braking mode the three-phase machines operate as generators; the braking power is dissipated in the resistor. 4.

Fig. 5 shows the basic circuit of the forced-commutated inverter. Each of the four three-phase inverters shown in Fig. 4 consists of three equal electric circuits, the phase modules, which are connected in parallel to the positive or negative terminals of the dc voltage supply. This well smoothed and fixed dc voltage, the so-called dc voltage link or intermediate circuit, classifies this converter arrangement.

By triggering the thyristors T1 or T2 alternately, the positive or negative polarity of the dc voltage can be switched to the output. As a thyristor can only be switched on by a trigger impulse, but not switched off, additional devices are required to achieve forced commutation: the commutation thyristors T3 and T4, capacitors C1 and C2 and reactors L1 and L2. Triggering and commutating occur in a very fast sequence and cover a range of some ten microseconds.

Control of the inverters is performed with the so-called subharmonic method, "Unterschwingungsverfahren," developed by BBC engineers. The duration during which the positive or negative polarity of the dc voltage is switched to the output is modulated to obtain the desired output voltage as a subharmonic of the higher rated pulse frequency. Current is smoothed by the motor's leakage inductance. The three phases R, S and T are realized by phase-displaced triggering of the three phase-modules.

The above mentioned demands on an effective speed control of an asynchronous motor are fulfilled with this inverter and its control method.

The sense of rotation of the motor can easily be reversed by electronically changing the triggering sequence without any additional mechnical contractors.

A converter system with a dc voltage link was selected, as it permits a modular system design using the very same motor inverter for different prime movers such as diesel engine (with generator), gas turbine (with generator) or power supplies such as accumulator, dc or ac overhead line.

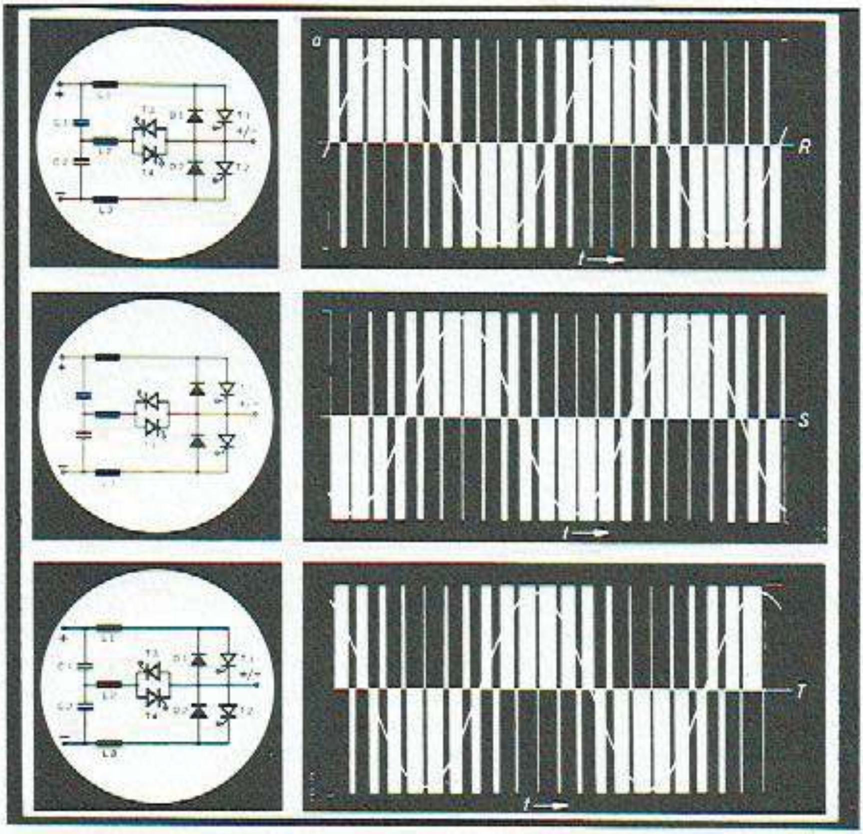

Fig. 5: *Basic circuit diagram of three-phase inverter and subharmonic control method.*

On June 30th, 1970, the HENSCHEL-BBC DE 2500 with three-phase power transmission accomplished its first official run on the tracks of the DB.

Its main ratings were:

Power:	1840 kW
Weight:	80 metric tons
Wheel arrangement:	CoCo
Maximuam starting effort:	270 kN
Maximum speed:	140 km/h (about 87 miles/h)

A period of extensive trials in cooperation with DB engineers followed. The locomotive was exhibited at the Hanover Fair in 1971 (Fig. 6). During the International Congress on Electric Railways (ICEB) in autumn 1971, it performed demonstration runs with congress participants between Augsburg and Munich.

Fig 6: *First DE 2500 on exhibition at Hanover Fair in April 1971.*

The new power transmission technology fulfilled the expectations in every respect. This was also shown in another experiment, proving in a very simple, but nevertheless impressive way, that slipping of an individual motor connected to a three-phase bus-bar is not possible. Therefore the locomotive was started against a high load (a train with its brakes on or against a rail end buffer). Then the rail under a single wheel rim was lubricated thus ruining the adhesion factor. Nevertheless, this wheel increased its speed only by the very small amount of the slip frequency. This is the difference between the rotation frequency of the axle and the stator frequency supplied by the inverter (Fig. 2). With the motors connected to the three-phase bus-bar, the improvement of the available adhesion factor can be measured.

If at very extreme conditions of adhesion and load all axles try to start slipping, the good dynamic response of the electronic control permits slipping suppression from the very beginning.

The new locomotive can deliver high tractive efforts in starting—without time limit—also at high running speeds (Fig. 7): it is essentially a multi-purpose locomotive.

The power transmission system has a high efficiency. In the starting range the diesel engine has to cover only the low transmission losses.

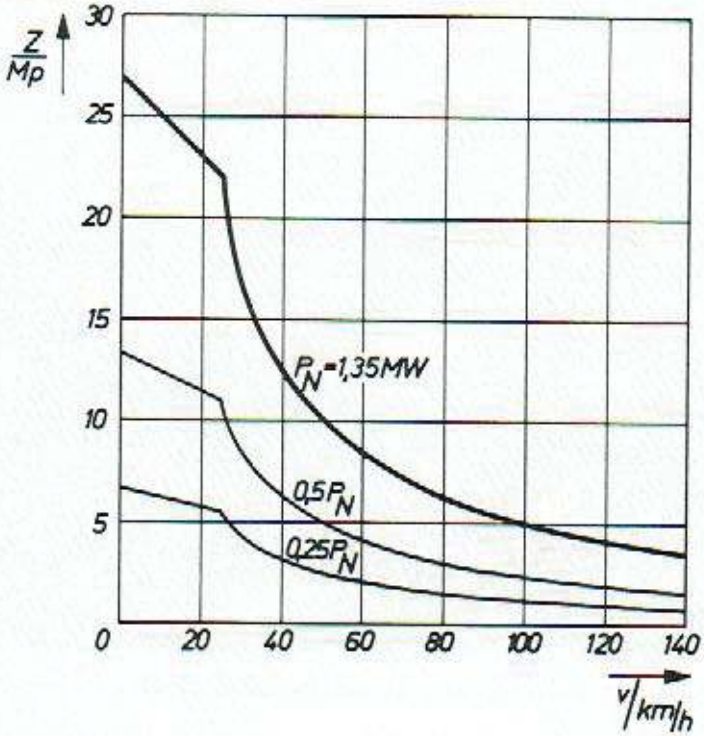

Fig. 7: *Tractive effort speed diagram of the DE 2500. Z tractive effort; v speed.*

As there is no physical relationship between the rotational speed of the diesel engine and that of the traction motors it is possible to operate the engine at optimal conditions, i.e. at its minimum fuel consumption for the entire power range.

Regenerative braking and reversal of rotation (of traveling) are possible with mere electronic means. If the braking energy cannot be regenerated, a resistor is necessary to dissipate the energy. Electrical braking with full torque can be provided down to standstill. To supply the train bus-bar (heating, air-conditioning) another inverter can be connected to the terminals of the dc link. These loads can possibly accept the energy in the braking mode (energy saving).

An extensive program of comparative trials performed by the DB proved the superiority to the diesel-hydraulic standard locomotives.

In 1972 a powered baggage car of the Swiss Federal Railways (SBB) modified by the Swiss BBC company was completed and tested (Fig. 8). This experimental vehicle, rated 1000 kW, was designed to investigate the basic conditions for a three-phase drive supplied from the 15 kV, 16 2/3 Hz catenary. The input circuit was executed without special means as the series connection of a phase-controlled and an uncontrolled rectifier bridge. The control methods used for the motor inverter equalled those described previously.

In 1973 the first DE 2500 was followed up by two more units: a CoCo- and a BoBo-version (Fig. 9). The original concept was adopted in these without essential changes. Improvements were confined to structural details and components.

Fig. 8: *Experimental inverter locomotive class Be 4/4 of Swiss Federal Railways.*

Fig. 9: *Family photo of DE 2500 locomotives.*

These components and modules (Fig. 10) laid the basis for a modular design concept covering a power range from 500 kW to 3000 kW. Subsequent series of different types of locomotives are fitted with these modular designs.

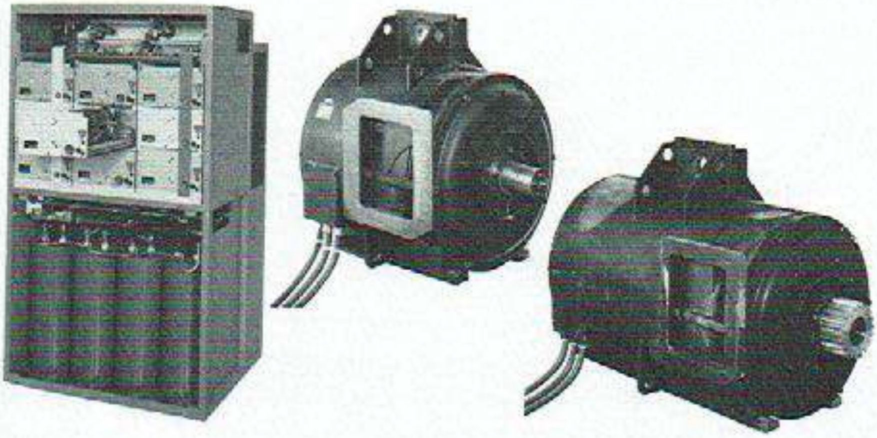

Fig. 10: *Main components for modular design concept type DE 2500. Three-phase inverter — Rated power: 770 kVA. Asynchronous traction motors — Rated power: 375 kW resp. 250 kW.*

The first electric high-power locomotive with three-phase drive

The German Federal Railway (DB) realized that three-phase traction was able to render essential contributions towards improving operation and towards reducing energy consumption and maintenance cost. As the DB had no near-future need for additional diesel locomotives, they looked directly at the application of three-phase drives to electric high-power locomotives. DB saw the tasks as follows:

Apart from the benefits of the new drive technology, DB also wanted to simultaneously acheive an optimal adaptation of the power transmission system to the specific conditions of the 16 2/3 Hz grid. Preceding experiences with vehicles fitted with phase-controlled rectifiers had led to acknowledging the importance of problems related to the (total) power factor, reactive power and harmonics. A new locomotive should not only be "friendly" to the track, but also to the grid.

From a physical point of view, the task was to draw the inherently pulsating power from the single-phase line with the lowest possible reactive power and harmonics and then—after suitable power conversion—to supply the asynchronous motors with constant power.

All conventional asynchronous motors produce a smooth non-pulsating torque, but even pulsating power was considered in the beginning of our studies.

A period of intensive investigations, studies and system evaluations followed, stimulated by this highly challenging task.

The solution finally selected consisted of a forced-commutated inverter as an input circuit operating in conjunction with an electric resonant circuit which is tuned to double the frequency of the grid. This inverter was similar to the motor inverter in both the power circuit and the control method. This brought electrical and mechanical design concepts into line. The term "Four-Quadrant-Controller" (Vierquadrantensteller 4qS) was chosen for this arrangement. The concept was investigated comprehensively and at considerable expense using analog and digital computers. Experts of the Technical University of Aachen (RWTH) confirmed the accuracy of the prediction.

Fig. 11 shows the basic circuit diagram of the 4qS. For more clarity commutating elements are neglected. The similarity to the circuit shown in Fig. 5 is evident. This arrangement supplies the input of the motor inverter with dc voltage. The power drawn

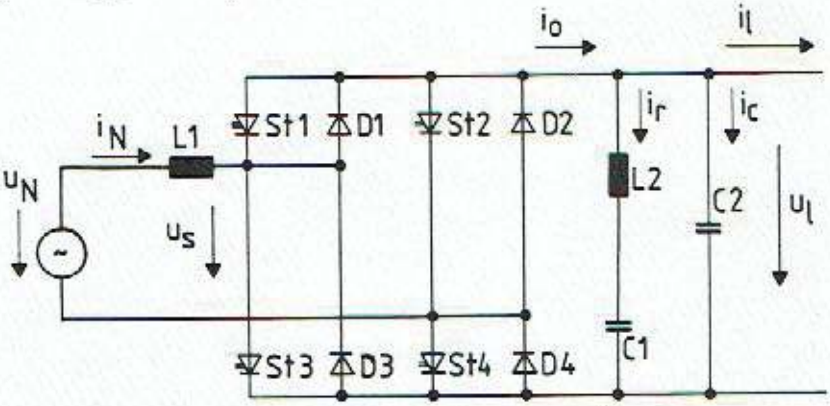

Fig. 11: *Basic circuit diagram of four-quadrant-controller.*

from the line is pulsating around the time average value (the active power). The average value corresponds to the constant power flow into the motor inverter (Ig. Ug), whilst the pulsating power is absorbed by the resonant circuit L^2, C^2). This solution not only meets the demand, but also offers powerful, electric regenerative braking. The concept represents a homogeneous system, as shown in the complete circuit, simplified to the essentials (Fig. 12).

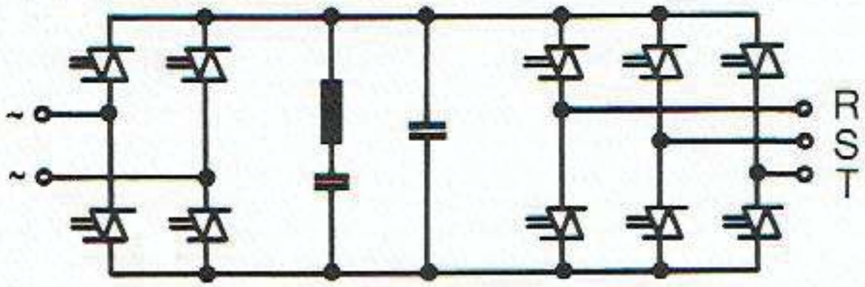

Fig. 12: *Converter arrangement with four-quadrant-controller and motor inverter.*

This solution not only fascinated the developing engineers in the BBC company, but also appealed to the later operator, the DB. The development of a completely new locomotive was taken into consideration. A development plan was established comprising a sequence of development steps:

- results gained from simulations and laboratory measurements should be confirmed by field trails on the rail;
- main components should be full-scale tested (4qS, motor inverter, motor, power transmission);
- building of a prototype locomotive.

Subsequent steps should follow the preceding ones only in the case of positive results.

The first scheduled step was the three-phase experimental vehicle (Drehstromversuchsfahrzeug). It consisted of the first DE 2500, which was coupled with a driving-trailer (Fig. 13). The DE 2500—its diesel engine dismounted and replaced by bal-

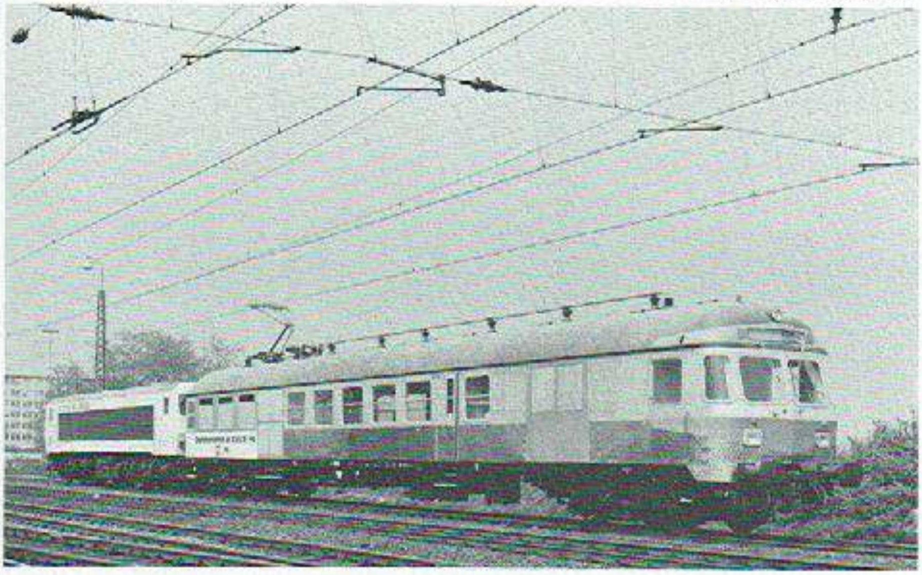

Fig. 13: *Three-phase experimental vehicle.*

last—carried the traction equipment (inverters, motors). The trailer housed the input equipment (pantograph, transformer, 4qS) and supplied the dc link to the "diesel" locomotive via a connecting cable. This obviously demonstrated that the traction equipment for a diesel electric and an electric locomotive can be the same after the dc link. From autumn 1974 to spring 1975 an extensive program of trials was conducted by and together with DB, partly also by the Swiss Federal Railways (SBB). The test results fulfilled the expectations concerning power factor (Fig. 14), harmonics and regenerative braking.

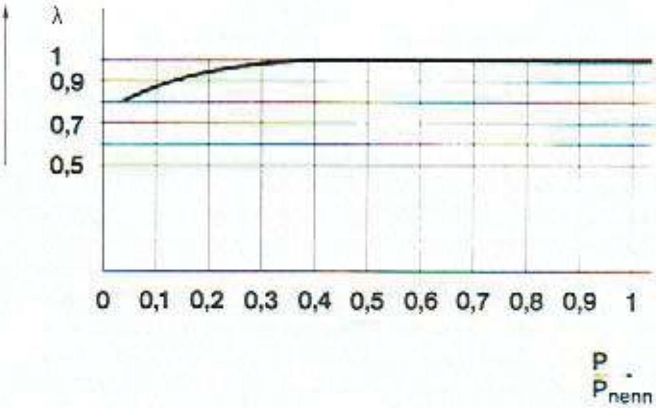

Fig. 14: *Three-phase experimental vehicle; Total Power factor versus Power.*

Now the next step could be taken: definition, construction and testing of the original components for an electric locomotive. First the specifications had to be elaborated in close cooperation between DB and BBC. The DB engineers' part was to formulate the demands based on their operation experiences, whilst BBC emphasized the technical possibilities.

The definition of an electric locomotive with four axles, rated 4.4 MW continuous, 84 metric tons of total weight and 160 km/h maximum speed laid the basis for the layout of the converters and motors.

In 1976 the components were tested thoroughly on the test-bench for large machinery at BBC in Mannheim (Fig. 15). One of the most essential results was that the motor could handle as much as 1.4 MW continuously (planned only as short-range peak power) instead of 1.1 MW only.

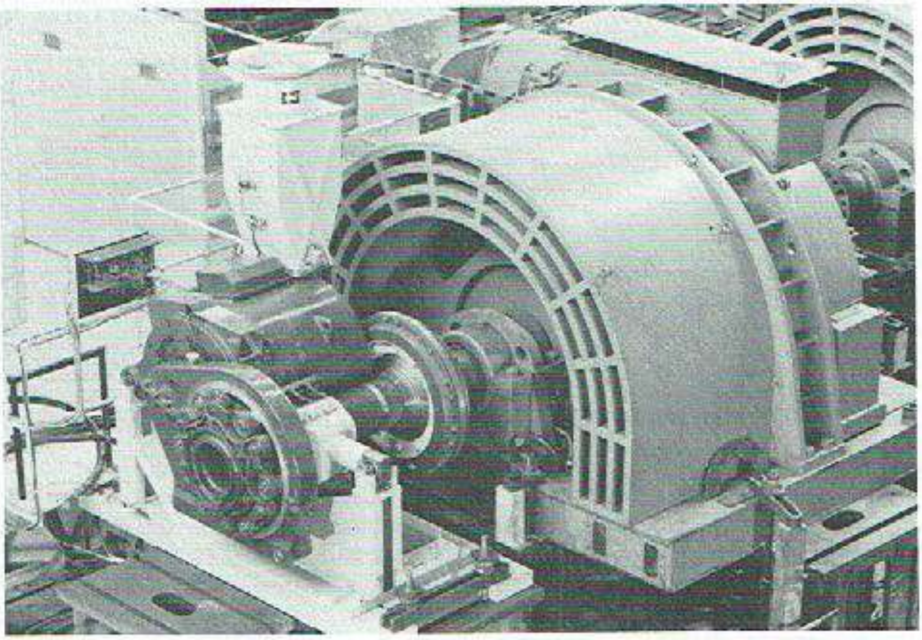

Fig. 15: *Prototype asynchronous motor with drive (foreground) for E 120 on test-bench.*

After the components had successfully passed the trials, the building of prototype locomotives could commence.

However, a variety of technical, economic, competitive and legal problems had to be settled first. Similar to the DE 2500 this new locomotive should not just house the new power transmission, but the mechanical layout should also make full use of the available advantages. DB entrusted the development of the mechanical part to a construction team comprising Kraus-Maffai (as leader), Thyssen-Henschel and Friedr. Krupp. BBC gained the development contract for the electrical equipment. Development contracts were signed in 1976. In 1977 DB ordered five prototype locomotives.

Only two years later, in spring 1979, the first electric multi-purpose high-power locomotive class E 120 of the new generation was completed (Fig. 16).

In summer 1979, it was presented in Hamburg at the International Transportation Exhibition (IVA) and belonged most probably to those objects which found the utmost interest among the experts.

Incidently, the IVA also featured the magnetically levitated vehicle TRANSRAPID

Fig. 16: *Electric multi-purpose high-power locomotive class E 120.*

05, which was controlled with power by inverter modules type DE 2500.

The high power density in the converters of the E 120 mandated oil-cooling instead of forced air cooling. Meanwhile (status summer 1982) the five locomotives have covered over 1.8 Million km under most varied and partly extreme conditions. Concept and technology have been proven (Fig. 17). All ratings within the tractive effort-speed-diagram

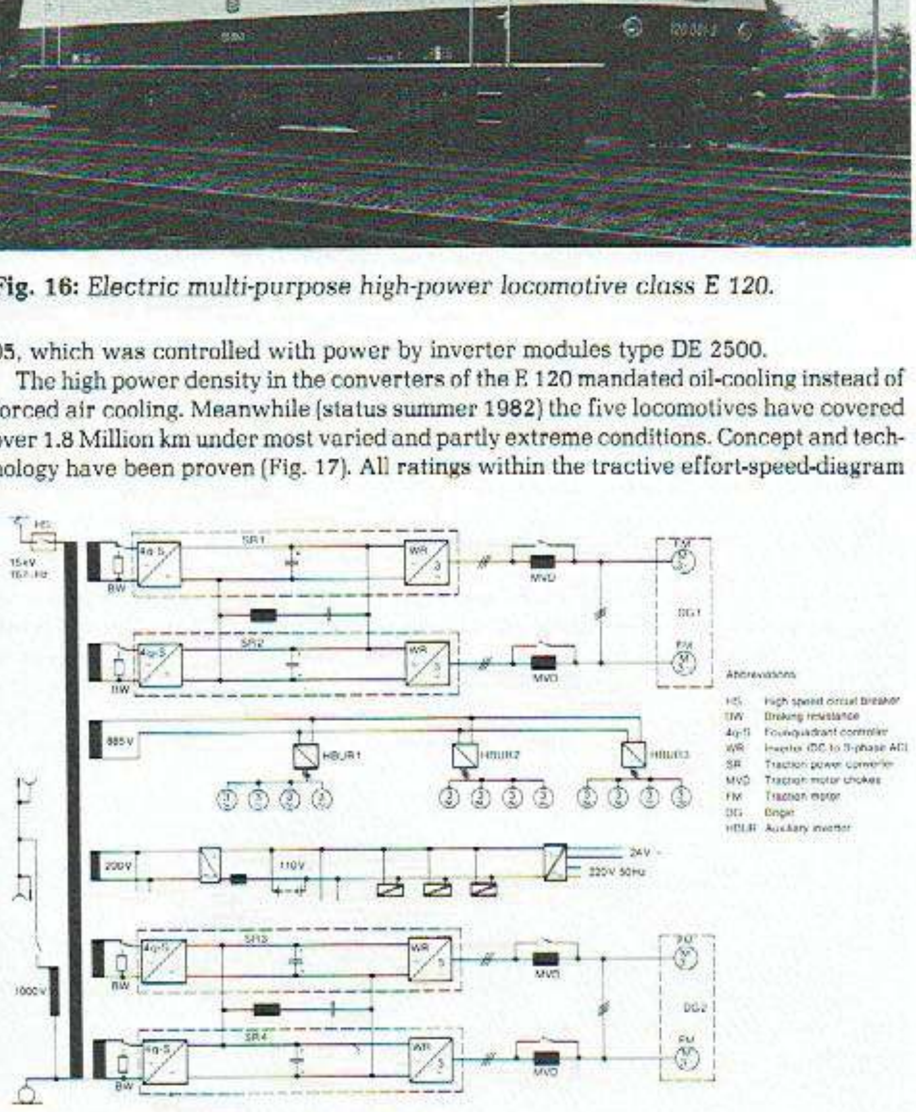

Fig. 17: *Basic circuit diagram of the E 120. HS-High speed circuit breaker; BW-Braking-resistance; 4qS-Four-quadrant controller; WR-Inverter (DC to 3-phase AC); SR-Traction power converter; MVD-Traction motor chokes; FM-Traction motor; DG-Railtruck (bogie); HBUR-Auxiliary Inverter.*

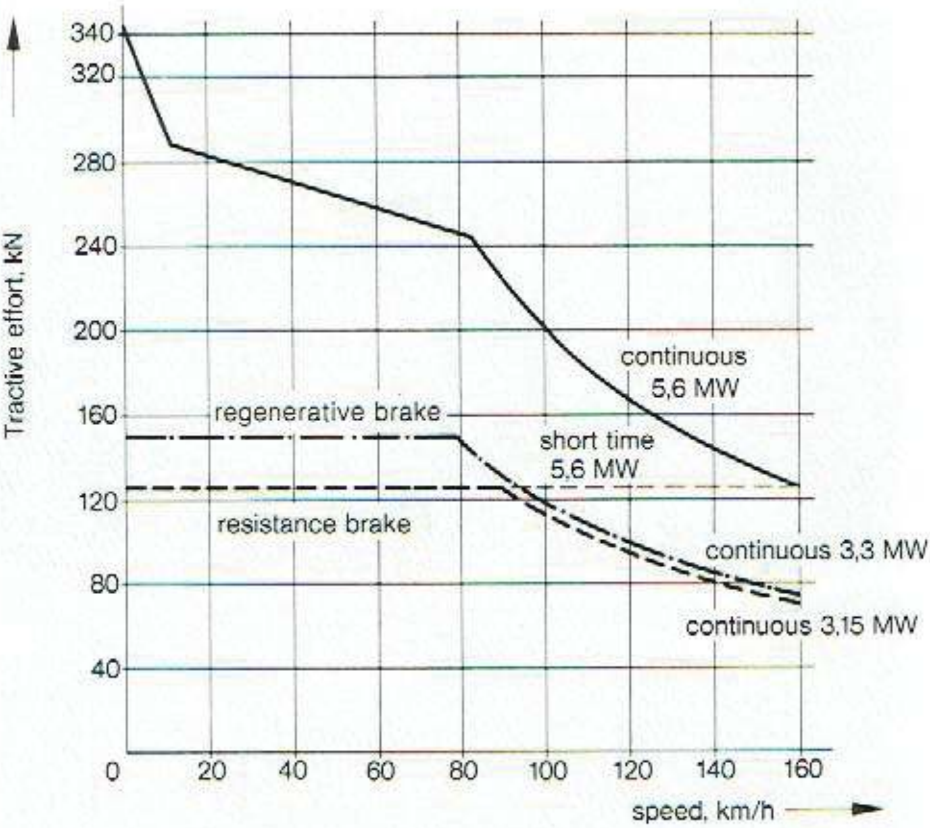

Fig. 18: *Tractive effort-speed characteristic of the E 120.*

have been attained (Fig. 18). Table 1 and Fig. 19 clearly show the mass reduction with the asynchronous motor compared to commutator motors. The prototype testing naturally revealed problem points. However, after the necessary improvements and modifications, the five locomotives with their favorable modular design concept—originally conceived as prototypes—can now be considered as pre-series types, to be followed by a series-procurement.

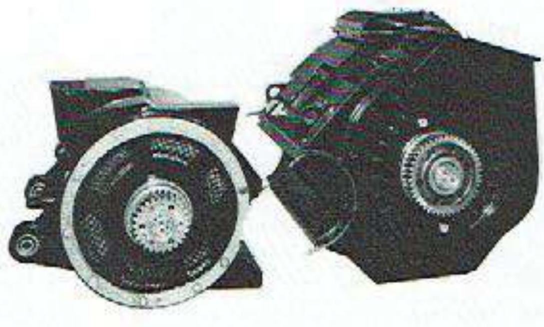

Fig. 19: *Asynchronous motor of E 120 (left) and ac commutator motor of E 110 (right).*

Table 1
Comparison of traction motors.

Motor type	WB 372	UZ 11664	QD 646
Loco type	110, 111, 140, 151	181.2	120
Kind of motor	AC commutator	undulated DC	three-phase asynchronous
U_{max}	585 V	1050 V	2200 V
I_{dd}	2250 A	830 A	360 A/phase
P_{dd}	0.95 MW	0.8 MW	1.4 MW_{dd}
P_{max}	ca. 1.4 $MW_{5\ min}$	1.4 $MW_{5\ min}$	1.4 MW_{dd}
n_{max}	1525 rpm	2210 rpm	3600 rpm
Diameter	1164 mm	950 mm	930 mm
Weight	3.9 Mp	3.1 Mp	2.4 Mp

Metamorphosis of a diesel locomotive

The Netherland State Railway (NS) was another railway administration becoming interested in the advantages of the three-phase drive. Their special attention was focused on the converter's potential reactions on their 1500 V dc grid. Phenomena had to studied very close to the original conditions. Therefore NS ordered an experimental locomotive class P. After having fulfilled its job in the three-phase experimental vehicle, the DE 2500 was used once more as a moving test-bench. It was converted to an electric locomotive and equipped with only one traction motor of the E 120, resulting in the strange wheel arrangement 1A1-3 (Fig. 20). As this motor requires a voltage of 2800 V a

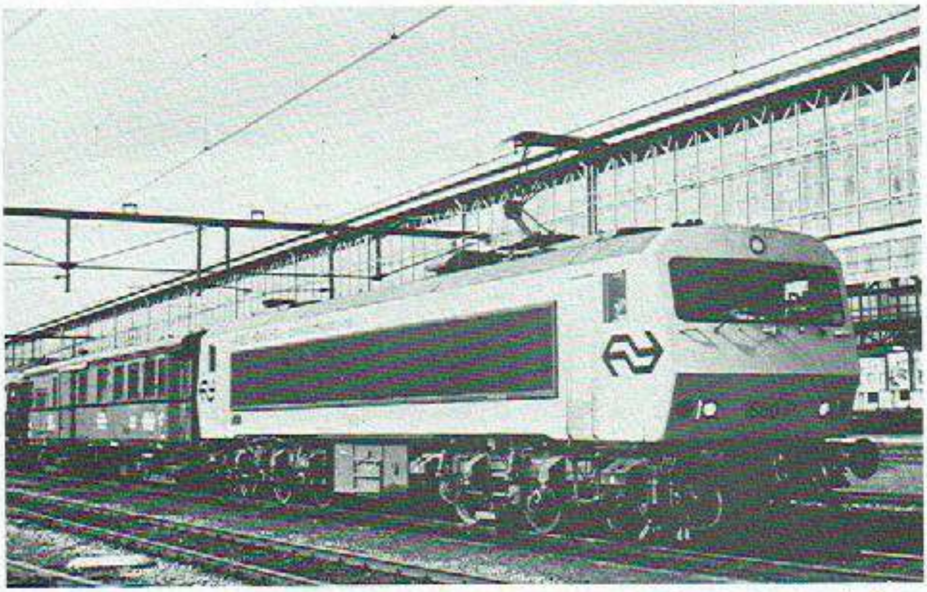

Fig. 20: *Experimental locomotive class 1600 P for Netherland State Railways.*

one-quadrant-controller (step-up chopper) was connected in series between the line and the motor inverter. It increases and regulates the voltage of the dc-link in the driving and the braking mode and controls the reactions to the line. The very low limits set for the harmoncis have been achieved.

The wheel arrangements of this experimental locomotive in connection with the high power motor made it especially apt to perform tests about the use of the available adhesion. The very detailed measurements brought new and essential understanding to this problem.

First orders

In parallel to the development of the locomotive E 120 the new technique brought in its first commercial successes:

- Swiss Federal Railways (SBB) ordered six diesel-electric locomotives with three-phase drive, class Am 6/6 (Fig. 21);

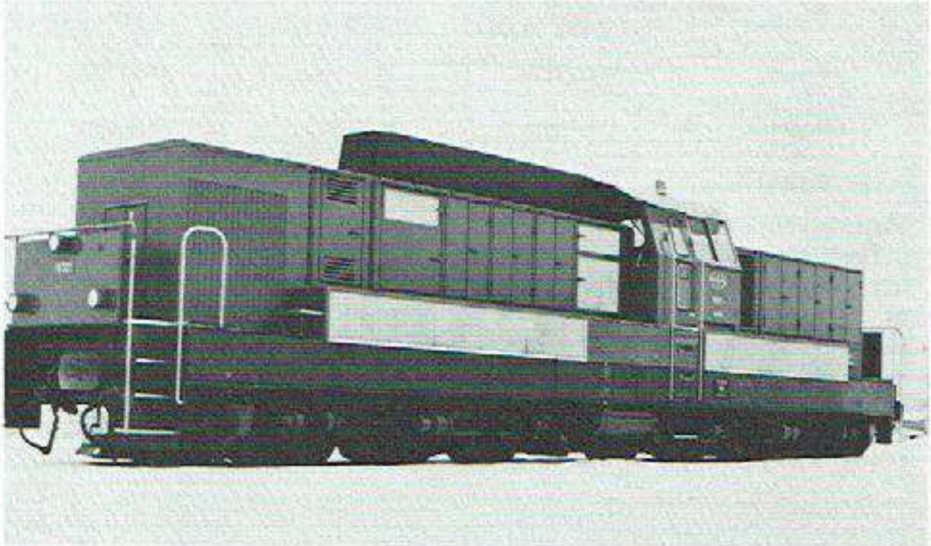

Fig. 21: *Diesel-electric locomotive class AM 6/6 for Swiss Federal Railways.*

- After extensive trials with DE 2500 locomotives in their respective rail networks, the Mine Railway and Port Installations Ruhr-Mitte of the Ruhr Coal Ltd. (Ruhrkohle AG = RAG) ordered six electric dual-frequency heavy industrial locomotives class E 1200 (Fig. 22) and Railways and Ports (Eisenbahn und Hafen = EH) ordered six electro-diesel bi-mode heavy industrial locomotives class EDE 1000/500 (Fig. 24), in the year 1975.

These were the first commercial orders and established for the new power transmission system a foothold in the market. The traction equipment for all those vehicles was the same (type DE 2500), whereas the power supplies were completely different.

The E 1200 are supplied from a 15 kV, 16 2/3 Hz or 50 Hz catenary (Fig. 23). The EDE 1000/500 are alternatively powered from a 600 V catenary or (at half power) by its built-in-diesel-engine with generator (Fig. 25).

These vehicles prove again the high flexibility of the chosen converter system with respect to different power supplies, always using the same three-phase drive system. In a schematic overview, Fig. 26 shows the variety of possibilities.

Fig. 22: *Commissioning of dual-mode electric locomotive E 1200.*

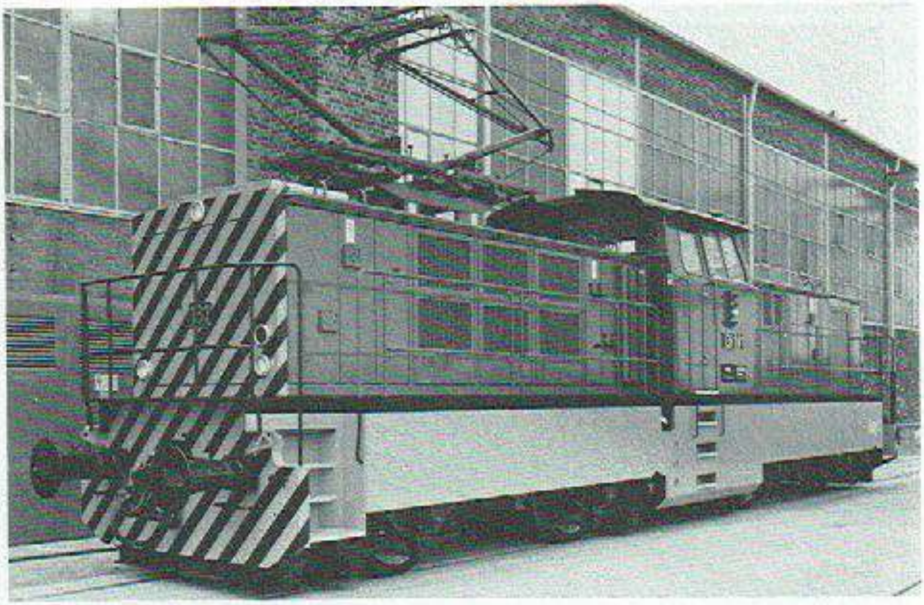

Fig 24: *Electro-diesel bi-mode locomotive EDE 1000/5000.*

Break-Through

With the first commercial orders, the ice was broken. In short intervals further railway authorities and industrial customers convinced themselves of the advantages of the new drive system and purchased locomotives with three-phase traction equipment.

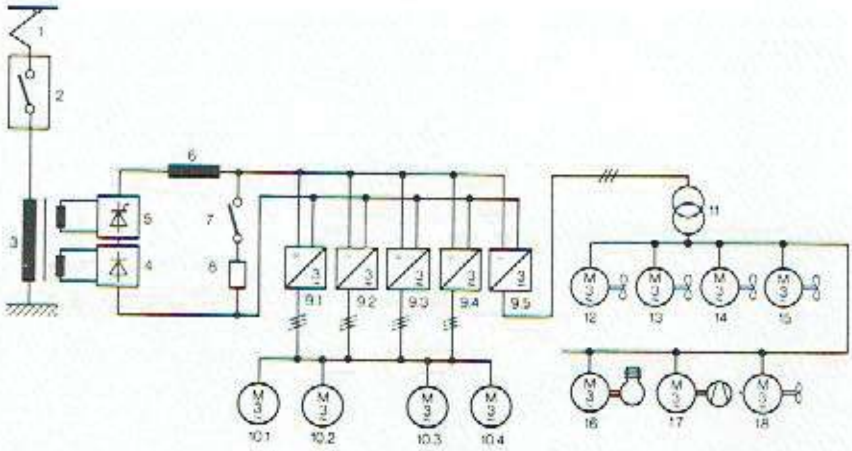

Fig. 23: *Circuit diagram of the E 1200. 1) Pantograph; 2)* Circuit breaker; *3) Main transformer; 4) Rectifier bridge; 5) Semi-controlled rectifier bridge; 6) Smoothing choke; 7) Braking contactor; 8) Braking resistor; 9.1 to 9.4) Traction inverter; 9.5) Auxiliary inverter; 10.1 to 10.4) Asynchronous traction motor; 11) Auxiliary transformer; 12) Blower for rectifier; 13) Blower for inverter; 14) Blower for inverter; 15) Blower for traction motors; 16) Air compressor; 17) Oil pump for transformer; 18) Blower for transformer oil cooler.*

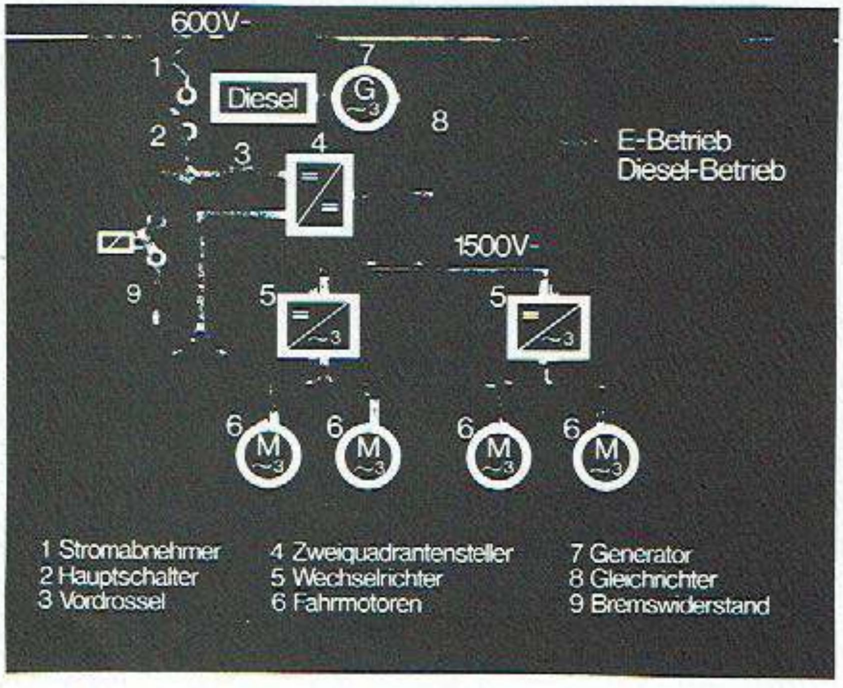

Fig. 25: *Circuit diagram of the EDE 1000/5000. 1) Current-Collector; 2) Main Circuit Breaker; 3) Choke; 4) Two-Quadrant Controller; 5) Inverter; 6) Drive motors; 7) Generator; 8) Rectifier; 9) Braking Resistor. E-Betrieb = Electric Operation. Diesel Betrieb = Diesel Operation.*

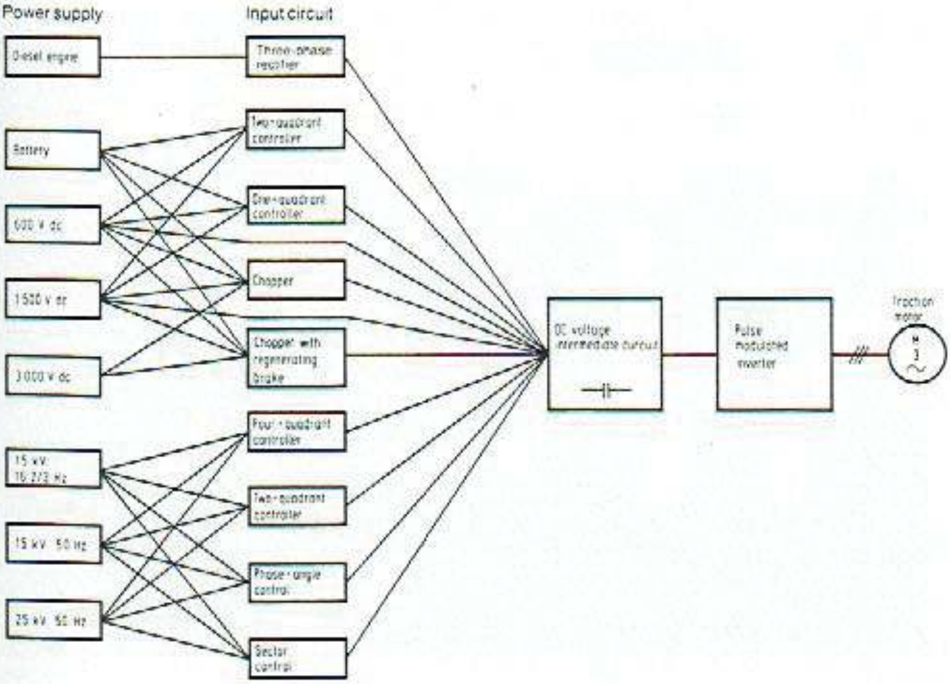

Fig. 26: *Possibilities of power supplies and input circuits to supply the dc voltage intermediate circuit.*

Fig. 27: *Diesel-electric locomotive with three-phase drive class ME for Danish State Railways and class Di 4 for Norwegian State Railways.*

Table 2: *Main specifications of locomotives equipped with BBC three-phase drives.*

Power supply	Diesel engine								
Manufacturer	ThH	ThH/SLM	ThH	ThH/ Scandia	O&K	Krupp-MaK	KM	Krupp-MaK	TIBB
Railway	Prototype (DB)	SBB	NSB	DSB	div.	div.	div.	div.	FS
Type	DE 2500	Am6/6	Di 4	ME	MEC 502	DE 501	ME 05	DE 1002	D 145
Wheel arrangement	Bo'Bo' Co'Co'	Co'Co'	Co'Co'	Co'Co'	Co	Co	Co	Bo'Bo'	Bo'Bo'
Power ... kW	1,840	1,640	2,430 (2,800)	2,430	500	500	500	1,000	850
Maximum speed ... km/h	140	85	140	160	40	40(80)	40	90	100
Weight in running order ... t	80	111	108	112	max. 75	max. 75	max. 75	88	70
Starting effort ... kN	270	400	360	360	300	250	250	330	250
Dynamic brake	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electric train heating plant	yes	yes	yes	yes	—	—	—	possible	—

Power supply	16⅔ Hz 15 kV		50 Hz 25kV	16⅔ and 50Hz	16⅔ Hz 15 kV		600 V = and Diesel engine	600 V =	600 V = and Battery
Manufacturer	ThH/Krupp/ K M	ThH	BBC in coop with Siemens, ThH, Scandia	ThH	SLM	SGP	ThH	VOEST	ThH
Railway	DB	NSB	DSB	ZuH	SBB	ÖBB	EH	VOEST	RAG
Type	E 120	EL 17	EA 3000	E 1200	Ee 6/6	1063	EDE 1000/5000	E 250	ET 300 (Sch)
Wheel arrangement	Bo'Bo'	Bo'Bo'	Bo'Bo'	Bo'Bo'	Co'Co'	Bo'Bo'	Bo'Bo'	Bo	Bo
Power ... kW	5,600	3,400	4,000	1,500	1,000	1,520	1,000/473	250	300
Maximum speed ... km/h	160(200)	140	175	60	85	80	40	30	40
Weight in running order ... t	84	64	80	88	105	75.5	100	34	30
Starting effort ... kN	340	240	260	340	355	260	400	90	64
Dynamic brake	yes	yes	yes	yes	yes	yes	yes	yes	yes
Electric train heating plant	yes	yes	yes	—	—	—	—	—	—

The most important among these orders are:

- Thirty diesel-electric locomotives of class ME for the Danish State Railways (DSB) and 5 of class Di4 for Norwegian State Railways (NSB) (Fig. 27);
- six electric locomotives class Ee 6/6 for the SBB;
- six of class E1 17 for NSB.

Fig. 28: *Shunting locomotive De 501 with BBC three-phase drive.*

Table 2 lists the main characteristics of locomotives equipped with BBC three-phase traction drives.

Another important field of interest for the new technique was the application to shunting locomotives in the range of 500 kW. There, three-phase drives proved especially advantageous compared with drives using hydraulic trasmissions or conventional electric system (Fig. 28). Comparative measurements performed by customers quantified the advantages regarding energy consumption and use of adhesion (admissible loads). Further developments profitted from the progress in power semi-conductors and microelectronics made during the last few years and resulted in another essential volume and weight reduction of the electrical equipment.

At this time (summer 1982) more than 200 vehicles equipped with three-phase drives have either been delivered or are on order. Fig. 29 shows the accumulated values of traction power delivered by BBC versus time, since the start of the three-phase drive development. It is the typical shape for the introduction of a new product: an introduction period at low level turns—in the case of success—into a curve with steep rise.

Outlook

The story of the development and spreading of three-phase traction drive continues.

Quite recently, the Danish State Railways (DSB) decided to purchase electric locomotives, class EA 3000 with three-phase drives, within the frame of the electrification of their network. Norwegian State Railways (NSB) are equipping their new diesel-electric railcars class BM92 with three-phase drives. These orders prove that customers which are already operating locomotives with three-phase drives are satisfied with this equipment.

New technologies, especially in connection with power semi-conductors and their triggering pricipals, cooling methods, microcomputers, etc. will further promote ingenuity and engagement of engineers. As the development of the three-phase traction became only possible after certain components were available, the succesful development of the three-phase traction drive in turn will give new impulses to related technical fields (e.g. the components). However, the first and perhaps the most important chapter of the story has been written.

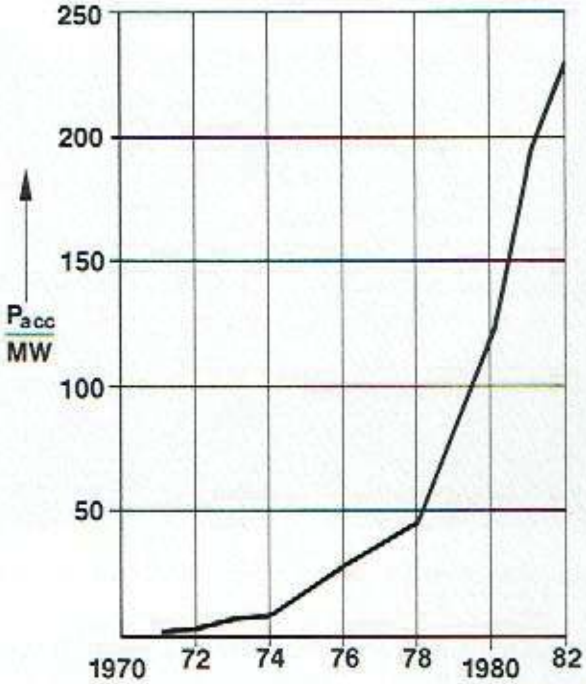

Fig. 29: *Accumulated power of three-phase traction drives delivered by BBC.*

Jörg Brenneisen

Brenneisen was born in Mannheim, Germany in May, 1940. He studied Electrical Engineering at the Technical University of Karlsruhe obtaining a degree as Dipl. Ing. with first class honors.

He joined Brown, Boveri & Cie. AG, Mannheim, where he started his work in the Central Development Department for Power Electronic Systems dealing first with inverters for uninterruptible power supplies and three-phase motor drives, since 1968 focusing on traction applications. In 1973 he became head of the Development Department in the Transportation Systems Division. Since 1977 he is Project Manager for Coach Equipment.

Mr. Brenneisen holds several patents and has authored numerous papers dealing mostly with power electronics. He is member of VDE and DMG.

Ehrhard Futterlieb

Futterlieb was born in Königsberg, Germany in December, 1940. He studied Electrical Engineering at the University of Hannover obtaining a degree as Dipl. Ing. in 1967.

In 1968 he joined the Central Development Department for Power Electronic Systems of Brown, Boveri & Cie. AG, Mannheim. Since that time—now as group leader—he has been engaged in a broad range of development work of converters (power and control systems) for different applications, but in the major part for three-phase traction drives.

Mr. Futterlieb holds several patents.

Joachim Körber

Korber was born in Potsdam, Germany in January, 1940. He studied Electrical Engineering at the Technical University of Aachen, obtaining a degree as Dipl. Ing. in 1965.

He joined the Transportation Systems Division of Brown, Boveri & Cie. AG, Mannheim, where he started work with the design of electrical equipment for railcars. Following activities were studies in railway systems engineering including unconventional propulsion systems, e.g. maglev vehicles, then responsibility for design and marketing of equipment for electric locomotives. Since 1979 he has been Manager, Subdivision Electric Locomotives and Multiple Units. It was in 1972 under his project management that the development work started on the application of the three-phase traction system also for line-fed electric locomotives, culminating in the building of the five high-power universal type locomotives E 120.

Mr. Körber is member of various committees of experts and of VDE and DMG.

Edmond Müller

Müller was born in Bruhl, Köln, Germany in February, 1935. He studied Electrical Engineering at the Staatliche Ingenieurschule Köln obtaining a degree as Ing. grad. in 1959.

He joined Brown, Boveri & Cie. AG, Mannheim, where he started work with the development of electrical control systems for various applications. Since 1963 he specialized in the Central Development Department for Power Electronic Systems on control systems for converters, later mostly related to three-phase traction drives. In 1970 he was appointed Oberingenieur. Since 1979 Mr. Muuller has been Project Manager, Diesel and Industrial Locomotives in the Transportation Systems Division.

Mr. Müller holds numerous patents. He is member of VDE and DMG.

G. Reiner Nill

G. Reiner Nill was born in Berlin, Germany on 14th May, 1940. He received a degree as Dipl Ing in electrical engineering from Stuttgart University in November, 1966.

He joined Brown, Boveri & Cie, Mannheim in their development department for transport. From 1969 he ran the group for power electronics in this department until 1980 when he emigrated to New Zealand.

Nill is now working with N.Z. Forest Products Limited. In 1981 he became a registered professional engineer of New Zealand and a member of the N.Z. Institution of Engineers.

During his employment with BBC he was involved with the development of main drives and auxiliary equipment for a wide range of vehicles. His major work concerned locomotives with asynchronous motors and its supply from AC and DC overhead wires. He holds four patents in the field of power electronics.

Manfred Schulz

Schulz was born in Berlin, Germany in October, 1940. He studied Electrical Engineering at the Fachakademie Beuth, Berlin obtaining a degree as Ing. grad. in 1963.

He joined the Radio and TV Station of Berlin, where he was engaged with video measurement, service and development questions. In 1966 he joined the Central Development Department for Power Electronic Systems of Brown, Boveri & Cie. AG, Mannheim, where he was involved in the development of inverters for uninterruptible power supplies and for motor drives. Since 1972 he has headed a technical group in the Transportation Systems Division concerned with the design of electrical and electronic equipment for diesel and industrial locomotives, mainly with three-phase propulsion systems.

Mr. Schulz holds several patents.

Herbert Stemmler

Stemmler was born in March, 1935 in Speyer am Rhein (Federal Republic of Germany). He attended the Naturwissenschaftliche Gymnasium in Ludwigshafen, where he graduated in 1955. He subsequently studied electrical engineering at the Technical University in Darmstadt specializing in control systems and was awarded his diploma in 1961.

In the same year he accepted a post as development engineer in the drives and control systems department of Brown, Boveri & Co. Ltd., Baden, Switzerland. From 1967 to 1970 he was in charge of the converter systems group.

In 1970 he submitted his thesis on "Methods of controling single-pulse and multipulse modulated inverters for supplying squirrel-cage motors" to the Technical University in Aachen. In the same year he entered the development department for control and power electronics as deputy manager. Dr. Stemmler was appointed head of this department in 1971.

Werner Teich

Teich was born in East Prussia, Germany in December, 1932. He studied in Tilsit (now U.S.S.R.) and the East German towns of Schwerin, Erfurt and Dresden. Subsequently in 1954 he took special training for the technical service of the East German Railway. In 1956 he joined the Transportation Systems of Brown, Boveri & Cie. AG, Mannheim. In 1961 he became Project Manager for Diesel and Gas Turbine Traction. Since 1979 he became Manager Subdivision Diesel and Industrial Locomotives and Coach Equipment.

The development of the inverter-fed induction type traction motor drive for diesel vehicles started under his leadership in 1965. W. Teich has illustrated as well as defended this revolutionary propulsion technique in many publications and congresses inside and abroad. Under his responsibility a modular three-phase traction system was designed, which made the realization of each performance class possible withn the range from 250 kW to 3.000 kW. Further outputs of his activities include publications in the field of control equipment for diesel vehicles, of DC traction equipment for railway application, and of automaticallay controlled pit railway system.

Teich is member of several committees of experts, and of VDE and DMG.

Previous Elmer A. Sperry Awards

1955 to *William Francis Gibbs* and his Associates for development of the S.S. United States.

1956 to *Donald W. Douglas* and his Associates for the DC series of air transport planes.

1957 to *Harold L. Hamilton, Richard M. Dilworth* and *Eugene W. Kettering* and Citation to their Associates for the diesel-electric locomotive.

1958 to *Ferdinand Porsche* (in memoriam) and *Heinz Nordhoff* and Citation to their Associates for development of the Volkswagen automobile.

1959 to *Sir Geoffrey De Havilland, Major Frank B. Halford* (in memoriam) and *Charles C. Walker* and Citation to their Associates for the first jet-powered aircraft and engines.

1960 to *Frederick Darcy Braddon* and Citation to the Engineering Department of the Marine Division, *Sperry Gyroscope Company,* for the three-axis gyroscopic navigational reference.

1961 to *Robert Gilmore Letourneau* and Citation to the Research and Development Division, *Firestone Tire and Rubber Company,* for high speed, large capacity, earth moving equipment and giant size tires.

1962 to *Lloyd J. Hibbard* for application of the ingitron rectifier to railroad motive power.

1963 to *Earl A. Thompson* and Citation to his Associates for design and development of the first notably successful automobile transmission.

1964 to *Igor Sikorsky* and *Michael E. Gluhareff* and Citation to the Engineering Department of the Sikorsky Aircraft Division, *United Aircraft Corporation,* for the invention and development of the high-lift helicopter leading to the Skycrane.

1965 to *Maynard L. Pennell, Richard L. Rouzie, John E. Steiner, William H. Cook* and *Richard L. Loesch, Jr.* and Citation to the Commercial Airplane Division, *The Boeing Company,* for the concept, design, development, production and practical application of the family of jet transports exemplified by the 707, 720, and 727.

1966 to *Hideo Shima, Matsutaro Fujii* and *Shigenari Oishi* and Citation to the *Japanese National Railways* for the design, development and construction of the New Tokaido Line with its many important advances in railroad transportation.

1967 to *Edward R. Dye* (in memoriam), *Hugh DeHaven* and *Robert A. Wolf* and Citation to the research engineers of *Cornell Aeronautical Laboratory* and the staff of the Crash Injury Research projects of the *Cornell University Medical College.*

1968 to *Christopher S. Cockerell* and *Richard Stanton-Jones* and Citation to the men and women of the *British Hovercraft Corporation* for the design, construction and application of a family of commercially useful Hovercraft.

1969 to *Douglas C. MacMillan, M. Neilsen* and *Edward L. Teale, Jr.* and Citations to Wilbert C. Gumprich and the organizations of *George G. Sharp, Inc., Babcock and Wilcox Company,* and the *New York Shipbuilding Corporation,* for the design and construction of the N.S. Savannah, the first nuclear ship with reactor, to be operated for commercial purposes.

1970 to *Charles Stark Draper* and Citations to the personnel of the *MIT Instrumentation Laboratories:* Delco Electronics Division, *General Motors Corporation,* and Aero Products Division, *Litton Systems,* for the successful application of inertial guidance systems to commercial air navigation.

1971 to *Sedgwick N. Wight* (in memoriam), and *George W. Baughman* and Citations to William D. Hailes, Lloyd V. Lewis, Clarence S. Snavely, Herbert A. Wallace, and the employees of *General Railway Signal Company*, and the Signal & Communications Division, *Westinghouse Air Brake Company*, for development of Centralized Traffic Control on railways.

1972 to *Leonard S. Hobbs* and *Perry W. Pratt* and the dedicated engineers of the Pratt & Whitney Aircraft Division of *United Aircraft Corporation* for the design and development of the JT-3 turbo jet engine.

1975 to *Jerome L. Goldman, Frank A. Nemec* and *James J. Henry* and Citations to the naval architects and marine engineers of *Friede and Goldman, Inc.*, and *Alfred W. Schwendtner* for revolutionizing marine cargo transport through the design and development of barge carrying general cargo vessels.

1977 to *Clifford L. Eastburg* and *Harley J. Urbach* and Citations to the Railroad Engineering Department of *The Timken Company* for the development, subsequent improvement, manufacture and application of tapered roller bearings for railroad and industrial uses.

1978 to *Robert Puiseux* and Citations to the employees of the *Manufacture Francais des Pneumatiques Michelin* for the design, development and application of the radial tire.

1979 to *Leslie J. Clark* for his contributions to the conceptualization and initial development of the sea transport of liquefied natural gas.

1980 to *William M. Allen, Malcolm T. Stamper, Joseph F. Sutter* and *Everette L. Webb* and Citations to the employees of *Boeing Commercial Airplane Company* for their leadership in the development, successful introduction and acceptance of wide-body jet aircraft for commercial service.

1981 to *Edward J. Wasp* for his contributions toward the development and application of long distance pipeline slurry transport of coal and other finely divided solid materials.