

Elektrische Bahnen

Railway Electrification

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Steffen Röhlig, Chief Editor

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eb – Elektrische Bahnen

interesting facts about the electric traction

Germany is the first country in which the electric traction was turning up: In 1879 ran in Berlin inside exhibition grounds the first electric railway of the world. In 1881 the first electrically operated tramway circulated in Lichterfelde, today a district of Berlin. In 1882, the world-wide first electrical colliery railway was put into operation in Freital near Dresden. The first motor for single-phase alternating current was developed in 1889 and in 1903 high-speed tests with a three-phase A.C. traction were undertaken on the military railway line Marienfelde-Zossen. Finally in 1905 the line Murnau – Oberammergau in Bavaria being the first line in Germany electrified with alternating current AC 5,5 kV 25 Hz was opened for the public transport.

It is fully justified to say that Germany is the mother country of the electric traction. Company names as AEG und Siemens are tightly linked to this history.

Therefore it is not astonishing, that already 112 years ago in 1903 the first edition of the magazine *Elektrische Bahnen* was published and since then follows and documents the development of the electric traction. No other magazine is dedicated with a comparable technical depth to the operation and the engineering of the electric railways. Over time a technical archive was built up which covers comprehensively themes of the branches electric power supply of railways including catenaries and the technology of rolling stock and secondary technologies, both for direct current and alternating current railways for short and long distance traffic. This archive helps to answer corresponding questions. For quite a lot of questions raised nowadays, at least partly answers can be found in older editions of the magazine. With this, the reporting is not limited to Germany. From the beginning, the reports on electrical traction covered the whole of Europe as well as America.

Today the world of rail looks somewhat different: meanwhile the biggest high speed networks with electric traction are located in China as well as the sub-urban networks in the mega-cities whose size



reaches or outpaces the rail systems of European urban cities or of New York. In a short period of time in these regions a development took place for which in the "old" railway countries much more time was needed. Nevertheless, China relied also on the European experiences and some of these connections are demonstrated in *eb*.

For subscribers, in the meantime a voluminous archive is available. At present, more than 60 annual volumes are accessible. This allows conducting extensive researches.

This edition is by this time the third edition purely in English. It contains translated articles, which were mostly published during the last year in the normal editions of the magazine *eb – Elektrische Bahnen*. By this, the articles become accessible to a bigger number of readers. The selection of subjects focuses on the AC railways for main line services.

Dr. Steffen Röhlig
Chief Editor



INT 2/ 2015

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**Railway
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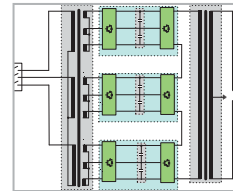
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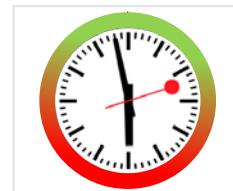
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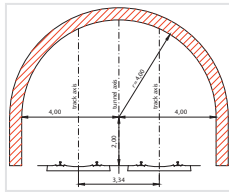
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Citybanan – new railway tunnel for the local traffic in Stockholm



Figure 1:
Suburban train on the railway bridge over the Söderström
(Photos: Röhlig).

Since 2009 a new railway tunnel is being built below Stockholm city centre (Sweden). This should relieve the chronically overloaded two-track line south of the main station Stockholms central and allow an increase in suburban traffic. The commissioning is planned for 2017.

The existing line between the stations Stockholms central (Stockholm C) and Stockholms södra is used by commuter trains (*Pendeltåg*), regional trains, inter-city and freight traffic and has reached its limits with a capacity of 24 trains per hour and direction (Figure 1). Disruptions on this section lead to delays in the entire Stockholm metropolis. To achieve a noticeable improvement to the offer especially in suburban traffic it was essential to build a new parallel line. On the basis of the inner city situation the only possible solution was a tunnel. The new tunnel will double the capacity for the railway traffic through Stockholm. Construction work has been completed and the tunnel is currently being equipped with railway technology.

The 6km long new underground line begins at the northern edge of Stockholm and branches off there from the northern approach to Stockholms C. The tunnel passes beneath the city centre to the east of the existing line then passes under this line south of Stockholms C below Riddarholmen. It then runs underground parallel to the existing line to the overground station Stockholms södra (Figure 2). The tunnel consists of a two-track tunnel tube blasted from the rock (Figure 3). Only beneath the Söderström between Riddarholmen and Söder Mälmarstrand the tracks run through a floating rectangular concrete tunnel (Figure 4). There is a service tunnel housing important safety and telecommunications technical equipment and other auxiliaries parallel to the railway tunnel (Figure 5).

Two stations have been built along the line: the two-track station Odenplan and the four-track station Stockholm City, which is very close to the station Stockholms C. There are also optimal possibilities to change to the crossing lines of the Metro (*T-Bana*) there.

The line in the tunnel is equipped with a conductor rail and for the reduction of magnetic fields, with a booster transformer system. The cable-wound booster transformers have been installed at a distance of around 500 m (Figure 6) and are directly connected to parallel running cables, which have been laid close together in a cable duct to minimise magnetic fields. The overhead line is directly connected to the booster feeder conductor at the booster transformer location. The booster return wire is connected with the tracks at the mid-point between the booster

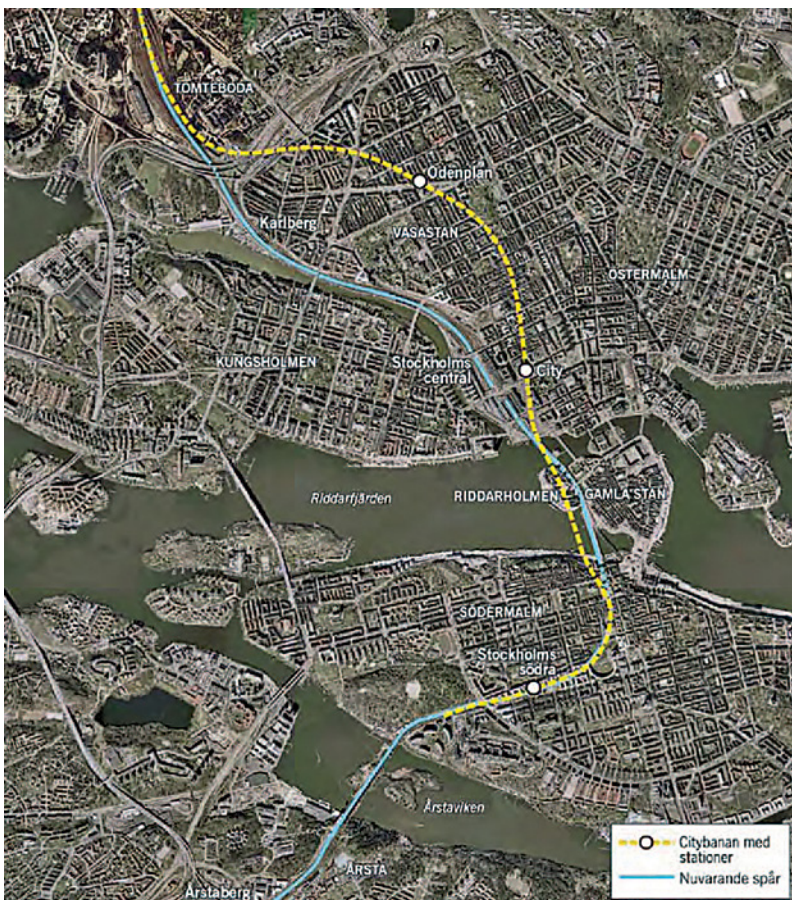


Figure 2:
Overview of the position of the new tunnel (yellow) and the existing line (blue) [1].

Electric Traction – Motive Power – Energy Supply – Steimel

The book intends to convey mechanical fundamentals of electric railway propulsion, which includes rail-bound guidance, transmission of traction effort from wheel to rail under the influence of non-constant levels of adhesion and the transmission of motor torque to a spring-mounted and thus swaying drive wheelset.

The focal point of the book will be the disposition of electric traction units powered by three-phase induction motors. We shall discuss the stationary and dynamical behaviour of the squirrel-cage induction motors and the principle and construction features of pulse-controlled inverters, as well as scalar and field-oriented control systems and four-quadrant power converters, feeding the DC link of the inverters.

As is appropriate to the lesser importance these drive systems have nowadays, we will consider DC and AC commutator motors only in a cursory fashion, as well as their voltage control.

Editor: *Andreas Steimel*

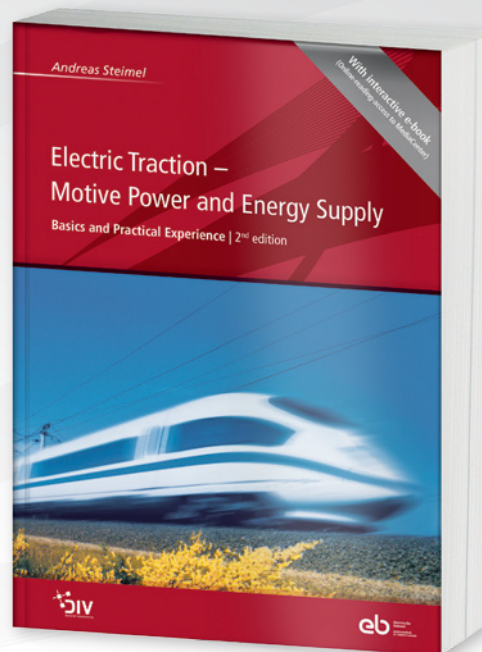
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Railway converters from Europe for the railways worldwide

Two companies in Germany and one in Switzerland supply frequency converters for railways in Europe and the USA and now also phase converters for railways in Australia.

On the 2AC high-voltage networks of DB, ÖBB, SBB and RhB – connected either directly or via coupling transformers – rotating machines will continue to stabilise the network in the traditional way with their rotating mass for several decades. Along with the turbo generators mentioned in [1] in Mannheim, Kirchmöser and Schkopau a 110MW machine in Lünen power station also works on the network (Figure 1). The machines of the railway hydro power stations in southern Germany, Austria and Switzerland are particularly long-lasting; several stand a good chance of reaching one hundred years of service and in Ticino they even gain in number (page 264 in *eb* 5/2015). As power electronics has replaced the traditional complicated slip-frequency control with auxiliaries, rotating transformers and other oddities in the rotor circuit of the asynchronous machines, moving-coil converters will also continue to be in existence for years to come. 7% to 9% of the converter apparent power was to be installed as apparent power of these control converters.

Further power increases will come by static frequency conversion from the 3AC national grid, partly as transmission of energy which already belongs to the railway. The development and introduction of this technology started 45 years ago in Scandinavia, where the railway 2AC networks were not allowed to develop from their first beginnings and the railway lines were therefore to be supplied using a decentralised structure. The Swedish company ASEA and their successor ABB thereby took on a pioneering role. Also in the USA several such systems for the conversion of 3AC 60Hz into 2AC 25Hz – most of which were supplied from Europe – already came into being in the 20th century.



Figure 1: Lünen coal power station of STEAG, view from the northwest (Photo: STEAG).

Two decades ago the status at the time was reported in this magazine, i.e. after the first 25 years (Figure 2) [2]. This should now be continued here for the following twenty years. In Table 1 the national subsidiaries are not differentiated, the converter suppliers are named rather than the system constructors such as Adtranz until 2000 and Balfour Beatty today.

Tabelle 1: Liste der weltweit installierten und geordneten Bahnstromrichteranlagen.

Jahr	Besteller	Land	Ort	Typ	Zahl und Leistung in MVA	Lieferant
1972	SJ	S	Moholm/Hagalund	DU	1 × 6,0 = 6,0	ASEA
1976	SJ	S	Hallsberg	DU	2 × 15,7 = 31,4	ASEA
1978	SJ	S	Moholm	DU	2 × 15,7 = 31,4	ASEA
1979	SJ	S	Nässjö	DU	2 × 15,7 = 31,4	ASEA
1981	SJ	S	Eksund	DU	2 × 15,7 = 31,4	ASEA
1983	SJ	S	Malmö	DU	2 × 15,7 = 31,4	ASEA
1984	SJ	S	Ånge	ZKU (Thyr.)	3 × 8,2 = 24,6	ASEA
1985	SEPTA	USA	Wayne Junction	DU	1 × 16,5 = 16,5	ASEA
1986	SJ	S	Åstorp	ZKU (Thyr.)	3 × 8,2 = 24,6	ASEA
1988	SJ	S	Ockelbo	DU	3 × 13,2 = 39,6	ABB
1988	SJ	S	Älvsjö	DU	3 × 15,7 = 47,1	ABB
1990	SEPTA	USA	Wayne Junction	DU	2 × 16,5 = 33,0	ABB
1990	Banverket	S	Mellansel	ZKU (GTO)	3 × 14,0 = 42,0	ABB
1991	Banverket	S	Erweiterung Nässjö	ZKU (GTO)	1 × 14,0 = 14,0	ABB
1991	Banverket	S	Alingsås	ZKU (GTO)	2 × 14,0 = 28,0	ABB
1991	Banverket	S	Erweiterung Ånge	ZKU (GTO)	1 × 14,0 = 14,0	ABB
1992	BG&E	USA	Baltimore	DU	2 × 11,0 = 22,0	GE
1992	Banverket	S	Järna	ZKU (GTO)	3 × 14,0 = 42,0	ABB
1993	NSB	N	Sarpsborg	ZKU (GTO)	2 × 14,0 = 28,0	ABB
1994	SBB	CH	Giubiasco	ZKU (GTO)	2 × 25,0 = 50,0	ABB
1994	Banverket	S	Hässleholm	ZKU (GTO)	2 × 15,0 = 30,0	ABB
1994	DR/DB	D	Muldenstein	ZKU (2 × GTO)	1 × 15,0 = 15,0	Siemens
1995	Banverket	S	Erweiterung Älvsjö	ZKU (GTO)	1 × 14,0 = 14,0	ABB
1995	AMTRAK	USA	Sunnyside Yard	ZKU (GTO)	4 × 12,0 = 48,0	ABB
1995	DB	D	Jübek	ZKU (2 × GTO)	1 × 15,0 = 15,0	AEG
1996	Stadtwerke	D	Bremen	ZKU (GTO)	1 × 91,0 = 91,0	ABB
1996	Banverket	S	Erweiterung Malmö	ZKU (GTO)	1 × 15,0 = 15,0	ABB
1996	Banverket	S	Eldsbirga	ZKU (GTO)	2 × 15,0 = 30,0	ABB

Jahr Betriebsbeginn, ab 1996 voraussichtlich
 Thyr. Thyristor-Stromrichter an beiden Netzen, am 1 AC-Netz Zwangskommütierung
 GTO Thyristor-Stromrichter am 3 AC-Netz, GTO-Stromrichter am 1 AC-Netz
 2 × GTO GTO-Stromrichter an beiden Netzen
 DU Direktumrichter ZKU Zwischenkreisumrichter
 SEPTA Southeastern Pennsylvania Transportation Authority
 BG & E Baltimore Gas & Electricity

Figure 2: Static frequency converter for railways from 1972 to 1996 (Table 1 in [2]).

Static frequency converters – world’s first application for 50 Hz/50 Hz

Igor Perin, Simon Matthews-Frederick, Peter F. Nussey, Geoffrey R. Walker, Brisbane (AU)

Static Frequency Converter (SFC) technology has the capability to reduce the single phase AC railway network impact on power quality and improve the supply utilization and hence generally reduce the overall costs of railway electrification. Aurizon, Australia’s largest heavy haul railway operator, has commissioned the world’s first 50Hz/50Hz SFC installation as part of the *Bauhinia* Electrification project.

STATISCHE FREQUENZUMRICHTER – ERSTE ANWENDUNG FÜR 50 HZ/50 HZ WELTWEIT

Die Technologie der Statischen Frequenzumrichter (SFC) ermöglicht es, die Auswirkungen des einphasigen Wechselstrombahnnetzes auf das gesamte AC Netz zu reduzieren und damit die Versorgung zu verbessern sowie die Gesamtkosten der Bahn-Elektrifizierung zu reduzieren. Aurizon, Australiens größter Schwerlast-Bahnbetreiber, hat die erste 50Hz/50Hz SFC-Anlage der Welt bestellt als Teil des *Bauhinia* Elektrifizierungsprojektes.

CONVERTISSEURS STATIQUES DE FRÉQUENCE – PREMIÈRE APPLICATION POUR 50 HZ/50 HZ À L’ÉCHELLE MONDIALE

La technologie des convertisseurs statiques de fréquence (SFC) permet de réduire l’impact du réseau électrique monophasé du chemin de fer sur le réseau triphasé général. Ceci contribue à une amélioration de l’alimentation et en plus à une réduction du coût total de l’électrification du chemin de fer. Aurizon, l’opérateur le plus important en Australie pour du trafic lourd, a commandé l’installation d’un convertisseur 50Hz/50Hz SFC qui est le premier du monde et forme une partie du projet d’électrification *Bauhinia*.

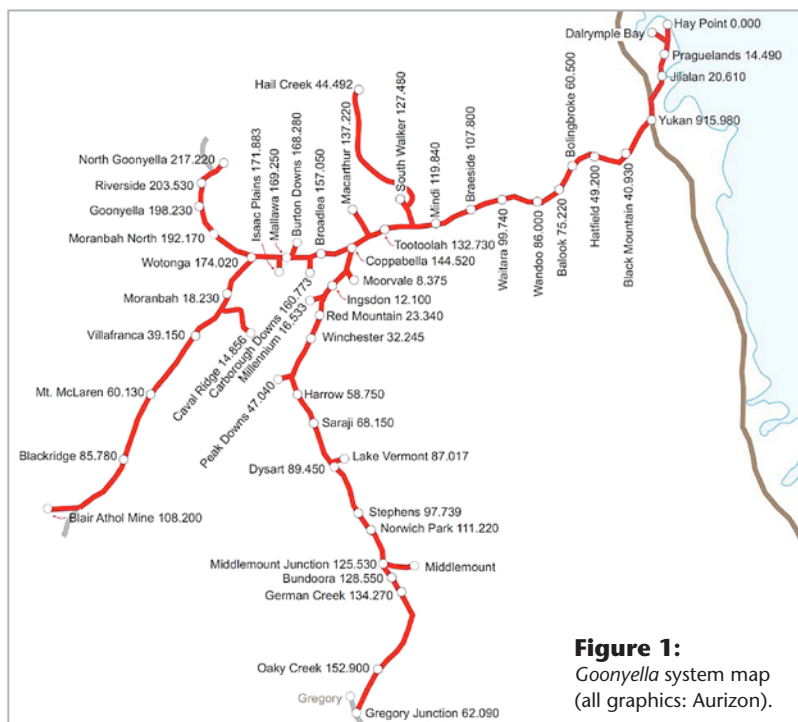


Figure 1: Goonyella system map (all graphics: Aurizon).

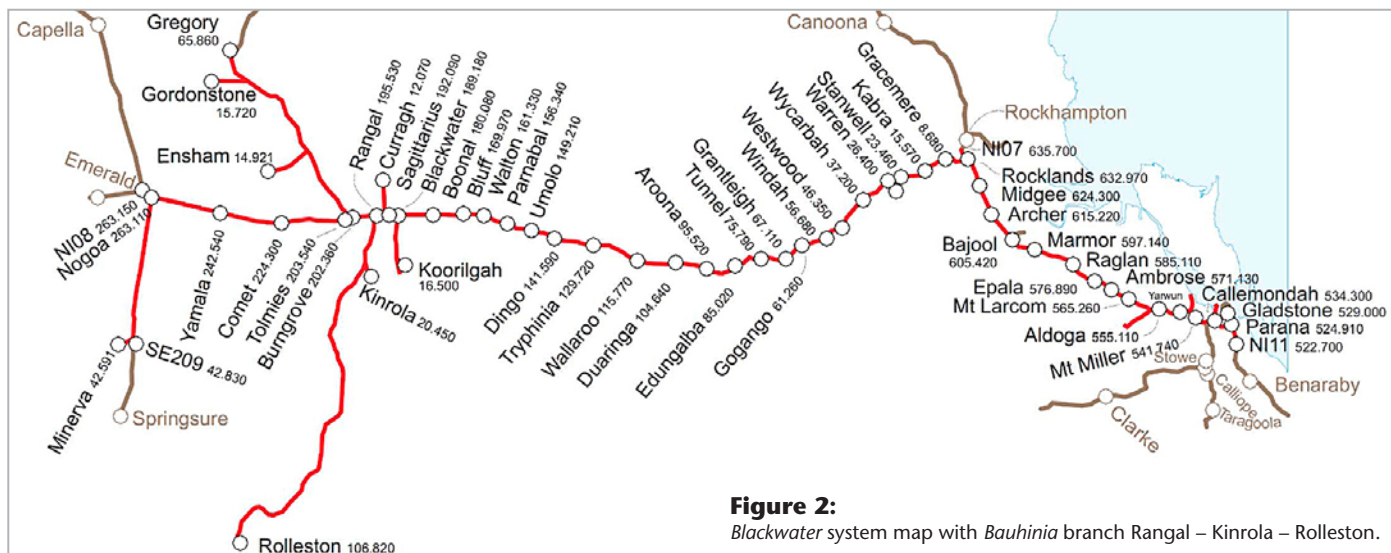


Figure 2: Blackwater system map with Bauhinia branch Rangal – Kinrola – Rolleston.



Figure 3: Electric locomotives 3800 class (Photo: Siemens).

1 Introduction

1.1 Aurizon’s electric rail system

The Queensland heavy haul railway system at 1 067 mm gauge was electrified during the 1980s, using an AC 50 kV/25 kV auto transformer (AT) traction overhead line (OHL) system with locomotives operating at 1 AC 25 kV 50 Hz [1]. The electric railway system is today owned and operated by *Aurizon Network Pty Ltd* and consists of two networks: *Goonyella* and *Blackwater* [2; 3]. Both networks are located in Central Queensland, servicing the *Bowen Basin* coal region and linked at *Gregory Junction*. The *Goonyella* system delivers coal to the *Hay Point* and *Dalrymple Bay* coal terminals, while the *Blackwater* system links coal mines with the Port of Gladstone (Figures 1 and 2).

Aurizon’s electric rail network is conventionally supplied via feeder stations (FS), located at approximately 30 km to 60 km intervals alongside the rail corridor. The electric power is provided by two

Queensland’s network authorities, i.e. *Powerlink* for transmission at 275 kV or 132 kV and *Ergon Energy* for distribution at 132 kV. Power is distributed via single phase 132 kV/50 kV power transformers to the 50 kV traction network and transmitted using 50 kV overhead and feeder lines. Track sectioning yard (TSY) are connected in between FS to facilitate sectioning (Figure 3).

1.2 Aurizon’s heavy haul traction modes

Two classes of Bo’Bo’Bo’ electric locomotives are used in Aurizon’s system: older generation 3500 class and modern 3700/3800 class (Table 1, Figure 3). The 3500 class is thyristor controlled and a source of significant harmonic distortion and reactive power. The new generation is equipped with 3AC drives at IGBT converter components and has a considerably reduced harmonic injection spectrum as well as power factor controlled nearly at unity [4].

TABLE 1

Aurizon’s locomotives for heavy haul coal transport.

3500, 3700 and 3800 electric, 4000 Diesel

Class		3500	¹ 3700	3800	4000
in service		1986–1989	2003–2007	2007–2010	1999–2005
Wheel arrangement		Bo’Bo’Bo’	Bo’Bo’Bo’	Bo’Bo’Bo’	Co’Co’
Weight	t	110	126	132	120
max. tractive effort	kN	375	500	525	460
power ²	kW	2890	4000	4000	2460
max. speed	km/h	80	80	80	100

¹ using refurbished bodies of former 3100/3200 class, first QR’s electric locomotives in the 1980s

² electric at wheel rim, Diesel at engine shaft

Traction power converters 50 Hz / 50 Hz

Axel Brandt; Christoph Saniter; Jörg Janning; Ivan Mikes, Berlin (DE)

For electrical power supply of a heavy freight line in Queensland (Australia) two static frequency converters (SFC) are used and in operation since December 2014. These are voltage source converters based on IGBT technology. This is the first time that power electronic converters are employed to feed a 50 Hz electric railway. In this case, they couple a three-phase 132 kV 50 Hz grid with a single-phase ± 25 kV 50 Hz railway line network.

BAHNENERGIEUMRICHTER 50 Hz / 50 Hz

Für die elektrische Versorgung einer Eisenbahnstrecke mit schwerem Güterverkehr in Zentral-Queensland (Australien) werden zwei statische Umrichter eingesetzt, die seit Dezember 2014 in Betrieb sind. Dabei handelt es sich um Spannungszwischenkreisumrichter in IGBT-Technik. Erstmals wird damit die Leistungselektronik dafür benutzt, ein Drehstromnetz 132 kV 50 Hz mit einem Einphasenbahnnetz ± 25 kV 50 Hz zu koppeln.

CONVERTISSEURS 50 Hz / 50 Hz POUR LA TRACTION ÉLECTRIQUE

Pour l'alimentation électrique d'une ligne ferroviaire de trafic marchandises pondéreuses en Queensland/Australie ont été mis en service en Décembre 2014 deux convertisseurs statiques. Il y s'agit de convertisseurs de source de tension réalisés en technique IGBT. C'est la première fois que l'électronique de puissance est utilisée pour coupler un réseau triphasé 132 kV 50 Hz à un réseau monophasé ferroviaire ± 25 kV 50 Hz.

1 Introduction

The first traction power converter in regular service was supplied by AEG for the Wiesentalbahn near Basel in Germany. That converter supplied the single-phase railway grid at a frequency of 15 Hz out of a 50 Hz three-phase grid and went on stream in 1936 [1]. At that time, the converter ensured sufficient voltage quality (Figure 1).

Converter technology could not yet reached maturity, and for many decades the single-phase catenary voltage was either generated by rotating machines or, in countries with identical grid frequencies, by section-wise supply from the three-phase grid. In case of new 16,7 Hz installations, power electronic converters have replaced rotating converters completely. Key factors are the significantly higher

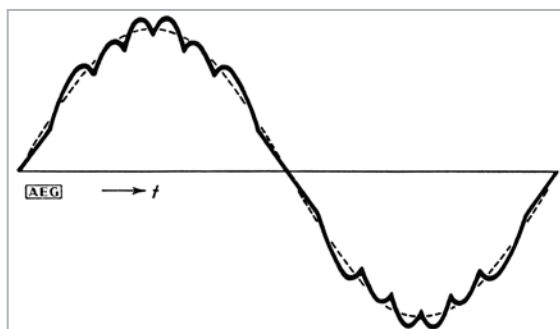


Figure 1: Output voltage of the seven-anode converter of the Wiesentalbahn.

efficiency, lower maintenance costs and, above all, lower investments.

Today, power electronics have become an alternative for 50 Hz traction power supply as well. The advantages of the static frequency converter (SFC) solution become obvious in the overall system design despite the higher investment costs of the converter installation when compared with the standard transformer solution. In 2014, General Electric (GE) commissioned the first static frequency converter station for a 50 Hz rail system fed from a 50 Hz three-phase utility grid.

2 Advantages of the converter solution

Main advantage of the SFC solution is the almost complete decoupling of the two grids, the railway grid and the three-phase distribution network. This allows for the three-phase grid to be loaded symmetrically and provided with any reactive power independently of the reactive power in the single-phase rail grid. The effect of the harmonics distortions of the single-phase current (highly variable train load) is also limited owing to a DC link coupling in SFC. In that way, large filters or static VAR compensators are not required.

Symmetrical loading also enables supply from a high-voltage grid with low short-circuit power, or from a distribution grid with lower voltage level (even medium voltage networks are possible). Con-

sequently, the switchgear is significantly cheaper and the variety of possible connection points is much higher (especially in the urban areas this may be the only option). In comparison of the cost, despite of the higher cost of the SFC system the savings on the switchgear and on the connection to a high-voltage grid could already mean that the SFC solution is a better economical choice. Additional savings can be achieved in terms of operating costs. This is because utilities are increasingly favoring symmetrical loads through lower energy prices whilst penalizing asymmetrical consumption. Thanks to these savings during operation, the investment in a traction power converter can pay off within a short time.

In addition the SFC technology enables a controlled recuperation back to the three-phase network as well as improves the consumption of the regenerated energy within the rail network itself. It appears that using the regenerative braking could save between 10% and 20% of the traction energy used [2].

At the railway grid end, the advantages of an SFC solution apply to both, the design of the overhead line as well as to the train operation. As the single-phase rail voltage is decoupled it can be synchronized to any frequency and voltage level. This means that comparing to standard transformer solution no phase change is needed. As a result the SFC solution creates consistent energy supply network without disconnection points and neutral sections. With the SFC system the overhead line system can also be fed from both sides between feeder stations. Feeding an overhead line section from both sides reduces the

voltage drop thus allowing for fewer feeders station further apart.

When in operation, overhead line with sectioning points requires more intensive inspection than continuous system. Furthermore, neutral sections permanently interrupt the power supply of a train. These interruptions cause stress to the vehicle's propulsion and onboard power equipment and, depending on the technology of the drive equipment, can adversely affect passenger comfort, for instance, in terms of lighting and air conditioning. Especially during high-speed operation, the reduction in average traction performance due to the short-time interruptions in power supply is a factor that adversely affects vehicle performance. A continuous overhead line network (all section breakers normally closed) enables very fast reconfiguration in case of a feeder station outage by only disconnecting the affected station.

One of the other major advantages of the converter solution is that the converter can provide the single-phase grid with reactive power in order to boost and stabilize the voltage. This is even possible, when the three-phase grid is not available.

For power upgrade of existing lines with SFC technology the fact that the short-circuit current is limited to nominal values can significantly reduce the cost of the earthing and bonding scheme already in place.

Table 1 shows a selection of general advantages of the SFC solution. More information on comparison of a SFC solution and standard transformer system can be found in [3].

TABLE 1

Selected general advantages of an SFC solution.

	Selected issues	50 Hz Transformer	50 Hz SFC Stations
Utility grid	Balanced three-phase grid load	no	yes
	Reactive power	given by train load	controllable; an SFC can independently provide any reactive power in utility grid
	Ratio utility grid voltage / rail grid voltage	given by fixed transformer ratio, changeable only if mechanical tap changer is used	wider range, can be adjusted electronically
	Harmonics	given by train load	known and relatively stable values
	Required grid short-circuit power	high; often high voltage grids must be used	lower values are acceptable, medium voltage grids even with low short circuit power might be sufficient
	Recuperation	not controllable by feeder station	controllable; recuperation can be adjusted or blocked remotely if required by grid status
Rail grid	Reactive power	given by train load	controllable; an SFC can independently provide any needed reactive power in rail grid in order to support grid voltage or to optimize load sharing between feeder stations
	Recuperation	only within a feeder section (2 ... 3 trains)	across entire railway grid
	Feeder stations density	X	~ half
	Continuous train power supply	no	yes
	Surge at section breaks	yes	no
	Protection function	no	limited short-circuit current
	Earthing & bonding	higher short-circuit current endurance required	reduced sizing due to lower short-circuit current level

Analysing frequency components of rail traction current load profile as a function of rail operations

Julius Bosch, Zollikofen (CH)

The significant load fluctuations in the Swiss Federal Railways (SBB's) 16,7-Hz rail traction current supply will increase in the future. We can explain these load fluctuations by analysing the characteristic frequency components of the overall load profile and analysing them by filtering over time. This shows that, in theory, peak loads can be reduced by adjusting the integrated regular interval timetable. As this is not an option, however, alternatives will be presented here.

FREQUENZKOMPONENTEN DES BAHNSTROMLASTGANGS – ZUSAMMENHÄNGE MIT DEM BAHNBETRIEB

Die erheblichen Lastschwankungen der 16,7-Hz-Bahnenergieversorgung der Schweizerischen Bundesbahnen (SBB) werden künftig noch zunehmen. Werden mit einer Frequenzanalyse charakteristische Frequenzkomponenten des Gesamtlastverlaufs extrahiert und mit Filtern im Zeitbereich analysiert, lassen sich die Lastschwankungen erklären. Es zeigt sich, dass Lastspitzen theoretisch durch den Eingriff in den Integralen Taktfahrplan reduziert werden könnten. Da dies jedoch nicht diskutabel ist, werden dazu Alternativen vorgestellt.

COMPOSANTES SPECTRALES DE LA COURBE DE CHARGE – LES INCIDENCES SUR LE TRAFIC FERROVIAIRE

Les variations de charge considérables de l'alimentation en courant traction 16,7 Hz des chemins de fer fédéraux suisses (CFF) sont appelées à s'accroître à l'avenir. L'extraction des composantes spectrales caractéristiques de la courbe de charge totale et leur analyse avec des filtres dans une plage de temps donnée permettent d'expliquer les variations de charge. Il est démontré que les pointes de charge pourraient être théoriquement réduites par l'intervention dans l'horaire cadencé intégral. Mais comme une telle opération est hors de discussion, l'article présente des solutions alternatives.

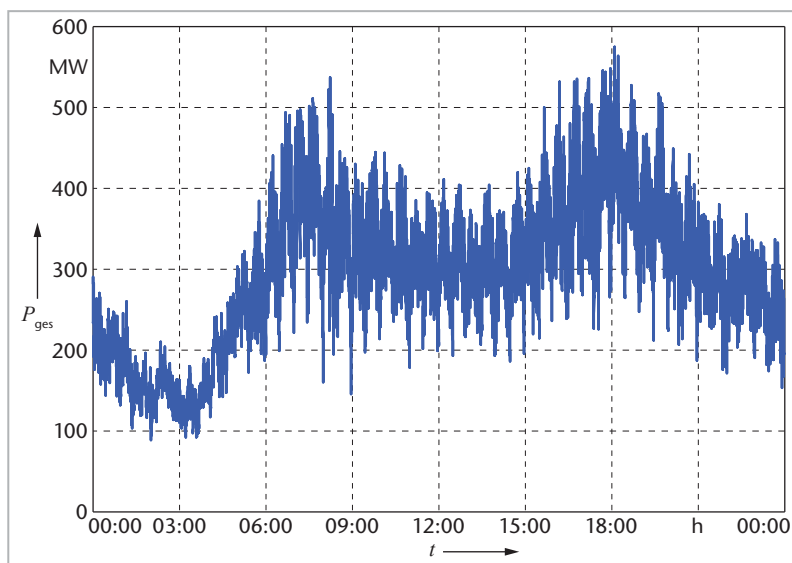


Figure 1: Load profile of overall load of the 16,7-Hz traction power network of SBB of September 4, 2013 (Figures 1 to 6 and 8: author).

1 Introduction

As well as its basic day-to-day pattern with its morning and evening peaks, the overall load on SBB's 16,7-Hz rail traction current supply also fluctuates considerably from 1 min, even from one second to the next (Figure 1). These extreme fluctuations pose a challenge to network control. Only by concentrating massively on the use of generating units which allow high power gradients, such as Pelton turbine sets, rotating and static frequency converters, we can cope with such major load fluctuations. These fluctuations also make it highly likely that major peak loads will occur, which entail increased investments into the availability of input power. Maximum peak-load power is set to increase in future, as trains become more powerful and the timetable more dense. Anyway, the input power available at any time must be sufficient to cover the network load and to ensure network stability.

Technical Specification Energy 2015 – Harmonized design of overhead contact lines

Thomas Nickel; Rainer Puschmann, Forchheim

In December 2014 the Technical Specification for Interoperability of the Energy subsystem of the railway systems in the European Union was published. This Technical Specification will be applicable from January 1, 2015 and replaces the individual Technical Specifications for the interoperability of conventional and high-speed railway systems in force to date. The document stipulates detailed rules for the design of the mechanical-kinematic gauge of the pantograph and the maximum lateral deviation of contact wires. The harmonized stipulations result in planning data for contact lines which differ from design values obtained previously.

TECHNISCHE SPEZIFIKATION ENERGIE 2015 – HARMONISIERTE AUSLEGUNG DER OBERLEITUNGEN
Im Dezember 2014 erschien die Technische Spezifikation Energie für die Interoperabilität des Eisenbahnsystems in der Europäischen Union, die die bisher gültigen technischen Spezifikationen für konventionelle und Hochgeschwindigkeitsbahnsysteme vereint. Diese Spezifikation ist ab 01.01.2015 in Europa anzuwenden. Sie enthält detaillierte Berechnungsregeln zur Bestimmung der Stromabnehmerbegrenzungslinie und der nutzbaren Fahrdrachtseitenlage. Die Anforderungen dieser neuen Technischen Spezifikation Energie führen zu Planungsergebnissen von Oberleitungen, die von den bisher gewohnten Ausführungen deutlich abweichen.

SPECIFICATION TECHNIQUE ENERGIE 2015 – UNE CONCEPTION HARMONISE DES CATENAIRES
En décembre 2014 est parue la nouvelle spécification technique Energie relative à l'interopérabilité des systèmes ferroviaires dans l'Union européenne. Elle réunit les spécifications techniques qui étaient jusqu'ici en vigueur pour les systèmes ferroviaires conventionnels et à grande vitesse. Cette spécification est applicable en Allemagne à la date du 1er janvier 2015. Elle contient des règles détaillées pour le calcul du gabarit des pantographes et de la position latérale utilisable de la caténaire. Les exigences de cette nouvelle spécification technique Energie génèrent des données de conception de caténares fondamentalement différentes des données appliquées jusqu'à présent.

1 Introduction

On December 12th 2014 the European Union published the Technical Specification for the Interoperability of the Energy Subsystem (TSI ENE) [1] in their Official Journal. The publication as a *Regulation* does not require implementation into national law. The TSI applies directly and has been in force since January 1st, 2015 [2]. The new TSI ENE combines the previous separate specifications for high-speed rail systems [3] and for conventional rail systems [4]. The TSI ENE encompasses planning, installation and operation of overhead contact line systems within the Trans-European Network (TEN) of the European Union. The origin of the TSI ENE and their essential contents has been described in [5].

The European Railway Agency (ERA) commissioned an investigation into the provision of stable and reliable information on system design within the member states because it realized that differing system design tools used by European infrastructure managers pose a barrier between the countries of Europe.



Figure 1: ICE 3 and overhead contact line type Sicat on the high-speed line Cologne – Frankfurt (photo and graphics: SPL Powerlines Germany).

The space to be kept free for the passage of the pantograph and the usable contact wire lateral position on the pantograph form essential interfaces between the subsystems *Energy and Rolling Stock* [6] (Figure 1). The calculations of the interfaces are based on the specifications of the mechanical-kinematic pantograph gauge also called pantograph limit gauge. For this purpose the new TSI ENE [1] contains detailed instructions for calculation, which shall be used by all infrastructure managers in Europe and, therefore, harmonizes the national calculation rules used to date. The verification, that, the mechanical-kinematic pantograph gauge is met, forms a part of the EU certification of the subsystem *Energy* for overhead contact lines as an interoperability constituent.

2 Pantograph gauge

2.1 General

The pantograph gauge determines the space to be kept free for the unhindered passage of pantographs. Except for the contact wire, the steady arms and the wind stay, no other components are permitted within the pantograph gauge. On each line on which different pantograph profiles are used the longest pantograph head determines the pantograph gauge.

The establishment of the pantograph gauge is based on the calculation procedures for the structure gauge, however also includes some specifics. During operation the pantograph contacts the contact wire continuously and, therefore, the pantograph height varies. Accordingly, the height and consequently the width of the pantograph gauge vary as well.

The structure gauge is determined in accordance with standard EN 15273 Part 1 [7], Part 2 [8] and Part 3 [9]. The first part of EN 15273 [7] deals with general aspects which affect the infrastructure and the rolling stock, then the reference gauges and the corresponding standards. The second part [8] includes rules for the calculation of the vehicle gauge, depending on the rolling stock characteristics, on the chosen structure gauge and the related calculation instructions. The third part [9] contains calculation instructions for the structure limitation lines, also called structure gauges, which are necessary for the operation of railway rolling stock.

The standard distinguishes between the responsibility of the *infrastructure* and *rolling stock subsystems*. The reference gauge *B* as an interface separates the responsibility of the infrastructure and rolling stock structures (Figure 2). The infrastructure manager guarantees the open passage for the rolling stock with pantographs within the pantograph gauge while the rolling stock manager ensures that the operating rolling stock stays within the individual rolling stock gauges. Outside the reference gauge, the structure gauge *C* is defined based on the calculation rules according to EN 15273-1 [7]. The rolling stock gauge *A* is obtained using the calculation rules in EN 15273-2 [8] and starting from the reference gauge *B* (Figure 2).

The individual reference gauge, the rolling stock gauge and the structure gauge differ according to the calculation method used. EN 15273-3 distinguishes between the static, kinematic and dynamic calculation methods.

For determining the pantograph gauge the TSI ENE [1] uses the kinematic calculation method, which leads to the *mechanical-kinematic pantograph gauge*. The electrical minimum clearances are not taken into account when applying the calculation method according to EN 15273-3 [9] and have to be considered in addition by the infrastructure manager. Within the area of the pantograph, the *electrical kinematic pantograph gauge* is created by adding the individual electrical clearances to the *mechanical-kinematic pantograph gauge*, which corresponds to the pantograph structure gauge.

2.2 Calculation method

2.2.1 Mechanical-kinematic pantograph gauge

The width of the mechanical-kinematic pantograph gauge at the lower and upper verification points, respectively, results from [1]

$$b'_{u(i/a),mec} = (b_w + e_{pu} + S'_{i/a} + qs'_{i/a} + \sum_j u)_{max} \quad (1)$$

and

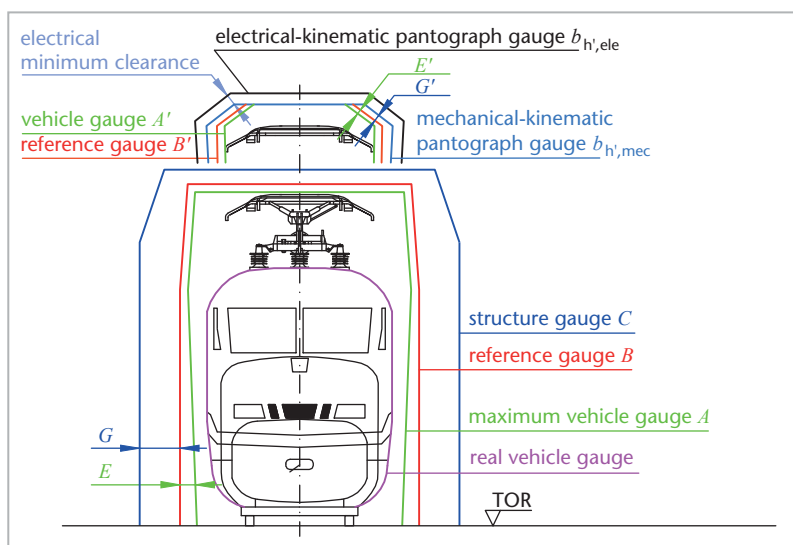


Figure 2: Rolling stock gauge, reference gauge and structure gauge.

TSI Energy 2015 – Reference parameters for overhead contact lines

Thomas Nickel; Rainer Puschmann, Forchheim

The useable contact wire lateral position, determined in accordance with TSI ENE 2015 and EN 15273, based on the displacement of the pantograph in relation to the track axis, may be reduced by 16%. This reduced lateral position results in up to 8m shorter span lengths for DB's standard contact line types and, therefore, in increased capital costs. The reasons are the reference parameters for the lateral displacement of vehicles, established for the determination of the infrastructure gauge, also provided for vehicle inclination on straight tracks, to improve reliability. These reference parameters have been empirically derived from conditions in existing railway infrastructure. However, for new installations these provisions are not necessary. The TSI Energy 2015 should be corrected such that contact line designs with proven performance over long periods can also be used in the future.

TSI ENERGIE 2015 – REFERENZWERTE FÜR OBERLEITUNG

Die nutzbare Fahrdratseitenlage, nach TSI ENE 2015 und EN 15273 aus der Seitenbewegung des Stromabnehmers relativ zur Gleichachse ermittelt, reduziert sich im Vergleich zur bisherigen Methode um rund 16%. Dies hat für Standardoberleitungen der DB AG bis zu 8m kürzere, maximale Längsspannweiten und damit höhere Investitionen zur Folge. Die Ursache liegt in den für die Bestimmung des Lichtraums festgelegten Referenzwerten für die seitliche Fahrzeugverschiebung, die zur Erhöhung der Zuverlässigkeit auch in Gleisgeraden eine Fahrzeugneigung vorsehen. Diese Referenzwerte wurden aus den Bedingungen in Altanlagen abgeleitet. Für Neuanlagen sind diese nicht erforderlich. Die TSI Energie sollte so korrigiert werden, dass über Jahrzehnte bewährte Bauweisen auch weiterhin möglich sind.

STI ENERGIE 2015 – PARAMÈTRES DE RÉFÉRENCE POUR LES LIGNES DE CONTACT

La position latérale utilisable du fil de contact, spécifiée par la STI Energie 2015 et la EN 15273 en tenant compte du mouvement latéral du pantographe par rapport à l'axe du rail, est réduite d'environ 16% par rapport à la méthode en cours. Il en résulte pour la caténaire standard de la DB AG la nécessité de réduire de 8m les distances entre les supports de caténaire et par conséquent une augmentation des investissements. La raison est l'application de paramètres de référence pour la définition du gabarit pour le déplacement latéral des véhicules qui prévoient pour augmenter la fiabilité une inclinaison des véhicules aussi pour des voies en alignement. Ces paramètres de référence étaient déduits des conditions valables pour les lignes existantes. Pour les installations nouvelles, ces paramètres ne sont pas nécessaires. La STI Energie devrait être corrigée afin de permettre d'utiliser dorénavant les types de construction qualifiés pendant des longs périodes.

1 Introduction

The need for free access of wagons and trains within the railway systems of Europe led to a specification for an internationally valid vehicle gauge as a basis for the design of freight and passenger wagons even before the electrification of the railways started. The first version of a vehicle gauge was specified in *Technical unit within the railway system* (TE) [1] in 1913. For this TE the vehicle gauge was determined for a stationary vehicle located centrally on a track.

For the design of the infrastructure gauge no international mandatory rules existed at that time. Therefore, it was open to the individual railway managers to specify the distances between the vehicle gauge and the infrastructure gauge to be observed when

constructing new lines. The first harmonization of the specification for the infrastructure gauge was initiated by the *Verein deutscher Eisenbahnverwaltungen* (Association of German Railway Entities) and summarized within the *Technical agreements on the installation and operation of main line railways and secondary railways* (TV) [2]. This formed the basis for the standard infrastructure gauge included in the *Installation and operation regulation* (BO) [3] and the *Railway installation and operation regulation* (EBO) of 1967 [4].

During the 1950s the *International Union of Railways* (UIC) prepared a harmonized international vehicle gauge. The introduction of more vehicles with softer suspension designs and the higher running speeds of trains led to a transition from static considerations applied up to that period, to kinematic

Tensioning devices for overhead contact lines – quo vadis?

Arnd Stephan, Sebastian Terfloth, Dresden (DE)

During the last years tensioning equipment for overhead contact lines have been launched on the market which make use of other tensioning principles than conventional wheel tensioners with weights. Some of these designs meet the requirement to install the tensioning equipment inside of poles. These different types were investigated and assessed in comparison. In view of the increasing utilization of overhead contact line installations weight based tensioning equipment will be the first choice also in the future to meet the rising requirements concerning low life cycle costs, high availability and efficiency as well as absence of maintenance. In the rare event of a failure the period for repair can be reduced, if weight-based tensioning devices with a drop protection device are adopted.

NACHSPANNEINRICHTUNGEN FÜR OBERLEITUNGEN – QUO VADIS?

In den letzten Jahren kamen Nachspanneinrichtungen für die Kettenwerke von Oberleitungen auf den Markt, die andere Nachspannprinzipien als Radspanner mit Gewichten verwenden und spezielle Forderungen an den Einbau der Einrichtungen in Masten erfüllen. Diese Einrichtungen wurden vergleichend untersucht und bewertet. Infolge einer zunehmenden Anlagenausnutzung werden Anforderungen hinsichtlich geringer Lebenszykluskosten, hoher Verfügbarkeit und Wirkungsgrad und Wartungsfreiheit auch zukünftig zur Wahl gewichtsbasierter Nachspanneinrichtungen führen. Im seltenen Fall eines Versagens lässt sich die Instandsetzungsdauer reduzieren, wenn gewichtsbasierte Radspanneinrichtungen mit einer integrierten Einrastvorrichtung eingesetzt werden.

QUEL AVENIR POUR LES APPAREILS TENDEURS DE CATENAIRES?

Ces dernières années, on a mis sur le marché des appareils tendeurs de caténares qui utilisent d'autres principes de tension que les tendeurs munis de contrepoids, et qui surtout répondent à des exigences spécifiques pour leur installation sur les supports. Ces nouveaux types ont fait l'objet d'un examen et d'une évaluation comparés. Suite à une utilisation accrue des installations, les exigences portant sur de faibles coûts de cycle de vie, une disponibilité et une efficacité élevées ainsi que l'absence d'entretien feront privilégier aussi à l'avenir le choix d'appareils tendeurs fonctionnant avec des contrepoids. Dans le rare cas d'une rupture de la caténaire, la durée de la réparation peut être réduite si l'on utilise des appareils tendeurs à contrepoids avec un dispositif d'encliquetage intégré.

1 Introduction

The interaction between pantographs and overhead contact lines effects decisively the traversing quality of the contact line and the wear performance of contact wires and pantographs. A high traversing quality is achieved by automatic tensioning of contact wire and catenary wire with a tensile force as high as possible. Reliability and availability of the overhead contact line depend, therefore, also on the tensioning devices. The chair for electric railways at Technische Universität Dresden is devoted to the electric railway as a system and educates engineers in this special subject. Contact lines form a main focus in research and education of the chair. In a special lesson the students learn basics and requirements as well as electrical and mechanical design of contact line installations. In close cooperation with contractors long-term research activities in the subject of



Figure 1:

Test stand at TU Dresden Technical University for the investigation of efficiency and aging performance of tensioning devices.

Tensioning devices based on wheel assemblies for overhead contact lines

André Doelling, Erlangen (DE)

Tension wheel assemblies type *Sicat 8WL5070/71/78* of Siemens AG are balancing weight-based tensioning devices according EN 50119. They were designed in the early 21st century and tested based on most recent European standards. Main features are tensioning forces up to 40 kN, capable of being integrated in all overhead contact line systems in mainline and mass transit systems, high-level and long-term stable efficiency, maintenance-free design and adjustment length of up to 2,3 m.

NACHSPANNEINRICHTUNGEN MIT RADSPANNERN FÜR OBERLEITUNGEN

Radspanner der Serie *Sicat 8WL5070/71/78* zählen zu gewichtsbasierten Nachspanneinrichtungen nach EN 50119. Sie wurden Anfang des 21. Jahrhunderts auf Basis der neuesten europäischen Normen gestaltet und geprüft. Wesentliche Merkmale sind Spannkraft bis zu 40 kN, Integration in alle Oberleitungsanlagen des Nah- und Fernverkehrs, hoher und langzeitstabiler Wirkungsgrad, wartungsfreie Konstruktion sowie Regulierlängen von bis zu 2,3 m.

APPAREILS TENDEURS AVEC TENDEURS À POULIE POUR CATÉNAIRES

Les tendeurs à poulie de la série *Sicat 8WL5070/71/78* sont des appareils tendeurs à contrepoids conformes à la norme EN 50119. Ils ont été conçus et vérifiés au début du XXI^e siècle sur la base des dernières normes européennes. Leurs principales caractéristiques sont des forces de tension jusqu'à 40 kN, l'intégration dans toutes les lignes aériennes de contact des réseaux grandes lignes et urbains, un rendement élevé et stable sur le long terme, une conception sans entretien ainsi que des longueurs de compensation jusqu'à 2,3 m.

1 Introduction

When it comes to contact line systems, automatic tensioning devices are important in ensuring a high quality of interaction between pantograph and overhead contact line. Faults and low efficiencies produce position changes of the contact line system. Tension wheel equipment compensate temperature-related position changes of the contact and catenary wires and keep the tensile force of the tensioning section constant. Weight-tensioned assemblies are predominant worldwide thanks to their simple, reliable and low-cost design. These devices boost the force due to weight with mechanical transmission ratios of 1:1,5 to 1:5.

To the middle of the 1990s, tensioning wheel assemblies were designed for tensile forces up to 20 kN and were then reinforced for 30 kN to accommodate high-speed traffic. At the beginning of the 21st century, Siemens developed the *Sicat@8WL5070/71* product family (Figure 1) for tensile forces up to 40 kN and with mechanical transmission ratios between 1:3 and 1:1,5, which compensates clearly larger-scale length changes. They require no maintenance thanks to dry bearings, i.e. greaseless bearings. The family also in-

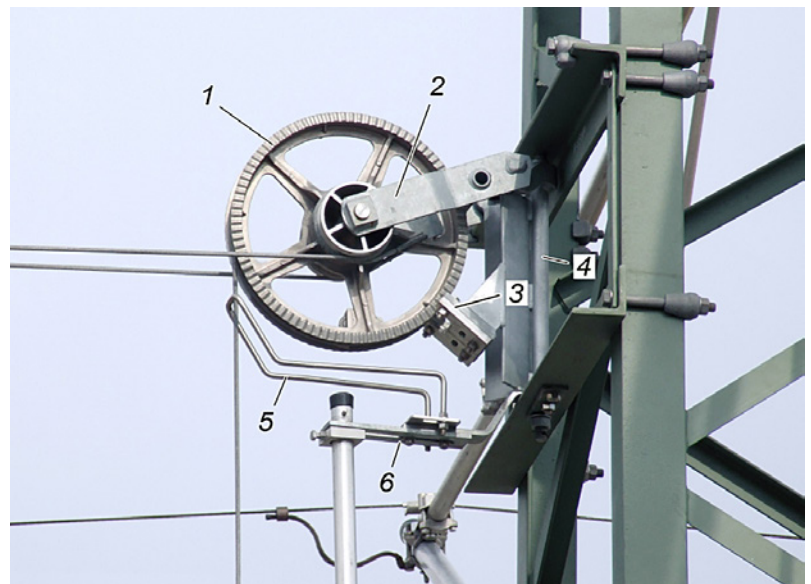


Figure 1:

Sicat 8WL5070 tension wheel assembly with mechanical transmission ratio of 1:3 and 40 kN operating force (all figures by Siemens).

- 1 tension wheel
- 2 swing lever with axle
- 3 fall arresting device
- 4 suspension
- 5 safety hoop
- 6 mounting support for guide tube



Figure 2: *Sicat 8WL5078* tension wheel assembly with mechanical transmission ratio of 1 : 3 up to 24 kN operating load, with integrated weight stack in a H-type pole and installed *Sicat CMS* contact line monitoring system in the network of the mass transit authority Hallesche Verkehrs-AG.



Figure 3: Tension wheel assembly with a mechanical transmission ratio of 1 : 3 and 30 kN operating load, *Sicat 8WL5000* on DB's new high-speed line between Leipzig and Erfurt.

cludes the low-cost *Sicat 8WL5078* tension wheel assembly (Figure 2) for up to 24 kN. The four-spoke tension wheel of the *Sicat 8WL5000* series up to 30 kN (Figure 3) was subsequently converted to the greaseless bearing version. Today, these tension wheel assemblies are used in the German Rail network under the names Ebs 08.02.02, Ebs 08.04.02 and Ebs 08.06.02.

2 Requirements

2.1 System and environment-related requirements

Tensioning devices with wheel assemblies and weight sets fulfill the requirements of EN 50119 [1] and EN 50125-2 [2] as well as the following application-related requirements:

- Usability for all current overhead contact line systems
- Suitability for ambient temperatures between -40 and $+50^{\circ}\text{C}$

- Compensation of variations in length due to Joule heat, to creep of contact and catenary wires and to contact line wear
- Arrangement of weights outside publicly accessible areas or use of drop protection devices for personal safety
- Easy installation requiring little effort
- No or at least low maintenance
- Low lifecycle costs, for example due to maintenance-free bearings and corrosion-resistant materials
- High availability and operational security

It is possible to install the tension wheel devices in overhead contact lines in different ways. Fastenings on poles or structures, horizontally or vertically offset arrangements and arrangements integrated in poles are standard nowadays.

Locking or blocking facilities are required to avoid consequential damage as far as possible in the event of a wire break, for example due to distortion of the catenary system and damage to components. Wire breaks as such are rare and mostly caused by external influences such as falling

Overhead contact line type N-FL of Swiss Rail – Extension of application

Kurt Bader, Bern (CH), Jörg Mohrich, Leipzig (DE)

Older contact line designs, like the Swiss contact line type N-FL, exist in conventional railway networks to a great extent. Their low maximum permissible speed conflicts with the goal of increasing the maximum line speed. The high effort for a replacement of the complete contact line requires looking for a reasonable alternative for the increase of the running speed. By means of simulation, modifications of the existing contact line type N-FL in view of increasing the running speed were investigated. Higher tensile forces of the contact wire and the installation of stitch wires have proven to be promising adjustments.

OBERLEITUNG BAUART N-FL DER SBB – ERWEITERUNG DER ANWENDUNG

Ältere Oberleitungsbauarten, wie die Bauart N-FL der SBB, sind häufig auf vielen Streckenkilometern in Bestandsnetzen zu finden. Häufig begrenzt die geringe maximale Befahrgeschwindigkeit dieser Bauarten die Streckengeschwindigkeit, die damit nicht erhöht werden kann. Der hohe Aufwand für einen Ersatzneubau der Oberleitung veranlasst die Suche nach preisgünstigeren Alternativen zur Erhöhung der Befahrgeschwindigkeit. Mit Hilfe von Simulationen wurden Änderungen der N-Fahrleitung höhere Befahrgeschwindigkeit untersucht. Höhere Zugspannungen im Fahrdraht und der Einbau von Y-Beiseilen an den Stützpunkten ergaben sich als vielversprechende Anpassungen.

SYSTÈME DE FIL DE CONTACT DU TYPE N-FL DES CHEMINS DE FER FÉDÉRAUX SUISSES (CFF) – EXTENSION DE SON APPLICATION

Souvent on rencontre des systèmes de fil de contact plus anciens, comme le type N-FL des CFF, sur beaucoup de kilomètres des lignes des réseaux existants. Souvent les vitesses maximales de circulation permises sur ces lignes sont déterminées par les vitesses limites imposées par le système de fil de contact. Une augmentation des vitesses de circulation demanderait donc le renouvellement coûteux du système de fil de contact. Pour éviter cela, on a étudié à l'aide de simulations des modifications du type N-FL qui permettraient une augmentation des vitesses de circulation. Comme premières mesures prometteuses se sont révélés l'augmentation de l'effort de tension du fil de contact ainsi que le montage de suspensions en Y aux points de support.

1 Introduction

Swiss Federal Railways (SBB) operate a railway network with around 8000 km of overhead contact lines. These contact lines can essentially be classified under two types: Contact line type N-FL and contact line type R-FL. The type N-FL is an old design which has been in use since the 1930s. It can still be found frequently on old line sections and especially in stations. The type R-FL is the current standard design on tracks outside stations and on main-tracks in stations.

The number of trains in the timetable is constantly expanding. In addition, there is also the requirement of shortening travel times by increasing the commercial line speeds so that adherence to timetables can be improved. In order to satisfy this requirement on lines equipped with the N-FL contact lines, this contact line type is often replaced with the R-FLOCL. This requires major financial resources, which are

currently limited. For this reason, consideration has been given to how the N-FLOCL can be updated

TABLE 1			
Technical data between supports of SBB's N-FL OCL type.			
			Remarks
Messenger wire	mm ²	50	Copper-clad steel wire
Tensile force, fixed by terminated messenger wire	kN	8 oder 6	at –20°C, depending on system height 1,9 m or 2,4 m
Contact wire	mm ²	107	Cu-ETP
Tensile force	kN	8,5	
System height	m	1,9 oder 2,4	
Maximum distance between supports	m	58	new 52
Number of droppers	-	6	
Mean contact force	N	75	
Ampacity	A	490	

with minor technical modifications to accommodate higher speeds and thereby significantly delay its complete replacement.

In order to meet this technical challenge, running under the N-FLOCL should first be simulated and the matching of the results with available measurements be checked. Then, technical modifications should be simulated and the modifications showing promise should be derived. This report covers this initial step for the technical adaptation of the N-FLOCL for higher commercial speeds.

2 The type N-FL contact line of SBB

2.1 History

The contact line type N-FL has been in use by the SBB since around 1930. It comprises an automatically tensioned contact wire and a fixed messenger wire and was designed for a commercial speed of 125 km/h. The design has been improved over the past 80 years such that there are two variants with partially different components currently in use. One version is a supported contact line and the other is a suspended contact line. The suspended N-FL version is predominantly installed in stations.

2.2 Technical data

Table 1 contains important technical data of the N-FLOCL and Figure 1 shows the suspended N-FLOCL version which is used in new installations.

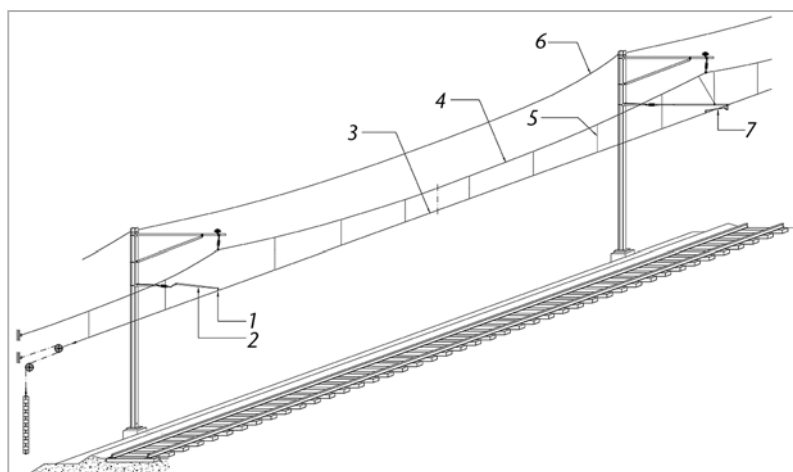


Figure 1:

Contact line SBB N-FL.

- | | | |
|--|---------------------------------------|--------------------------------|
| 1 Contact wire stagger on straight sections +/-0,15 m, | 3 Contact wire AC107 | 7 Steady arm type R (pull-off) |
| 2 Steady arm type D (pull-off) | 4 Messenger wire 50mm ² | |
| | 5 Dropper | |
| | 6 Return conductor 95 mm ² | |

2.3 Importance of the N-FLOCL type in SBB's OCL network

The N-FL is found throughout the SBB railway network. It is of particular interest with respect to higher speeds of travel, particularly on open sections between stations and sections passing through stations. On the basis of positive measuring results, N-FL sections can be travelled at up to 150 km/s only by using one pantograph in operation. There are currently 665 km of N-FL section in operation on which speeds higher than 125 km/h are adopted currently or planned for the future. The goal of a streamlined enhancement of the N-FLOCL for higher speeds with a limitation to no more than four pantographs in operation is to delay complete conversions and the investments involved for 10 to 15 years.

3 Simulation of different versions

3.1 Introduction

Simulations of the dynamic interaction between overhead contact line OCL and pantograph, referred to hereinafter as simulations, have already been an established method for the development of new catenary designs for all speed ranges and generally recognised for at least two decades. They are used increasingly for the assessment of contact lines, pantographs, and subsystems according to TSI Energy and TSI Locomotives and Passenger wagons. The author are currently aware of twelve simulation programs from Italy, Portugal, Spain, South Korea, Germany, Japan, France, Sweden, and China which have been developed and are used by universities, research institutions, railway infrastructure operators, manufacturers of railway equipment and inspection bodies.

3.2 The TracFeed® CATMOS® simulation program

The TracFeed® CATMOS® simulation program used by Balfour Beatty Rail GmbH and created by predecessor companies AEG Bahnfahrwegsysteme and Adtranz was used for the optimisation of SBB's N-FLOCL type [1].

Mathematical models of contact line and pantograph are used for the simulation. The waves created in the OCL by the compression force of the pantograph are described using the wave propagation method based on D'Alembert's principle. By using this method, excellent simulation results are obtained, in which non-linear characteristics of the contact line, such as buckling of the droppers, are taken into account.

The Great Western Electrification in Southern England

Sinan Al-Jawad, Swindon (UK), Rainer Puschmann, Forchheim (DE)

The Great Western Railway runs from London to West and South West England as well as Wales and like no other railway line, reflects the rise and gradual decline of the British railway. The great British railway engineer, Isambard Kingdom Brunel, began with the construction of this railway line in 1833 and used 2140 mm (7ft. 0-1/4 in) broad gauge, which was rebuilt into 1435 mm standard gauge beginning in 1869. After the foreseeable end of steam traction in 1934, the first diesel locomotives travelled on this line and diesel trains are still utilized as of today. In 2012, the government adopted a national electrification programme, which includes the electrification of this route with AC 25 kV 50 Hz to be completed by 2017.

GREAT-WESTERN-BAHN – ELEKTRIFIZIERUNG IN SÜDENGLAND

Die Great Western Eisenbahn verläuft von London nach West- und Südwestengland sowie nach Wales und spiegelt wie keine andere Eisenbahnstrecke den Aufstieg und Niedergang der englischen Eisenbahn wider. Der großartige englische Eisenbahningenieur *Isambard Kingdom Brunel* begann 1833 mit dem Bau dieser Strecke und nutzte 2140 mm (7ft. 0-1/4 in) Breitspur, die ab 1869 in 1435 mm Standardspurweite umgebaut wurde. Nach dem absehbaren Ende der Dampftraktion führen 1934 die ersten Diesellokomotiven auf dieser Strecke, die bis heute noch verkehren. 2012 hat die Regierung ein Nationales Elektrifizierungsprogramm beschlossen, welches auch die Elektrifizierung dieser Strecke mit AC 25 kV 50 Hz bis 2017 umfasst.

LA LIGNE DU GREAT WESTERN – L'ÉLECTRIFICATION DANS LE SUD DE L'ANGLETERRE

La ligne du Great Western relie Londres à l'ouest et au sud-ouest de l'Angleterre ainsi qu'au Pays de Galles et reflète comme nulle autre la splendeur et la décadence du rail britannique. Le prestigieux ingénieur anglais des chemins de fer *Isambard Kingdom Brunel* avait commencé la construction de la ligne en 1833 en utilisant un écartement de 2140 mm (7ft. 0-1/4 in) qui fut converti à l'écartement standard de 1435 mm à partir de 1869. En 1934, préfigurant la fin de la traction vapeur, les premières locomotives diesel firent leur apparition sur la ligne où elles sont encore en circulation aujourd'hui. En 2012, le gouvernement a voté un programme national d'électrification qui comprend aussi l'électrification de cette ligne en CA 25 kV 50 Hz à l'horizon 2017.

1 Introduction

The *Great Western Railway* (GWR), one of several British railway companies, operated its own railway network (Figure 1). The GWR railway lines connect London with South West England, West England and South Wales. The GWR was the only company that continued to exist under the same name after the reorganization of the British railway system in 1923. In 1948 the company was integrated into the state-owned *British Railways* company (now *British Rail*). After the privatisation of British Rail in 1994, the GWR resumed its traditional name of *First Great Western*. Today's *First Great Western*, which does not yet have electrified routes, operates basically the same area. The infrastructure management com-

pany, *Network Rail*, is working to get the 1000 km long rail network electrified by 2017 with the AC 50 Hz 25 kV system. This first and most comprehensive modernization of the *Great Western Railway* in the last 25 years requires extensive knowledge and many years of experience in terms of planning and construction of overhead contact line systems, which are lacking due to the long interruption of the large scale electrification projects on the British railway network. Consequently, *Network Rail* has sought experience from Germany and has commissioned SPL Powerlines Germany for consulting on the application of European standards, interoperability and German experiences.

2 Historical development

2.1 Construction of the first routes in England

With the first locomotive designed and built in 1814 by George Stephenson, operation of the first railway in the world began under his leadership on September 27, 1825 between Stockton and Darlington. The *Stockton & Darlington Railway Company* (S & DR) became the first public railway in the North East of England and started passenger transport from Bishop Auckland to Middlesbrough. Initially, 4ft 8 1/2 track gauge was used, which is 1435mm and later became the standard gauge worldwide. Historical studies demonstrate the origin of this gauge to be the distance between the ruts of Roman chariots extending all the way to England as part of the Roman Empire's long distance routes [1; 2].

The success of the *Stockton & Darlington Railway* led to the opening of the next 1435mm railway line in 1830 between the port city of Liverpool and the textile industry city of Manchester. The *Rocket* served as the locomotive on this new track, which reached a maximum speed of 48km/h. For the first time passengers and freight were transported based on a schedule.

The success of this line had a lasting influence on the railway development in the UK and abroad.

2.2 The Great Western from London to Bristol

Since freight transport went increasingly through the port of Liverpool, the Bristol harbour was to maintain its position as the second most important port in the country with the construction of a railway line from London to Bristol. After a founding assembly meeting in 1833, Parliament commissioned the construction of the railway in 1835. The then 27-year-old *Isambard Kingdom Brunel* (Figure 2) was engaged as chief engineer.

Brunel made two important decisions. The first concerned the choice of the wider 7ft track gauge (2140 mm) which was to guarantee smoother running than the 1435mm gauge at high speed. The second decision concerned the route through the Marlborough Downs and through the valley of the Thames to London. There were no major cities in this region and consequently little resistance against the construction of the track.

Brunel did the survey of the entire route personally. The first 22,5 km section between London Paddington station and Taplow by Maidenhead were able to be opened already in 1838. After construction of the Box Tunnel in 1841, the railway reached the Temple Meads station in Bristol with the world's

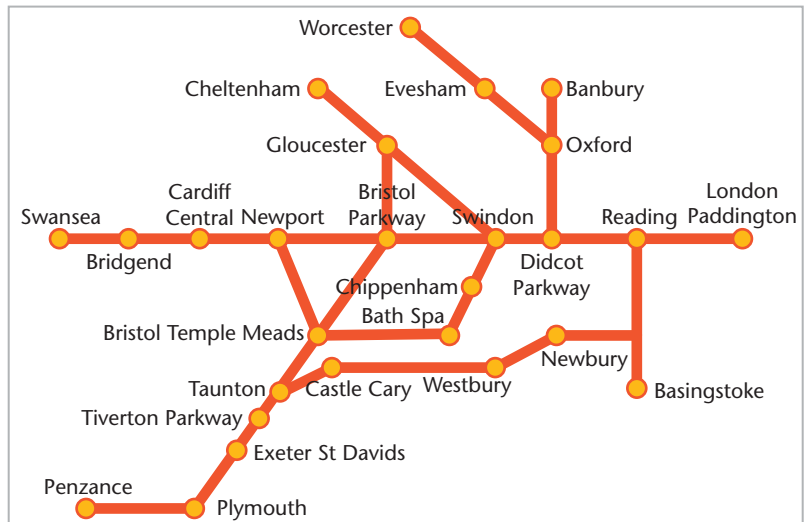


Figure 1:

Route network of the Great Western Railway, as of 1947 (Figures 1 to 6: Network Rail).

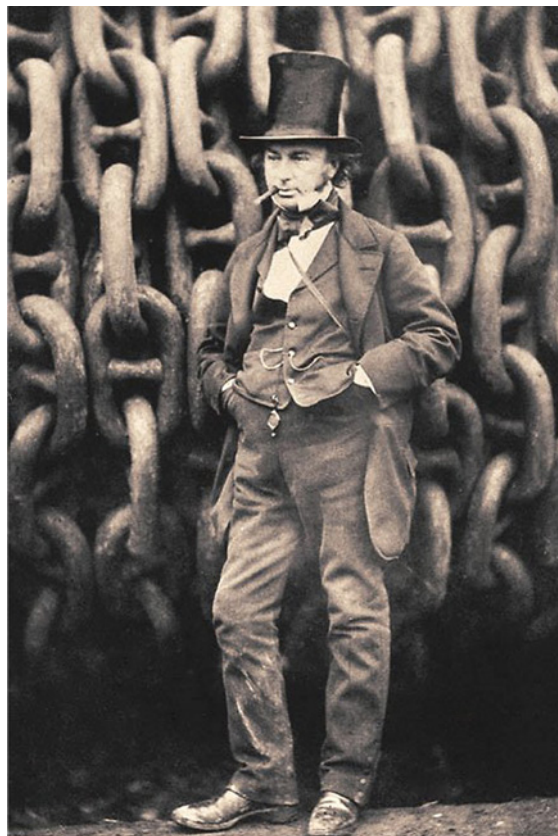


Figure 2:

Isambard Kingdom Brunel.

first commercial telegraph line, which was put into operation already in 1839. Other major routes followed (Figure 1):

- Bristol – Exeter – Plymouth 1849 (South Devon Main Line) and
- Plymouth – Penzance 1860 (Cornish Main Line),
- Bristol – Newport – Cardiff – Swansea 1903 (South Wales Main Line)

AC traction power supply for India's metro lines

Jens Krumpolt, Erlangen (DE)

After the opening and extensive expansion of the metro network in Delhi, the relatively late development, planning and construction of metro lines in India's large population centres led to the proliferation of mass rapid transit systems in numerous other megacities. The experience gained with AC 25 kV 50 Hz systems and their standard application in mainline services combined to make a unique selling point for metro networks. AC traction power supply systems and the associated overhead contact line equipment for separate rights-of-way and elevated or underground lines have proven to be a suitable alternative to conventional DC-operated networks.

AC BAHNENERGIEVERSORGUNG IM NAHVERKEHR INDIENS

Die relativ späte Entwicklung, Planung und Aufbau von Metrolinien in den Ballungsstädten Indiens führte mit der Eröffnung und umfassenden Erweiterung des Netzes in Delhi zu einem rasanten Aufschwung weiterer Nahverkehrsnetze in den zahlreich vorhandenen Millionen-Metropolen. Die Erfahrungen mit Anwendungen der AC-25-kV-50-Hz-Wechselstromtechnik in Metronetzen stellen ein Alleinstellungsmerkmal dar. Aufgrund der separat aufgeständerten oder unterirdisch verlaufenden Trassenführungen konnte sich ein alternatives AC-Oberleitungssystem neben den konventionellen mit DC betriebenen Netzen etablieren.

ALIMENTATION ÉLECTRIQUE EN COURANT ALTERNATIF POUR LES LIGNES DE MÉTRO EN INDE

Après le développement, le planning et la construction relativement tardifs de lignes de métro dans les zones de grande concentration urbaine Indiennes, l'ouverture et l'expansion extensive du réseau du métro de Delhi menait à un essor fulgurant des réseaux de trafic suburbains dans les méga-cités. L'expérience gagnée avec les systèmes AC 25 kV 50 Hz et leurs applications sur des réseaux de métro représentent un argument de vente exceptionnel. Sur la base de tracés en surélévation ou enterrés pouvaient être conçus des réseaux d'alimentation électriques à courant alternatif avec des fils de contact correspondants qui forment une alternative aux réseaux à courant continu conventionnels

1 Introduction

India has the fourth largest railway network in the world (Figure 1). It currently covers 64,000 track km, of which 23,500 km are electrified. Every day the railway infrastructure is faced with new challenges resulting from an ever increasing population and thus a growing demand for rail-based transportation. The early days of the electrification of the national rail network were marked by close collaboration between the French national railway operator *Société Nationale des Chemins de fer Français* (SNCF) and *Indian Railways* (IR). French studies on electrification, components and designs for the overhead contact lines were duly reflected in the first specifications for the new metro lines that were to be planned and built.

In India, certifications and supervision of the traction power supply systems are the responsibility of the *Research Development Standard Organization* (RDSO), which comprises the *Central Standard Office* (CSO) and the *Railway Testing and Research Centre* (RTRC).

IR operates around 15 000 trains every day, 9 000 of which are passenger trains. The commuter trains

deployed in the urban centers correspond to the regional and rapid transit trains (*S-Bahn*) in Germany. With the major cities growing at a tremendous rate, there is an urgent need to plan, develop and construct modern metro systems. In addition to the measures for continuous expansion and maintenance of the rail system, IR is also investing in electrified and separate rail freight lines. Over the years, the *Delhi Metro Rail Corporation* (DMRC) has gathered appropriate experience as an operator and currently represents many customers of the new national rapid transit systems in a consulting role, advising them from the specification stage to project execution and, finally, to the start of metro line operation.

2 Delhi Metro

2.1 Summary

Today, Delhi is home to India's largest metro network with a total of six lines (Figure 2). The Phase III

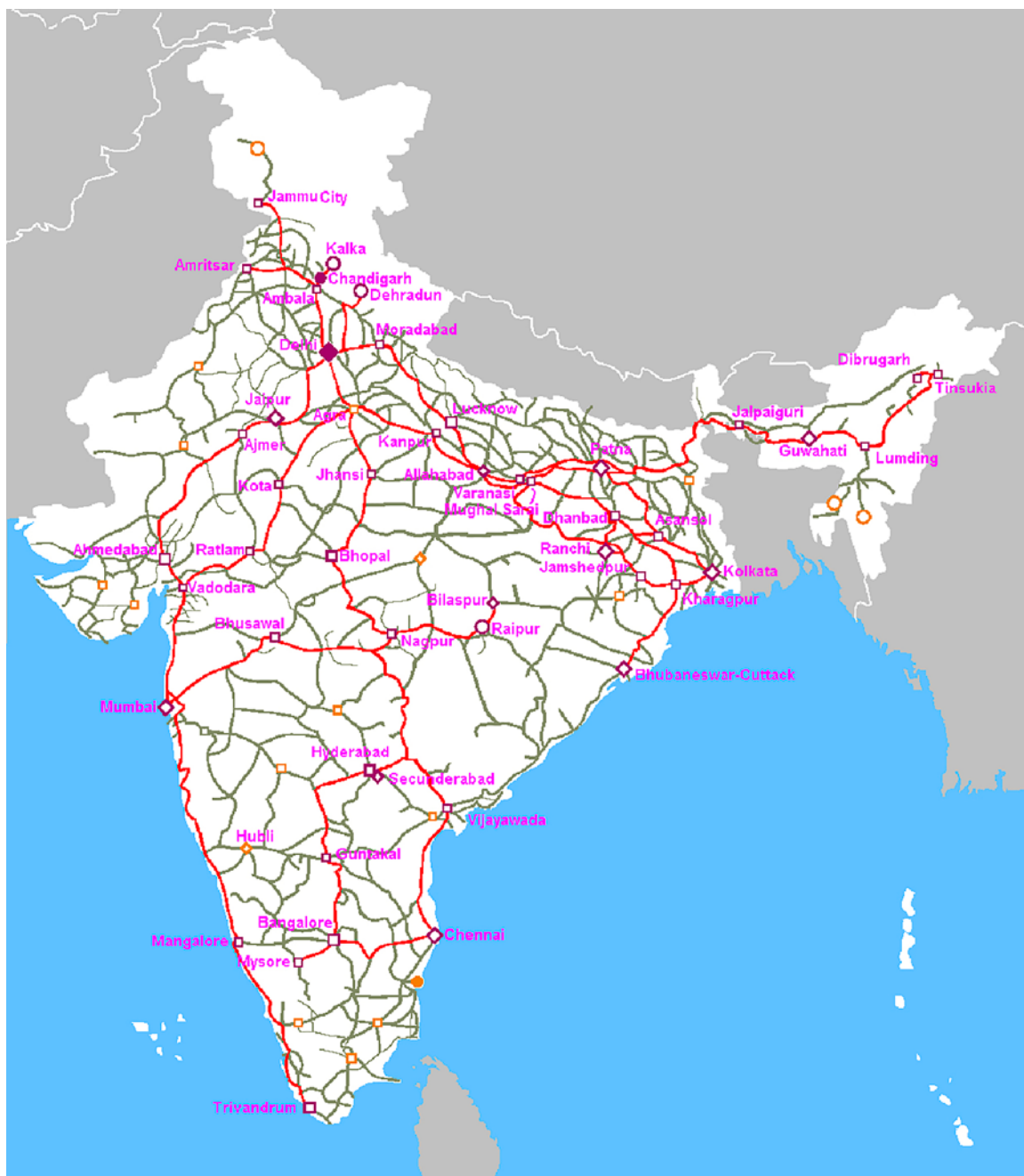


Figure 1:
Indian Railways (IR) network (all figures: Siemens).

expansions are already in the planning and execution stages. Phase IV will follow on immediately and is scheduled to run until 2021. Delhi is truly a mega-city with a population of eleven million, whereby this figure does not include the city's outlying suburbs.

The rail systems are routed separately from the road system and run on viaducts or in tunnels; only the depots are at ground level. The operating speed is 80km/h. The Airport Express line from New Delhi railway station to the new airport used to run at a higher speed, but since its integration into the DMRC it is now subject to the same conditions as

the rest of the network. The articulated metro vehicles run in formations of six or eight cars, whereby every second car is powered and equipped with an own pantograph.

2.2 Overhead contact line

Many details in the system design and configuration of the overhead contact lines in Phases I and II betrayed French roots. Initial plans for using a DC traction power supply were quickly abandoned in favor of a simple AC 25 kV 50 Hz power supply sys-

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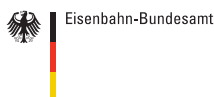
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