ABB review

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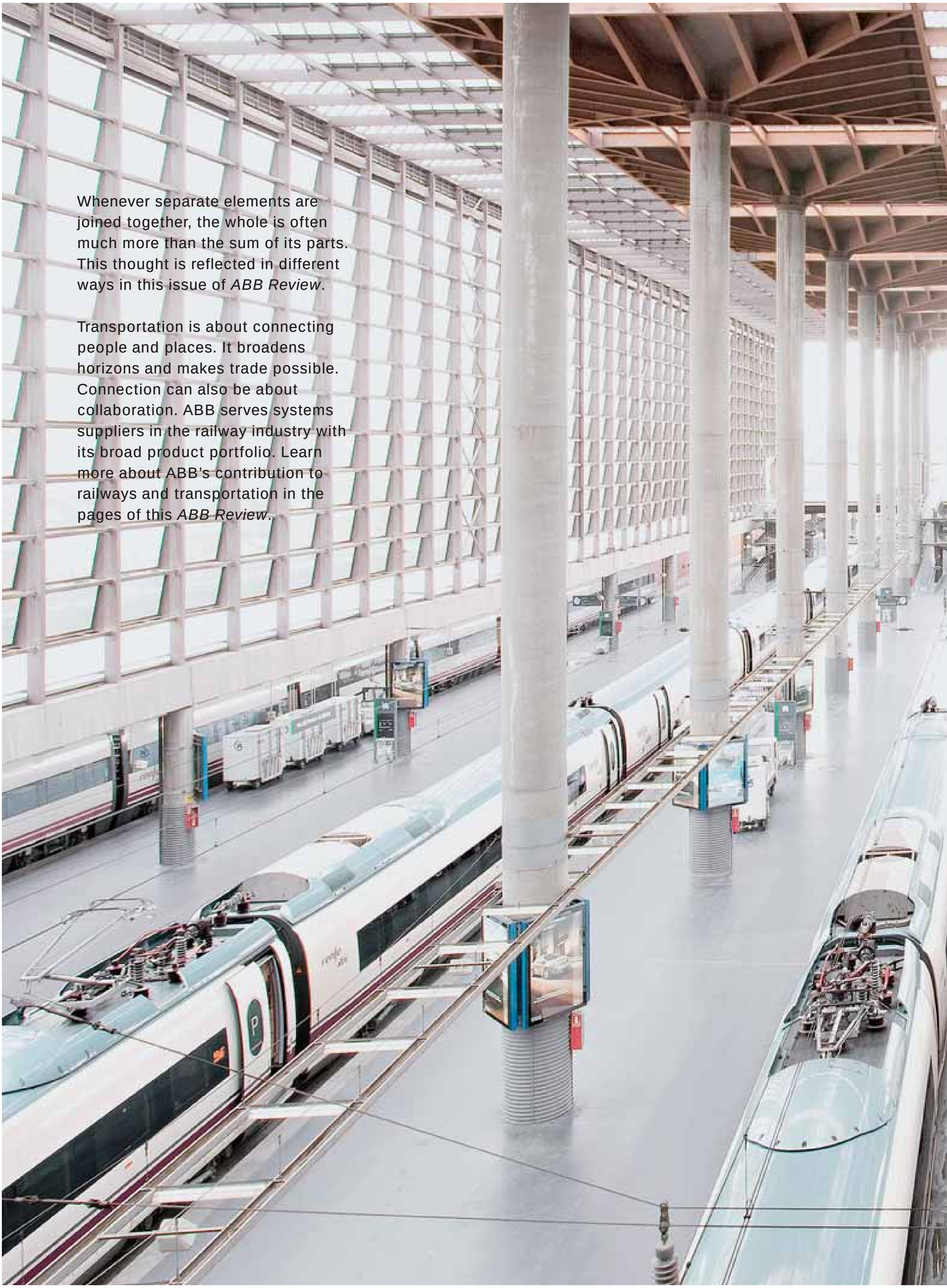
The corporate technical journal

Railways and transportation

Power and productivity for a better world™



Whenever separate elements are joined together, the whole is often much more than the sum of its parts. This thought is reflected in different ways in this issue of *ABB Review*.

Transportation is about connecting people and places. It broadens horizons and makes trade possible. Connection can also be about collaboration. ABB serves systems suppliers in the railway industry with its broad product portfolio. Learn more about ABB's contribution to railways and transportation in the pages of this *ABB Review*.

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ABB and railways

Peter Terwiesch
Chief Technology Officer
ABB Ltd.

Dear Reader,

Mobility is a central aspect of our lives and activities. Whether we are commuting to work, travelling for business or taking a vacation, we depend on a reliable and affordable means of locomotion. Furthermore, transportation does not just affect us as individuals: The mechanized movement of goods has permitted the concentration of industry and hence modern manufacturing methods. Similarly, the existence of large cities depends on the ability to reliably and continuously supply them with food and other necessities.

Just as transportation helped create and develop many aspects of modern society, insufficient transportation can be detrimental to it. If goods cannot be delivered or people cannot reach their destination in a reasonable and predictable time, economic and other repercussions can be heart felt. This challenge is accentuated by ongoing developments: Growing urbanization is increasing strain on infrastructure and adding to congestion. At the same time, concerns over air quality, CO_2, limited reserves of fossil fuels and also the spatial footprint of transportation are calling for cleaner and more efficient solutions.

Railways are well positioned to meet these requirements. Within city areas, suburban railways and metros make an important contribution to relieving road congestion while offering a low carbon footprint, and if electrified, zero emissions at point of delivery. Whereas cities such as London or Paris are expanding existing systems, many booming metropolises in developing countries are facing the challenge and opportunity of creating new systems from scratch.

High-speed trains can provide an attractive alternative to both driving and short-haul flights. They are relatively weather-independent and offer passengers a comfortable environment in which to relax or work. Whereas the first generation of high-speed trains ran in Japan and Europe, they have considerably broadened their appeal. Soon high-speed trains will be running on five continents.

The freight sector is also experiencing exciting developments. In Europe especially, more and more countries are opening their rail freight markets to competition, leading to high levels of traffic growth.

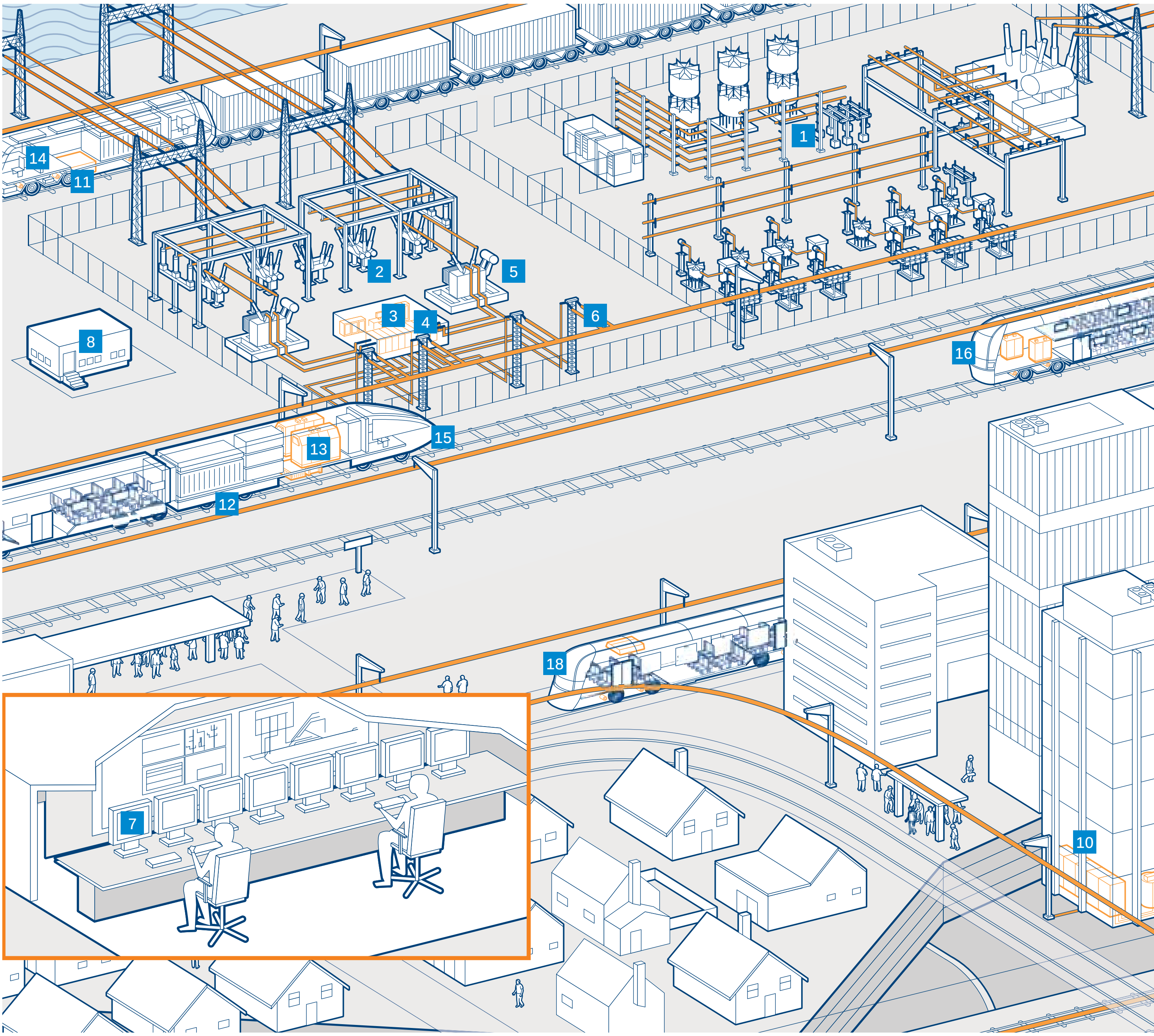
While not a train manufacturer as such, through its expertise in the power and automation sectors, ABB can offer many products and technologies to the railway industry. Electric railways are major consumers of electricity, and this consumption can fluctuate strongly and in short time periods. ABB's grid management technologies ensure power is delivered reliably while maintaining the stability of the supplying grids. To transfer power from grids to railways and to support the operation of both, ABB provides substations and components (including transformers, frequency converters, switchgear and FACTS devices). For the trains themselves, ABB's offering includes traction transformers, switchgear, motors, converters and turbochargers. This issue of *ABB Review* looks at these product types.

ABB has grown its rail activities considerably in recent years, growing from the position of an outsider to a major supplier for several of the leading train manufacturers. To present a broader industry perspective, *ABB Review* interviewed Michael Clausecker, Director General of UNIFE (Union of European Rail Industries).

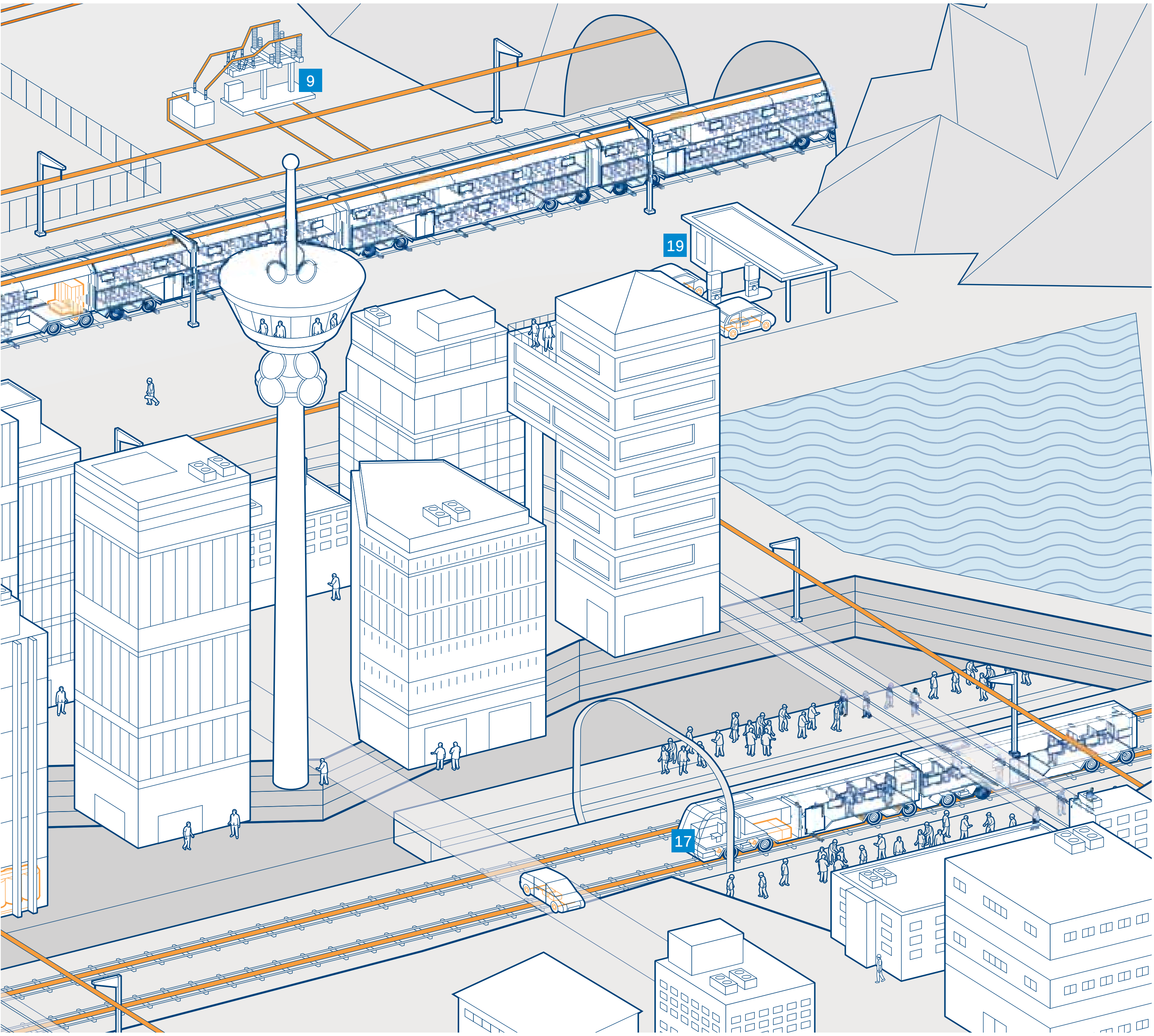
Besides supplying the rail sector, ABB plays a part in the broader spectrum of sustainable transportation and electrical mobility. Activities presented in this edition of *ABB Review* include charging technology for electric cars and a power supply to reduce the operating hours of ship engines while in port.

Enjoy your reading

Peter Terwiesch
Chief Technology Officer
ABB Ltd.



ABB, railways and transportation



As a major player in the power and automation sectors, ABB supplies many technologies that serve the rail industry. FACTS devices support both supplying and railside grids and help maintain stability and power quality ➔ 1. High- ➔ 2 and medium-voltage switchgear ➔ 3, frequency converters ➔ 4 and transformers ➔ 5 convert and supply power for the railway's overhead lines (OHL) ➔ 6 and control and monitoring systems ➔ 7 (including substation control and operation centers ➔ 8) permit the optimal operation of these assets. Compact autotransformer modules ➔ 9 support the OHL supply in long distance applications. DC electrifications are served by traction power substations with transformer-rectifier units ➔ 10.

ABB equipment can also be found onboard trains. The company supplies traction transformers ➔ 11, motors and generators ➔ 12. It also manufactures converters to supply the train's traction and auxiliary power ➔ 13. The company's portfolio furthermore includes low-voltage products, medium-voltage circuit breakers as well as semiconductors and surge arresters. For diesel trains, the company supplies turbochargers.

ABB technologies and equipment serve in different types of rail applications, ranging from freight ➔ 14 through high speed ➔ 15 to suburban railways ➔ 16, metros ➔ 17 and tramways ➔ 18.

Furthermore, ABB is not just a manufacturer but also provides service, maintenance and retrofit. In the broader area of transportation, the company is involved in marine applications and charging stations for electric road vehicles ➔ 19.

Discover more about these topics in the pages of this edition of *ABB Review* and on www.abb.com/railway.

Rail solutions to the mobility challenge

Interview with Michael Clausecker, Director General of UNIFE, and Jean-Luc Favre, CEO of ABB Sécheron and Head of ABB Rail Sector

The mobility of people and goods is essential to today's economy: Global trade is calling for the affordable and timely transportation of freight over long distances. Business and tourism depend on people travelling between cities. Growing urbanization means people are also commuting over longer distances within cities. At the same time, concerns over the environment, energy prices and congestion are calling for ways to minimize the economical, ecological and spatial footprint of transportation. It is thus no surprise that governments across the world are rediscovering railways. From urban metros through national and international high speed trains to trans-continental freight corridors, railway investment is growing. Michael Clausecker, Director General of UNIFE, and Jean-Luc Favre, CEO of ABB Sécheron and Head of ABB Rail Sector, discussed the challenges and outlook of tomorrow's railways with *ABB Review*.

Mr. Clausecker, could you briefly introduce UNIFE?

Michael Clausecker: UNIFE[1] was set up to support railway equipment manufacturers in Europe. It does this:

1 By seeking technical harmonization and regulation of railway systems.
2 By lobbying for policies that are favorable to the development of the rail segment.
3 By launching and supporting programs to help member companies conduct research jointly with railway operators and by facilitating the associated application for European funds.
4 By ensuring the superior quality of the products of its member companies throughout the entire value chain, using its quality-management program, IRIS[2].

UNIFE is funded by its members, who are all private European companies supplying to railways across the world. The organization also has associate members (mostly national rail supply associations). There are about 70 companies in UNIFE and almost 1000 in its national associations. UNIFE thus speaks for the largest part of the European rail industry.

What are the major challenges and developments that the railway industry will face in the next decade?

Michael Clausecker: Let us start with high speed. Today, major projects are underway in France, Spain and Great Britain. In the United States too, the debate about high-speed lines has finally begun. Russia is making progress on the Moscow to St. Petersburg project. The Chinese are investing more than anybody else and building thousands of kilometers of high-speed lines. The sector is experiencing massive growth.

Where do you see future priorities?

Michael Clausecker: The vast majority of high-speed connections today are national: in France, Germany, Spain etc. There are of course also international services, such as Eurostar or Thalys, but the further development of high speed in Europe will need to have a more international focus.

For governments, the key issue for the next 10 years will be investment in infrastructure. I believe we will see growing willingness to invest in rail, and also more innovation in financing such schemes. This can include public-private partnerships and build, operate and transfer models.

> The future will see more cross-border freight transport in Europe. This will call for more multi-system locomotives compatible to different voltages and signaling systems.

And in other parts of the world, such as Eastern Europe or India?

Michael Clausecker: I hope we will see the construction of the first high-speed line in Eastern Europe in the next decade. There is already a plan to start building a high-speed line in Poland by 2014.

In the case of India, it is difficult to foresee when high-speed will become a reality. The main developments there today are in metros and urban rail.

Jean-Luc Favre

We have to consider the effect of demography. Most probably there will be nine billion people on the Earth by 2050. There is also a strong trend towards urbanization. In 2008, for the first time, half of the Earth's population was living in cities. There is a clear case for sustainable transportation and rail can deliver that ➔ 1.

In China, huge investments are going on in freight and passenger rail and also electrification projects. The high-speed network is growing at an astonishing rate. For ABB, China has been the fastest growing market over the last two to three years. Europe is also a strong market, but when it comes to network growth and investments in new locomotives and trains, it is in China that we are seeing the most significant developments.

In India too, we are starting to see projects move forwards. Freight corridors are being created – freight can be moved more efficiently in dedicated corridors. However, the fastest growing market in India is metros. The government wants all cities above three million to have a metro. There are huge projects in Bangalore, Kolkata, Mumbai and Delhi. We are also expecting a high-speed market to emerge there in the next five to ten years.

You have both mentioned urban transportation. What are the main trends there?

Michael Clausecker: Large cities are becoming even larger, and with them the importance of transportation. It is becoming more and more difficult for citizens to get to and from work in the morning and evening. Clearly public transport is an efficient way to address that challenge. It is no surprise that we are seeing many major cities implementing transit systems, in particular in China. But even cities such as Paris and London are struggling with traffic congestion and realize that they need to add transit capac-

Footnotes

1 UNIFE: Union des Industries Ferroviaires Européennes, (Union of European Rail Industries)
2 IRIS: International Railway Industry Standard. See also inset 7 on page 23.

1 In 2008, for the first time, half the Earth's population was living in cities. The importance of urban transit is growing.

2 Trams are not just environmentally friendly; they are also people friendly. They contribute to making city centers more attractive.

ity to retain their positions as attractive and competitive places to do business.

The development of urban transit will continue to accelerate in the coming years. In particular, there is a push to encourage the private sector and individuals to contribute. For example, land owners around stations who make a contribution to transit development can benefit through the increased value of their land or business. I also think that we will see more road pricing schemes of the type implemented in London. In both cases, users are making an increased contribution to the external costs of their transport use, and in doing so supporting the further development of public transit.

The developing world presents a special challenge. There is little infrastructure in place and everything has to be developed from scratch. If we can support regional governments in proving that a metro will attract investment capital, bring additional jobs and increase tax revenues, this can help those governments secure loans and create a clear business case.

Smaller cities often require transit systems that are lighter and cheaper than metros.

Michael Clausecker: There are two tendencies. In Germany, some towns are introducing larger buses. Double articulated buses are relatively cheap and do not require special infrastructure. On the other hand, many new tramway projects are being realized across Europe and in the United States. Trams provide a higher capacity than buses, and don't share their downsides: They produce zero emissions at the point of use and are quieter. But they are not just environmentally friendly: They are also people friendly. Trams contribute to making city centers more attractive → 2. So we see a strong trend towards tramways even though competition from bus makers is very inventive in seeking to emulate these advantages at lower cost.

We are also seeing a sort of grey area between the two in the form of trams running on tires …

Michael Clausecker: Anything is possible, and if it serves its purpose it should be explored. When you compare trams with buses weight-wise, you can rightly ask whether they are facing the same safety requirements. It is difficult to predict how the market will develop, but the industry will not stop seeking ways of making its product lighter and more competitive.

Every kilogram we save and every bit of additional space we can provide to carry additional passengers leverages the train's overall economic and ecological advantage.

How about freight railways?

Michael Clausecker: Due to the economic downturn, freight operators have had to mothball many locomotives and wagons. The first challenge in the coming decade will be to return freight volumes to the levels of 2007. Only then can the equipment that has already been built be used to its intended capacity.

Another trend will be towards a greater international use of locomotives. The future will see more large rail operators, but also small companies providing transport across borders in Europe. This will call for more multi-system locomotives compatible with different voltages and signaling systems.

In other parts of the world, tendencies are more difficult to recognize. But wherever you look, locomotives are about efficiency and reliability and price. I'm sure that more and more customers will be concerned about energy consumption and overall lifecycle cost and as an industry we must be able to provide them with data that enables them to compare products and options.

Will increased competition raise the total volume of rail freight?

Michael Clausecker: Absolutely. Those countries in Europe that have really opened their networks to competition have seen traffic grown by between 60 and 130 percent over the last 15 years. Furthermore, usually over the last five to six years, rail freight has grown faster than road freight. Assuming that further countries will open their markets, we can count on a continuation of this strong growth over the next decade → 3.

3 Privatization and competition are leading to massive growth in rail freight: between 60 and 110 percent in the last 10 years.

4 The largest lever in to reduce transport emissions lies in shifting traffic from roads and air to railways.

If you compare the number of locomotives sold in the last decade, the number has practically tripled compared to the 1990s. Half of these locomotives are in the hands of customers that didn't even exist a decade ago. The opening of markets to competition is definitely growing the market for rail freight.

Despite this growth, rail freight in Europe remains low compared to the United States.

Michael Clausecker: We have different national markets, and the share of rail differs from country to country. Look at Sweden for example: a country which geographically speaking can be compared with the United States. Not in size of course, but in terms of population density. Rail freight has a market share above 30 percent – a figure comparable to the United States. However, the US is not Europe, and rather than being a continent with population concentrated along the East and West coasts, Europe has a much more distributed population. Transport distances are shorter making it more difficult for railways to compete with roads.

However, I'm sure that with markets opening and the development of more international, trans-European rail paths, we will see the market grow.

Rail is already one of the most environmental and sustainable means of transportation. What can the rail industry do to further reduce its carbon footprint?

Michael Clausecker: Let us put things into perspective. The largest lever in the hands of politicians today to reduce transport emissions undoubtedly lies in shifting traffic from roads and air to railways. These gains can be enhanced by technological improvements on the trains themselves, but the largest contributor remains the shift itself → 4.

What can rail itself do to improve its carbon footprint? The most important strategy here is electrification. It's not a surprise that if we look at the Unted Kingdom, for example, where the majority of railway lines are operated with diesel trains, we see that the government is thinking a bit more than other European governments about using electrification as part of its strategy to address climate change and provide real and sustainable solutions in the transport sector.

So in terms of energy efficiency, the ball is with the governments?

Michael Clausecker: Yes, but we have to support such strategies by developing more attractive products that help railways attract passengers and goods.

Concerning energy consumption, one great opportunity lies in capturing braking energy and using it for acceleration or storing it on the vehicle or along the lines.

Jean-Luc Favre: The most effective way to shift people from air and road to rail is to supply competitive and cost-effective solutions. When we are moving passengers at 350 km/h for example, every kilogram we save and every bit of additional space we can provide to carry additional passengers leverages the train's overall economic and ecological advantage. We will therefore continue to optimize our equipment in terms of space and weight, but also reliability and efficiency.

The number of locomotives sold in the last decade has practically tripled. Half of these are in the hands of customers that didn't even exist a decade ago.

Normally we consider (besides Japan), Europe as one of the pioneering regions for high-speed know how. Can these lessons be applied in other parts of the world?

Jean-Luc Favre: When it comes to technology for high speed and very high speed, Europe is dominating the market together with Japan. However, we are now seeing that in China, Chinese companies are developing their own high-speed trains. There was even a recent announcement that GE and a Chinese company were partnering to jointly develop high-speed corridors in North America. The market is developing quite well for newcomers.

So far we've looked at products and technologies. Another area that is growing in importance is service.

Jean-Luc Favre: There are markets where contracts do not only include the delivery of the vehicle, but also encompass the service for a period. But this tendency is not universal. There are many markets in which operating companies prefer to continue to do all maintenance in-house.

Looking at liberalization, newcomers are primarily interested in operating trains and moving people. They are therefore more open to outsourcing maintenance. On the other hand, incumbent operators typically have their own maintenance shops and staff. Understandably, outsourcing this kind of activity isn't a priority for them.

As far as our ability to offer service is concerned, ABB is in the unique position of being able to offer a global service network: We are Chinese in China, Indian in India and European in Europe.

Michael Clausecker: There is a differentiated picture between rolling stock maintenance and infrastructure maintenance. For rolling stock, the only examples of which I can think where industry did not just supply the vehicles but also provided the associated maintenance serve operators that are private companies. For us as manufacturers, involvement in service has helped better understand the performance of our vehicles in day-to-day service and close the feedback loop. This allows us to use the knowledge gained to make better product and ultimately benefit our customers.

The infrastructure industry is slightly different. A typical structure involves the customer having its own people for maintenance, but also tendering parts of the work out to third parties. So we are looking at a situation where we as suppliers are to some extent competing with our customers, creating a rather different business situation. As with rolling stock, we can provide value to our customers because we often know the product better than they do. By applying a mix of preventive and corrective maintenance we can reduce both costs and downtime.

What is ABB's role in, and contribution to UNIFE?

Michael Clausecker: ABB is a truly international and global company. This makes ABB's participation in UNIFE very valuable. ABB is still a relatively new member, and we at UNIFE and the other members are keen to benefit from ABB's experience in foreign markets and also to do business together. We are heavily involved in developing railway standards here in Europe and are pleased to have ABB's input and contribution, which I value.

Jean-Luc Favre: In 2005, ABB decided to develop its railway business. We've been incredibly successful in growing sales from 200 million in 2004 to 1.3 billion in 2009. We work closely with the industry's key players – Bombardier, Alstom, Siemens – who are European companies. For ABB, it's really important to be back in the railway market, working with these partners and participating in UNIFE. We joined in June 2009 and are now also one of the Brussels representatives of UNIFE members and also serve on the infrastructure committe of UNIFE. The strong message we want to send to this industry is that we are part of it and will be contributing to it in the long term. We have vital technologies including breakers, transformers, converters, semiconductors, motors, generators, turbochargers and fixed installations. We can supply electrification, AC and DC substations and their components. We can offer a global production and know-how footprint. For example, we are already producing transformers in North America, South America, China and India and are local in all those markets. These are the strengths of ABB as a global company and are just as applicable in the rail sector as they are in other sectors.

It may sound surprising, but as recently as 2002, even inside ABB hardly anybody knew what our involvement with railways was. We had excellent technologies but these were hardly known.

Where do you see the most significant current contribution to railway technology? What constitutes ABB's leadership?

Jean-Luc Favre: Our portfolio and footprint makes us unique on the market. We can work with all the different suppliers and benefit from a strong technology base. We have all the key technologies that are needed to bring traction power to the line and inside the vehicle. That is the main reason that we grew so fast over the last five years. We grew by more than 40 percent a year, more than 10 times faster than the market. Today, according to my calculations, we rank among the five major suppliers to the railway industry, supplying technologies to OEMs for end-users

Michael Clausecker: ABB helps keep this industry diverse. We have seen quite some consolidation in the rail supply industry. When we look at system integrators, there are rapidly growing manufacturers such as Stadler, CAF, and Talgo. These companies rely on independent suppliers of traction and propulsion technologies, and ABB is clearly a leader here, if I may say so. ABB is also important in terms of bringing technologies to the market, especially in view of its global approach which is helping experienced European companies in offering their technologies to a world-wide market.

> The largest lever in the hands of politicians today to reduce transport emissions undoubtedly lies inshifting traffic from roads and air to railways.

Jean-Luc Favre: Exactly. We are not only able to support our partners in Europe but also to work with them in China for example. We started to do business there with Alstom in 2004, because they needed to localize traction transformers. Our supply to Alstom was limited before that, but now we have become important partners.

ABB is a large and diverse company. It has a global power and automation business and a lot of experience and know how in a broad range of fields. Do you see any areas in which the rail business can benefit from this broader knowledge base?

Jean-Luc Favre: Most certainly. Let us look at traction motors, for example: When we decided to design a new traction motor, we could draw on the motor technology and business of ABB, a business of $2 billion. Similarly, we benefit from having a global supplier base. We use the same suppliers and also the same ABB factories for industrial motors as we do for traction motors. If we look at transformers or converts we see a similar picture.

Do you think the rail industry can learn from the automotive industry?

Michael Clausecker: We can always learn, but we must not copy blindly. We looked at the auto industry when we were reconsidering quality management in our own industry, but then actually benchmarked our system to that of the aviation sector. We are in a position to look at different industries and cherry pick the methods that are most applicable to us.

It is interesting to observe that many people in our industry are coming out of the automotive industry: management and purchasing organizations for example.

One difference between our industry and automobiles is that the lot sizes we work on tend to be much smaller. We try to counter that by platforms and standardization (strategies also found in car manufacturing). This helps us create product platforms which we no longer sell only in one country but sometimes across the globe. The key here lies in the clever design of the product platform permitting it to meet different standards (obviously the international standardization of those requirements is also a goal worth pursuing). As common railway standards are agrred on here in Europe, more and more countries in the world are copying them or using them as a reference, hence the importance of our work in this area. We have seen China, for example, adopting many of our railway standards. For example, the Chinese have adopted the ERTMS [3] specification for signaling on new high-speed lines. They selected ERTMS because it is the best developed standard in the world and because a large number of companies across the world can offer products

Michael Clausecker is Director General of UNIFE.
Jean-Luc Favre is CEO of ABB Sécheron and Head of ABB Rail Sector.
This interview was conducted by
Andreas Moglestue of *ABB Review*.
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Footnote

3 ERTMS (European Rail Traffic Management System) is a European initiative working towards a single standard for signaling and train control systems.

Michael Clausecker, UNIFE Director-General

Born in Stuttgart, Germany in 1966, Michael Clausecker studied business economics and began his professional career at Daimler-Benz, subsequently moving to the German Privatisation Office. In 1993 he was appointed Managing Director at DWA Deutsche Waggonbau AG, later Bombardier Transportation, and led it to become the leading rail freight car manufacturer in Europe. 1999 saw Clausecker become Head of Division at Siemens AG in Erlangen and Munich with worldwide responsibility for locomotives. In 2001, he was appointed Managing Director of the German rail supply industry association – VDB and in early 2007, Clausecker was appointed Director-General of UNIFE. Michael Clausecker holds an MBA from the Open University in the United Kingdom.

Jean-Luc Favre, Head of ABB's railway business and CEO of ABB Sécheron

Born in Thonon, France, in 1962, Jean-Luc Favre began his professional career as electrical engineer at BBC. Following a three-year experience at IBM, he was appointed manager of the transformer business at ABB Sécheron SA in Geneva. In 2001 he became General Manager of the company and was appointed Head of ABB's railway business in 2005. Jean-Luc Favre holds a degree of electrical engineering from the Federal Polytechnic School of Lausanne.

On the fast track

ABB is contributing to high-speed trains

PASCAL LEIVA, MELANIE NYFELER – The importance of mobility is growing. It is becoming more and more common for people to travel distances of hundreds of kilometers between major cities for work or leisure. This is increasing pressure on motorways, railways and short-haul flights. Concerns over carbon emissions and congestion of road and air space are causing many countries to reassess their transportation policies. Studies show that traveling by rail requires a quarter to one-third the CO_2 of the same trip by plane or car[1]. High-speed trains are particularly effective at taking pressure off short-haul flights and bringing cities closer together.

13,469 km of high-speed lines are under construction and 17,579 km are planned. The world's high-speed network could reach 41,787 km by 2020.

The Eurostar service through the Channel Tunnel cut journey times between Paris and London to 2 hours 15 minutes and now represents 70 percent of the travel market between the two capitals [1]. The Madrid-to-Barcelona high-speed link reduced intercity travel time to 2.5 hours and grabbed 50 percent of the market. High-speed trains have scored similar successes on the Paris-Lyon, Paris-Brussels and Hamburg-Berlin lines (among others). In the wake of these successes, governments across the world are seeking to invest in high-speed railways.

Speed ≥ 250 km/h

High-speed trains can offer numerous advantages: These include reduced journey times, increased frequency, comfort, safety, reliability and less environmental impact. The International Union of Railways (UIC) defines high speed as operations of at least 250 km/h (the maximum speed for conventional lines is 200 to 220 km/h). Typical attributes of high-speed trains are:

- Use of train sets rather than conventional locomotive and cars formations. These offer better power-to-weight ratios, aerodynamic conditions, reliability, safety, etc.
- Use of dedicated high-speed lines on at least part of the journey. Such lines are built to sustain high speeds (through their choice of transverse sections, track quality, catenary, power supply, special environmental conditions, etc.) However, one strength of high-speed trains is that they can also operate on conventional lines with certain restrictions [2], so reducing the necessary investment or permitting a phased introduction.
- Use of advanced signaling systems, including in-cab signaling.

Development of high speed trains

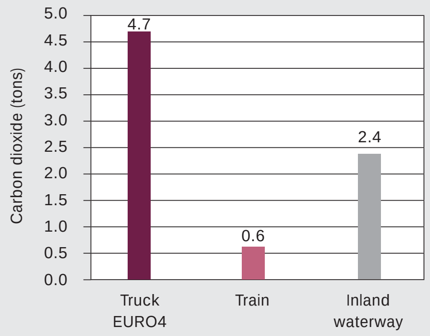
As early as 1903, a speed of 210 km/h was attained using an experimental three-phase electrification in Germany, demonstrating the aptitude of electric traction for high speeds. In 1955, a series of tests in France culminated in a record of 331 km/h. Notably, the trains and catenary used were closely based on equipment that was used in everyday service. This demonstrated the safety margins of the technology and indicated the feasibility of the commercial operation of high-speed trains.

Day-to-day speeds, however, remained much lower, with the fastest trains operating at top speeds of around 160 km/h ➔ 1. The first commercial train that can be considered high speed in the modern sense is the Japanese Shinkansen. It was inaugurated in 1964 on the 515 km line between Tokyo and Osaka, and initially operated at a top speed of 200 km/h (increased to 210 km/h the following year). This route is still the world's busiest high-speed corridor, carrying more than 360,000 passengers every weekday. Today, Shinkansen trains oper-

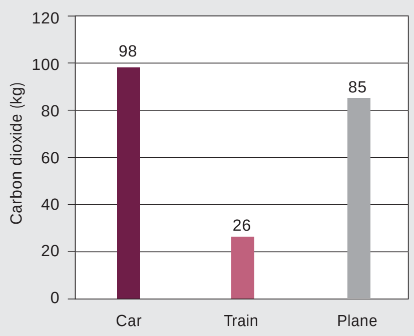
Footnote

1 The environmental impact of a journey in Europe can be calculated on www.ecopassenger.org.

Environmental performance of rail



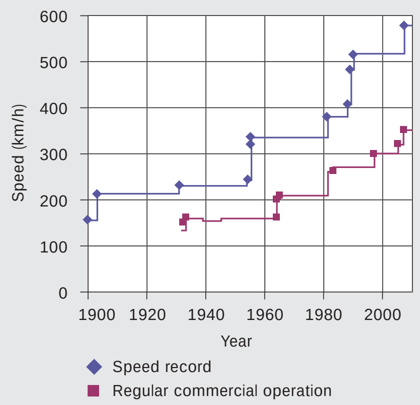
CO_2 emissions by transport type
(100 tons cargo, Basel – Rotterdam, 700 km)



Carbon dioxide (CO_2)
(2 people, Berlin – Frankfurt, 545 km)

Source: www.ecotransit.org, 2008

1 The development of high-speed rail



ate at a top speed of 300 km/h, with higher speeds being planned.

France inaugurated its first TGV (Train à Grande Vitesse) train in 1981, connecting Paris and Lyon (417 km). The initial maximum speed of 260 km/h has incrementally been raised to 320 km/h. At 1,900 km, France today has Europe's largest high-speed rail network. There are plans to increase this to 4,000 kilometers by 2020. SNCF, RFF [2] and Alstom Transport hold the world speed record of 575 km/h, achieved on a test run in April 2007.

> ABB has strategic alliance contracts with many rolling stock manufacturers including Alstom, Bombardier, CAF, Siemens, Skoda and Stadler.

Spain, however, plans to surpass France's high-speed network in terms of length. It is envisioned that by 2020, 90 percent of all Spaniards will live within 50 km of a station served by AVE (Alta Velocidad Española) trains. The top speed of these trains will be 350 km/h.

Today, Belgium, France, Germany, Italy, Spain, the United Kingdom, Taiwan, Japan, Korea and the United States have high-speed lines in operation. China, Iran, the Netherlands and Turkey have systems under construction and Argentina, Brazil, India, Morocco, Poland, Portugal, Russia and Saudi Arabia have systems under development. Globally, there were 10,739 km of lines for 250 km/h or greater in 2009, with almost 1,750 train sets in service [3]. A further 13,469 km of lines are under construction and 17,579 km are planned. The world's high-speed network could reach 41,787 km by 2020 [4].

ABB has been playing a major role as a supplier to the railway industry for several decades. Drawing on its expertise in the power and automation sectors, the company is contributing reliable and cost-efficient solutions for both infrastructure and rolling stock.

Infrastructure

ABB designs, engineers, constructs and commissions complete traction power supply products, systems and solutions. The company supplies a comprehensive range of traction substations containing all the necessary switchgear and fault analysis equipment. ABB's portfolio includes:

- Products for traction power supply applications
- Traction substations for AC and DC applications
- Static frequency converter stations.
- Power quality systems
- Network management systems
- System analysis and dynamic traction power supply simulations

Static frequency converters

Much of the electric energy used by railways is drawn from national grids. However, for historical reasons, the frequencies used for railway electrification often differ from these grids. The state-of-the-art solution is converters using power electronics → 3.

FACTS for power quality

Modern traction systems present demanding challenges to supply grids. Usually, the single-phase railway supply is connected between two of the three phases of the national grid. It can hence cause a substantial imbalance in a network not originally built for this kind of operation.

ABB offers different solutions to maintain power quality in grids. Dynamic shunt compensation devices of the SVC or STATCOM types use power semiconductors to control reactive power. Thanks to their cycle-by-cycle controllability, they can counteract even the most rapid voltage transients and protect the grid from serious voltage variations. Additionally, they can control the grid's voltage profile and raise its stability limit, enhancing grid capacity while making it more robust, flexible and predictable.

A total of four SVCs have been supplied for the Channel Tunnel Rail Link (the high-speed line linking the Channel Tunnel to London). Each of the three feeding points is supported by an SVC on the traction side of the transformer. The

Footnote

2 SNCF (Société Nationale des Chemins de Fer Français) is the French national railway company. RFF (Réseau Ferré de France) is the French railway infrastructure agency.

2 Transformers for Spanish high-speed lines

ABB won the contract to supply all transformers for the Barcelona-Figueras section of the AVE line that will connect Madrid via Zaragoza and Barcelona to the French border. These transformers will be located in the substations along this section at Baro de Viver, Riudarenes and Santa Llogaia.

The contract was awarded by the SILFRA-SUD consortium, made up of Siemens and Inabensa, and consisted of four transformers of 60 MVA, 405 / 27.5 kV produced in ABB's Cordoba factory and two transformers of 60 MVA, 220 / 27.5 kV made in ABB's Bilbao factory, Spain.

Since 1990, ABB has supplied a total of 85 transformers for high-speed lines all over Spain, and it is also the selected supplier through a frame agreement signed with ADIF (the Spanish rail infrastructure administrator), which covers the supply of traction transformers until 2014 and includes 52 additional units.

3 Static frequency converter projects

ABB is currently realizing the world's largest and most powerful static converter system in conjunction with E.ON Kraftwerke GmbH of Germany. This converter system is rated at 413 MW and connects the 50 Hz national grid to the 16.7 Hz railway grid. The completion of the order is scheduled for 2011. Other static frequency converters supplied to German Railways include the eight 15 MW units at Limburg supplying the high speed line between Cologne (Köln) and Frankfurt am Main. Converters have also been supplied to the Austrian and Swiss railway operators.

For more information on these projects, please see "Static converters, dynamic performance" on page 42 of this issue of *ABB Review*.

fourth SVC is used for load balancing. This technology is discussed more fully in "Knowing the FACTS" on page 35 of this issue of *ABB Review*.

Transformers

A high-speed train can draw considerable power, especially while accelerating. Transformers convert the grid voltage to the correct line voltage for the railway ➔ 2.

Rolling stock

Manufacturers of high-speed trains are continuously refining their designs to meet rising demands in terms of performance, efficiency and reliability, and are placing similarly high demands on their suppliers. In recent years, ABB has extended its expertise for traction transformers and is now the world leader in this field. The company has strategic alliance contracts with the rolling stock manufacturers including Alstom, Ansaldo Breda, Bombardier, CAF, Siemens, Skoda and Stadler. Various types of traction transformers have been designed and delivered to practically all railway integrators and are in use all over the world.

Traction transformers

A traction transformer is a key component of a train's onboard traction chain. Special criteria it must fulfill include:

– It is a single transfer point for energy between catenary and motors, and must therefore meet high reliability levels.
– It must be compact in terms of size and weight.
– Many transformers must deal with multiple voltages and frequencies due to the different electrification systems used across Europe (and sometimes within one country).

An ABB traction transformer was used on the record-breaking AGV train that attained 575km/h in April 2007, ABB is supplying traction transformers for the high-speed trains of Alstom (AGV) ➔ 4, Siemens (Velaro) ➔ 5 and Bombardier (ZEFIRO) ➔ 6.

The evolution of market requirements has led to the following situation: While "classical" European high-speed trains such as the ICE-1 and the TGV are powered by dedicated power units at the ends of the train, the new generation of high-speed trains such as the Velaro and the AGV use traction distributed along their entire lengths. This permits a better use of adhesion due to the lower power required per axle. Furthermore, by placing the complete traction chain under floor (including transformers, converters, motors and control equipment), practically the full length of the train is available for passengers (a gain of up to 20 percent). The transformers ABB is supplying for both AGV and Velaro are compatible with Europe's main railway voltages and frequencies.

> An ABB traction transformer was used on the record-breaking AGV train that attained 575 km/h in April 2007.

Traction converters

ABB has supplied traction converters for the retrofit project of DB's (German Railways) ICE-1. This is discussed in the inset on page 76.

Motors

Together with Bombardier, Ansaldo Breda, Alstom, and Firema, ABB is part of the Trevi Consortium supplying the ETR 500 to Trenitalia (Italian railways). Trenitalia chose to electrify its new high-speed lines at 25 kV AC rather than the 3 kV DC used on the classic network. Therefore, between 2006 and 2008 the 3 kV ETR 500 fleet was upgraded for dual voltage capability. In February 2006 the trains commenced regular service at a commercial top speed of 300 km/h on the new high-speed lines connecting Milan to Turin, Florence, Rome and Na-

4 AGV: Transformation at speed

SNCF, RFF and Alstom Transport broke the world speed record for classical wheel-on-rail technology in a test run on April 3, 2007, during which the train reached 575 km/h. The new generation of AGV-trains (Automotrice à Grande Vitesse) of Alstom Transport will attain commercial speeds of 360 km/h. An increased use of composites and aluminum allowed Alstom to make the AGV lighter: An entire train weighs 395 t (compared with 430 for a TGV) and uses 15 percent less power.

The first new AGV train will enter service in late 2011 in Italy and be operated by a new private company: NTV (Nuovo Transporto Viaggiatori). NTV has ordered 25 trains.

Picture: Alstom Transport

5 Velaro: The new generation

In June 2009, Siemens Mobility selected to use ABB transformers for their flagship Velaro high-speed train for DB (Germany Railways).

Two traction transformers will be fitted to every eight-car train. In order to reduce weight, the secondary windings of these transformers also serve as line inductances for the power converters when the train is operating under a DC power supply.

See also "High-speed transformation: Transformers for the Velaro high-speed train" on pages 64–67 of *ABB Review* 4/2009.

Picture: Siemens press picture

6 Orders for China, Spain and Italy

In September 2009, Bombardier Transportation announced that its Chinese joint venture, Bombardier Sifang (Qingdao) Transportation Ltd., was to supply 80 ZEFIRO 380 km/h high-speed trains for the country's rapidly growing high-speed rail network *. ABB will supply the traction transformers.

ABB Sécheron also supplied the traction transformers for the AVE high-speed trains that Bombardier is jointly producing with Talgo (Talgo/Bombardier AVE102 and Talgo/Bombardier AVE130) for RENFE (Spanish Railways) and for the ETR 500 for TrenItalia (Italian Railways).

Picture: Bombardier press picture

Footnote

* See also "China's rail revolution" on the following pages.

ples. ABB delivered more than 280 traction motors for the ETR 500. For more information on ABB's traction motors, see "Standardizing the traction motor" on page 66 of this edition of *ABB Review*.

Fast growing market

Looking at present orders and deliveries, 2,500 high-speed trains capable of running at over 200 km/h will be in operation

> 2,500 high-speed trains capable of running at over 200 km/h will be in operation worldwide by the end of 2010.

worldwide by the end of 2010. China alone has 10,000 km of new high-speed lines under construction and an additional 3,000 km are planned [4]. The western European market is also still growing, and the replacement of first-generation high-speed trains will commence soon in France and Germany. Developments in the eastern European, South American and North African markets are also likely to lead to growth in the high-speed market. In the United States, President Barack Obama has vowed to spend $13 billion over five years to develop high-speed rail links between major cities. The outlook for high-speed rail is bright.

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China's rail revolution

ABB technologies are helping transform China's rail network into the fastest and most technologically advanced high-speed railway system in the world

CÉCILE FÉLON, FRÉDÉRIC RAMELLA, HARRY ZÜGER – Rail is perhaps the principal means of transporting large numbers of people and goods in China. However, for many decades rail journeys tended to be long and very uncomfortable. In addition, the geographical vastness of the country meant millions simply had no access to any form of rail travel. Then along came decades of strong economic growth that brought with it a desire to open the country up to further development and trade. While this growth has created a middle class who is considerably wealthier than the generations before, the downside is that many have abandoned the bicycle in favor of the car. The result is serious traffic congestion and an increase in China's already fast-growing greenhouse gas emissions.

In addressing these issues, the Chinese government has been generously funding the upgrade of conventional railway lines, and the construction of tens of thousands of kilometers of high-speed passenger lines since 2004. Many home-grown and imported technologies, some of which have come from ABB, are employed to supply a rail network that will be the envy of many countries when it is completed. ABB is the leading supplier of power products – in particular traction transformers and switchgear – to the Chinese electric locomotive segment. The company's strengths and technology leadership are well recognized by its partners in the global rail industry and are fully demonstrated in a variety of projects discussed in this article.

1 Leading-edge BOMBARDIER ZEFIRO technology enables operating speeds of 380 km/h. Source: Bombardier pictures press

Over the years, countries such as Japan, Italy, France, Germany, Spain and South Korea have developed incredibly speedy train networks. This list can now be extended with the addition of China. In fact as of December 2009, China can boast the fastest express train in the world on what is considered the longest high-speed track on the planet at 1,068 km. The train runs from the central city of Wuhan, through the provinces of Hunan and Hubei and down to Guangzhou at the south coast at a top speed of 350 km/h, transforming a 10.5 hour journey into one that takes no more than three hours!

This is but one example that demonstrates the continuing success of China's ambitious and rapid high-speed rail development program. As the country's economy and population continue to expand, the need to spread economic development is an important goal that is best achieved if a proper and speedy rail network is in place. When the major rail lines are completed by 2020, it will become the largest, fastest and most technologically advanced high-speed railway system in the world.

According to China's "Middle and Long Term Railway Network Development Plan" the total operating rail network will exceed 120,000 km by 2020, and the percentage of double tracks and electrified railways will surpass 50 and 60 percent respectively. China will complete construction of four north-south and four east-west passenger lines, as well as intercity passenger rail networks connecting developed and densely populated areas, with the total length of high-speed passenger lines topping 18,000 km by 2020. Almost three-quarters of this or 13,000 km (8,000 km of which will be 350 km/h lines) is expected to be completed by 2012 [1].

The Chinese government has been generously funding the upgrade of conventional lines, and the construction of tens of thousands of kilometers of high-speed passenger lines since 2004.

China's high-speed trains use a wide range of domestic and imported technologies from around the world. For its part, ABB has supplied and will continue to supply advanced power solutions to support China's vigorous railway and urban metro construction efforts.

Transforming rail transport

To begin with, equipment, such as ABB's well-known and innovative traction transformer, has been installed in many of China's locomotives and electric multiple unit (EMU) trains. These transformers are high capacity, compact and light-weight, and are highly resistant to mechanical impact and heat resistance, which in turn makes them very reliable. As essential components of a train, the transformers also contribute to the energy efficiency of rail transportation.

ABB traction transformers first entered the Chinese railway market in 2004 when they were selected for Bombardier's Regina trains, more popularly known in China as CRH1A and CRH1B [1]. ABB delivered traction transformers for the CRH1A and CRH1B [2] EMU trains that

Footnotes

1 CRH refers to high-speed trains. The number succeeding these three letters is a reference to the company supplying the train, and in this case "1" represents Bombardier Transportation while "3", for example, indicates the train was manufactured by Siemens. The letter(s) or number(s) that follow – A and B in this instance – refer to the different versions of a train.

2 Most CRH1 trains were allocated to the Guangshen Railway to replace all locomotive-hauled trains between Guangzhou and Shenzhen in Guangdong Province. Some are also used on the Shanghai–Nanjing rail line.

2 ABB's traction transformer are used for Siemen's Velaro high-speed platforms.

can reach speeds of up to 250 km/h (155 mph) in regular service. In September 2009, Bombardier Sifang Power won a further contract to supply the Chinese Ministry of Railways with 80 Zefiro 380 very high-speed (VHS) trains [3] → 1. A total of 1,120 rail cars will be built for China's 6,000 km of new high-speed railways and ABB will supply the traction transformers for all these trains.

> ABB's well-known and innovative traction transformer has been installed in many of China's locomotives and electric multiple unit (EMU) trains.

ABB traction transformers can also be found on some of Siemens Mobility Velaro high-speed platforms (trains) → 2. Known as the CRH3-380, these trains are capable of service speeds of up to 380 km/h and can be seen on the Beijing-Tianjin [4], Wuhan-Guangzhou and Zhengzhou-Xi'an dedicated passenger lines. The transformers were supplied by ABB Datong Traction Transformers Co. Ltd. [5] (CNDAT), after being awarded the contract by Tangshan Railway Vehicle Co. Ltd. (TRC) and Changchun Railway Vehicle Co. Ltd. (CRC), two of the main train makers in China's railway market.

In 2009, ABB was contracted by Datong Electric Locomotive Co. Ltd. (DELC) to assemble traction transformers for the CRH2 (a modified E2-1000 series Shinkansen design from Japan) and to manufacture traction transformers for the CRH5 EMU trains (manufactured by Alstom and Changchun Railway Vehicles). Also in 2009, ABB was contracted to upgrade the traction transformer design for the Kawasaki-derived CRH2-380, an EMU train capable of speeds of up to 380 km/h.

Growth in freight transportation

A growing economy requires better and faster rail freight transportation if such growth is to be sustained. To meet this demand, the Ministry of Railways has also been enhancing its railway freight transportation capacity by increasing and upgrading its entire freight network, with of course the support of ABB → 3.

In 2005, Alstom and DELC signed a 350 million euro contract to manufacture a total of 180 electric 8-axle locomotives HXD2 [6]. This type of locomotive, used by the Daqin railway company Ltd., transports coal to power plants and factories around China. The first HXD2, also known as BoBo, was completed in December 2006 and arrived in TianJing in January 2007. Also in 2007, these two companies signed another contract worth 1.2 billion euros for the delivery of 500 HXD2B electric 6-axle locomotives. The HXD2B locomotive, also called CoCo in China, was designed by Alstom.

The traction transformers for both the HXD2 and HXD2B locomotives were supplied by ABB to Alstom, in a repeat of what have been past and successful ABB/Alstom collaborations → 4. And finally, ABB will also supply traction transformers for Alstom's HXD2C electric locomotives in the near future.

Switching into gear

Traction transformers are not the only power products supplied by ABB. For the Wuhan-Guangzhou high-speed rail project, ABB supplied a series of other products, including its 27.5 kV ZX1.5-R and 10 kV ZX0 GIS switchgear, as well as the SAFE-series SF_6 insulated switchgear that are used in the railway signal system power supply → 5. The ZX1.5-R GIS switchgear are modular and flexible single busbar two-phase panels and were specially designed at ABB China's medium-voltage technical center to address the highly specific railway power supply requirements of China's electrified high-speed railways. Manufactured by ABB Xiamen Switchgear Co. Ltd., ZX1.5-R GIS switchgear use up to 70 percent less space than other conventional products. Insulation is provided by SF_6, which is well known for its remarkable physical characteristics, especially its excellent insulating capacity. With fewer maintenance requirements, customers are able to lower their total investment and operating costs. Their deployment in substations will help provide safe and reliable power along the entire rail line.

Footnotes

3 The Zefiro 380 very high-speed (VHS) trains are based on Bombardier's Regina family

4 The first three 380 km/h EMU trains went into operation on the Beijing-Tianjin dedicated passenger line prior to the opening of the Olympic Games in Beijing in 2008.

5 ABB Datong traction transformer Co. Ltd. (CNDAT) was founded in 2005 and is a joint venture between ABB (China) Ltd. and Datong Electric Locomotive Co. Ltd.

6 Until now, the HXD2 locomotive has been considered the best – in terms of power (10,000 kW) and speed (maximum of 120 km/h) – heavy-load freight train in China.

3 Some passenger and freight railway facts and figures for China

- Some 33,300 freight trains running everyday transported approximately 3.3 billion tons of merchandise in 2007.
- Each year, the transport of goods, such as coal, iron and food increases by about 200 million tons
- In 2008, 68 new projects were started to develop 11,306 km of (freight and passenger) railway.
- At the end of 2008, there were 18,437 locomotives in China, including 6,305 electrical locomotives.
- At the end of 2009, the length of the rail network in China was 86,000 km. By 2012, it is expected to increase to 110,000 km.

4 Alstom's HXD2B electric locomotive. Source Alstom Transport pictures press

As well as traction transformers, ABB supplied its 27.5 kV ZX1.5-R and 10 kV ZX0 GIS switchgear, as well as the SAFE-series SF_6 insulated switchgear for the Wuhan-Guangzhou high-speed rail project.

The very same switchgear are also used in the Zhengzhou-Xi'an express passenger line, which spans 485 km and is capable of supporting a top speed of 350 km/h. The travel time between the two cities, Zhengzhou in central Henan and Xi'an in the northwestern Shaanxi province, has been slashed from six hours to less than two. The line, part of a major east-west railway artery between Xuzhou in Jiangsu province and Lanzhou in Gansu went into operation in February 2010 [2]. In addition to the Wuhan-Guangzhou and Zhengzhou-Xi'an express passenger line projects, ABB has also participated in the Wuhan-Hefei, Shanghai-Hangzhou, Shanghai-Nanjing, Ningbo-Taizhou-Wenzhou, Wenzhou-Fuzhou, Fuzhou-Xiamen and Guangzhou-Shenzhen-HongKong line projects. In the urban metro sector, ABB has contributed to metro and light rail construction projects in Beijing, Shanghai, Guangzhou, Shenzhen, Nanjing and Changchun.

Sharing knowledge

In January of this year, ABB announced it would set up the ABB Electrified Railway Training Center in cooperation with Beijing Jiaotong University [7] → 6. The center, complete with advanced railway traction power equipment donated by ABB, will support the development of the high-speed electrified railway industry in China by providing teaching, scientific research and training facilities for both the technical personnel employed by the Ministry of Railways, and teachers and students of the university. It will also organize exchange activities to share leading rail technology with other institutes.

According to the agreement, ABB will donate advanced railway traction power equipment, including gas-insulated switchgear, vacuum circuit breakers, insulated ring main units and models of box-type substations specially designed for railway use. In addition, ABB's senior technicians will provide training on a regular basis. After its establishment, the center, affiliated to the Electric Traction Education Department, will serve as the university's engineering research center.

Pierre Comptdaer, vice-president of ABB China, said that "ABB ... closely cooperates with a number of nationwide universities. Working with the country's leading universities not only bolsters innovation at ABB, but also helps to cultivate new talent for the development of many industries." Chen Feng, vice-president of Beijing Jiaotong University, added that "Cooperation on electrified railway training ... promotes vocational training while improving our ability to conduct leading edge research. The training center will allow us to ... support the rapid development of China's railway construction."

Footnote

7 Beijing Jiaotong University, under the jurisdiction of the Ministry of Education, is an official training school of the Ministry of Railways and is famous for its innovations in railway technology.

5 ABB's ZX1.5-R gas insulated medium-voltage switchgear for railway application

6 ABB and Beijing Jiaotong University set up the Electrified Railway traing center

Pierre Comptdaer, Vice President of ABB China (left), Chen Feng, Vice President of Beijing Jiaotong University (right)

7 The International Railway Industry Standards (IRIS)

ABB Sécheron, ABB's center of excellence for power products for the rail sector and ABB Datong Traction Transformers Co. Ltd. are both certified by the International Railway Industry Standards (IRIS). IRIS is an internationally recognized standard for the evaluation of railway industry management systems. It was developed by UNIFE, the Independent Association of European Railway Industries, and is supported by system integrators, equipment manufacturers and operators such as Bombardier Transportation, Siemens Mobility, Alstom Transport and Ansaldo Breda. An interview with the Director General of UNIFE, Michael Clausecker, can be found on pages 8 to 13 of this issue of ABB Review.

IRIS Certification

This is not the first collaboration between ABB and a Chinese university. In fact, ABB has consistently supported education in China to ensure the availability of highly skilled technicians. For example, in 2008 the company set up the ABB Power Technology Education Center in Tongji University and supplied it with a complete set of transformer substation and feeder automation products as well as primary products, such as medium-voltage switchgear, a ring main unit (RMU) and outdoor products, to encourage more advanced teaching and research. In addition, ABB also cooperates with Tsing-Hua University, North China Electric Power University, Tianjin University, Shanghai Jiaotong University and Chongqing University on various research projects.

The ABB Electrified Railway Training Center, in cooperation with Beijing Jiaotong University, will support the development of the high-speed electrified railway industry in China.

Being connected

By improving connections, China's high-speed rail network will no doubt make travel available to ever larger numbers of people. In fact, high-speed rail is likely to be just as fast as air travel at half the price! According to Si Xianmin, chairman of China Southern Airlines, the largest domestic airline by fleet size, "High-speed rail has three advantages over air travel: it is more convenient, more punctual and has a better safety record. This could help erode the airlines' market shares."[3] In addition, a good rail network may help spread economic development more quickly and evenly around the country.

The success of ABB in the Chinese Railway market is based on the close cooperation between ABB Sécheron and ABB Datong → 7. While ABB Sécheron is the global leader in design, research and development, marketing and sales as well as service of power products for the rail sector, ABB Datong focuses on the production of traction transformers for the Chinese market. ABB is currently positioning itself in the Chinese EMU market to become the supplier of choice of power products and systems for China's increasing number of commuter trains.

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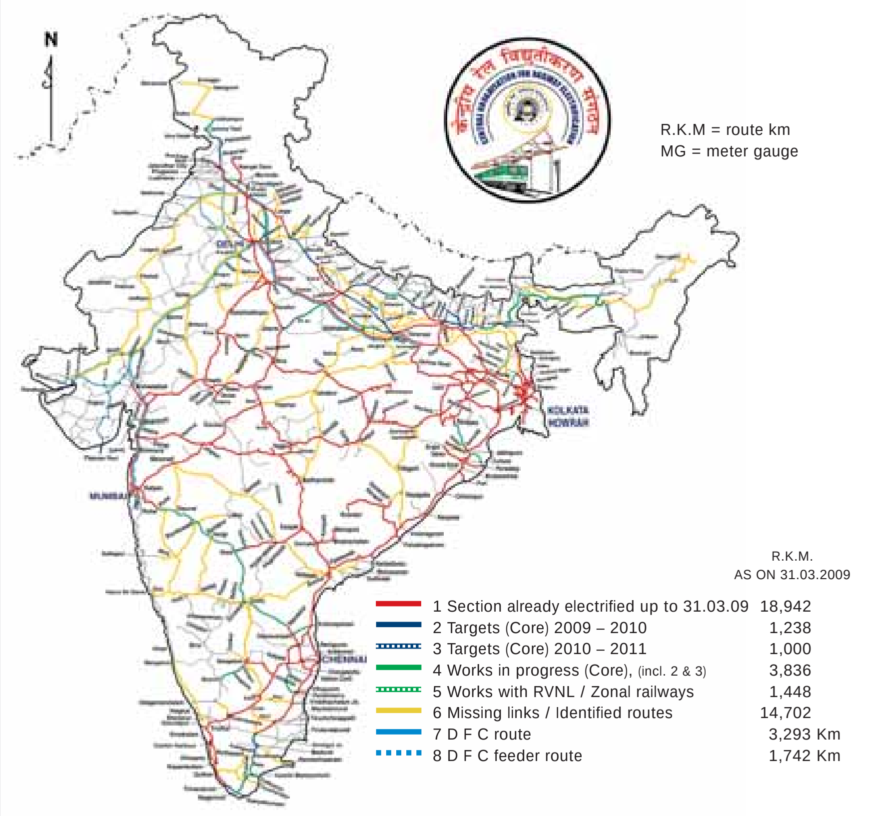
Greener rail for India

ABB is helping upgrade India's railways

LALIT TEJWANI – Since India's (and indeed Asia's) first train steamed from Mumbai in 1853, India's railway network has grown to more than 64,000 route km. It now transports approximately 2.5 million tonnes of freight and 19 million passengers every day. This article looks at some of the developments that are preparing India's railways for the future, and shows how ABB's technologies can make railways greener and more efficient.

1 Indian Railways electrified routes as of 31, March 2009

Status of electrification on Indian Railways



Planwise progress of electrification ob IR (First electric train started on 3.2.1925)

Plan Period	Pre. Indep. 1925-47	1st 1951-56	2nd 1956-61	2rd 1961-66	Annual plan 1966-74	4th 1969-74	5th 1974-78	Inter plan 1978-80	6th 1980-85	7th 1985-90	Inter plan 1990-97	8th 1992-97	9th 1997-2002	10th 2002-2007	11th up to 31.3.09
R.K.M. Electrified	388	141	216	1,678	814	953	533	195	1,522	2,812	1,557	2,708	2,484	1,810	1,299
R.K.M. Cumulative	388	529	745	2,423	3,237	4,190	4,723	4,918	6,440	9,252	10,809	13,517	16,001	17,811	18,942*

* 168 R.K.M. MG electrified line dismantled

Source: http://www.core.railnet.gov.in/_MapElectrificationofIR_eng.htm

Indian Railways (IR) is one of the world's largest railway systems under single management and the largest employer in the world with approximately 1.4 million staff. Organizationally IR is owned and controlled by the Government of India. Day-to-day operations are managed by the Railway Board. In addition to being a rail operator, IR is unique compared with other major rail operators in having its own rolling stock manufacturing facilities. IR manufactures approximately 3,000 coaches annually as well as 500 diesel and electric locomotives, and major aggregates such as wheels, axles and traction motors.

As of March 31, 2008 IR's fleet consisted of 47,375 passenger coaches, including EMUs (electric multiple units). There are almost 8,400 locomotives in operation, 3,400 of which are electric. Electric trains currently account for more than 65 percent of freight traffic and over 50 percent of passenger traffic.

Sustainable growth

Development of the railway network has gained higher priority in recent years due to urbanization, mobility issues and severe road congestion. Rail transportation is far more energy efficient, economical in land use and cost-efficient than road transportation. Among the various modes of rail transportation, electric traction has established itself as the most energy efficient. Since 1925, when India's first electric train ran in Mumbai, there has been a major push for electrification: As of March 31, 2009, IR had electrified 18,942 route km, which is 28 percent of the country's total railway network. The target is to electrify 1,500 km of existing lines every year ➔ 1.

On main lines, electrification has permitted the operation of heavier freight and faster passenger trains. By virtue of their high acceleration and braking capability, EMUs are ideal for suburban services [1]. Another important catalyst for electrification has been India's will to reduce its dependence on costly imported fossil fuels. By centralizing the generation and distribution of energy, electric traction furthermore offers the advantage of reduced air and noise pollution for travelers and the environment.

India's early electrification projects used DC, but since the 1950s, all new projects have used single-phase 25 kV / 50 Hz. IR draws its power from the 220 / 132 / 110 / 66 kV / 50Hz three-phase regional grids, converts it for traction power requirement and supplies it to trains using overhead line (OHL) electrification. Currently, IR consumes more than 2,000 MW of power, mainly through a national network of 400 traction substations.

Since 1980, IR has been automating its substations with microprocessor-based Supervisory Control and Data Acquisition (SCADA) systems to permit their remote

Footnote

1 Electric multiple unit (EMU) refers to coaches used for (mostly suburban) train services that have multiple prime movers for each car. The same car that carries passengers also has integrated motive power, as opposed to the normal situation where the passengers are in coaches that are not self-propelling and a locomotive hauls the train.

control and operation. A divisional SCADA facility can control a region extending some 200 to 300 km. SCADA allows remote monitoring of electrical parameters (voltage, current, power factor, etc.) in real time and the remote operation of switchgear, as well as automatic fault detection and isolation. This facilitates better control of demand peaks, troubleshooting, etc. SCADA is replacing an older system that was based on electromechanical remote-control apparatus.

ABB's contribution

Challenges that IR is currently faces on many of its electrified lines include the following:

- Wide voltage variation between 17 and 31 kV, mainly due to the line impedance varying with the position of trains
- Poor power factor (in the range of 0.7 to 0.8) caused by the inductive nature of the traction load, and the ineffectiveness of existing fixed capacitor banks to adequately compensate dynamic loading
- Low-order harmonics injected into the traction network by conventional locomotives using DC traction

These characteristics cause high system losses, reactive power absorption, and interference with sensitive electronics in signaling and telecommunication equipment. ABB is deploying state-of-the-art technology to address these issues and improve overall efficiency and availability.

Traction transformers

AC electric locomotives and EMUs draw power from the single-phase 25 kV OHL, and then convert it to a lower voltage for the traction motors using the traction transformer. Besides high demands on reliability and performance, traction transformers must also be compact and lightweight and display high efficiency. ABB is the world's leading manufacturer of traction transformers, and can supply them for different sizes, shapes and power ratings, permitting installation in different parts of the train ranging from the roof to the under-floor area [2]. In India, ABB traction transformers are successfully running in high-power electric locomotives, EMUs, and metros.

Vehicle Propulsion & On-Board Auxiliary Power Supply

In IR's locomotives with three-phase drive, the propulsion converters were originally GTO-based. IR has launched a program to upgrade these locomotives with IGBT-based propulsion converters [3]. IR selected ABB's 's BORDLINE CC series of water-cooled converter, which is based on 4.5 kV low-loss HiPak™ IGBTs. The most important accrued benefits are:

- Enhanced tractive effort, performance and availability due to use of axle control and a new generation of adhesion-control system.
- Improvement in overall power-converter efficiency due to lower semiconductor losses for an equitable operating point when compared to GTO-based traction converters.
- Improvement in the quality of motor-current waveform leading to reduced motor losses, torque ripple and better ride quality.

> In order to meet rising passenger traffic, and offer more competitive intercity travel, IR is improving passenger facilities, increasing platform lengths and introducing more train services.

2 BORDLINE M 180 kVA auxiliary converter (H Module)

3 STATCON panel used to control reactive power power flows

In conventional IR locomotives with DC traction system, rotary converters were used to generate three-phase supply (3 × 415 V / 50 Hz) required by machine-room auxiliaries. In addition to the high maintenance requirements of such rotary converters, their drawbacks include poor voltage regulation, low input power factor, low conversion efficiency, presence of lower order harmonics at output and lack of diagnostic facilities. To overcome these limitations, rotary converters are gradually being replaced by static power converters.

ABB caters to this market with its energy-efficient air-cooled BORDLINE M180 auxiliary converters that utilize solid-state IGBTs to generate a sinusoidal and balanced three-phase voltage supply [2]. This solution, featuring an active PWM (pulse-width modulation) rectifier at the input,

Footnotes

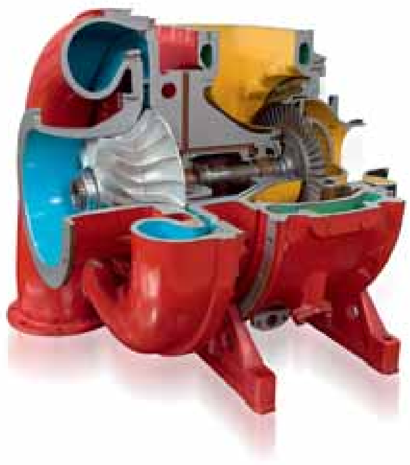
2 See also "Annual Year Book, Indian Railways, 2007-08" and "Emerging Technologies & Strategies for Energy Management in Railways," October 2008.

3 See also www.abb.com/railways

4 FSKII 25kV outdoor breaker to IR specifications

5 ABB turbochargers for Indian diesel locomotives

TPR 61 type turbocharger



VTC 304 type turbocharger

Indian Railways (IR) is one of the world's largest railway systems under single management and the largest employer in the world with approximately 1.4 million staff.

enables unity power factor (cos ϕ) operation and lowers line-side harmonic distortion. Furthermore, the converter's controlled startup and sinusoidal waveform reduce stress on motor insulation, eliminating the need for special motors. These converters are customized to mechanically and electrically fit into existing locomotives, permitting them to be retrofitted → 2.

Reactive power compensation

The power requirement of trains across the network is characterized by its high variability in demand. In addition, traction converters inject low-order harmonics into the traction network. The line voltage is thus prone to high fluctuations. IR conventionally employs fixed-shunt capacitor banks at most substations to compensate the lagging power factor. The drawbacks of switched capacitor banks are the coarse size of the switching steps and their response time. Power suppliers not only penalize IR when the power factor is lagging, but in some cases also when the power factor is leading as a result of over-compensation. Sub-stations thus need reactive power compensation that can be adjusted dynamically and in real time.

ABB's STATCON is a voltage source converter / inverter that can both absorb and deliver reactive power → 3. It uses IGBT switching devices and is modular, permitting future expansion should demand rise.

STATCON is shunt-connected and therefore easy to install. It totally relieves the source from reactive power, resulting in better utilization of the supply equipment and network. Also by providing very fast dynamic compensation, it improves voltage profile and reduces system losses and hence the loading on incoming power transformers, switchgear, cables, etc.

FSKII outdoor breaker

IR uses 25 kV outdoor circuit breakers and interrupters in all of its traction substations and switching posts. In consultation with IR, ABB has developed its FSKII magnetic actuated range of breakers and interrupters that offer increased reliability due to radically fewer moving parts [2]. The magnetic actuator is a bistable device, meaning that it does not require energy to keep it in the open or closed position → 4.

Turbocharger

Every year, IR rolls out approximately 300 new diesel locomotives from its two plants in India. ABB turbochargers have been boosting the performance of these locomotives since 1975. High-efficiency turbochargers such as ABB's TPR 61 and VTC 304 improve reliability and reduce fuel consumption by 5 percent → 5. ABB is also involved in IR's emission-reduction program, and is performing overhauls on turbochargers. IR's workshops have also built rolling stock for export to more than 10 Asian and African countries. ABB's turbochargers are also frequently used on such export locomotives, not least because of the global presence of ABB's service network.

Urban transportation

According to the 2001 census, India has 300 cities with a population of more than 100,000, and 35 cities with a million or more – compared to only five cities in the

6 Delhi Metro Rail Corporation

Delhi Metro Rail Corporation (DMRC) was incorporated to implement and operate a mass transit system in the Delhi area. ABB has been a partner of DMRC since 2002 and provided products and systems for both the traction power supply and rolling stock. These include traction, receiving and auxiliary substations, overhead electrification, SCADA systems, integrated building and asset management solutions, and traction transformers and motors. The system is electrified at 25 kV / 50 Hz. It features ABB's compact gas- and air-insulated switchgear, 25 kV pole-mounted vacuum interrupters and circuit breakers with magnetic actuator mechanisms.

DMRC is the first independent metro operator in India, and has proven to be a role model for on-time project execution and efficiency. DMRC is now providing consultancy services to most of the new metro projects in India, and is also taking on international consulting assignments.

Phase I of the metro, comprising a route length of 65.1 km, was completed in 2006. Phase II, set to be completed in 2010, will add a further 128 km. Upon completion of this second phase, daily passenger trips are expected to reach 2 million per day. DMRC plans to have 381 km of metro operational by 2021.

Of the total 193 km of phases I and II, ABB has executed or is implementing the electrification of approximately 163 km.

7 DMRC SCADA control room

latter category in 1951. Approximately 30 percent of India's population lives in urban areas, which contribute 55 percent of the GDP. India is being urbanized at a faster rate than the rest of the world: Migration is adding millions to urban populations every year. This urban growth is exerting increasing pressure on infrastructure. The deterioration of urban transport systems can rapidly lead to lower economic productivity. Urgent measures are thus needed to improve urban transportation.

Public transport occupies less road space and causes less pollution per passenger-km than personal vehicles. Of the wide variety of public transport options available, high-capacity rail-based metro systems are deemed to be the most suitable for India's densely populated cities. Under the aegis of the Ministry of Urban Development, the central and local state governments are setting up independent organizations to advance urban transport development. Solutions selected include build-own-operate models with private partnerships.

An important catalyst for electrification has been India's will to reduce its dependence on costly imported fossil fuels.

Today, Kolkata and Delhi → 6 are the only two cities to have operating metro systems. Besides ongoing expansion of these systems, new metro projects are at various stages of implementation in Bangalore, Mumbai, Chennai and Hyderabad. In Delhi, Mumbai, and Bangalore, independent metro operators are procuring their own coaches according to international specifications and global tendering processes. With an increasing number of projects, annual demand for metro coaches is expected to grow beyond 1,000 coaches within the next few years. Bombardier Transportation has already set up a coach factory in western India and is supplying coaches for Delhi Metro. Other international transportation companies and Indian rolling-stock manufacturers are also seeking to enter this business through collaborations and technology tie-ups.

SCADA

Delhi's DMRC → 6 needed one unified SCADA control center (with backup), and hence sought to upgrade and integrate the old SCADA system and RTUs[5] with the new system without losing operating time. ABB's latest MicroSCADA Pro system provided one common system for the complete network and delivered high availability as well as savings on maintenance and spare parts → 7.

Because of its experience with DMRC, as well as metros in Mumbai and Bangalore, ABB has emerged as the leader in terms of market share for turnkey electrification, SCADA and power products for metro rail networks in India.

Future outlook

India's growing industrialization and population present an ever increasing need for transportation. Riding on the waves of economic success, IR has witnessed a dramatic turnaround leading to an unprecedented financial turnover in the last few years. This has been made possible by:

- Higher freight volumes without requiring substantial investment in infrastructure
- Increased axle loadings
- The reduction of turnaround times for rolling stock
- The reduced unit cost of transportation
- The rationalization of tariffs resulting in an increased market share for freight.

In the Eleventh Five Year Plan (2007-12), investment in the railway sector is estimated at $65 billion[4]. Almost 17 percent

Footnotes

4 See also "Projections of Investment in Infrastructure during Eleventh Plan, GoI report"(October 2007)

5 RTU: remote terminal unit.

of this investment will be via public-private-partnership (PPP) projects in the freight and high-speed corridors, urban transport systems, rolling stock manufacturing and captive-industrial and port connectivity.

In order to meet rising passenger traffic, and offer more competitive intercity travel, IR is improving passenger facilities, increasing platform lengths and introducing more train services. IR needs to acquire more than 4,500 coaches annually for main-line services (660 of which should be air conditioned). Current captive manufacturing facilities are not able to meet this requirement, and this is limiting the launch of new train services and the rate of replacement of old coaches. To increase the supply, IR is by itself and in partnership with private manufacturers setting up new production units. New diesel and electric locomotive production facilities using the PPP model are also being discussed as a way to augment IR's locomotive fleet with higher power and technologically advanced locomotives.

DMRC is the first independent metro operator in India, and has proven to be a role model for on-time project execution and efficiency.

Freight

Although the freight business is a significant revenue earner, and also helps subsidize IR's passenger business, passenger trains are given a higher priority in scheduling. To nevertheless improve freight throughput and offer industry better transit times, the Dedicated Freight Corridor (DFC) project is being advanced featuring 3,300 km of double-track lines and is budgeted at $12 billion. DFC will permit freight trains with higher axle loadings to run at 100 km/h (compared to the current average of 25 km/h). The western DFC between Mumbai and Delhi is expected to carry mostly container traffic from the ports on the western coast, whereas the Delhi-Howrah eastern DFC will carry mostly bulk cargo such as coal, iron ore, steel, etc. As part of the DFC project, a Special Purpose Vehicle (SPV) is to be developed with foreign funding and expected to be completed by 2015.

High speed

High speed rail takes pressure off roads and short-haul flights and so reduces air pollution, congestion, noise and accidents, and also frees travelers from the frustrations of traffic congestion and airport security lines. In Europe, carbon dioxide emissions per passenger-km on Europe's high-speed trains are equivalent to one third of its cars and only one-fourth of its planes [6]. In India, feasibility studies have already been initiated for a high-speed corridor to link Mumbai and Delhi at 350 km/h. Further links are likely to be added in the future.

IR is continuously adopting new energy-saving and renewable-energy options in rolling stock and non-traction loads [7]. These initiatives range from redesigning the air-conditioning and lighting systems in passenger coaches to harnessing solar power for station facilities, or using wind farms to supply power to manufacturing units. Due to their lack of guaranteed availability, such renewable sources are not suitable for traction loads. They are, however, deemed suitable for stationary non-traction loads. Drawing on both available technologies and experience and the force of innovation, India is on its way to establishing a more efficient rail network for its future.

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Footnotes

6 See also The Hindu (7 Jan. 2010) "Encouraging high-speed trains," and "Vision 2020, Indian Railways"(December 2009).

7 Non-traction loads are defined as the energy consumed by the production units, various workshops, and other infrastructure.

Photo © AlpTransit Gotthard Ltd.

Switzerland by rail

Supplying traction power for the country's major railway initiatives

RENÉ JENNI, REMIGIUS STOFFEL, MELANIE NYFELER – Switzerland is generally considered a pioneer when it comes to public transport. In no other part of the world are trains, trams and buses used as often as they are in this small Alpine country. In fact, so beloved is the public transportation system in Switzerland that its people have repeatedly voted in favor of extending the already comprehensive rail network even further. The country's aim is to carry more travelers on public transport and transfer more freight from road to rail. ABB is participating in this effort, supplying the power for the two new base tunnels through the Alps – the Lötschberg and the Gotthard – as well as DC traction substations for public transport in the conurbations around the cities of Zurich, Bern and Luzern.

Studies repeatedly show that the Swiss are world champions when it comes to traveling by train. On average, each of the country's residents travels 40 times each year on Swiss trains, amounting to about 900,000 people on the Swiss railroad system every single day [1,2] ➔ 1. Not surprisingly Switzerland has the highest frequency of train services in the world.

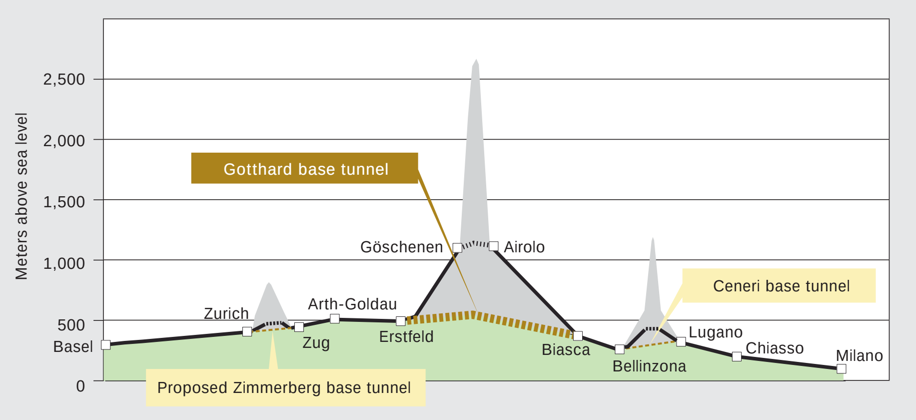
Thanks to the strategic transportation policy of the Swiss government, Switzerland has a very well developed rail network, which ensures that rural areas can be reached and offers rail connections between cities that operate every hour or even every half hour. To meet the growing demand, Swiss Federal Railways (Schweizerische Bundesbahnen, or SBB) has not only increased the frequency of its timetable, it also continually upgrades its rolling stock.

When it comes to rail transport in an international context, the Alpine country also sets milestones and pursues an active policy of transporting goods by train rather than truck, where possible. Today Switzerland is the most important transit country for goods crossing the Alps by rail. In 2008, 40 million tons of freight were transported through Switzerland, more than half of which – around 25 million metric tons – were transported by train [3]. Many referenda have also demonstrated the Swiss' support for transport of goods by rail. An important step in enabling such rail transport is the construction of the New Railway Link through the Alps (NRLA), which integrates Swit-

1 Comparison of European railways (2007) [1]

Country	Total km of rail	Number of train journeys per resident
Switzerland	3,158	40
Luxembourg	275	33
Denmark	2,133	29
Austria	5,702	24
Germany	33,890	22
The Netherlands	2,776	20
Belgium	3,374	19
Czech Republic	9,460	17
France	29,918	16
Spain	13,368	11
Italy	16,335	9

2 Alpine base tunnels (©AlpTransit Gotthard Ltd.). Train route from Basel, Switzerland to Milano, Italy via the 57 km long Gotthard base tunnel



zerland into the growing European high-speed network. Thanks to the two NRLA axes – Gotthard and Lötschberg – the annual capacity of goods transported by rail will more than double from 20 million metric tons in 2003 to around 50 million metric tons once the two routes have been completed in 2017.

Traction power for Lötschberg

The Lötschberg base tunnel was opened in December 2007 after a construction and planning period of about 10 years. This new rail tunnel considerably reduces travel time from the north to the Valais region of Switzerland in the south. Every day around 40 passenger and 110 goods trains pass through the Alps at an altitude of about 800 m – about double the numbers that pass through the much higher link between Goppenstein and Kandersteg, which has been used to date also as a car shuttle.

This once-in-a-century achievement, with numerous cross-galleries and huge excavations for the technical systems, also provided a tremendous challenge for ABB. The company was responsible for the design, supply, installation and commissioning of the 16.7 Hz traction power supply system and the 50 Hz energy distribution system.

The supplied medium-voltage system provides the power to the infrastructure for the lighting, signaling, communications, ventilation and air conditioning systems, as well as the safety doors in the entire tunnel. The medium-voltage distribution system includes 21 transformer stations with UniGear ZS1 air-insulated medium-voltage switchgear, 30 distribution transformers and two 5 MVA coupling transformers for connecting the two networks of the local energy suppliers.

The second part of the order involved the 16.7 Hz traction power supply system. To connect Switzerland to the high-speed European network, the contact lines in the tunnel were specially designed for train speeds of up to 250 km/h. The traction power supply system is designed in such a way that several train configurations with up to six locomotives and freight trains of up to 1.5 km in length can be supplied with power simultaneously. Consequently, the switching and protection equipment must be able to handle short-circuit currents of over 40 kA.

ABB installed air-insulated single-phase UniGear R36 switching panels, which offer maximum security to personnel and systems. The traction power supply assemblies, including its highly sophisticated substation automation and protection system, are installed in containers. The containers are then placed in different operating centers housing all systems required to safely operate the railway system. Two local control centers near the northern and southern tunnel portals contain the workstations from which the power supply systems are controlled and monitored.

The world's longest rail tunnel

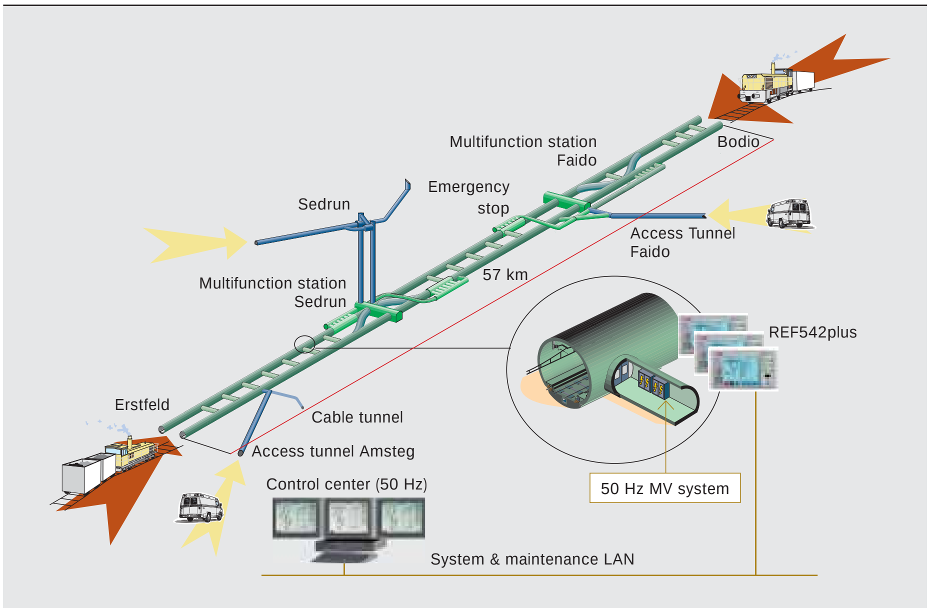
To the east of Lötschberg and nearly in the center of the country, the work on Switzerland's second cross-Alpine link is powering ahead. The base tunnel of the Gotthard is the heart of the NRLA and is expected to make a marked improvement in travel and freight options in central Europe. When it goes into operation in 2017, the Gotthard base tunnel will, at about 57 km, be the longest tunnel in the world → 2. The building project is both immense and pioneering. Creating the twin tubes with connecting crossways means removing – in sections – a total stretch of 152 km of rock. This work will be completed in autumn 2010. Installation of the electrical equipment is already underway in some parts of the tunnel.

Here too, ABB is supplying the power engineering equipment. The company is to supply gas-insulated medium-voltage switching panels and protection equipment for the 50 Hz tunnel infrastructure. The 875 medium-voltage units will provide a reliable supply of power and, at the same time, must withstand harsher than usual climatic conditions while requiring a minimal amount of maintenance.

> In 2008, 40 million metric tons of freight were transported through Switzerland, more than half of which were transported by train.

The two parallel, single-track tunnel tubes are connected to each other every 325 m by a 40 m long crossway. The systems for supplying electricity to the tun-

3 AlpTransit Gotthard tunnel overview (© AlpTransit Gotthard Ltd. Adapted by ABB)



4 REF542plus is providing fault protection in the Gotthard tunnel.

nel infrastructure are installed in these cross-galleries, which serve as escape routes between the two tunnel tubes → 3. Because conditions in the tunnel are harsher than usual – factors such as salt deposits, brake dust, soot particles and abraded material from the rails and contact wires come in to play – ZX0-type gas-insulated switchgear is used. An important feature of this switchgear is that it is extremely compact, with a field width of only 400 mm. By combining up to six fields to form a fully functioning switchgear block, it is possible to exchange complete switchgear units within a very short time in the event of a fault. This functionality is critical for the operation of the Gotthard base tunnel, because rail traffic will have to be interrupted when access to the crossway is needed.

Exposure to the elements

Because the environmental conditions are so hostile, the relevant control cabinet must be designed to comply with protective class IP65. In addition, a standard feature of the medium-voltage part of the switchgear is that it is gastight. These design elements eliminate the risk of any ingress of environmental elements – ie, dust or water.

The intense fluctuations in pressure in the crossways place high demands on the materials. Because the trains pass the crossways at speeds of up to 250 km/h, variations in pressure of ±10 kPa are produced. Thus, pressure resistance of the ZX0 switchgear, including the control cabinet, has been ensured. The reliability and availability of these systems is essential for safety in the tunnel. This task is primarily handled by the REF542plus multifunction protection and control unit, which has been on the market for more than 10 years → 4.

Over 500 units of this type have been installed at different points throughout the length of the tunnel. Here, the REF542plus performs its most important task using the newly developed, multi-stage distance protection. In order to provide optimum selectivity in a network, while at the same time provide a stable and reliable supply, fast identification of the fault type and the location of the fault is important, so that just the faulty parts of the network can be switched off. Information on both these points is transferred immediately to the tunnel control system.

REF542plus also enables remote service. Not only is it possible to access stored programs and protective data remotely via Ethernet LAN, but the data can also be changed and replaced. To date, REF542plus is the only protective equipment that offers this unique feature. Installation of the rail equipment has already begun and the 50 Hz supply is scheduled to start in 2011. The switchgear will then operate for decades, helping to safely transport millions of passengers through this unique tunnel system.

Urban transport system in Zurich

ABB is not only providing the power required to cross the Alps by rail – the company's power supply systems have also been used successfully for light rail and urban transport. In the Zurich region, a new light rail system is being built, which will link the adjacent Glattal residential and business area with the dynamic center of the country's largest city. The 150,000 inhabitants and 120,000 employees in its catchment area will benefit from the modern 12.7 km long tram line, which is being completed in stages and will be finished by the end of 2010 → 5.

> ABB is supplying the 50 Hz tunnel infrastructure with 875 gas-insulated medium-voltage switching panels and protection equipment for the Gotthard tunnel.

As the main contractor, ABB is working with the local construction companies Implenia Ltd. and Walo Bertschinger to provide the entire energy supply system.

5 Glattalbahn on the Balsberg viaduct (Photo: Daniel Boschung)

By 2012 ABB will deliver five rectifier substations, which will supply the city of Bern's tram lines with 600 V DC and also provide appropriate protection for the contact line system.

ABB is responsible for the design, supply, installation and commissioning of the rectifier substations providing the necessary traction power. The energy supply system includes eight rectifier substations, which supply the contact line with 600 V DC. The rectifier transformers are rated at 900 and 1,400 kVA, depending on the location.

ABB is also responsible for the low-voltage main distribution system, which is supplying all 22 stops on the Glattal light rail line with the required power (230 V) so that ticket vending machines, information boards and track switches all operate seamlessly. ABB has also installed the lighting, ventilation and fire alarm systems in the rectifier stations.

Development of urban transport

As is the case in Zurich, suburbs are booming – in and around Bern, Switzerland's capital city, the volume of traffic is also increasing. The city has opted for the tram as a means of public transport. In contrast to the trolleybuses used to date, the two new tram lines create direct links between the west, town center and east of Bern.

By 2012 ABB will deliver five rectifier substations, which will supply the tram lines with 600 V DC and also provide appropriate protection for the contact line system. The RTU560D remote system will connect the rectifier substations to the higher-level control system operated by the local utility.

ABB is also carrying out other contracts, including one for the municipal transport authorities in Lucerne to renew rectifier substations for their trolleybus lines.

Switzerland as a role model

Thanks to its well-developed public transport network, Switzerland is considered to be a positive role model and has influenced the trend toward the "ecological fast track." Its government wants to protect the Alps and the people living in the most densely populated areas of the country from the negative consequences of transit traffic. According to the director of the Swiss Federal Office of Transport [4], there are also economic reasons why they must succeed in shifting traffic – and above all, the expected growth in such traffic – to the railway. ABB is playing a key role in this shift with its innovative railway technology.

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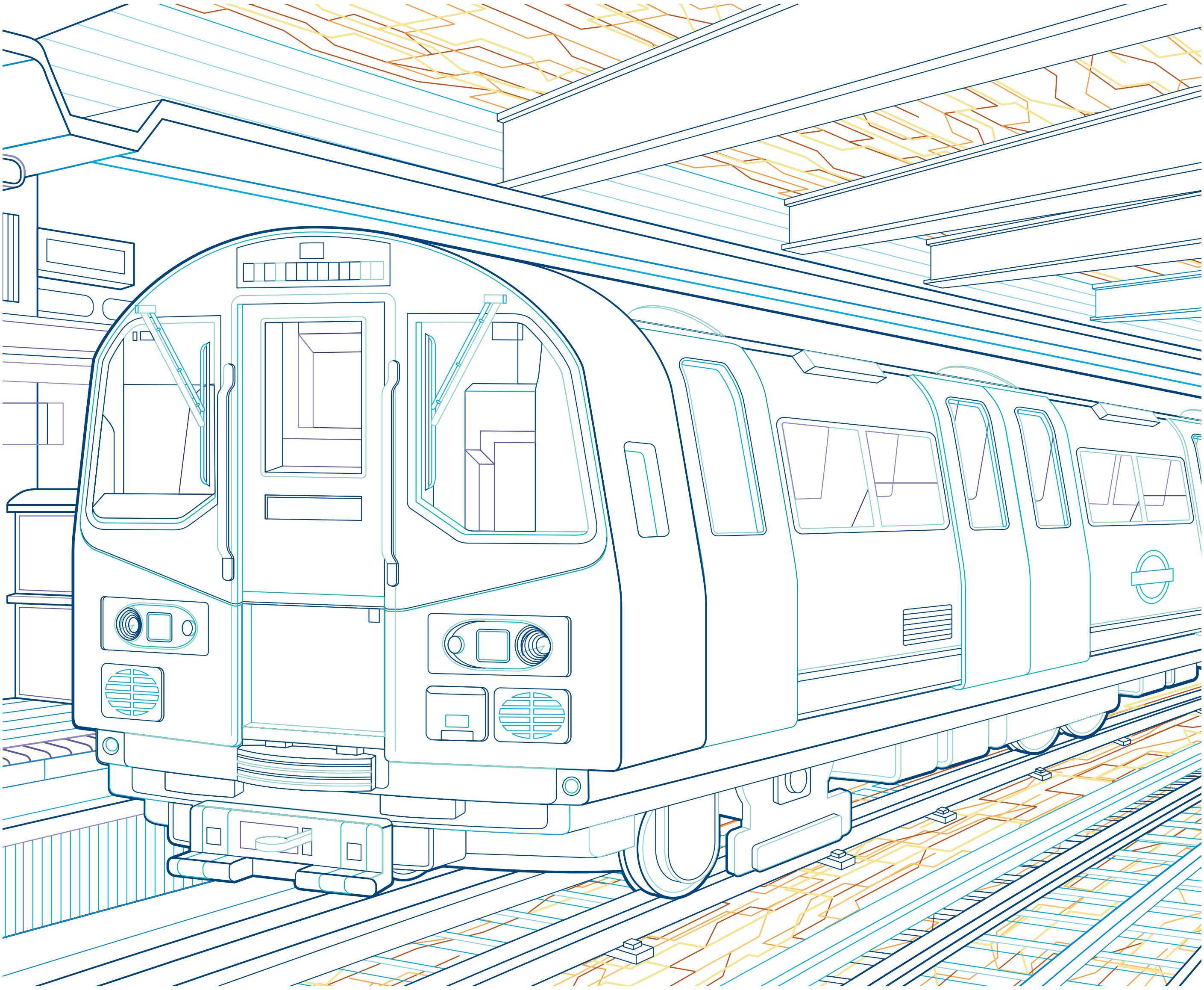
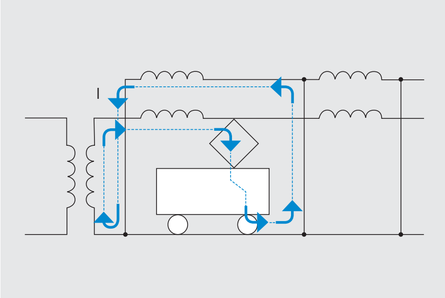


Knowing the FACTS

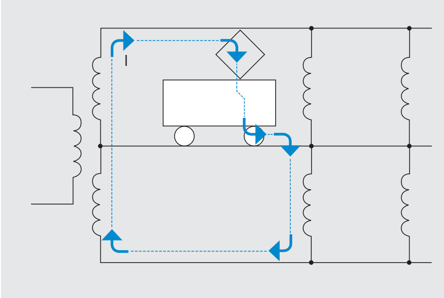
FACTS that enhance power quality in rail feeder systems

ROLF GRÜNBAUM, PER HALVARSSON, BJÖRN THORVALDSSON – The increase in traffic on existing tracks combined with new high-speed rail projects mean rail traction is fast becoming an important load on electric supply grids. This in turn is focusing a lot of attention on voltage stability as well as the power quality of the surrounding grids. Trains taking power from the catenary need to be sure the supply voltages are stable and do not sag. Voltage and current imbalances between phases of AC supply systems must also be confined in magnitude and prevented from spreading through the grid to other parts of the system. Voltage fluctuations and harmonics need to be controlled if they are to stay within the stipulated limits.

1 Two transformer schemes are used to supply high and efficient power



1a Booster transformer scheme



1b Auto-transformer scheme

There are several ways to feed traction systems with electric power. One scheme used in many traditional electrification systems is to supply it directly using the fundamental frequency main power, ie, 50/60 Hz. The transmission or sub-transmission voltages are then directly transformed by a power transformer to the traction voltage.

On the traction side any one of two transformer schemes can be used to supply high and efficient power: the booster transformer and auto-transformer schemes ➔ 1. In the booster transformer scheme, the main voltage is transformed into a single-phase catenary voltage. One end of the power transformer traction winding is grounded and the other is connected to the catenary wire. In the auto-transformer scheme, the traction winding is grounded at its midpoint. One end of the winding is connected to the catenary wire while the other end is linked to the feeder wire. In both schemes the grounded points are connected to the rail.

On the transmission network side the power transformer is connected between two phases. Frequently, two isolated rail sections are fed from the same feeder station, and in this case the power transformers are then connected between different phases.

Nowadays, the traction load, P_{load}, tends to be relatively large, often with power ratings between 50 MW and 100 MW per feeding transformer. These loads will create imbalances in the supply system voltage if they are connected between two mains phases. As a rule of thumb, if the fault level of the grid is represented by S_{ssc}, the imbalance, $U_{imbalance}$, is equal to

$$U_{imbalance} = \frac{P_{load}}{S_{ssc}}$$

A common requirement is that the negative phase sequence voltage resulting from an unbalanced load should not exceed one percent. Assuming loads of between 50 MW and 100 MW, the feeding system must have a short-circuit level of at least 5,000 MVA to 10,000 MVA if it is to stay within the imbalance requirements. In many cases the traction system is relatively far from strong high-voltage transmission lines. Weaker subtransmission lines, however, normally run somewhere in the vicinity of the rail and can therefore be used to supply the rail in cases where an imbalance caused by the traction load can be mitigated.

Flexible AC transmission systems

Flexible AC transmission systems (FACTS) is a family composed of static devices that are controlled using state of the art computerized control systems in conjunction with high power electronics. One such device, the conventional static var compensator (SVC) as well as the more recently developed SVC Light® (STATCOM) can be used for imbalance compensation, ie, they serve as load balancers when used with special control algorithms. Load balancing is concerned with transferring active and reactive power between different phases ➔ 2.

SVC and SVC Light devices can also be used to dynamically support sagging catenary voltages and mitigate harmonics emanating from thyristor locomotives. In the case of SVC Light, a certain number of these harmonics can be removed by active filtering.

FACTS in rail traction

Power grids feeding railway systems and rail traction loads benefit enormously by using SVC and STATCOM. These benefits, listed in ➔ 3, reduce, if not eliminate, the investments needed to upgrade [1] the railway power feeding infrastructure.

FACTS devices in a system also enable adequate power quality to be achieved with in-feed at lower voltages than would otherwise be possible. This means, for example, that it may be sufficient to feed a railway system at 132 kV rather than at 220 kV or even 400 kV.

Load balancing by means of SVC

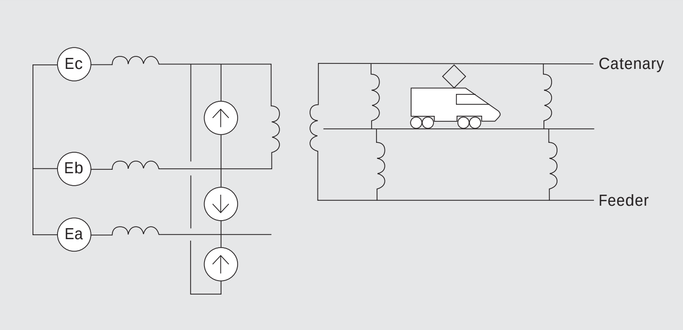
An SVC is a device that provides variable impedance, which is achieved by combining elements with fixed impedances (eg, capacitors) with controllable reactors. Surprisingly, this combination is capable of balancing active power flows ➔ 4. The reactors also have fixed impedances but the fundamental frequency component of the current flowing through them is controlled by thyristor valves, which results in apparent variable impedance. In ➔ 4, this type of reactor is known as a thyristor controlled reactor (TCR).

A TCR is a shunt (parallel) branch consisting of a reactor in series with a thyristor valve ➔ 5. The branch current is controlled by the phase angle of the firing

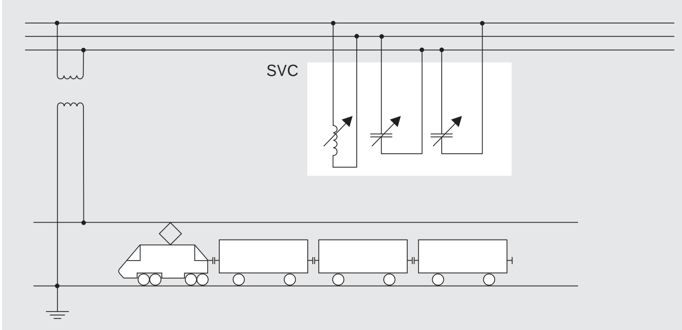
Footnote

1 Reinforcing would involve building new transmission or sub-transmission lines, substations and feeder points.

2 FACTS for load balancing



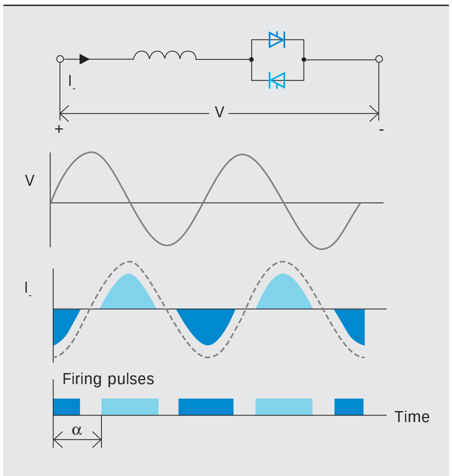
4 Load balancing and reactive power compensation by SVC



3 Benefits of using SVC and STATCOM

- Non-symmetrical loads fed from two phases of three-phase supplying grids are dynamically balanced.
- Voltage fluctuations in the feeding grids caused by heavy fluctuations of the railway loads can be dynamically mitigated.
- Harmonics injected into supply grids from traction devices can be eliminated.
- Regardless of load changes and fluctuations, power factor correction occurs at the point of common coupling. This means the power factor is high and stable at all times.
- SVC and STATCOM provide dynamic voltage support of catenaries feeding high power locomotives. This in turn prevents harmful voltage drops along the catenary and allows heavy traction capability to be maintained despite weak feeding. If an outage happens to occur at a feeding point, the locomotives will still receive adequate power. In fact the use of SVC and STATCOM may help reduce the number of feeding points required.
- From a power quality point of view, the feeding grid can be chosen with a lower voltage with FACTS, for example, 132 kV instead of 220 kV or higher.
- And finally, FACTS devices provide dynamic voltage control and harmonic mitigation of AC supply systems for DC converter fed traction (typically underground and suburban trains).

5 The fundamental principle of a thyristor controlled reactor (TCR)



pulses (firing angle control) to the thyristors, ie, the voltage across the reactor equals the full system voltage at a firing angle of 90 degrees and is zero at a firing angle of 180 degrees. The current through the reactor is the integral of the voltage; thus it is fully controllable between the natural value given by the reactor impedance and zero.

To address the issue of space as well as benefiting from advanced semiconductor technology, the thyristor valves make use of a bi-directional device, a semiconductor component which allows the integration of two anti-parallel thyristors in one silicon wafer. Using these thyristors reduces the amount of units needed in the valves by 50 percent ➔ 6. The thyristor is a five-inch device with a current handling capability of about 2,000 A (rms).

In the conventional SVC, load balancing is achieved when, by controlling the reactive elements, active power is transmitted between the phases. In its simplest form the load balancer consists of a TCR connected between two power supply phases and a fixed capacitor bank in parallel with a TCR connected between two other phases. Power factor correction is obtained by a fixed capacitor bank in parallel with a controlled reactor between the remaining two phases. Harmonics are normally suppressed by the addition of filters. These can be connected either in a wye (Y) formation or directly in parallel with the reactors.

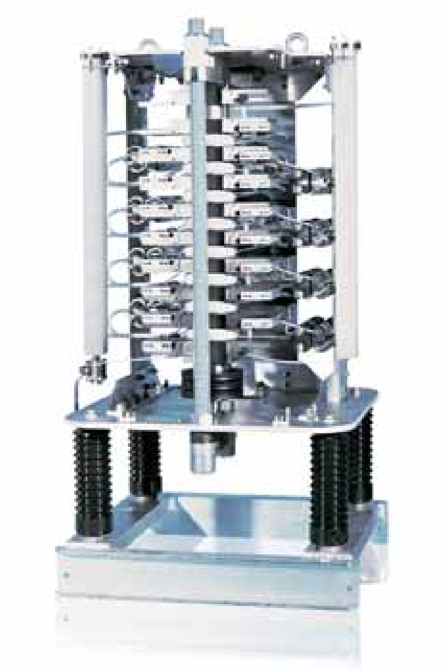
The control of the load balancer may be based either on the fact that three line-to-line voltages with the same magnitude cannot contain a negative phase sequence voltage or on a more sophisticated system that derives the different phase sequence components and acts to counteract the negative one. The control of the positive sequence voltage normally has a lower priority compared with that of the negative, ie, it is only fully controlled when the load balancer rating is large enough to allow for both balancing and voltage control.

SVC and the HS 1 rail link

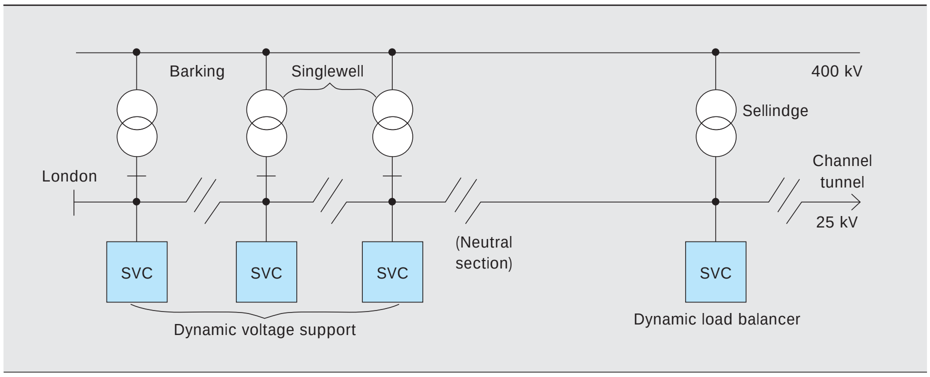
A total of seven SVCs were supplied to High-Speed 1 (HS 1), a 108 km high-speed rail line between London and the channel tunnel at Dover which was formerly known as the channel tunnel rail

The increase in traffic on existing tracks combined with new high-speed rail projects mean rail traction is fast becoming an important load on electrical supply grids.

6 A bi-directional control thyristor (BCT) valve

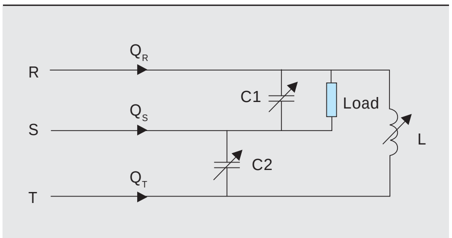


7 High-Speed 1 (HS 1) SVCs



8 HS 1 dynamic load balancer

9 Balancing an asymmetrical load



FACTs devices such as the conventional static var compensator (SVC) and SVC Light® (STATCOM) can be used for imbalance compensation, as well as for the dynamic support of sagging catenary voltages.

link (CTRL). With this link in operation, it is possible to travel between London and Paris in just over two hours at a maximum speed of 300 km/h.

Even though it is primarily designed for high-speed trains, HS 1 also accommodates slower freight traffic. As modern trains have power ratings in the range of 10 MW, the power feeding system must be designed to cope with large fluctuating loads. The HS 1 traction feeding system is a modern direct supply of 25 kV with a mains frequency of 50 Hz, and each of the three traction feeding points between London and the channel tunnel is supported by SVCs → 7. Direct transformation from the power grid via transformers connected between two phases is used, and the auto-transformer scheme is implemented to ensure a low voltage drop along the traction lines.

Dynamic voltage support

Six of the SVCs are used mainly for dynamic voltage support and are connected on the traction side of the power transformers. A seventh SVC is needed for load balancing. At three of the feeding points, one of two identical single-phase SVCs is connected between the feeder and earth and the other is connected between the catenary and earth.

There were three main reasons for investing in SVCs. The first and primary reason is to support the railway voltage in case of a feeder station trip. When this happens, two sections have to be fed from one station. It then becomes essential to keep the voltage up in order to maintain traction efficiency.

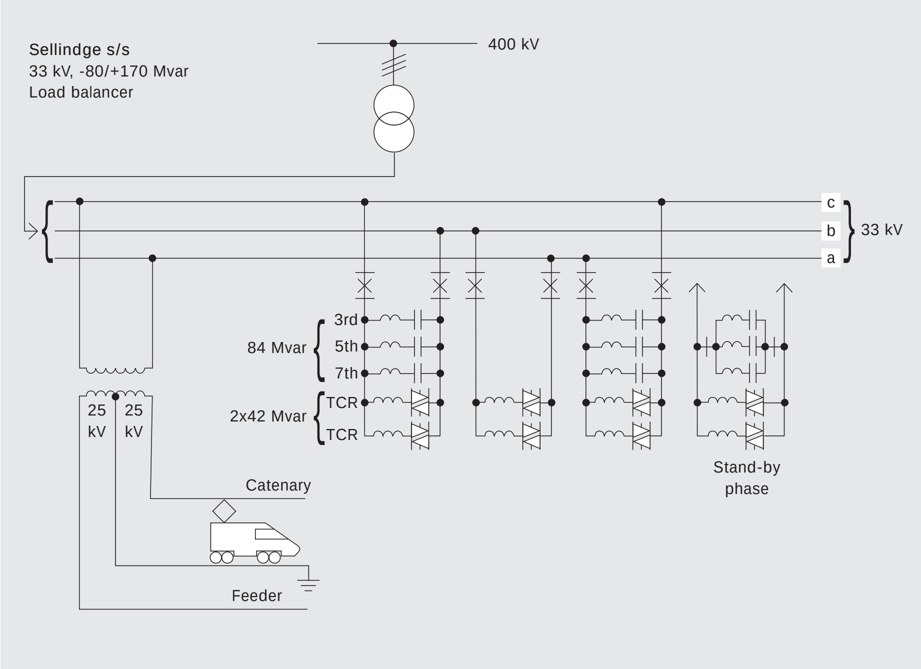
The second reason is to maintain unity power factor seen from the super grid transformers during normal operation. This ensures a low tariff for the active power consumed. And finally, the SVCs are installed to mitigate harmonic pollution. SVC filters are designed not only to accommodate the harmonics generated by the SVC but also those created by the traction load. There are stringent requirements on the allowed contribution from the traction system to the harmonic level at the connection points to the supergrid.

The SVCs operate in a closed-loop power factor control; an outage at a feeder station automatically changes operation to closed-loop voltage control.

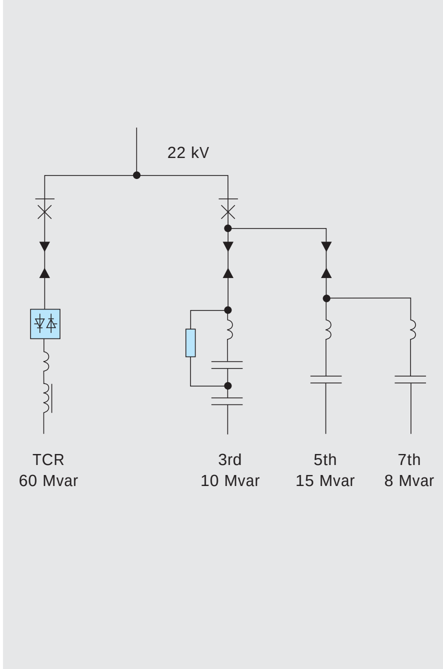
Load balancing

The traction load, with a power rating of up to 120 MW, is connected between two phases. Without compensation, this load would give a negative phase sequence voltage of about 2 percent. To counteract this imbalance, the load balancer, an asymetrically controlled SVC, was installed → 8.

10 A High-Speed 1 (HS 1) load balancer main scheme



11 A single-line diagram of a typical SVC used by the London underground



A load connected between two phases of a three-phase system can be made to appear symmetrical and have unity power factor – as seen from the three-phase feeding system – by applying reactive elements between the phases, as shown in → 9. The per-phase reactive powers can be related to a set of phase-to-phase reactive powers as follows:

$$Q_{RS} = Q_R + Q_S - Q_T$$

$$Q_{ST} = Q_S + Q_T - Q_R$$

$$Q_{TR} = Q_T + Q_R - Q_S$$

If a single-phase load consumes an active power P and a reactive power Q, the reactive values needed between the phases for total three-phase symmetry as well as unity power factor are given by:

$$Q_{C1} = Q$$

$$Q_{C2} = P/\sqrt{3}$$

$$Q_L = P/\sqrt{3}$$

In the case of comprehensive traction loads, the aggregate values of P and Q change substantially with time. By means of SVC, the effective phase-to-phase susceptances also become variable, thereby satisfying the above equations in all instances.

The load balancer schematic in → 10 is optimized to handle a load connected between the "a" and "c" phases. In accordance with load-balancing theory, to balance a purely active load, a reactor needs to be connected between the "a" and "b" phases and a capacitor between the "b" and "c" phases. The traction load has a reactive part which also needs to be balanced. Not only is the asymmetry compensated for, but the addition of a capacitor between the "c" and "a" phases also regulates the power factor to unity.

The load balancer is controlled to compensate for the negative phase sequence component present in the current drawn from the supergrid. Furthermore, the power factor is regulated to unity. The positive phase sequence voltage can also be controlled if the capacity is available. This depends, however, on the load balancer working point.

VSC and IGBT technologies have been brought together to create a highly dynamic and robust system with a high bandwidth known as SVC Light.

Connecting the London underground

In order to take power from the public grid, the London underground needed to close its old gas/oil-fired power plant at Lots Road. Because the underground load consists mainly of diode converters that feed DC current to the trains, special measures had to be taken to limit or even prevent disturbances, such as voltage fluctuations and harmonics, from reaching the public grid.[2]

In 2009, an SVC was commissioned for the 11 kV feeding grid to work together with several other SVCs in operation since mid 2000. This brings to six, the number of SVCs (as well as some standalone harmonic filters) that now operate at critical points of the London underground 22 kV and 11 kV grid. Space issues and their proximity to underground stations – and thus large groups of people – meant the SVC installations had to

Footnote

2 Extensive system studies were undertaken to map sources of distortion and identify the measures needed in order not to exceed the permitted disturbance limits at the points of common coupling.

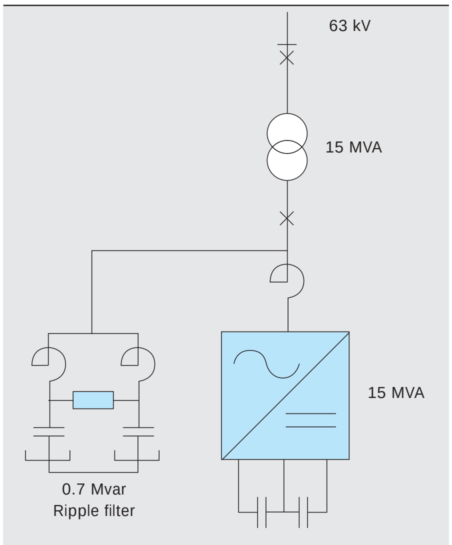
12 Categorizing the SVCs used in the London underground

Rated voltage, kV	Dynamic range, Mvar	TCR rating, Mvar	Quantity of SVCs
22	-27/+33	60	2
22	-37/+23	60	3
11	-16.5/+16.5	33	1

13 The TCR iron-core reactor arriving on site in London

14 An SVC showing the thyristor valve (left) and valve cooling system (right)

15 SVC Light single-line diagram



16 The IGBT valve hall at one of the French sites

The converter valve is suspended from the ceiling, and the DC capacitors and bus are shown in the foreground.

be compact and completed in such a way as to confine noise and magnetic fields. In fact the magnetic field must not exceed 1.6 mT at the boundary of any of the SVCs.[3] For these reasons, the SVCs use iron-core TCR reactors instead of the more common air-core reactors.

Typically, each SVC consists of one TCR and a set of harmonic filters that are individually tuned and rated → 11. By means of phase angle control of the TCR, a continuous variable output, from maximum Mvar capacitive to maximum Mvar inductive reactive power, can be obtained from steady state. Harmonic filter arrangements vary from site to site, depending on the fault level of the feeding grid at each site and the harmonic requirements. The main parameters of the six SVCs can be sub-divided into different categories → 12.

With its ability to generate voltages of any amplitude and phase angle, SVC Light has what it takes to fulfil the role of a load balancer.

An iron core reactor arriving on site in London is shown in → 13 and an on-site picture of an SVC is shown in → 14.

SVC Light

With the advent of controllable semiconductor devices capable of high power handling, voltage source converters (VSCs) with ratings beyond 100 MVA are now feasible. Now VSC [4] and insulated gate bipolar transistor (IGBT) technologies have been brought together to create a highly dynamic and robust system with a high bandwidth known as SVC Light, for a variety of power conditioning tasks in grids and beyond. Using pulse width modulation (PWM), an AC voltage almost sinusoidal in shape can be produced without the need for harmonic filtering.

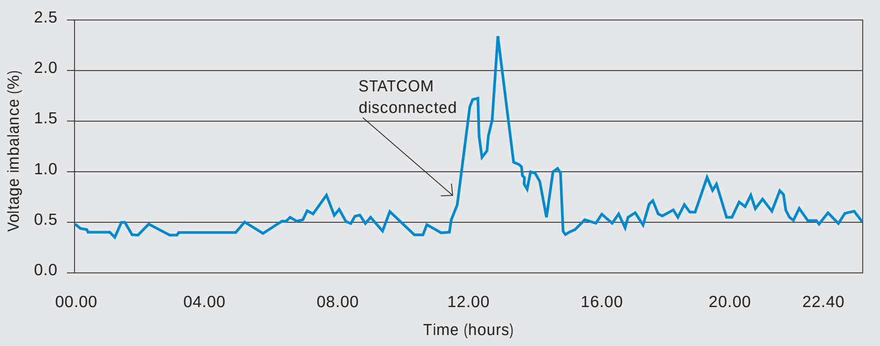
Balancing rail traction loads

With its ability to generate voltages of any amplitude and phase angle, SVC Light has what it takes to fulfil the role of a load balancer. By connecting the VSC to the grid, SVC Light can be treated as a synchronous machine in which the amplitude, phase and frequency of the voltage can be independently controlled. In addition, with high frequency PWM switching, the VSC is also capable of synthesizing a negative sequence voltage.

Compared to the classical SVC based on delta-connected TCRs for the same rated power, an SVC Light with phase-wise connected valves and a common DC link can compensate a train load that is $\sqrt{3}$ times larger. The delta-type connection is less efficent for balancing unsymmetrical active power than it is for symmetrical reactive power compensation. This difference does not exist if a phase-wise connection is used.

Two SVC Light installations are in operation in the French railway system. Both are fed from the national power grid, one at 90 kV and the other at 63 kV subtransmission levels. At both sites, SVC

17 Measurement of voltage imbalance (values taken every 10 minutes)



Light is used to dynamically balance the asymmetry between phases caused by the mode of traction feeding. In these cases, the thyristor locomotives are fed power from two phases of a three-phase grid. The locomotives generate harmonics which are then actively filtered by SVC Light. [5]

In ➔ 15, the load balancer is rated at 63 kV, 15 MVA and can accommodate a single-phase active load of up to 16 MW. Its task is to confine grid unbalance at 63 kV to no more than 1 percent under normal network conditions and no greater than 1.8 percent for abnormal (N-1) network conditions. One double-tuned filter, tuned to the 40th and 51.5th harmonics, has been installed on the AC side. No passive harmonic filters are used on the 63 kV side. This gives a robust solution which can be applied to varying network configurations.

> To meet the requirements of imbalance if SVC Light were not available, the supply network in-feed would have to be increased, which in turn would require the erection of new overhead lines and the upgrading of many substations.

The second SVC Light installation is rated at 90 kV, 16 MVA to accommodate a single-phase active load size of up to 17 MW ➔ 16. Its task is to confine the grid unbalance at 90 kV to no more than 1 percent for $S_{ssc} \geq 600$ MVA under normal network conditions and no greater than 1.5 percent for 300 MVA $\leq S_{ssc} \leq$ 600 MVA for abnormal (N-1) network conditions. Measurements taken since SVC Light was installed show a distinct improvement in voltage imbalance [1]. To be more specific, the voltage imbalance does not exceed 1 percent ➔ 17.

SVC Light cost benefits

SVC Light offers not only a technically but also an economically advantageous solution [2]. To illustrate this point, suppose SVC Light is not available. Therefore, to meet the requirements of imbalance, the supply network in-feed would have to be transferred from 63 kV to 225 kV or 400 kV. This in turn would require the erection of new overhead lines as well as the upgrading of a number of substations currently supplied with 63 kV or 90 kV.

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Footnotes

3 Measurements have confirmed that this requirement has been fulfilled.

4 In the SVC Light, the VSC uses switching frequencies in the kHz range.

5 Active filtering is possible because of the high bandwidth inherent in the SVC Light concept. Active filtering occurs as long as there is the capacity to do so, for example, when the load is lower than the compensator rating.

References

[1] Courtois, C., Perret, J.P., Javerzac, J.L., Paszkier, B., Zouiti, M. (2006). VSC based imbalance compensator for railway substations. Cigré B4-103, 2006.

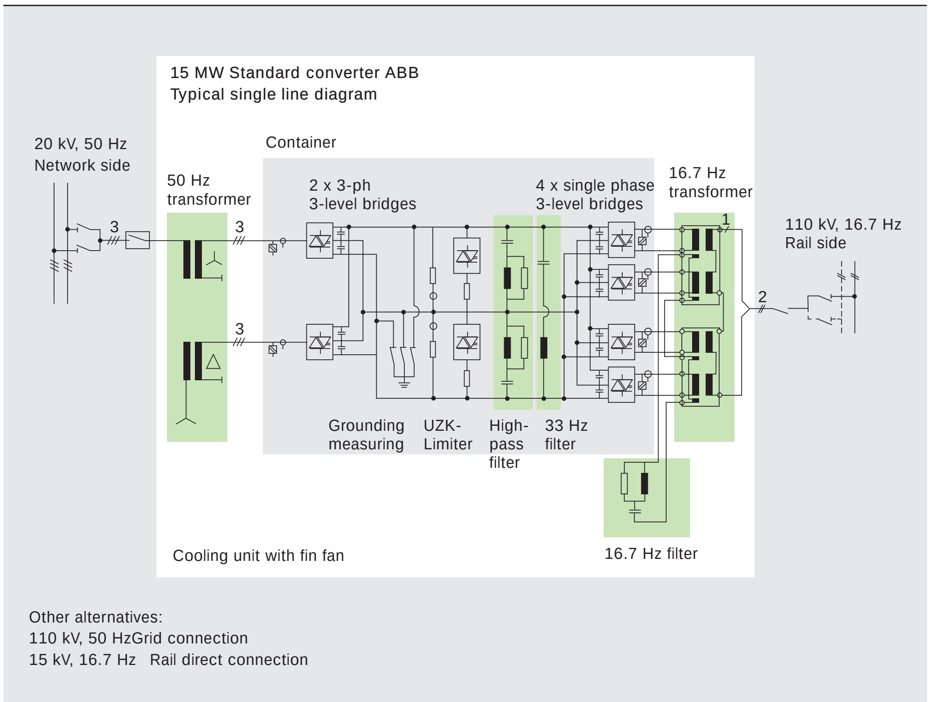
[2] Grünbaum, R., Hasler, J-P., Larsson, T., Meslay, M. (2009). STATCOM to enhance power quality and security of rail traction supply. ELECTROMOTION 2009, Lille, France.

Static converters, dynamic performance

Providing railway grids with the right frequency

GERHARD LINHOFER, PHILIPPE MAIBACH, NIKLAUS UMBRICHT – There are significant differences between railway electrification and national grids. One of these is that AC-electrified railways generally use only a single phase, whereas domestic grids generate, transmit and distribute three-phase power. Furthermore, frequencies are in many cases different from those of the national grid. Even when the same frequency is used, this is not necessarily synchronized. Nowadays, large frequency converters based entirely on power electronics are used to transfer electricity between national and railway grids. ABB has installed numerous 15 MW frequency converters, for example the railway power supply to the new Swiss Lötschberg tunnel. Today, even larger power classes are implemented, in particular the 413 MW station being built for E.ON in Germany – the most powerful static converter so far.

1 Single line diagram of a converter station



Electric railways have a huge demand for power. In fact many operate their own high-voltage power grids and some even operate dedicated generating plants. Few railways, however, are totally autonomous: Power must be exchanged with the national grids. Today, three main power systems are used for electric mainline railways.

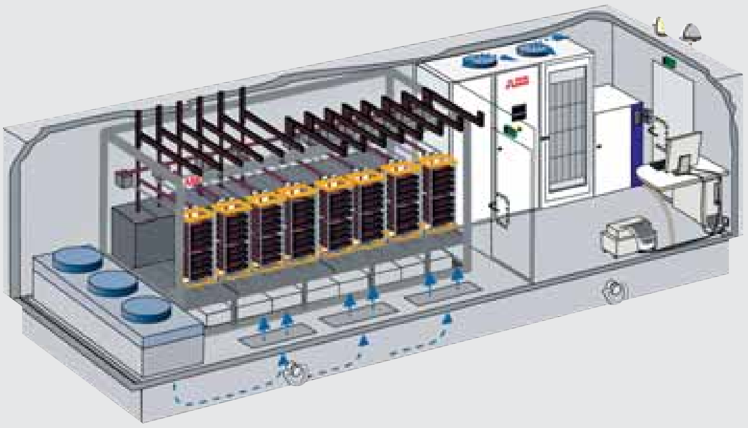
– In countries or regions where railway lines were electrified relatively recently, the catenaries are often fed from the public grid at a frequency of 50 Hz (or 60 Hz), mostly at a line voltage of 25 kV.
– In some countries, where railways were electrified much earlier, direct current (DC) was chosen (typical line voltages are 1.5 and 3 kV).
– Other countries use single-phase alternating current with a low supply frequency. These include the East Coast of the United States, using 25 Hz, and Norway, Sweden, Germany, Austria and Switzerland, using 16.7 (formerly 16 ²/₃) Hz.

In the past, rotary converters were used to exchange power between single-phase railway grids and three-phase national grids. They basically consisted of two electrical machines with a different number of pole pairs arranged on a common mechanical shaft. In a more recent development, frequency converters based on power electronics became suitable for this purpose. In fact, the total power of such static frequency converters taken into operation over the past 15 years is about 1,000 MW. Approximately two-thirds of these were supplied by ABB. Converters totaling more than 800 MW are presently being built or have been ordered.

From the point of view of the converter (be it rotary or static), the interconnection of a three-phase and a single-phase grid is more demanding than the interconnection of two three-phase grids. One principle reason for this is the fact that the power in the single-phase grid oscillates at twice the grid frequency, whereas in the three-phase grid it is basically constant. In the case of rotary converters, the ensuing torque and power fluctuations are absorbed and damped by the rotating masses. The resulting vibrations must however be absorbed by their mechanical anchoring and foundations. This leads to additional complexity in the design of both the machine and its foundations.

In the case of static frequency converters, the oscillation is filtered using a capacitor bank and an inductance that are tuned to twice the operating frequency of the railway grid.

The compact design led to the development of standardized converter modules and permitted converters of various power classes to be built.



Components of the converter container
– Space cooling system
– Converter and voltage limiter modules with control electronics close to the converter
– DC-link bus bars and capacitors behind the converter modules
– Bus bar feeders to the transformers
– Power distribution for auxiliary power and instrumentation and control system (control, measurement and protection)
– Uninterruptible power supply for the instrumentation and control system
– Local operation using HMI and event printer

Another challenge lies in the fact that the static converter not only has to act as a voltage and reactive power source, but must also be able to handle – without interruption – the transition from interconnected system operation to island operation in case of disturbances in the grid. Furthermore, it must be capable of acting as the sole power supply to an isolated section of railway, and be able to subsequently resynchronize with the rest of the railway grid after the disturbance has been cleared.

Long tradition of static converters

ABB can draw on a long history of static converter technology. The first railway power supply converters with powerful turn-off semiconductors in the form of GTOs (gate turn-off thyristors) were taken into operation in Switzerland in 1994. Since then a new semiconductor element, the integrated gate-commutated thyristor (IGCT), was developed that features a much more advanced switching capability, lower losses, and a low-inductance gate unit as an integrated "component." The compact design led to the development of standardized converter modules and permitted converters of various power classes to be built. Today, more than twenty converters in the 15 to 20 MW range are in operation and performing to the customers' fullest satisfaction.

15–20 MW: converter station for the Lötschberg rail tunnel

One of these deliveries was the Wimmis converter station for the new Lötschberg rail tunnel (Switzerland) [1], through which trains are able to operate at 200 km/h. In 2005, ABB supplied four converter units for this railway. The customer was the Bernese Power Utility (BKW), which was at the time responsible for providing electrical power to the railway. Each of the four converter blocks, with a power of 20 MW, first converts the three-phase supply from the 50 Hz network into DC (direct current). The energy is briefly stored in a DC link before being changed by an inverter into a single-phase, alternating voltage with a frequency of 16.7 Hz.

The single line diagram of a complete converter station such as the one installed for the Lötschberg tunnel in Switzerland is shown in → 1. It features the following components:

> The static converter not only has to act as a voltage and reactive power source, but must also be able to handle the transition from interconnected system operation to island operation in case of a disturbance.

50 Hz converter

This converter consists of two standard three-phase, three-level units. Two phases are combined in one stack to form a double-phase module. The converter is realized in a real 12-pulse configuration. Hence, only 12-pulse characteristic harmonics ($n = 12k \pm 1$; $k = 1, 2, 3, 4 \ldots$) are generated.

16.7 Hz converter

This converter consists of four standard two-phase, three-level units. Two phases are combined in one stack assembly to form a double-phase module. The 16.7 Hz converter is implemented in an eight-step configuration. The converter output voltage levels are summed by means of series connection of the line-side transformer windings of the four offset-pulsed three-level H-bridges.

Voltage limiter

Should the DC link voltage exceed an upper threshold, it is discharged via a resistor until a lower threshold is reached. The voltage limiter control works independently of the control system for the converter on the two-phase AC (railway-side) and the three-phase AC (mains-side). This ensures that the DC link voltage remains within the defined range at all times.

DC link

All double-phase modules of the converter are connected to each other on the DC side by a common bus bar. This carries the individual converter module connections for the directly coupled DC

Footnote
1 See also "Switzerland by rail" on page 31 of this edition of *ABB Review*.

Supplied in a weatherproof container, the converter and the associated control system are fully wired and tested.

link capacitors, the DC link filter banks and voltage measurements.

The DC link forms the connection between the 50 Hz and 16.7 Hz converters. It consists of the following main components:
- Directly coupled capacitor bank as energy storage
- 33.4 Hz filter to absorb the power fluctuation from the railway grid
- High-pass filter to absorb the higher frequency harmonics from the railway grid, in particular the distinct third and fifth harmonics of the railway grid

Converter container
Supplied in a weatherproof container, the converter and the associated control system are fully wired and tested. The cooling system is located in a separate container. Both containers are mounted onto a common support base. A cross-sectional view of the converter container is shown in ➔ 2.

50 Hz transformer
The transformer of the 50 Hz converter feeds the two IGCT-based three-phase bridges. A three-phase transformer consists either of a three-limb core in double-tier design with intermediate yoke or of two three-limb cores contained in one tank.

16.7 Hz transformer
The transformer of the 16.7 Hz converter is used to add up the four partial voltages to a nearly sinusoidal single-phase voltage with a rated frequency of 16.7 Hz. The transformer consists of four single-phase units. The rectangular partial voltages are generated from a DC voltage source (DC link) with the help of four single-phase IGCT converter bridges using the pulse-width modulation method and are fed to the four valve-side windings of the transformer. The adding up and adaptation to the railway grid voltage occurs in the high-voltage winding. A filter is connected to the series-connected tertiary windings or to the railway grid.

The world's largest rail converter station is now under construction in Datteln, North Rhine Westfalia, Germany.

Line filter
On the 16.7 Hz side, a filter is used to reduce the very low harmonic distortion caused by the converter to even lower values. On the 50 Hz side, this is also required in some cases.

Remote control
In the case of the static converters at the Swiss Lötschberg project, the whole system is remotely controlled by an ABB system-control computer, known as ALR [2], which captures and analyzes the data from the four 20 MW converters and the two rotary converters via standardized interfaces. The ALR continually calculates the optimum use of the available production units (static and rotary converters) on the basis of the power demand in the railway network or based on manual settings. Thus, the necessary power reserve can be connected to or disconnected from the network by the control computer within a matter of seconds.

All control, regulation and safety functions are equipped with the proven, fully digital power-electronic control system [3]

Footnotes
2 ALR is an abbreviation for Anlageleitrechner (system control computer).
3 On earlier installations: PSR (Programmierbarer Schneller Rechner), on current installations: AC 800 PEC.

3 The Wimmis converter station for the new Lötschberg rail tunnel

The two × 30 MW converter station in Timelkam, Austria

The ALR continually calculates the optimum use of the available production units (static and rotary converters) on the basis of the power demand in the railway network or of manual settings.

from ABB. This system is designed for use in precise and very fast servo loops for converter/inverter systems. The operator workstations of the ABB MicroSCADA power control system in the central control room guarantee the reliable display of the measured values and calculations as well as the operation of the supervisory circuits and sequences of all parts of the system. Hot standby operation of the supervisory power control system components (ALR and operator workstations) guarantees very high availability of the system.

The installation is shown in → 3. The 50 Hz transformer can be seen on the left-hand side, including the 50 Hz filter circuit above the transformer (mounted on a portal). The single phase 16.7 Hz transformer is on the right-hand side and the converter container is in the middle between the transformers.

Increase of unit power to 30 MW

Due to the modular design, other power classes can be implemented very easily (in steps of 15 MW). The additional converter modules are connected in parallel. This converter generation sets new standards in terms of performance, footprint and short erection and commissioning times. Positive feedback shows that ABB's standardized railway converter is well suited to meet customer needs.

Following the successful introduction of the 15–20 MW converters, customers sought a further increase of unit power. ABB thus developed another standard frequency converter for 30 MW with optional overload capability, depending on application and environmental conditions. Two or more 30 MW units can be combined in parallel to achieve higher power ratings per station.

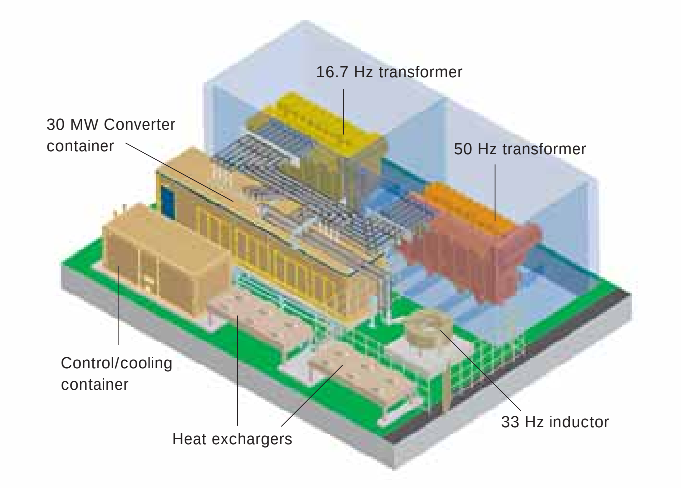
30 MW: converter station Timelkam

At the end of 2007, the Austrian Railway System ÖBB ordered a new rail converter station for installation near the town of Timelkam in the province of Upper Austria. The station comprises two independent 30 MW converter stations, which are fed from the national grid at 50 Hz / 110 kV and convert this to 16.7 Hz / 110 kV. A total of 60 MW of electric power is thus available for the railway grid with no transportation losses thanks to its proximity to the power generation facility. The first 30 MW converter went into commercial operation in July 2009 → 4.

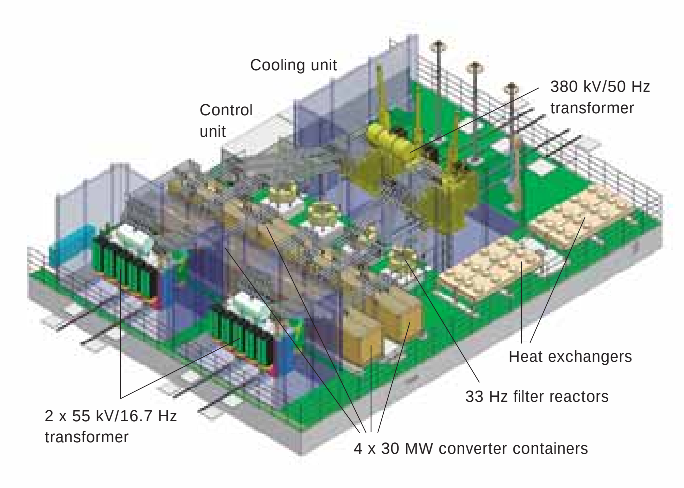
413 MW: Datteln converter station

The world's largest rail converter station is now under construction in Datteln, North Rhine Westfalia, Germany. The station was ordered by the German power supplier E.ON in 2007 and will provide a power rating of 413 MW. It will replace existing 16.7 Hz generators of the power plants Datteln 1–3, which have reached the end of their economic and technical lifespans. The converter station will receive power at 50 Hz from the new nearby Datteln 4 power station and feed power at 16.7 Hz into the 110 kV network of the German Railways (DB). The Datteln node is one of the most important "supply points" of DB's grid. A very high availability is therefore required of the converter station. ABB is responsible for the entire engineering of this project, ie, the design of the converter system, specification of all the components and

4 30 MW converter station



5 One of the four converter units (103 MW)



development of control and protection software. Since it is a turnkey project, installation and commissioning is also part of the project scope.

The scope of supply for ABB includes four independent converter stations each with a rated power of 103 MW, obtained from four standard 30 MW converters. The built-in overload capability allows the customer to still receive the nominal power of 413 MW even if one of the four converter stations is not in service. Each converter unit has the following main components:

- One converter transformer on the 50 Hz side
- Four converter containers including intermediate circuit filters
- One control container
- One cooling container (housing the cooling system)
- Four water/air heat exchangers
- Two series connected converter transformers on the 16.7 Hz railway side

Apart from the technical challenge presented by this major project, logistics and good planning are essential to enable the equipment to be delivered on time. The long contract duration (completion is scheduled for 2011) accompanied by a rigid timetable is a distinctive feature. This project may also pioneer further applications: Four converter blocks with 103 MW each set a new standard in terms of power for static frequency converters ➔ 5.

Outlook

ABB is market leader for this type of system. The modular approach allows a flexible response to various power requirements. In coming years there will be an increased demand for 15 MW converter units as many rotary converters reach the end of their lifespan. ABB is committed to following up on its recent successes by further advancing this technology.

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Building on success

FSK II outdoor vacuum circuit breakers make the connection for UK rail projects

KAREN STRONG, BRYCE DENBOER – Outdoor circuit breakers form a vital part of the power infrastructure that supplies electricity to mainline trains via the overhead catenaries. They are used for isolating the supply to the catenaries, as well as for sectionalizing parts of the track during inspection and maintenance. ABB's FSK I outdoor vacuum circuit breakers have established a significant global reputation for their reliability, performance and long life, especially in projects in the United Kingdom. So when ABB launched the new FSK II with a range of innovative features, such as a maintenance-free combination of magnetic actuator and electronic controller, it was natural that it would quickly attract the interest of contractors working on Network Rail projects.

1 Part of Birmingham's cross-city eletrification project included the replacement of old circuit breakers with new ones from ABB

1a ABB's FSK II vacuum circuit breakers

1b New electronic controller at ground level

ABB has developed the FSK II outdoor vacuum circuit breaker specifically for single (1 × 25 kV) and two-phase (2 × 25 kV) 50 Hz traction power supply switching applications (see picture on page 48). The design builds on the success of the earlier FSK I currently in widespread use around the world. The FSK II, however, features an important new development that replaces the mechanical linkage, traditionally used on this type of switchgear to couple the control box (at ground level) with the elevated vacuum interrupter, by an electronic controller linked by cable to a magnetic actuator at the base of the interrupter.

The main advantage of the FSK II's magnetic actuator and cable connection approach is that it eliminates several moving parts, creating an installation that is essentially maintenance-free, robust and reliable. This in turn significantly reduces service time and costs. In addition, the simple flexible design makes the FSK II easy to adapt and integrate into new or existing installations. It is also fast and simple to install and commission as there is no need for mechanical adjustment on site.

ABB has paid particular attention to the design of the connections between the FSK II and its associated cables or busbars. This ensures a particularly neat and compact solution that minimizes the required installation footprint and reduces environmental impact. The FSK II also utilizes environmentally friendly nitrogen and vacuum insulating technology.

One of the first UK contractors to adopt the FSK II was Carillion plc, a leading support services and construction company that had two major rail infrastructure projects underway for Network Rail, the owner and operator of the United Kingdom's rail infrastructure.

ABB's FSK II's innovative magnetic actuator and cable connection approach eliminates several moving parts, creating an installation that is robust, reliable and essentially maintenance-free.

The projects were concerned with the replacement of life-expired circuit-breakers on structure mounted outdoor switchgear (SMOS) installations. The first project was carried out in the North West Leeds area and the second focused on the first two phases of Birmingham's cross-city electrification.

Carillion decided to use ABB's FSK II circuit breakers because, as Darryl Hackett, Carillion Project Manager for Power Systems explains, "After considering a number of options it was apparent that ABB's new FSK II would offer the ideal solution for us. This was based on its simplicity, elegance and compact design, especially with respect to electrical clearances, so it required a smaller installation footprint. It was also easy to install (and) requires very low maintenance."

The Carillion project moved swiftly from the time the first purchase order was made in July 2007 to the factory acceptance test (FAT) in Geneva in November 2007. The first batch of 50 circuit breakers was delivered in February 200, and to date well over 100 FSK II circuit-breakers have been delivered to Carillion.

Engineering support

The key to the success of the Carillion projects was not just confined to the technical advantages of the FSK II design; ABB's high level of engineering support was also a crucial factor, in particular the attention given to ensure the circuit breakers were correctly installed. Carillion was operating within tightly defined periods of "possession," ie, when the sites could be taken out of service. By ensuring that the circuit-breakers were delivered in a ready-to-fit condition, ABB helped Carillion reduce the duration

2 ABB used a modified cable extension between the control box and interrupter

3 Network Rail Certificate of Acceptance

Recently, ABB received Network Rail's formal Certificate of Acceptance for use of the FSK II 27.5 kV outdoor vacuum breaker in electrical traction power systems. This formal certification follows the successful installation of a large number of FSK II circuit breakers under trial conditions for several major UK projects, including the Carillion projects as well as the West Coast Main Line (WCML) power upgrade.

of the required outage by a third! So for example, larger feeder sites with six or seven breaker replacements were completed in just four weeks. This fast-track approach was well received by Network Rail as it helped minimize the potential disruption to rail services.

Customized solutions

The Leeds project was relatively straightforward as the new FSK II circuit breakers were replacing older ABB circuit-breakers of a similar design. The Birmingham project, however, was more challenging for several reasons:

- The new circuit breakers were replacing a significantly different design from another manufacturer.
- They had to be mounted onto the existing steel skeleton superstructure.
- Network Rail was keen that only the physical replacement of the circuit-breakers was required and as much of the original cabling as possible should be retained.

> The connections between the FSK II and its associated cables or busbars ensures a compact solution that minimizes the required installation footprint and reduces environmental impact.

In answer to the mounting requirement, ABB, in close cooperation with Carillion's experienced site installation team, devised a special adaptor interface that used the same terminations and bolt spacings → 1. Effectively, it became a like for like replacement but one which incorporated the latest technology. To retain as much of the original cabling as possible, ABB provided a control cable extension for the FSK II and reused the existing field cables → 2.

The final verdict

Darryl Hackett would have no hesitation in recommending ABB's FSK II circuit breakers for similar projects → 3. Complementing the company's professional approach, he said there had been a seamless interface between Carillion and ABB's own operations in the UK and Switzerland. This, he added, provided a smooth transition from the initial FAT to final delivery.

"What was particularly impressive was ABB's flexibility in adapting the FSK II design to meet the individual preferences of both Carillion and Network Rail, such as in the positioning and labelling of switches. It was also particularly refreshing to be kept fully informed of progress, even to the finest detail such as when a shipment was leaving the factory, to when it was arriving in the UK and when it could be expected to reach our warehouse – all without us ever needing to chase or follow up."

The FSK II is available either as loose equipment or complete with mounting brackets. It has achieved over 5,000 operations under test conditions, which is equivalent to a service life of well over 20 years in most normal railway applications.

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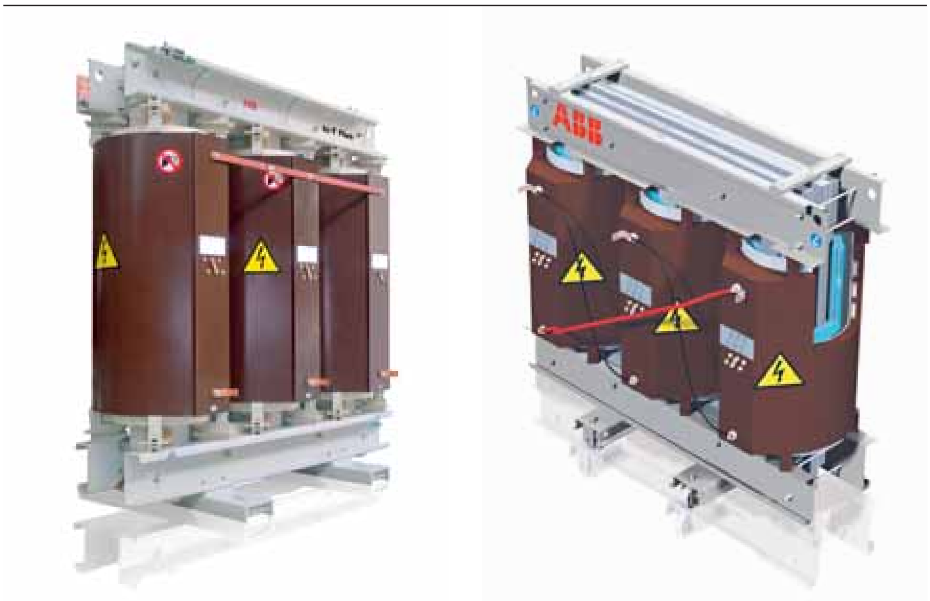
Transforming ideas into movement

ABB vacuum cast coil dry transformers are doing excellent (under)ground work in Istanbul

RAFAEL BUENACASA, JOSÉ ANTONIO CANO, CARLOS GARCÍA QUIRÓS, BERTA OBIS – Istanbul is the only city in the world that belongs to two continents. It is perhaps the most important financial and cultural center in Turkey and certainly one of the most important in the world. As a thriving city with a population of over 13 million people, it may be surprising to learn that its transport network, by comparison with other major cities, is still in its infancy. While that may be the case, no effort is being spared in developing a rail network that will elevate Istanbul to the transport levels of other prominent cities.

1 ABB's hi-T Plus cast coil dry transformer



Like many other cities of its size, Istanbul has been beset by serious traffic congestion problems for many years. To alleviate some of this congestion, construction of the first underground railway in Istanbul only started as recently as 1992, and the first line began operation in the second half of 2000. While this has gone a long way in helping to reduce the number of cars on the streets, much still needs to be done.

Since it began in 1992, construction work has been ongoing. For example, the Kirazli-Olimpiyat metro line is the third line built in Istanbul on the European side, while the Kartal-Kadikoy line was the first set up on the Asian side. ABB has been active in both projects as the supplier of choice of vacuum cast coil transformers. In fact, the company has supplied a total of 133 of these types of transformer: 47 vacuum cast coil transformers with a power rating ranging from 2,000 kVA to 3,300 kVA for the Kirazli-Olimpiyat metro line; and 86 dry transformers – 60 vacuum cast coil transformers with a power rating ranging from 250 kVA to 5,000 kVA, class 36 kV for distribution application, and 26 hi-T Plus vacuum cast coil 12 pulse rectifier transformers with a power rating of 3,300 kVA, class 36 kV for traction applications – for the Kartal-Kadikoy line.

Why ABB transformers?

ABB vacuum cast coil dry transformers are moisture-proof, making them suitable for operation in humid or heavily polluted environments. They can operate in environments with humidity levels higher than 95 percent as well as at temperatures down to – 25 °C. In addition demanding installation requirements, such as reduced noise, vibration levels and limited space made them the ideal choice. Vacuum cast coil dry transformers are designed to withstand seismic conditions, and given Istanbul's geographical position, ie, close to an active fault in North Anatolia, which has been responsible for several earthquakes, the anti-vibration accessories played an important part in the final decision to commission ABB's transformers.

ABB vacuum cast coil dry transformers are moisture-proof, making them suitable for operation in humid or heavily polluted environments.

Over 100,000 units are currently in operation around the world, including the more than 1,600 dry type transformers (with power ratings up to 16,000 kVA) present in railway networks. This makes ABB the most experienced supplier of this type of transformer by far.

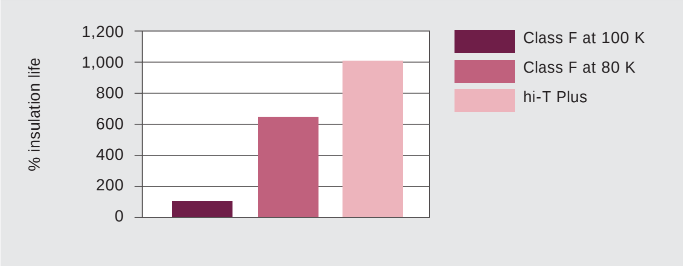
Vacuum cast coil dry transformers are produced in dedicated focus factories. One such factory is located in Zaragoza, Spain, which manufactures customized transformers.

The portfolio of vacuum cast coil transformers for railway projects is broad. However, there are basically two main applications where they are mostly used: substation distribution and traction. Providing energy for the second requires a different, more restrictive solution, namely in the form of hi-T Plus transformers → 1.

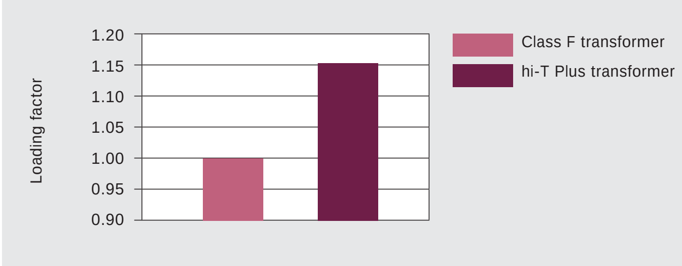
When heat is not a problem

ABB's hi-T Plus transformers differ from other vacuum cast coil transformers in that they can operate at much higher temperatures – thus the hi-T in the name. This is possible by the use of upgraded thermal insulation, which in this case is a class H material. Traditional vacuum cast coil transformers use a class F insulating material. Materials belonging to insulation class H are known for their enhanced mechanical and dielectric properties and high heat resistance. This means the hi-T Plus transformer can easily withstand an average temperature rise of 125 K with-

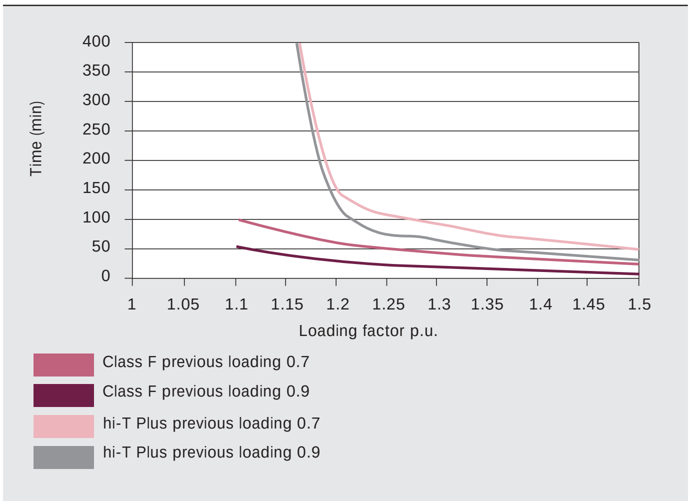
2 Expected insulation lifetime taking Class F at 100K as 100 percent



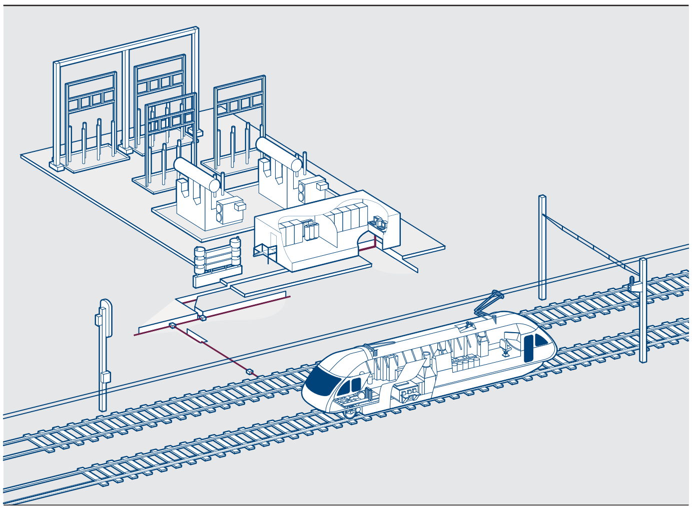
3 The overloading capabilities of the hi-T Plus transformer



4 hi-T Plus transformer capabilities without loss of life



A fixed railway substation. See page 72 for a detailed description



out affecting its insulation lifetime → 2. In fact this class H device has the added benefit of an increased insulation lifetime, and is by far the best choice for networks with high harmonic distortion, load peaks, sudden overloads and high un-

Compared to other vacuum cast coil transformers, ABB's hi-T Plus transformers can operate at much higher temperatures because the thermal insulation uses a class H material.

foreseen ambient temperatures. However, by design the rated temperature rise is limited to 100 K for a maximum ambient temperature of 40 ºC. In addition, the hi-T Plus transformer is characterized by its superb overloading capabilities, ie, continuous overloading, even at full rated power, will not decrease the lifetime of the device → 3 and → 4. The transformers are designed to work under overloading conditions at a temperature never exceeding their insulation class, thereby ensuring that degradation never occurs during these cycles.

These technical advantages, combined with the fact that it works within class B temperature rise limits, ie, a maximum average winding temperature rise of 80 K is allowed, enable a reduction in the transformer footprint of a hi-T Plus device with the same power rating as its F-class counterpart. This in turn enables engineering companies and end-users to reduce their operating costs.

Transformer rated power for railway applications is identified with one of the cycles included within the EN50329 or IEC60146 standards. Moreover, harmonics are taken into consideration, and if no information is available, standard values are taken as reference. This removes any uncertainties that, in the past, were usually solved by oversizing the transformer or limiting its temperature rise.

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Transforming suburban transport

ABB traction transformers helping to move millions of commuters

CÉCILE FÉLON, HARRY ZÜGER – A train speeds out of a calm suburb and into the bustling city, opens its doors and releases hundreds of passengers onto the platform. Soon the doors close and power once again flows to the train through overhead lines allowing it to accelerate rapidly to 60 km/h in a few seconds. Within a few kilometers the train decelerates and glides into yet another station to unload still more commuters. These events are repeated hour after hour, day after day, year after year. In cities around the world commuters rely on the high-performance of ABB traction transformers to reliably power their travel, quietly, and efficiently, while they prepare for another day at work.

Unlike regional rail systems, which operate between towns and cities, commuter rail services usually connect city centers to outlying suburbs within a range of around 60 km. These suburban railway networks carry large numbers of passengers under demanding conditions.

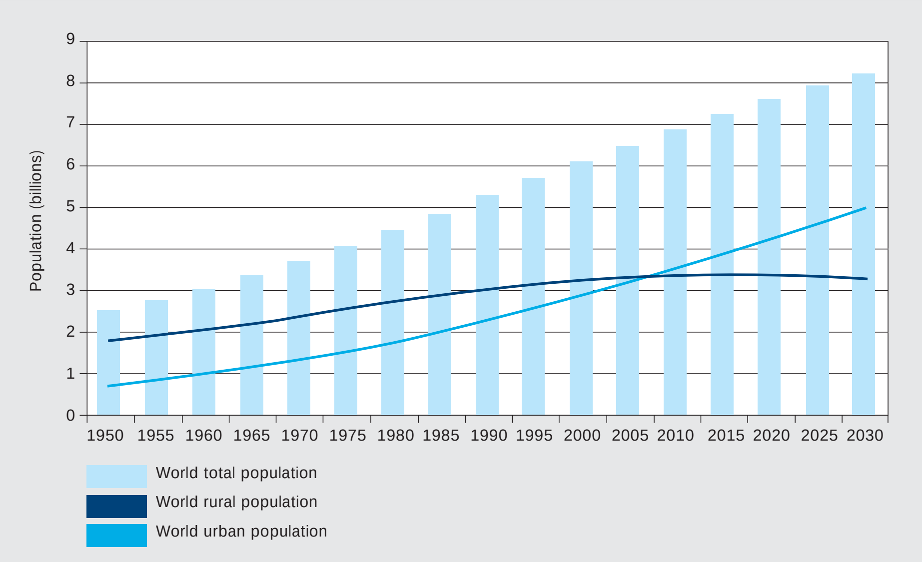
Commuter trains are expected to stop frequently, and decelerate and accelerate rapidly, placing severe strain on components. Despite these harsh operating conditions, the train is expected to perform reliably and provide a dependable service, no matter the environmental conditions.

ABB is a leading supplier of compact, lightweight, reliable traction transformers tailored to suit the specific requirements of the commuter train manufacturers and operators. ABB has an unrivaled track record, having manufactured several thousand traction transformers that are in operation around the world today. Now more than ever, ABB can provide a level of technical experience that facilitates the delivery of traction transformer technology regardless of the constraints faced by commuter train suppliers.

ABB's traction transformer improves urban quality of life

2008 represented a landmark year in global urbanization with more than half of the world's population living within urban areas for the first time. Forecasters predict that 60 percent of the global population will live in urban neighborhoods by 2030, and that the trend is set to continue. By 2015, it is estimated that 560 cities across the globe will have a population in excess of one million people ➔ 1.

1 The urban and rural population of the world, 1950 to 2030



This urban expansion is placing considerable strain on existing transportation infrastructure, with unprecedented levels of congestion becoming widespread in many urban areas. Evidence of this pressure can be seen in cities around the world, ranging from those in Germany, where commuters spend an average of 65 minutes each day travelling to work, to China, where this figure rises to 83 minutes a day. Not only does this level of congestion impact upon the quality of life of those subjected to it, but it also generates high levels of air pollution locally. In order to satisfy the increasingly critical need for a solution to this problem, cities are moving to expand the reach and capacity of their public transport networks.

As a leader in propulsion technologies, ABB is helping cities in this battle against congestion and pollution by contributing several key technologies to the electric multiple units (EMUs) used by many modern commuter network operators around the world. These vehicles display significantly higher levels of energy-efficiency when compared to diesel trains and buses and require relatively little space to transport large passenger numbers. By some estimates, convincing a commuter to switch from car to train will reduce CO_2 emissions by 50g / km [1]

To encourage passengers to use rail, mass transport operators must offer an affordable, reliable, and pleasant transport experience. Often rail operators collaborate closely with rolling stock manufacturers to ensure this.

ABB's long and extensive track record in commuter trains

ABB provides traction transformers for suppliers of commuter rail rolling stock

> Ester oil displays excellent performance characteristics at the high temperature frequently experienced when these vehicles undergo periods of heavy acceleration. Such innovations maintain transformer efficiency while providing the client with a readily biodegradable product.

around the globe. The effective implementation of innovative ideas and the ability to serve the world-wide market have helped ABB establish itself as a leading supplier of cutting-edge traction transformers.

Within the last five years, the dramatic growth of commuter rail networks has helped ABB strengthen this reputation further. The company has delivered transformers to serve dozens of cities in Europe, India, and even to new markets such as North America and Africa.

New Jersey

In North America, the NJ (New Jersey) Transit system is a commuter rail network that serves the New Jersey suburbs of New York City, Newark, Trenton and Philadelphia. NJ Transit is the fourth busiest commuter rail network in North America, carrying approximately 252,000 passengers every weekday. Unlike many commuter trains in Europe, the trains that operate on this system use electric locomotives rather than EMUs. Bombardier is the supplier of the ALP 46 (American Locomotive Passenger) locomotive fleet to the NJ Transit system. These locomotives are required to be able to transition from zero to full throttle instantaneously, a practice that is commonly called for on North American rail systems. Instantaneous acceleration generates a violent thermal shock as the equipment undergoes a rapid temperature rise, a situation heightened under cold weather conditions. Bombardier chose ABB to supply transformers for these locomotives, supporting their reliability under these challenging conditions → 2.

Paris and suburbs

ABB has also supplied Bombardier with traction transformers for use on their SPACIUM EMUs in France. These trains

2 ABB traction transformer for Bombardier's ALP 46 locomotive

3 The last generation of traction transformer for Alstom's Porteur Polyvalent platform

are to be operated by SNCF (the French National Railway Company) in and around Paris, as part of an overall plan to extensively renew the countries regional rail network. These new EMU's were derived from Bombardier's AGC (Autorail à Grande Capacité) family of trains. ABB had already delivered traction transformers for the standard AGC platform and the AGC XBiBi versatile version. Drawing on these experiences, the most significant challenge facing ABB engineers on this SPACIUM project was to produce transformers with minimal noise emissions. ABB installed roof mounted, silent running traction transformers, as well as cooling systems that ensure lower noise emissions. The commuter and regional services operating in and around Paris account for around 1 billion trips per year, or 80 percent of national rail usage. This figure highlights the importance of suburban rail networks and their potential to improve efficient and reliable mass transport. In the case of Paris the development of the RER (Regional Express Network) has successfully combined existing rail infrastructure with the Paris Metro system so that the city centre and the surrounding suburban areas are connected providing an efficient and fully integrated transport system.

French regional

Further renewal of French suburban rail networks has led to investments in Alstom's Coradia Polyvalent trains named Régiolis by their French operator. The prime consideration for Alstom in the design of this single level modular train was to reduce the weight as much as possible. ABB won the contract to supply traction transformers to power these trains and worked closely with the client to produce a transformer, with DC line filter reactors and an auxiliary converter inductor with a total weight of only 2,650 kg → 3.

Switzerland

Switzerland has some of the worlds most highly integrated and efficient public transport systems. Although annual passenger numbers only total approximately 360 million, Switzerland's reliance on rail systems on a per capita basis is huge, with each citizen taking an average of 49 rail journeys per year representing the highest per capita usage of rail services for any European country.

Within the last six years, ABB has supplied a large number of traction transformers for the Swiss railway market. ABB won an order from Stadler Rail in 2003 to equip its FLIRT (Fast Light Innovative Regional Train) initially built for Switzerland → 4. Drawing on this successful project, ABB won repeat orders in the following years to equip further trains of the FLIRT platform for use in many other countries including Germany, Hungary, Algeria, Finland, and Norway. Today, almost 800 traction transformers have been delivered to Stadler Rail and in the year 2009, the total number of transformers ordered for the FLIRT platform surpassed 1000 units.

Based on their successful long term partnership, Stadler Rail again chose ABB as supplier for the traction systems

2008 represented a landmark year in global urbanization with more than half of the world's population living within urban areas. With forecasters predicting 60 percent of the global population will live in urban neighborhoods by 2030, it is widely accepted that this global trend is set to continue.

4 ABB has received orders for more than 1,000 traction transformers for Stadler Rail's FLIRT trains.

5 ABB traction transformer for Siemen's Desiro train

of its new generation of double-decker multiple-unit train (DOSTO) for use on Zurich's S-Bahn network. There are already follow-up orders for this type of double-deck EMU from Switzerland, Austria, and Germany. The DOSTO collaboration is likely to repeat the FLIRT success story.

India

In 2004, ABB was awarded a contract from Siemens Mobility to supply transformers for 172 EMUs intended to service the Mumbai commuter rail system. This project presented specific challenges for ABB's engineers with the transformers being required to function in India's high tropical temperatures. The traction transformers were designed to provide increased energy efficiency at higher temperatures. The Mumbai system is one of the most intensively utilized public transportation networks in the world and the Mumbai Suburban Railway alone carries more than 6.1 million commuters daily.

> Within the last six years, ABB has supplied a large number of traction transformers for FLIRT trains for Switzerland, Germany, Hungary, Algeria, Finland, Norway and other countries.

Scotland

In another project with Siemens Mobility, ABB was contracted to supply traction transformers for trains destined for the Scottish railway franchise Scotrail. Siemens required environmentally-friendly, highly efficient mono-system transformers for use on a new generation Desiro commuter train ➔ 5. ABB responded to this challenge by producing transformers that used ester oil rather than conventional mineral oil as coolant. Ester oil displays excellent performance characteristics at the high temperature frequently experienced when these vehicles undergo periods of heavy acceleration. Such innovations maintain transformer efficiency while providing the client with a readily biodegradable product that makes its ultimate decommissioning more cost effective, and presenting fewer adverse environmental implications throughout the product's working life. Further benefits include the oil's high fire point, which allows it to meet the UK safety requirements for operation in tunnels. These new trains will be used by Scotrail to serve Glasgow's metropolitan area.

Algeria

In 2006, Algerian State Railways placed an order for 64 new FLIRT trains from Stadler (with ABB traction transformers) for use on local services around the capital Alger (Algiers). These trains are notable because they are designed to carry high passenger densities of up to 10 per m^2, in searing temperatures up to 55 °C.

This project illustrates the strengths of standardization. The cooling of the FLIRT transformer was designed for 15 kV. The Algerian FLIRT, however, uses the same system at 25 kV, providing a greater cooling reserve and so making the train suitable for either higher ambient temperatiures or higher power.

South Africa

In South Africa, ABB traction technologies will power the Gautrain, an 80-kilometer rapid mass transit railway linking Johannesburg and Pretoria to Tambo International Airport. The Gauteng province is at the heart of South Africa's economy. It creates one-third of South Africa's gross domestic product and is home to around 10 million people, one-fifth of the population. ABB is playing a vital role in this project providing traction solutions for the 24 electric train sets that will operate at speeds of up to 160 km/h ➔ 6.

The Gautrain is a variant of Bombardier's award-winning Electrostar train, which is widely used in the United Kingdom and is powered by ABB traction transformers.

Modifications were made to ABB's standardized transformer design for the Electrostar to meet Gautrain's specific re-

6 The Bombardier's Gautrain train with ABB traction transformers

quirements for fast acceleration, low noise emissions and adaptability to the African climate. These adaptations have enabled ABB to offer high-class traction solutions at an unbeatable quality to price ratio. Chief among these modifications is a huge increase in power of around 40 percent to boost the train's acceleration.

ABB, the irrefutable leader

ABB has worked closely with leading suppliers in the rail industry, providing

> The SPACIUM EMUs were derived from the AGC (Autorail a Grande Capacite). ABB delivered traction transformers for both AGC and SPACIUM.

traction transformers for numerous commuter trains. These transformers have accrued a high number of operation hours worldwide and enabled millions of trips to work and leisure in the world's cities.

Reducing weight of traction transformers

ABB Sécheron factory in Geneva, the Group's global "Centre of Excellence" for traction transformers

Building on several decades of experience in the traction transformer business, ABB has worked tirelessly to reduce the weight of its transformers, while continuing to provide the best possible performance.

The driving force for the efforts to reduce weight was and remains the commuter- and high-speed train market, where each kilogram has a material impact on operating costs and speed.

Weight is a primary consideration from the very beginning of the design process for ABB transformers. Once the target weight has been established, the transformer is designed using the best available technology to achieve the goal. ABB's team of engineers works closely with industry research and development partners to ensure the best insulation components are used to minimize weight, without compromising the dielectric capacity.

A transformer's design must accommodate load cycles, as specified by the customer, using the minimum weight of copper required to avoid any risk of overheating. Transposed wires are used to minimize harmonic losses and additional weight reduction can be achieved, in some cases, by integrating the converter's reactors into the transformer's housing, where they benefit from hydraulic cooling. Finally, software is used to establish the minimum distance between the transformer's winding and its tank. This ensures that the transformer is as compact as possible, without exceeding the external levels of magnetic flux specified by the customer.

The weight of a transformer's tank, whether made of steel or aluminum, is optimized using the finite element method (FEM) to ensure mechanical robustness while minimizing weight. In most transformers of this type, one or more cooling units are incorporated into the tank in order to simplify the hydraulic circuits and make each transformer an independent, self-cooling unit. Such cooling systems are compact and highly effective with low-noise (< 93dB) motor fans.

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A perfect fit

ABB's powerful propulsion converters are energy efficient, reliable and very compact, making them suitable for all rail vehicle designs

HARALD HEPP – In modern rail vehicles driven by electric motors, all movement is controlled and powered by traction converters built on insulated gate bipolar transistor (IGBT) semiconductors. ABB is a leading supplier both of power semiconductors and of a very broad portfolio of power electronic systems and applications, in particular of motor drives for all industry segments and power ranges. In the past ten years, ABB, leveraging a unique combination of power electronics expertise, brought new, highly successful traction converters to the railway market that excel in energy efficiency, reliability, compactness and service-friendliness. In the global market, ABB is one of the very few independent suppliers of traction converters or even complete traction chain packages. ABB is not building rail vehicles but supplying key power sub-systems.

1 ABB's 2.3 MW BORDLINE Compact Converter used to drive three axles in dual-system CoCo locomotives

If one compares the electric traction motors in trams, motor coaches or locomotives to muscles in the human body, the traction converters would be both the heart and the cerebellum. As the heart, the converter ensures the proper energizing bloodstream, and as the cerebellum it takes care of smooth and precise movement and coordination through sophisticated control algorithms. Speaking more in the language of railway electrics, a traction converter provides the exact voltage wave patterns for the traction motors to control their speed and torque as well as the energy flow to the wheels – or from the wheels back when the vehicle brakes in regenerative mode. A state-of-the-art energy-efficient 1.5 MW converter from ABB (BORDLINE™ CC1500_AC) for double-deck EMU trains of Stadler Rail is shown on page 60. The traction converter is the "intelligent link" between, on the one side, the energy supply through catenary, transformer or Diesel-generator, and the traction motors on the other side.

Motor-side challenges

On the motor side, the traction converter receives input signals from the motors, for example phase currents, speed, and motor temperature. This information is combined with the driver's or vehicle control's commands which tell the converter how the train shall start, accelerate or brake. Control algorithms process these signals in milliseconds, taking into account the motor characteristics in different regimes of the motor frequency/load diagram. In reality, however, a drive control system for rail vehicles is much more complex. The system has to cope with wheel slippage, which depends on weather conditions, slope, and the wear of the rail track and wheels. Another challenging aspect can be the coordination of different motor axles of the vehicle. As an example, ABB converters showed benchmarking traction effort in field trials with a new multi-system CoCo locomotive of the Spanish system integrator Construcciones y Auxiliar de Ferrocarriles (CAF) S.A. → 1. The most essential functions of the drive control are the protection algorithms that make sure that the control reacts properly, reliably and safely in all imaginable irregular states of the complete propulsion system.

> If the electric traction motors in trams, motor coaches or locomotives were compared to muscles in the human body, the traction converters would be both the heart and the cerebellum.

One of the key advantages of ABB traction converters is that they are built on the AC 800PEC control platform [1], probably the most powerful modular controller for high-speed performance on the market → 2. This control platform is also used in ABB wind converters, high-power industrial drives, plant automation, high-power rectifiers and many other applications. The AC 800PEC software is implemented on three performance levels, and this provides an excellent range of control and communication functionality in cycle times that extend from the sub-microsecond to the millisecond level. The controller is complemented by a variety of input/output modules as well as engineering and service tools → 3.

2 ABB's control platform AC 800PEC, which is employed in ABB traction converters

3 A BORDLINE CC1500_AC control frame with the AC 800PEC controller, reflecting a neat and lean hardware structure

Several teams of ABB hardware and software engineers dedicated entirely to working on traction converters, develop traction-specific hardware configurations and software modules, and tailor them to the customer's vehicles and projects. Compared to most other commercially available traction control systems, the application software in the AC 800PEC is built in a way that speeds up train commissioning significantly. The commissioning engineer can adjust parameters and algorithms in real time to ensure smooth and powerful motion over all speed and load ranges. Often the system integrators and rail operators are surprised at how quickly new vehicle designs using ABB converters and drive control come to life when they are powered and started for the first time.

ABB traction converters are built on the AC 800PEC control platform, probably the most powerful modular controller for high-speed performance on the market.

Line-input-side challenges

Since the train is an often fast moving system, the catenary contact is not perfectly stable. Hence, the converter has to compensate for fluctuations in input power. In weak electrification networks, like for instance in some parts of India, adapting to varying line voltages, is an even greater challenge.

Traction converter control should not only optimize the output voltage waveforms for the motors but it should also make sure that the traction chain does not cause perturbations, oscillations or higher harmonics on the input side. In diesel-electric vehicles, the converter control needs to minimize distortions in the generator waveform to reduce wear and optimize energy efficiency. For electric trains, line-input control is even more important in order to avoid safety-relevant interference with signaling installations. In certain networks, as described above, good traction converters in operation can even have a stabilizing effect on the line voltage level and waveform.

An example for these challenges is the system perturbation code in the Norwegian 15 kV/16.7 Hz rail network. The rail infrastructure agency Jernbaneverket demands a specific damping of low-frequency oscillations that arise through the load of trains running on long-distance parts of the network and the regulation of small hydropower plants feeding these lines. ABB traction converters, because of their powerful converter control programming, were more than capable of meeting these requirements by simply adapting software already running on

4 Adapted ABB control software on board a Stadler FLIRT train from Switzerland is given a test run in Norway

converters designed for trains in Switzerland. Test runs in Norway with a Swiss FLIRT train from Stadler Rail convinced the Norwegian State Railways (NSB). Today, ABB has orders for 300 BORDLINE CC750 Compact Converters and 150 ABB traction transformers for NSB → 4.

Designed to fit any vehicle design

In most rolling stock projects, the vehicle design imposes challenging constraints on the physical dimensions of traction converters, transformers and motors. Through very compact and lightweight constructions, the ABB equipment gives more freedom for the vehicle design. In principle, traction converters and transformers can be mounted in the machine room (see the converter in the title picture), under the floor → 5 or on the roof of the rail vehicle → 6. The traction converter design can also substantially reduce the size and weight of the transformer.

How can ABB traction converters achieve this compactness and high power-density? The recipe comprises internal liquid cooling, smart power module design and great care with the construction of the aluminum or stainless steel housing. Requirements for robustness of traction equipment are extremely tough; hence a wealth of expertise in materials selection and processing, welding and riveting technology, FEM analysis, cooling technology and other fields is necessary to achieve the weight reductions that ABB can offer in traction projects.

Internal liquid cooling for traction converters, for instance, is a technology that ABB has developed and optimized with great care in the last ten years. The advantages are manifold, ie, the temperature distribution in all parts of the converter is highly uniform, enhancing the lifetime of the power semiconductors. Power modules can be built so small and lightweight that one person can handle them. No machine room or other cooling air flow needs to enter the converter, and control electronics and power modules can be cleanly sealed from ambient dust, dirt and humidity.

Designed for retrofit

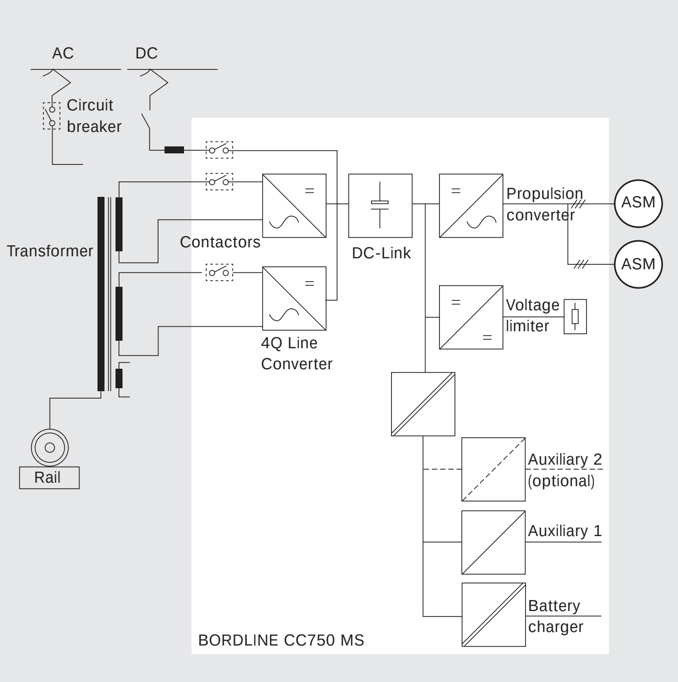
In refurbishment projects, the challenges of fitting traction converters to the existing vehicle are much tougher than in new designs because all interfaces, such as the train control system, the line-input side, motors, the cooling system, available space, and all fixings and connections are pre-defined. Nevertheless, these complex projects can have a high return on investment provided the converter supplier can offer a powerful modular platform with strong engineering and project management support. This can be illustrated with the retrofit solution for ICE1 high-speed trains in Germany with ABB converters. More details about this retrofit project can be found on page 70 of this issue of ABB Review.

Multi-system trains that know no borders

Nowadays rail vehicles increasingly need to cross borders of different electrification systems, eg, between countries with different DC and AC rail networks or between urban transport systems and mainline rail services. Coping with different input line voltages is a particular technical challenge for traction chains. ABB has come up with several smart and

Compared to most other commercially available traction control systems, the application software in the AC 800PEC is built in a way that speeds up train commissioning significantly.

5a Powerful ABB multi-system under-floor converters for narrow-gauge vehicles



5b Single-line diagram of this converter

ABB builds low-voltage and medium-voltage power electronic drives for all kinds of applications.

versatile solutions for such multi-system trains.

Consider, for example, Italy and Switzerland. Treni Regionali Ticino Lombardia (TILO), a subsidiary of the Swiss Federal Railways (SBB), is an operator of regional train services between Switzerland (15 kV AC 16.7 Hz electrification) and Italy (3 kV DC electrification). Between 2005 and 2009, TILO ordered a total of 31 FLIRT trains (3 MW) from Stadler Rail with ABB traction packages (the transformer was designed by ABB Sécheron and Compact Converters) that can run in both networks without interruption. The dimensions and most modules correspond to the pure AC version which SBB has bought for Switzerland in more than 80 trains since 2002. By doing this, SBB and TILO now reap the benefits of optimum service and spare part management, and reduced total fleet cost. It also showcases the satisfaction of SBB with the ABB solution. The same multi-system traction package design was also ordered by Südtiroler Transportstrukturen in 2007 for eight trains commissioned for service between Italy and Austria (15 kV AC).

For historical reasons, the mountain rail operator Rhätische Bahn (RhB) in Switzerland has different line voltages in their network. While most of it is powered by 11 kV 16.7 Hz, the line across the Bernina pass, listed in the UNESCO world heritage, one of the world's steepest adhesion lines with a 7 percent incline, has 1 kV DC electrification.

In early 2010, the first powerful dual-system mountain trains from Stadler Rail, called "Allegra", started commercial service after successful test runs in the last six months. For these narrow gauge trains, ABB developed under-floor mounted Compact Converters that comprise two 350 kW propulsion converters, galvanically insulated auxiliary converters and a battery charger, all in one very robust cubicle. Each train is equipped with four BORDLINE Compact Converters and two under-floor traction transformers – LOT1250 – designed by ABB Sécheron. Deliveries of 60 converters and 30 transformers will continue into the second half of 2010.

A unique market position

ABB builds low-voltage and medium-voltage power electronic drives for all kinds of applications: to propel ships; power wind tunnels; or control large and small motors in sophisticated industrial processes. These drives save huge amounts of energy, enhance automation, improve process quality and reduce mechanical wear. Related power electronic technology is used to feed energy from wind generators or photo-voltaic plants into the power grid or to stabilize power networks. Continuous innovation in these

6 Highly integrated BORDLINE Compact Converters that are mounted on the roof of tramways and narrow-gauge regional trains

The roof-mounted BORDLINE Compact Converters of ABB are examples of complete and highly integrated power-electronics sub-systems that consist of two motor inverters, two auxiliary converter outputs, a battery charger, a braking chopper and all control electronics. They are suitable for use on tramways and narrow-gauge regional trains at line voltages of between 600 and 1,500 VDC. They are characterized by adaptable mechanical, electrical and logical interfaces to the vehicle, very low weight and small dimensions. These types of roof-mounted converters have already been sold to public transport operators in Switzerland (Basel, Berne-Solothurn, the Lausanne region and the greater Zurich area), Germany (Bochum, Mainz, Munich, Nuremberg and Potsdam), Austria (Graz), China (Changchun), France (Lyon) and Norway (Bergen).

6a BORDLINE Compact Converter for light rail vehicles

6b Compact Converter that is mounted on the roof of narrow gauge EMUs

BORDLINE CC750 for EMUs. To date, Stadler Rail has bought more than 2,500 of this class of converter for FLIRT and GTW trains.

ABB applications also benefits from the fact that ABB is one of the leading suppliers of power semiconductors.

More and more rail vehicle manufacturers and fleet operators are turning to ABB for drive solutions, even those who have some converter production in-house. ABB's flexibility means customers can procure single components only – according to the customer's specifications – or they can buy complete optimized, energy-efficient and cost-effective traction chains. ABB leaves the application specification and system integration to the train manufacturer. However, leveraging economies of scale, ABB can optimize and standardize on the sub-system and module level.

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Hepp, H., Cavalcante, F., Biller, P. Performance on track: Electric power on trains – designed by ABB to make journeys more comfortable. *ABB Review* 2/2008, 25–29.

Standardizing the traction motor

ABB's innovative modular induction traction motor sets new heights in adaptability

PETER J ISBERG, MARK CURTIS – Trains are frequently custom made to accommodate the individual technical specifications of different rail service providers. Each new design requires a variety of unique, train-specific components that are supplied by additional independent original equipment manufacturers (OEMs). Traditionally the traction motor is among the many custom made components required by train manufacturers. These motors are intensively engineered to ensure function and quality, which results in increased complexity throughout the value chain and adversely affects their manufacturing lead time. To overcome these problems, ABB has developed a new range of induction traction motors with built-in flexibility so that customer-specific requirements can be met using a single modular design.

The traction motor is an electric motor used to power the driving wheels of a railway vehicle. Traditionally each traction motor was custom made to fit a specific vehicle. This inevitably resulted in long lead times to accommodate the design, engineering, product-specific supply chain logistics, quality assurance and the creation of new production line facilities.

ABB's new series of modular induction traction motors is the result of several years of product design and development. The project was initiated in 2007, not only to create a traction motor with universal appeal to train builders, but also to enable effective engineering, supply and production processes, and to maintain ABB's lead as an independent supplier of traction motors. An interdisciplinary team of engineers, suppliers, production specialists and researchers were brought together to create a new traction motor that would not only satisfy a wide variety of customers, but would also streamline production and the sourcing of supplies, reduce the cost of poor quality (COPQ) and ultimately lower the total costs throughout the product's life cycle, where energy consumption is a dominant factor. During this design phase, special attention was given to energy efficiency, reliability, and fast and easy maintenance to help lower operating costs for customers. During the design process all aspects of the traction motor could be freely manipulated with one exception. To maximize scalability, the new range of traction motors had to comply with the standard IEC (International Electrotechnical Commission) frame sizes specified for ABB's low-voltage (LV) motors. The frame sizes in the new series were designed to provide partial overlap in performance (power and torque) so that customers could be provided with the optimal traction motor to fulfill their needs concerning space and performance → 1.

Highly adaptable

To accommodate a variety of performance demands, ABB's new series of traction motors has an innovative modular design that provides flexible customized construction. A major feature of its adaptability is that drive and non-drive ends of the motor are not predefined. In addition the length of the motor can be adjusted to meet specific space and operation demands and the position of the terminal box and air in-take and outlet ducts can be adjusted to optimize performance and space constraints. Furthermore, the unit can be cooled either by open self ventilation (OSV) or by open forced ventilation (OFV) according to the customer's wishes. The flexible design means that an OFV can be converted to an OSV simply by adding an elongation ring and a fan and extending the shaft, providing customized traction motors from standardized modular components. This provides a standard structure for traction motors with different cooling methods so that the service and access to spare parts is simplified.

> ABB's new series of traction motors has an innovative modular design that provides flexible customized construction.

1 ABB's new modular traction motor

Cooling setup and mechanical interfaces are defined building blocks that ensure the major structure of the motor is standardized. Several positions are available for air intake or power cable connections on the housing providing great flexibility.

Flexible mounting

The modular induction traction motor range has mounting brackets that can be fitted in a variety of positions so that vehicle builders are free to fit motors by any method (suspended or non-suspended) to any bogie [1]. This means the optimal position of the motor can be found to integrate the motor within the least amount of space giving train manufacturers and OEMs the freedom to fit or retrofit ABB traction motors to both new and existing designs. The whole structure including the brackets and their associated attachment is designed to fulfill IEC 61373 (shock and vibration) standards without having to reduce the motor's mechanical performance.

Durable and versatile

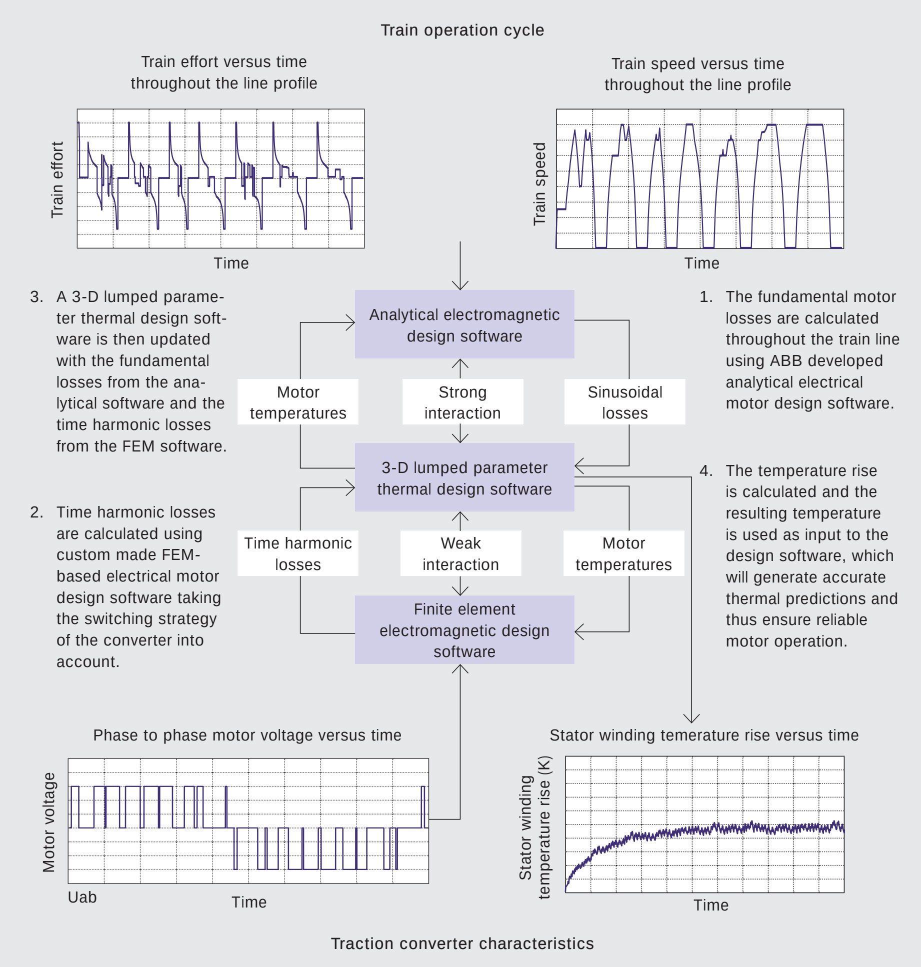
The modular induction traction motor series is designed to be durable and versatile. Many parts have integrated functions to help reduce the number of components and ensure the product is compact and robust. They are designed to endure extreme temperatures and polluted environments.

Customers want traction motors with the lowest possible weight and compact design, while at the same time providing a

Footnote

1 A bogie is a wheeled wagon or trolley. In mechanics terms, a bogie is a chassis or framework carrying wheels, attached to a vehicle. It can be fixed in place, as on a cargo truck, mounted on a swivel, as on a railway carriage or locomotive, or sprung as in the suspension of a caterpillar tracked vehicle.

2 Schematic picture representing tools and processes for the optimization of traction motors



high power and torque output over a lifetime of up to 20 to 30 years. In order to achieve high power density and reliability, it is not enough to only optimize the cooling capability and the electrical design. All aspects of the motor's design must be optimized.

Energy efficiency and reliability

The traction motor features a new electrical design, optimized for high energy efficiency and a competitive performance/weight ratio. A key design feature is that the rotor cage is made of aluminum, die-cast directly into the rotor laminations without the presence of any soldered interfaces. This is a robust and proven design that enhances the reliability of the product. Alternatively, the motor can be equipped with a copper rotor cage if slightly higher energy efficiency is desired. The traction motor is powered by a converter feeding the motor with voltage and frequency.

During the electrical design of traction motors it is essential to optimally match the motor and converter. The traction motors and traction converters fulfill very high specifications designed to meet precise requirements. In traction applications the switching frequency of the converter is usually low, which makes the harmonic effects in the motor more pronounced. With the help of state-of-the-art FEM (finite element method) software (developed by the Helsinki University of Technology and optimized solely for electrical machines), it was possible to get the best electrical design for the converter by taking into account its characteristics and certain optimization criteria:

– Torque ripple minimization [2]
– Low noise and vibrations
– High efficiency
– Low current
– Efficient cooling capability

Thermodynamic design

The temperature rise and thermal design is critical in traction motor applications. Very accurate estimations of the temperature rise of critical parts of the motor are crucial to its reliability. By coupling analytical electrical design software, FEM-electrical design software and 3-D thermal network software it is possible to simulate the expected motor temperature during its service with great accuracy. The structure of the software can be seen in ➔ 2. Inputs are the line simulation

The traction motor features a new electrical design, optimized for high energy efficiency and a competitive performance/ weight ratio.

of the train and the switching characteristics of the converter and outputs are the temperature rise of critical motor parts, such as stator winding and bearing temperature.

Special effort has been made to decrease harmonic losses, noise and torque pulsations, in a robust design and with production methods that ensure high quality standards. The insulation system contains corona resistant materials [3], has low water absorption properties, complies with temperature class 200 [4], and takes advantage of ABB's knowledge and experience having delivered traction motors since 1909.

Computational fluid dynamics (CFD)

Special care was taken to optimize thermal design. The output of the motor is thermally limited and the motor needs to be cooled efficiently. Cooling ducts (stator and rotor) and the fan have been optimized with respect to cooling efficiency as well as noise. Using CFD modeling, along with the electromagnetic computations, it was possible to predict the likely

Footnotes

2 The amount of torque measured by subtracting the minimum torque during one revolution from the maximum torque from the same motor revolution.

3 A corona resistant insulation material has higher resistance against deterioration when a high-voltage electrostatic field ionizes.

4 Temperature classification (also known as temperature class) defines the maximum continuous temperature that an insulation system can sustain in degrees Celsius.

3 Sectional CFD analysis of a fan

Contours of velocity magnitude (m/s)

location of hot spots in the event of motor overload, which helped identify areas in which modifications were made to improve cooling and reduce losses.

Furthermore CFD simulation of a fan provides a complete picture of its operation. It can identify areas where there are recirculation problems and determine the flow rate, but more importantly, it can help establish the cause of problems and reliably direct design improvements. The fan design can then be optimized to minimize energy consumption, lower losses, reduce noise levels, optimize blade number, prolong component life and provide greater flexibility in the traction motor system.

Optimized design

The structural design of the product provides a variety of options to further enhance or monitor the performance of the motor. ABB provides all types of bearing solutions from the traditional c4 steel bearings to more advanced hybrid bearings with ceramic ball and roller elements, including HUB solutions (hybrid bearings greased for life). New air filtering techniques are under development and thermal sensors can be placed in a variety of positions, eg, in the windings, stator core or bearings, the latter providing early indications of bearing failure. Integrated speed sensors help keep the motor compact, while allowing the sensors to be replaced without detaching the motor from the bogie. The modular design simplifies maintenance procedures for all parts. By taking into account the service needs of a bogie-mounted motor at the design stage and standardizing spare parts, the new traction motor can be partly serviced in the bogie helping to reduce operational downtime and costs over the product's life cycle.

Currently ABB is working to extend traction motor products to serve a range of transport needs from LRV (light rail vehicles) to locomotives. The focus is to further standardize the structure, increase the energy efficiency and reduce maintenance. Synchronous motor topologies are also under development, eg, permanent magnet motors, but despite the obvious advantages of such topology (ie, energy efficiency and torque density) there are also several disadvantages. These include greater sensitivity to shock, overheating, and complex production and maintenance procedures. ABB aims to strengthen the advantages and minimize the disadvantages with its future synchronous products.

ABB has been manufacturing industrial motors for more than 130 years; traction motors for 100 years and has supplied more than 30,000 traction installations during the last few decades. These installations range from heavy locomotives for intercity expresses through to light metropolitan tramways. The new series of modular induction traction motors will add to ABB's reputation as a global leader in power and automation technologies, providing a truly versatile traction motor designed to fit a wide variety of locomotives, enabling rail operators to improve performance while lowering their environmental impact.

> ABB is ready to meet increasing demands for energy efficient electric traction motors in the rail industry.

The ABB series of traction motors with their wide range of specifications and modular design are poised to meet increasing demand for energy efficient electric traction motors in the rail industry.

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Dedicated service

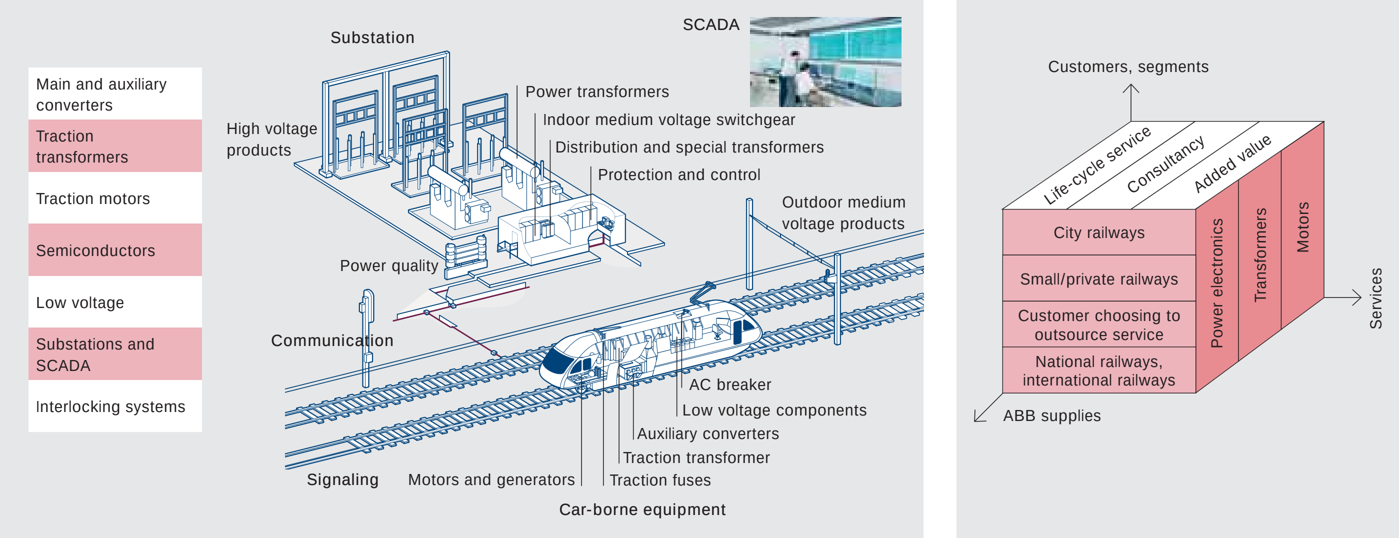
ABB offers a broad service palette for rail customers

VINCENT MOINE, HARALD HEPP, SANDRO MACIOCIA – The majority of articles published in *ABB Review* focus on the latest technologies and products. Whereas the newsworthiness of a technology often correlates with it being state-of-the-art, ABB is aware that in their day to day operations, many customers are dealing with far more than just the company's latest products. A typical customer's installed base may have been built up and developed over a period of 40 years or more, and will reflect the different technological paradigms of that period. ABB has hence developed a service portfolio to help customers face this challenge. Thanks to its vast knowledge base, the company can provide service for rolling stock regardless of type or age – even extending this service to the equipment of other manufacturers. Work performed can range from routine diagnosis and maintenance to retrofitting, re-engineering and heavy overhauls.

Traditionally, railway companies have performed their maintenance and engineering in-house, and frequently operated large and specialized workshops for this purpose. Recent years have seen a shift in this approach, with railways increasingly entrusting such work to external contractors. One factor that has lead to this change is that many new operators have entered the market in the wake of liberalization. These companies usually wish to concentrate on the operations side of their business, and hence outsource maintenance to specialists. However, not only new operators stand to gain from such arrangements. Developments affecting traditional railway companies include the loss of specialized knowledge through the retirement of an aging workforce, and also the introduction of modern technologies whose maintenance requires different skill sets.

From ABB's perspective as an equipment manufacturer, providing service to railway operators has the additional advantage that the understanding of maintenance needs and of the behavior of equipment throughout its lifetime is fed back within the organization and used to improve future designs. Ultimately, the closing of this feedback loop benefits both manufacturer and customer.

1 ABB manufactures a broad range of components for railway systems, and also provides service for these.



With many railways across the world expected to handle increasing traffic in an increasingly competitive environment, overhauls can often present an economically attractive alternative to replacement.

A look at much of the rolling stock built over recent decades reflects the development of the industry during that period. Until about 20 years ago, most manufacturers were local and many countries presented semi-closed markets in which suppliers enjoyed almost symbiotic relationships with their customers. The subsequent opening of these markets has led to a rapid concentration of manufacturing into larger international or even global companies, and permitted a greater standardization of platforms and components. However, the longevity of equipment means that trains manufactured prior to these developments will continue to see intensive use for many years. Today's service and maintenance providers are thus required to understand a broad range of designs and technologies.

The range of railway components which ABB manufactures, and also supplies service for, is shown in ➔ 1. At one end of the scale of its service offerings, ABB can support customers with spare parts and maintenance planning. At the other end, major retrofits can upgrade products permitting them to operate more efficiently and economically. Retrofit can sometimes present an interesting alternative to replacement. ABB's service offerings thus protect the customer's investment by reducing lifecycle costs, permitting equipment to work harder and longer and increasing reliability and availability.

Service planning

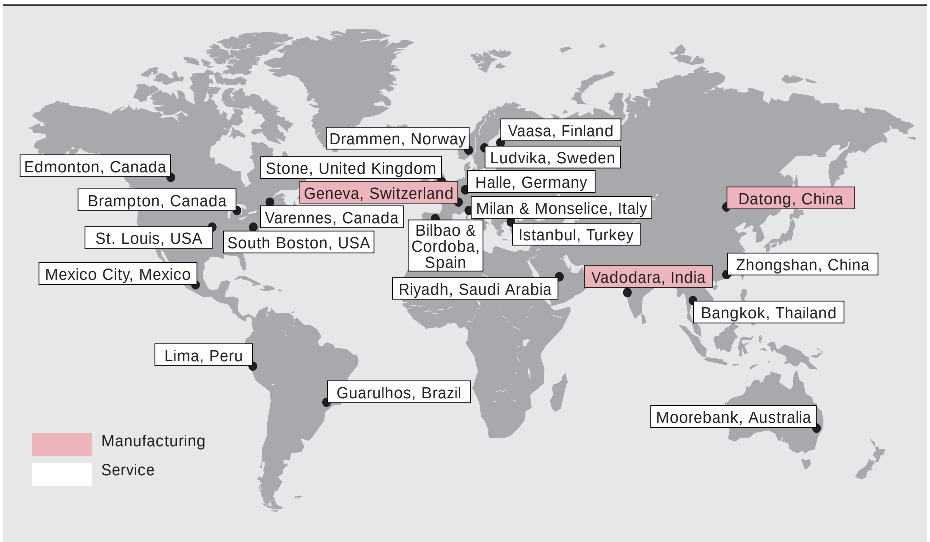
The collection and analysis of condition and diagnostic data throughout the lifecycle of equipment is permitting a shift from time-based to condition-based maintenance, maximizing availability and reliability while also reducing the costs of interventions and the associated downtime.

Besides smaller repairs during its lifetime, rolling stock often sees heavier engineering work at some point in its life. Typically, this takes the form of a so-called mid-life overhaul. The mid life-point splits the operating life of 30 to 40 years into two sections of about 15 to 20 years. The latter period is an optimal interval for heavy overhauls of such components as transformers and motors. Furthermore, the opportunity of such an intervention can be taken to make design modifications, either to suit changed demands or operating conditions, or to include the benefits of technological developments. For example older GTO- or thyristor-based converters can be replaced by modern IGBT-based ones, permitting more economic and efficient operation.

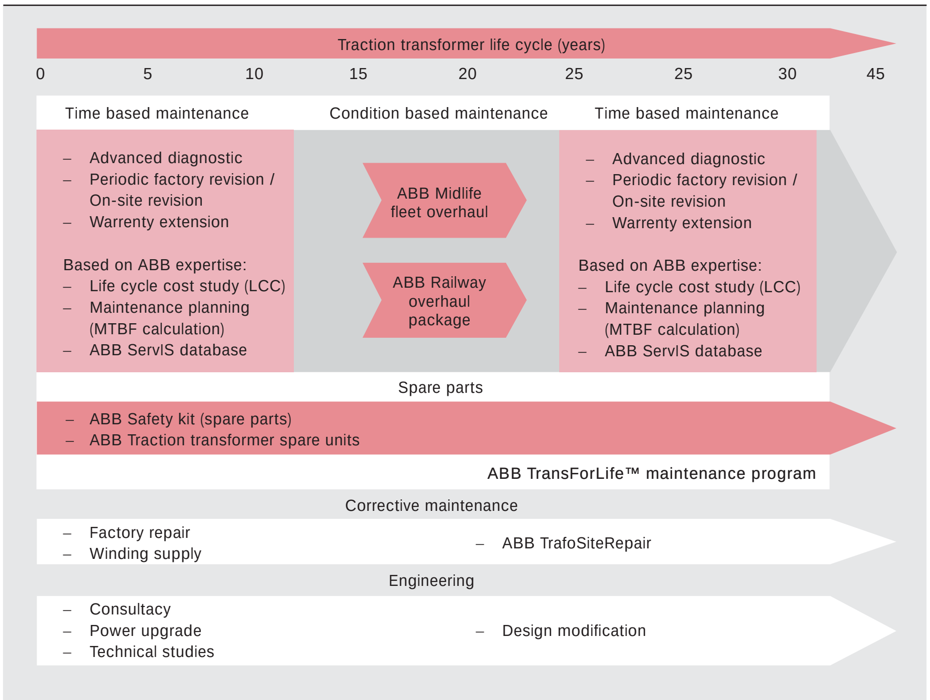
Transformers

Having been involved in AC railway electrification since the earliest days, ABB can look back on a long history of involvement in traction transformers. It is not uncommon to find examples aged 30 to 40 years in daily use today. With access to both experience and documentation from predecessor companies such as ASEA, BBC, SAAS, MFO and TIBB, ABB is well placed to provide service and support for traction transformers. Furthermore, ABB's transformer expertise is far from limited to railway applications:

2 ABB's global transformer expertise features 30 service centers and 1,000 experts



3 ABB TransForLife™ lifecycle service solutions for traction transformers



The company can draw on its broader knowledge by extending such offerings as parts of its ABB TransForLife™ solutions package to on-board traction transformers. This covers both on-site and factory repair/revision as well as maintenance contracts and spare parts. Similarly, traction transformers benefit from the company's simulation and diagnostics packages [1].

ABB estimates that some 70,000 of its traction transformers are in use today. Furthermore, the company's scope extends beyond these as was shown by some recent projects involving transformers of other suppliers.

ABB's global presence means that it has 30 centers of transformer expertise across the world, and can draw on the knowledge of some 1,000 experts ➔ 2. These ABB service centers are all able to offer transformer service and to support and to effect repairs. A typical traction transformer lifecycle is shown in ➔ 3. The diagram shows the services that ABB TransForLife™ Solutions can offer during the different phases of the vehicle's lifecycle.

Examples of recent refurbishment projects are presented in ➔ 4 and ➔ 5.

4 Repair of transformers for SNCF BB36000 locomotives

In 2008/09, ABB performed factory repairs on the transformers of three of SNCF's (French national railways) BB36000 locomotives. The work performed included:

- Inspection, cleaning, diagnostic measurements and expertise.
- Exchange of active part and reactors (windings and core)
- Replacement of all the gaskets and damaged accessories such as low voltage and high voltage bushings, oil level indicator, valves
- Revision of pump and cooling system
- Electrical routine tests according to IEC standards
- Oil Analysis after repair

These transformers were not ABB products, but originally manufactured by a French competitor. ABB's capacity to perform these repairs shows the company's ability to understand and work with third-party products.

Photo above: SNCF

Footnote

1 For more information on traction transformers see also "Transforming suburban transport" on page 55 of this edition of ABB Review.

5 Mid-life fleet overhaul of Euroshuttle locomotives

Eurotunnel operates a fleet of dedicated Bo-Bo-Bo locomotives on its shuttle trains transporting cars, coaches and lorries through the Channel Tunnel between England and France. As the tunnel is more than 100 m below sea level, trains enter it through inclined sections at either end. The locomotives must not only be powerful enough to start the heaviest train on these gradients, but the tunnel's special significance and length have led to stringent demands in terms of fire protection and redundancy which these locomotives must fulfill.

ABB won the order to overhaul the 15 years old traction transformers of 17 of these locomotives in a three-year contract lasting from 2006 to 2008. The scope of this preventive maintenance work included for each of the 17 traction transformers :

- Oil analysis, interpretation and recommendation
- Inspection, cleaning and diagnostic measurement
- Inspection and control of the active part (pressure of the windings, spacers)
- Mechanical optimization of the tank (O-ring gasket)
- Replacement of all gaskets, refilling with fresh oil
- Special tightness test under pressure with warm oil
- Electrical routine tests "as-new"
- Oil analysis after overhaul

Left-hand photo: Eurotunnel

6 Traction motor overhaul for Matterhorn-Gotthardbahn

The Matterhorn-Gotthardbahn (MGB) is a Swiss narrow gauge railway serving, among other destinations, the car-free resort of Zermatt at the foot of the world-famous Matterhorn mountain. Some parts of the MGB's route are rack railways and others are adhesion worked, with the rolling stock being able to work on both systems. During the last two years, ABB received several orders for products and services from MGB:

- Overhaul and repairs
- Supply of capital spares (complete rotors, complete stators)
- Supply of spare parts
- New windings and commutators for DC-Motors

Photo: Matterhorn-Gotthardbahn

Motors

Similarly to its transformer expertise, ABB's experience with traction motors goes back to the early days of railway electrification. ABB's predecessor companies were already making traction motors in the 1890s. ABB has thus inherited a great wealth of knowledge and experience and is now not only able to manufacture state-of-the-art traction motors but also to provide a full range of service, stretching from spare parts to overhauls and repairs, and covering both current and older types of traction motor.

The overhaul of a traction motor involves the comprehensive dismantling, control and exchange of wearing parts such as bearings or brushes in order to guarantee the specified number of kilometers of operation. This work typically involves the washing of parts in a spray booth and drying them in a vacuum oven. Where needed, motors can be rewound and parts replaced. Should replacement parts no longer be available, replica parts can be manufactured. Indeed, the scope of replacement can extend from spare parts, to capital spares (a complete stator or rotor), or even a complete replacement motor. Spare parts can also be supplied directly to customers to support their own inventory and maintenance activities.

At the core of a state-of-the art repair or overhaul is the Vacuum Pressure Impregnation (VPI) of stator windings using the patented Gemodur® (for DC-Motors) or Veridur®-Plus (for AC Motors) technology. These impregnation technologies guarantee strength of the electrical insulation system against both continuous and variation of high temperatures, as well as the mechanical stability of the windings and the iron core in view of vibrations. They also assure durable protection against dust, corrosion and hu-

ABB's global presence means that it has 30 centers of transformer expertise across the world, and can draw on the knowledge of some 1,000 experts.

midity. The repair or overhaul of a traction motor is concluded with the balancing of the motor, re-assembly, final testing, and painting with silicone-based varnish.

Extending beyond these repairs targeted at maintaining designed performance levels, motors can also be modified and improved beyond their original specifications. This may be necessary to cope with a different voltage or other changes in the power supply, or to permit the motor's rated power or speed to be increased [2].

An example of a recent motor refurbishment projects is presented in ➔ 6.

Converters

Converters play a key role in most large refurbishment projects for rail vehicles. When train fleets are renovated, typically after 15–20 years, operators often seek higher power, efficiency and reliability and lower maintenance costs.

Auxiliary converters

The demand for auxiliary power on trains has increased considerably in recent years. Staff and passengers increasingly expect HVAC (heating, ventilation and

7 Auxiliary converters for the Swiss regional train refurbishment project "Domino"

In 2006, Swiss federal railways (SBB) embarked on their largest refurbishment program for regional trains so far. This project, Domino, essentially consists of a general overhaul of the 20-year-old "NPZ"* motor and driving trailer cars and a replacement of the 40-year-old intermediate coaches. The tender to supply the new intermediate coaches was awarded to Bombardier while the general overhaul of the end cars is being executed in SBB's own workshops in Yverdon and Olten. Faiveley won the order for the new HVAC equipment of these cars. New auxiliary converters were needed for both the refurbished coaches (25 kVA) and the new ones (45 kVA). ABB managed to independently win the converter contracts from both Faiveley and Bombardier. This resulted in the advantage of a common auxiliary converter platform and a common stock of spare parts. More than 300 converters have been ordered for this project so far, with further options pending.

ABB's BORDLINE M** static (auxiliary) converters are very compact and rugged but lightweight units that include galvanic insulation, regulated DC- and three-phase AC-outputs, filters and all control electronics (see also "A perfect fit" on pages 60–65 of this issue of *ABB Review*). The scalable BORDLINE M platform for railway coaches with 1000 VAC/16.7 Hz train supply uses air-forced cooling (like most other BORDLINE M series). It features a battery charger with a flat-battery start function.

The delivery schedule for this major refurbishment project was very challenging with a prototype converter of the 45 kVA type to be delivered only two months after the awarding of the contract. Series deliveries started in July 2008 with up to four converters per week. Depending on how the refurbishment continues, converter deliveries will continue at least until the end of 2011.

Footnotes

* NPZ: Neuer Pendelzug

** See also "BORDLINE M: A very high efficiency AC/DC/DC converter architecture for traction auxiliary services", ABB Review 2/2009 pages 35–41.

Motors can be modified and improved beyond their original specifications, permitting rated power or speed to be increased.

Footnote

2 See also,"Standardizing the traction motor" on page 66 of this edition of *ABB Review*.

8 Propulsion converter retrofit solution for ICE1 high-speed trains of Deutsche Bahn (DB)

The ICE1 fleet was the first series production of high-speed trains in Germany. After about 14 years of operation, Deutsche Bahn (DB) launched a refurbishment program in summer 2005. The interior of all coaches was redesigned (for which the DB received the Brunel Award for railway design in 2008). For the power cars, DB launched a tender in 2007 with the goal of replacing older thyristor-equipped traction converters by modern IGBT converters.

Mainly due to high scoring high in terms of energy efficiency and life cycle costs, ABB could win the prototype order in September 2008. Within only 13 months, ABB developed and produced new traction converters for two 4.8 MW ICE1 power cars. Retrofitting a propulsion converter into an older train is in many respects much more demanding than developing a new traction chain from scratch. All major interfaces are fixed and given, in particular the physical and logical interfaces to the vehicle's older control system (which was retained), as well as the terminals and electrical characteristics of motors, transformer, cooling system and all mechanical parameters.

The new converter is based on ABB's three-level topology for power modules, resulting in much lower harmonics on both motor and supply sides. Among other positive effects, this minimizes energy losses and reduces stress on the motors, enhancing their life expectation. Compared to the thyristor converters being replaced, energy consumption was cut by 15 percent. Besides making the train greener, this substantially reduces operating costs (more than 100,000 Euros – ca. $ 140,000 – per year and train). The old thyristor power modules weighed 300 kg and were almost 1.5 m in length. ABB's three-level IGBT modules weight less than 35kg and have dimensions of about 80 × 40 × 20 cm meaning they can be exchanged by one person without any lifting tools. High modularity, increased reliability and sophisticated software for service and diagnosis also contribute to the reduction of maintenance requirements of the ICE1 fleet.

Test runs successfully began in November 2009. Following further thorough testing and re-homologation process, DB will decide whether it will refit a further 36 ICE1 power cars with this new IGBT converter.

Left-hand photo: DB

air-conditioning) systems and other facilities such as passenger information and entertainment systems, power sockets for laptops and vacuum toilets. Such offerings are largely standard on new vehicles [3], and if older vehicles are to remain attractive to passengers, they must offer comparable levels of comfort. Existing auxiliary power systems on trains are often not able to cope with present demands and must be re-designed from scratch. An example of an ongoing retrofit project is presented in ➔ 7.

Traction power

Refurbishment of traction converters typically seeks to increase efficiency and vehicle performance while reducing wear and maintenance costs and sometimes also weight [4].

Whereas components such as motors and transformers are usually refurbished during their mid-life overhaul, it often makes sense to replace traction converters. The reason for this is the higher pace at which technology has developed in this area. Components such as semiconductors, control electronics and software have developed rapidly over the past 15 to 20 years. Today's products are often so much more capable, effective and efficient that seeking to refurbish and retain old arrangements is often neither economical nor attractive. Furthermore, spare parts may be difficult to procure.

It is thus not surprising that ABB, as an independent component supplier, often receives requests from service companies, large workshops, OEMs, railway or mass transit operators concerning the replacement of converters.

ABB's traction converters are based on a modular platform, offering the advantage of short realization times and low development risk. The engineering effort of adapting or tailoring converters to a specific vehicle is thus most attractive when complete fleets or vehicle classes need to be refurbished. ABB recently supplied traction converters for the retrofit of an ICE1 German high-speed train ➔ 8.

Outlook

With many railways across the world expected to handle increasing traffic in an increasingly competitive environment, overhauls can often present an economically attractive alternative to replacement. ABB is well placed to offer services tailed to the customer's demands and the particularities of the equipment.

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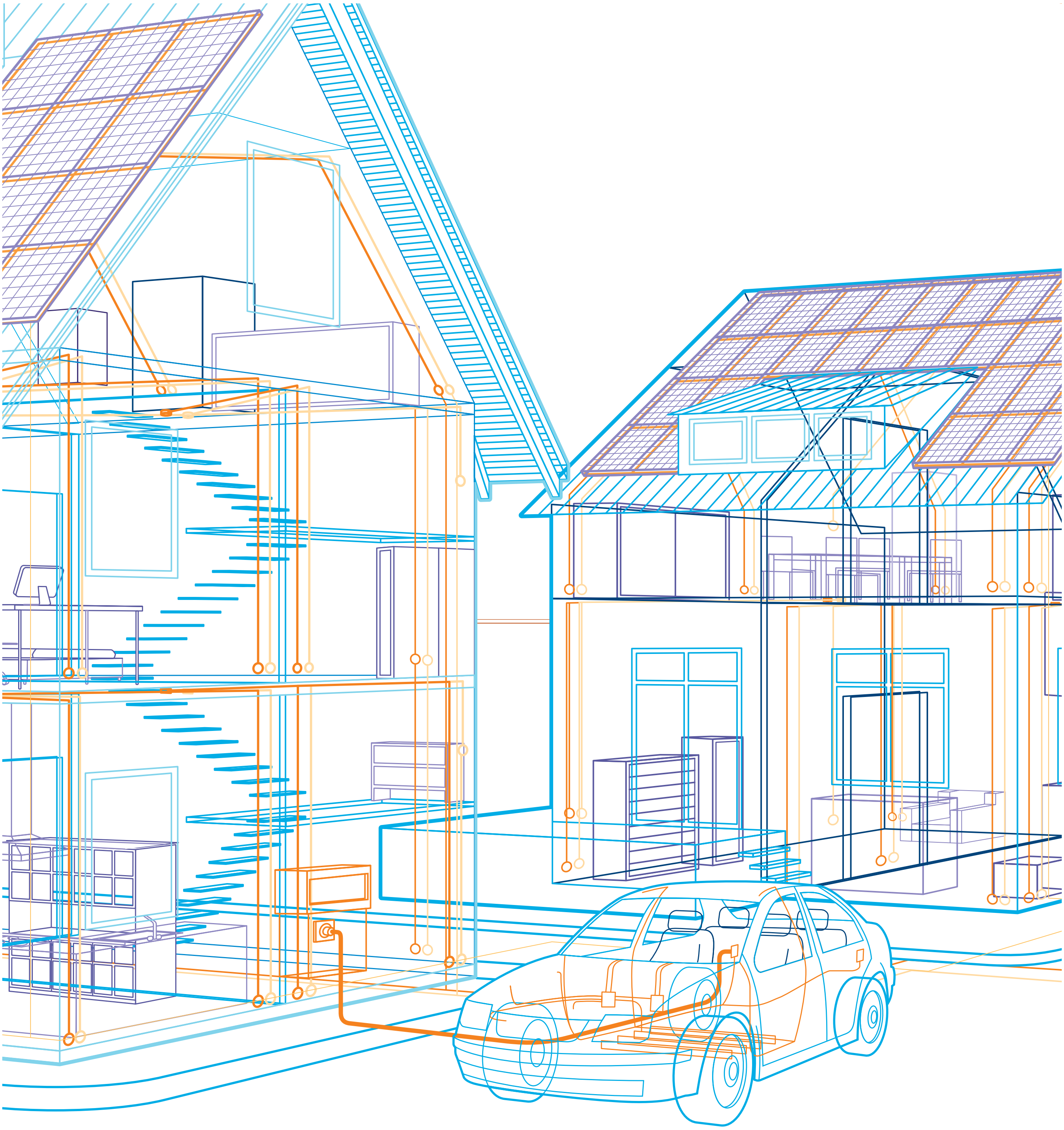
Footnotes

3 See also "Performance on track: Electric power products on trains – designed by ABB to make journeys more comfortable", *ABB Review* 2/2008 pages 25–29.

4 For more on traction converters, see also "A perfect fit" on page 60 of this edition of *ABB Review*.

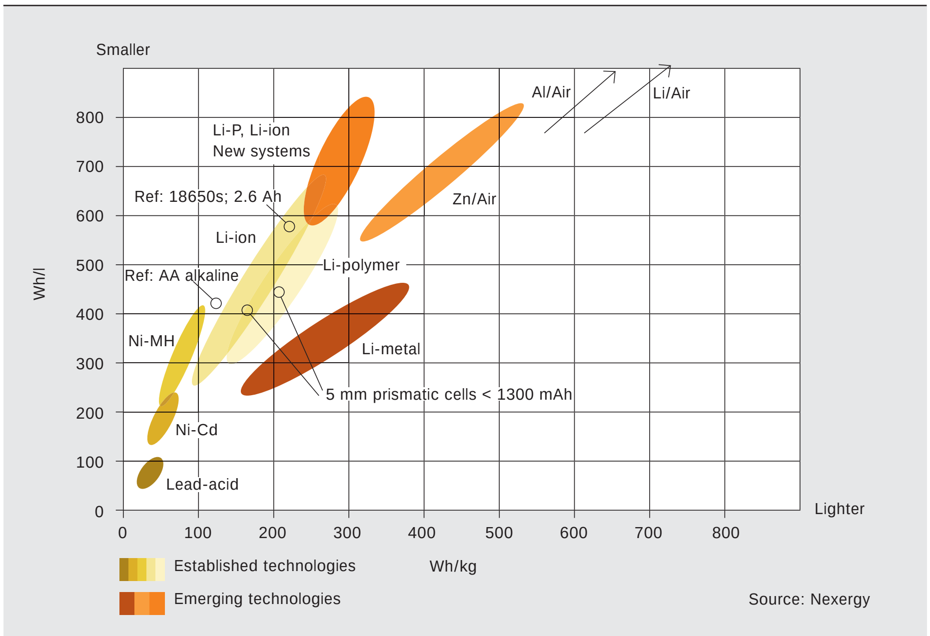


Dawn of a new age

ABB's electric vehicle charging units and smart grid technologies are supporting the vision of a new era of transportation

NICK BUTCHER, SIMON FELSENSTEIN, SARAH STOETER, CÉCILE FÉLON –
Refilling the tank now has new meaning at ABB. As part of its commitment to building a smarter grid, the company has extended its reach into a relatively new market, one that is discretely popping up in the parking lots of larger cities – electric vehicle charging. As more governments are pushing emissions legislation and offering incentives for electric car buyers, the demand for fully electric vehicles continues to grow, encouraging many carmakers to also expand into this new market. With this in mind, ABB is developing electric vehicle charging systems that foster a new vision of transportation.

1 Battery technologies



Although it would seem that electric cars have only recently made their way into the market, they have actually been around for almost 200 years. While the first electric cars were developed in the 1830s, it wasn't until the end of the century that such vehicles began to receive greater attention. Although there were also cars powered by steam and by internal combustion engines (ie, gasoline powered), electric cars had the advantage of being quieter, smoother (ie, little vibration) and less odorous than their competitors. In addition, gasoline powered cars not only required hand cranking to start but the gears were also extremely difficult to shift, and steam powered cars required very long startup times. Until about the 1920s, electric cars were quite successful.

But circumstances were changing. In the United States, for example, road systems were improving and as a result cities were being connected – this brought about the need for cars that could travel longer distances. In addition, crude oil was discovered in Texas, driving down the price of gasoline, and an electric starter was developed, which replaced the laborious hand crank. And mass production of cars with internal combustion engines made such cars more readily available and affordable than their electric counterparts.

Until the 1960s, the focus of the automobile industry was on cars with internal combustion engines, and progress in electric vehicle (EV) technology was slow at best. But it soon became clear that dependency on gasoline powered cars was necessitating the dependency on foreign crude oil, and the resulting emissions were demanding the exploration of alternative fuels. And so interest in electric cars picked up, and numerous electric car models were developed over the years. One of the more famous electric cars of this time is the Lunar rover, which in 1971 was the first manned vehicle to be driven on the moon.

Through recent advances in batteries, the dream of zero-emissions mobility may finally be within reach for the mass market.

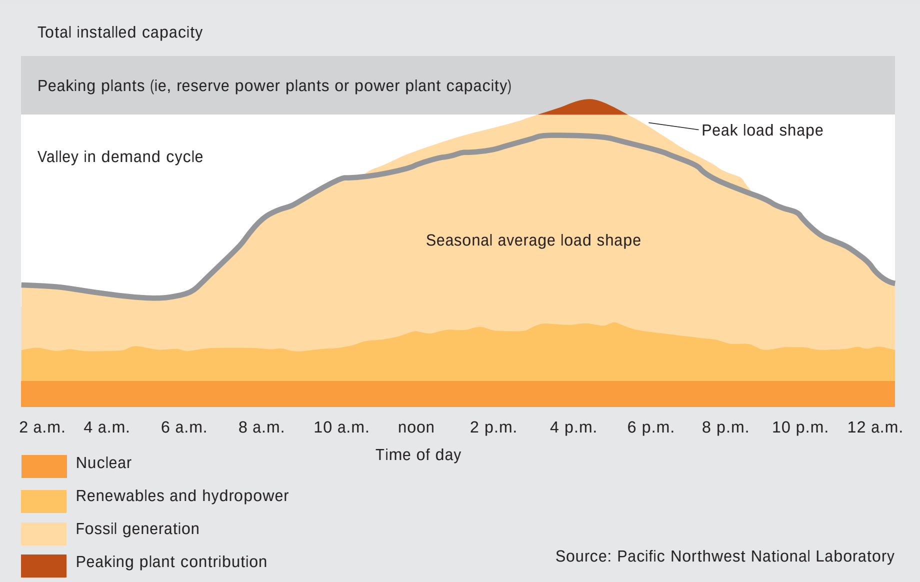
Dawn of the electric age

The debate continues as to whether the age of electric transport is truly here, or if this is simply another cycle of boom and bust. The skeptics' views are not without foundation – electric cars have suffered several such cycles in the past. The limitations of battery technology – still today the critical issue in electric vehicle success – have played a leading role. It is through recent advances in battery technology that the dream of zero-emissions mobility may finally be within reach for the mass market.

The first generation of electric cars used lead acid batteries. These were characterized by high weight and limited performance, powering only short-range vehicles, which were not attractive to the wider market. Lead acid batteries have made incremental improvements over the years, but the next generational leap in electric vehicles came with the nickel-metal hydride (NiMH) batteries in the 1990s. These saw dramatic improvements in range and performance, best personified in the highly capable GM EV1. Ultimately, however, the verdict from car manufacturers was that NiMH batteries, while much better than lead acid, were still not sufficient to meet market needs for fully electric vehicles in terms of price and lifetime.

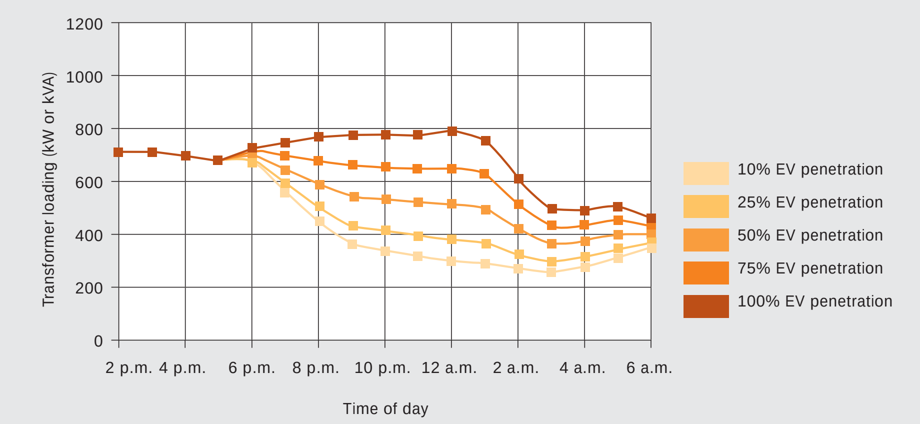
Within the last 10 years, a new rechargeable battery has been developed, driven by tremendous volume in the consumer electronics market. This battery, based

2 Demand cycle of the US electricity grid



Source: Pacific Northwest National Laboratory

3 Loading of a transformer with smart charging



Blending rail and road

The Urban Commuter (UC?), a lightweight two-seater electric city car developed by Rinspeed*, a Switzerland-based company, was showcased at the 2010 Geneva motor show. This fully electric car measures less than 2.6 m in length and is equipped with a permanent 3G network connection. The small electric power plant is not only designed to help prevent congestion in city centers, but it can also be easily loaded onto custom-built train carriages for long-distance trips and integrated into the train's charging grid. The driver can take advantage of the train's facilities or the vehicle's technological features such as video chat, IP telephone calls and e-mail while in transit. At the destination, the car is fully recharged and ready to go.

This visionary project not only develops the idea of the electric vehicle, but also of sustainable mobility that includes privately owned cars and public transportation. ABB can help make this possible.

* See www.rinspeed.com

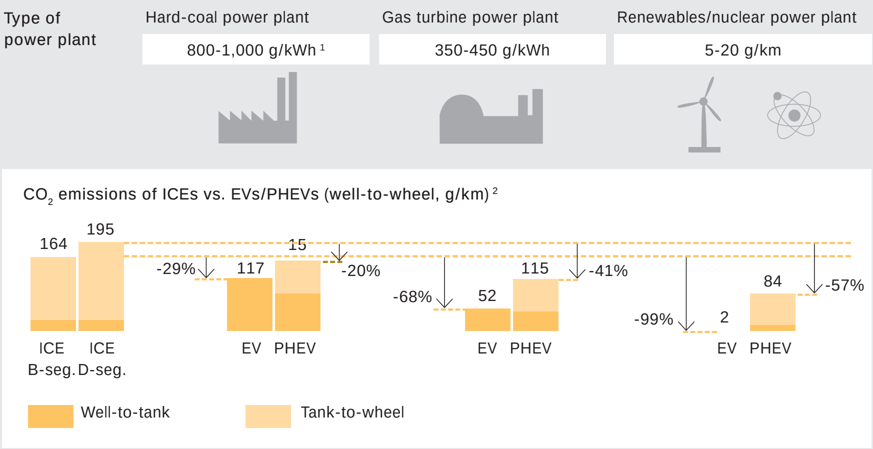
on variants of lithium-ion chemistry, delivers yet another giant leap ahead from what was achieved with NiMH. While lithium-ion batteries today still store much less energy per kilogram than oil – and are much more expensive than a tank of fuel – the extremely high efficiency of electric vehicle drivetrains and the low cost of electric energy per vehicle-kilometer mean that electric cars are finally in a position to go head-to-head with internal combustion rivals. Further major battery innovations are in the pipeline, many offering commercial promise on a surprisingly short timeframe → 1. Combined with concerns regarding climate change and energy security it seems likely that the electric age has finally come to stay – a premise reinforced by the announcements of models coming to market within 2010 by several vehicle manufacturers. These announcements refer not to small production-run concepts, but to electric vehicles to be produced in volumes of 100,000+/annum within the next one to two years. In total more than 20 different models of plug-in electric vehicles are expected to enter the market by 2012.

As the Li-ion battery is the critical part of an electric car, fully-automated large-scale production of dedicated automotive batteries needs to be implemented to ramp up volume and bring down costs. ABB provides turnkey solutions including the robotics used in cell manufacturing; module and stack assembly; as well as the power electronics to run test cycles of charging and discharging at every stage of the manufacturing process.

Electricity as fuel

Today, approximately 55 percent of all oil produced worldwide is used by the

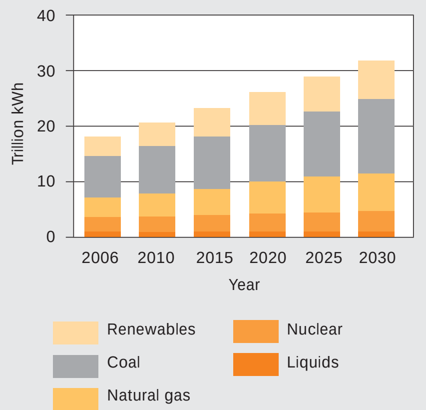
4 CO_2 emissions by power plant and vehicle type



1 EU hard-coal power plant installed today
2 Consumption of ICE B-segment vehicle: 5.9 l/100 km; ICE D-segment vehicle: 7 l/100 km; EV: 13 kWh/100 km; PHEV: 3.0 l and 8 kWh/100 km

Source: BMWI, World Nuclear Association, EU Commission, and Roland Berger

5 World electricity generation by source: business-as-usual predictions



Source: 2006 data source: Derived from EIA, International Energy Annual 2006 (June-December 2008), www.eia.doe.gov/iea. Projection data source: EIA, World Energy Projections Plus (2009).

transport sector, totaling almost 50 million barrels per day. One of the major perceived benefits of e-mobility is the creation of a transport system that is not dependent on oil as an energy source and has dramatically lower greenhouse gas emissions. With these goals come two critical questions: Where will the energy come from, and will the emissions be lower?

Challenge for the grid

In the case of electric vehicles, the answer to the first question is the electrical grid, though the grid is just a means of transmission, not generation. Energy is created in the wide range of power plants connected to the grid. For electricity to power cars, both the power stations and the electrical grid must have the capacity to transmit the electricity.

Generation management can be addressed by ensuring that car charging happens when energy is available, rather than randomly, which has the potential to create significant peak loads on the grid. With smart charging management, the existing power plants in many countries could provide energy for most of a vehicle fleet without any increase in nameplate capacity [1], primarily by using overnight capacity, which is presently underutilized. → 2 shows the large valleys in the demand cycle in the US electricity grid where electric vehicles could be charged with no additional peak loading. The generation profile also highlights the potential issue regarding the electricity source; this is discussed in more detail in the next section.

Taking the grid into account is critical to avoid unnecessary costs. For a local distribution transformer, "dumb" charging (ie, charging any time of the day) could result in transformer overload and a local blackout even if only one house in 10 was using an electric vehicle. With smart charging, however, the transformer load can be managed within the limits even when every house in the neighborhood makes the switch away from oil → 3.

Of course, every smart charging system needs to be integrated into the distribution management system and SCADA system to ensure interoperability and optimal benefit for both the grid and the electric cars. Today such grid management systems are to a large extent supplied by ABB.

More than 20 different models of plug-in electric vehicles are expected to enter the market by 2012.

Emissions and renewables

Electric vehicles are seen as a solution for clean sustainable transportation. They have no tailpipe emissions at all – in fact they have no tailpipe. But to draw a fair comparison with the existing oil-fueled fleet it is necessary to look at the whole energy delivery system.

The effective emissions of an electric car depend to a large extent on the emissions of the energy source creating the electricity. Electric cars that draw their power from an old coal power plant are only marginally cleaner from a greenhouse-gas perspective than the oil powered cars they replace, and may in fact be worse from a life-cycle perspective, especially when compared with the latest generation of diesel engines. However, they do still have all the benefits of massively reduced local air pollution → 4.

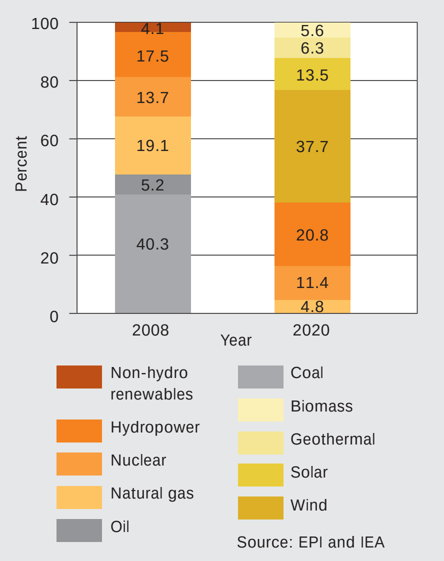
Thus, from a holistic perspective, a case is made for low-emissions electricity generation. Looking at new generation technologies, electric vehicles are already far superior to alternatives even with combined-cycle gas power plants, and when powered by truly low-emissions energy such as nuclear or renewable, they are almost completely greenhouse-gas-emission free.

The forecast presented in 2006 by the IEA will not derive the hoped-for benefits

Footnote

1 Nameplate capacity is the amount of energy that a generator is designed to produce.

6 World electricity generation by source: ultralow emissions possible



in reducing greenhouse gas emissions simply by switching to electric vehicles. To truly realize the benefits of electric transportation, a massive shift toward clean energy sources will be necessary ➔ 5. The economic and political feasibility of such a huge shift to clean energy remains to be seen, and it will take bold action to achieve targets as ambitious as those indicated in ➔ 6.

Particularly interesting is the potentially constructive interaction between electric vehicles and renewable generation such as wind and solar. By using smart grid technologies in combination with the storage reservoir (ie, the vehicle battery) to manage the supply and consumption of energy, the challenge of both electric vehicle and renewable energy integration could become much less daunting than either challenge considered in isolation.

The last mile – EV charging points

One of the often cited benefits of electric vehicles is that the cost associated with their infrastructure is much lower than, for example, hydrogen, because electricity is already widely available. While this is certainly a significant benefit, the reality is not quite so simple. The electricity still needs to be transferred from where it is (the grid) to where it is needed (the batteries onboard every electric vehicle). Furthermore, this must be done in a manner that is fast, convenient, simple, cost effective and safe. The solution, which ABB is working to provide, is the electric vehicle charging point. These units will be available in three primary types, depending on the application.

Residential charging

Home chargers deliver efficient, low-power vehicle charging that can refill a battery during the night, reaching full capacity before morning. Charging overnight ensures that the load on the grid is low, and the car is refilled economically using low-cost night-rate power. A range of home chargers are available to suit the needs of different homes – indoor, outdoor and wall mounted – and all incorporate the safety systems you can expect of any home appliance. ABB's portfolio contains everything that is needed to build safe and efficient home charging devices.

Public charging

Public chargers are semi-fast charging solutions that can charge a battery in a few hours while the driver is at work, or during everyday activities such as shopping or dining out. ABB products will be found in charging poles throughout the town or city at company parking lots, public buildings, stores and large parking garages.

These charging poles are built strong and safe to fit the requirements of a public space. In most cases the consumer will pay for the electricity used, so the charging pole will include an authentication and/or payment system.

> With smart charging management, the existing power plants in many countries could provide energy for most of a vehicle fleet without any increase in nameplate capacity.

Fast and ultrafast charging

Fast and ultrafast charging systems use high-power converters within the charger (rather than onboard the car) to rapidly charge the battery. Fast chargers compatible with existing batteries are already able to recharge 80 percent of the battery in less than 25 minutes. Future ultrafast chargers will allow a "fuel stop" equivalent for EVs, charging the car in the shortest possible time. Combined with the latest battery technologies, this could allow a full recharge in less than five minutes. These chargers will be installed in highway rest areas and convenient city refueling points. Grid energy management and power quality are provided by state-of-the-art power electronics, smart grid interfacing and integrated energy storage to manage the variations in power production. ABB's direct-current fast-charging station concept was presented at the International Geneva Motor Show 2010, together with Protoscar's LAMPO[2] EV concept. This high-power charger is capable of refueling a more than 100 km range in only 10 minutes.

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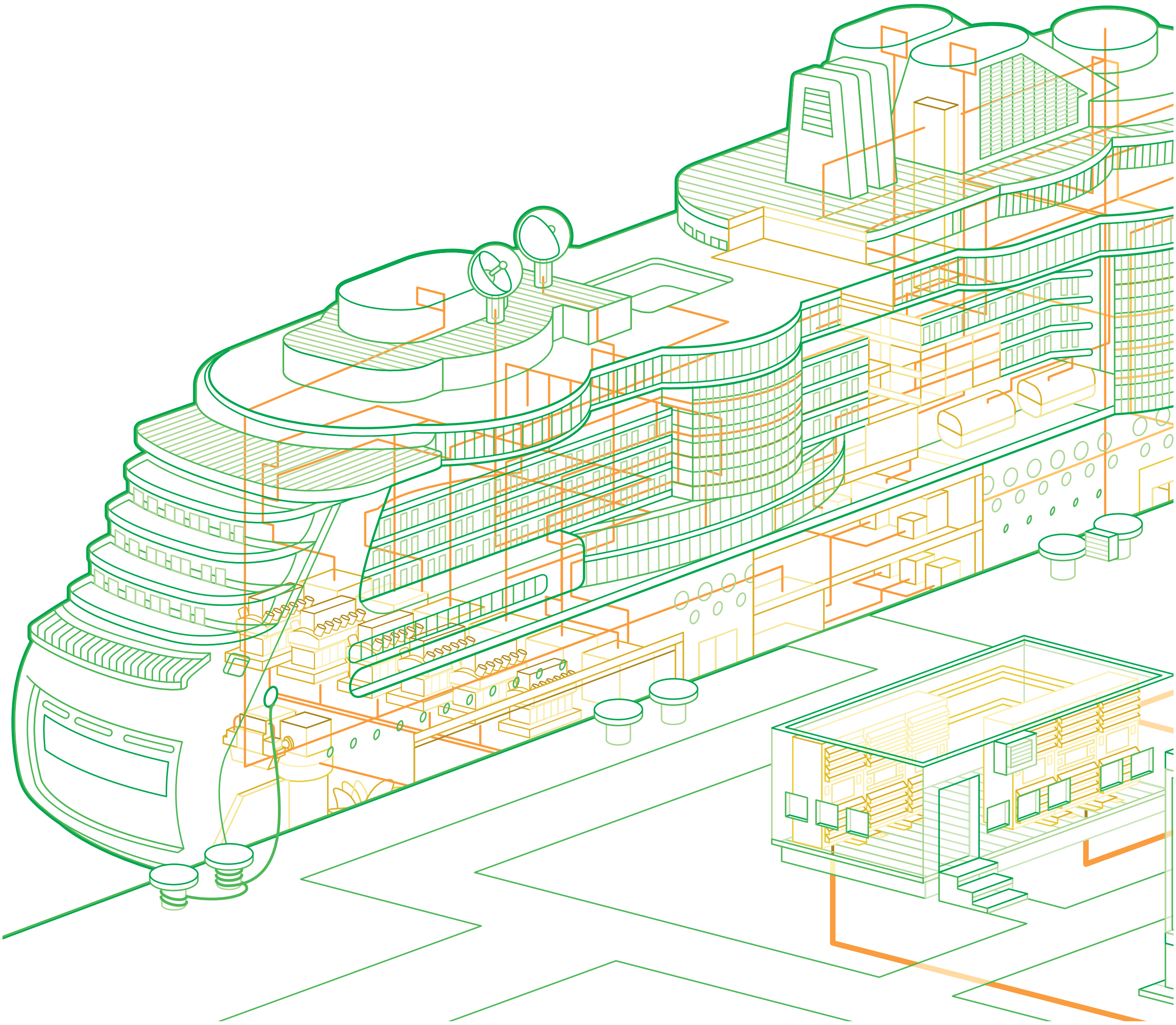
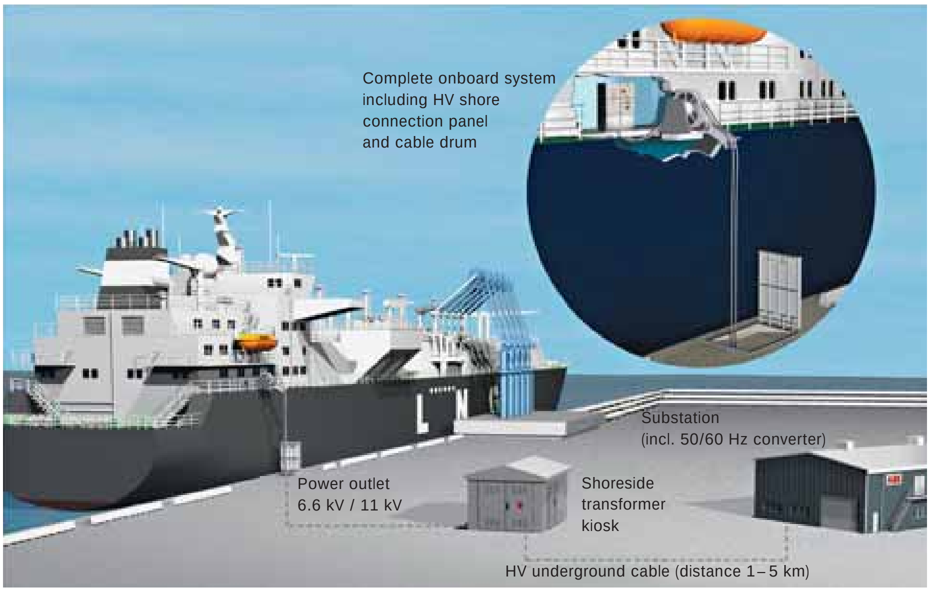


Power from shore

ABB shore-to-ship power solutions are cutting noise and greenhouse gas emissions by providing docked ships with shoreside electricity

KNUT MARQUART – Port authorities and ship owners have been seeking ways to reduce emissions as part of the global effort to mitigate climate impact. The increase in interest results primarily from the environmental benefits of using shore-based electrical power, but there are also economical benefits as costs related to fossil fuel consumption increase. ABB has thus developed optimized shore-to-ship power solutions for port authorities, ship owners and distribution companies.



During a 10-hour stay in port, the diesel engines of a single cruise ship burn 20 metric tons of fuel and produce 60 metric tons of CO_2. This is equivalent to the total annual emissions of 25 average-sized European cars. But these emissions can be eliminated by supplying the ship's infrastructure with onshore power.

In addition to reducing CO_2, shore-to-ship power helps ships eliminate sulfur dioxide, nitrogen oxide and particulate emissions. It also facilitates the reduction of low-frequency noise and vibrations and allows maintenance of diesel engines while the ship is at berth.

ABB provides the electrical infrastructure – both onshore and on the ship – as turnkey solutions, including system components such as frequency converters, high- and medium-voltage switchgear, transformers, and control and protection systems. In addition, ABB offers fully engineered and integrated systems and services ranging from the main incoming substation to retrofitting the vessel's electrical system to receive shore power.

Onshore, this requires the appropriate supply of power and includes the need to adapt the voltage level and frequency of electricity from the local grid to match that of the vessel. As the development of an onshore power supply can have a significant impact on the local grid, ABB also offers system studies to assess the overall effect, and can recommend solutions to upgrade and strengthen the local grid and port network to accommodate shore power connections.

ABB provides the electrical infrastructure – both onshore and on the ship – as well as fully engineered and integrated systems and services.

Solutions with single or multiple frequencies, regardless of power rating, are available for single and multiple berth applications, container terminals and city ports, as well as small footprint indoor concepts that can accommodate all major system components.

Onboard the ship, the power solution must be fully integrated with the vessel's electrical and automation system, enabling seamless power switching between the ship's own generation and the shore power supply.

A pioneer in this area, ABB successfully installed the world's first shore-to-ship electrical connection in the port of Gothenburg, Sweden in 2000.

A more detailed discussion of ABB's shore-to-ship offering will appear in an upcoming issue of *ABB Review*.

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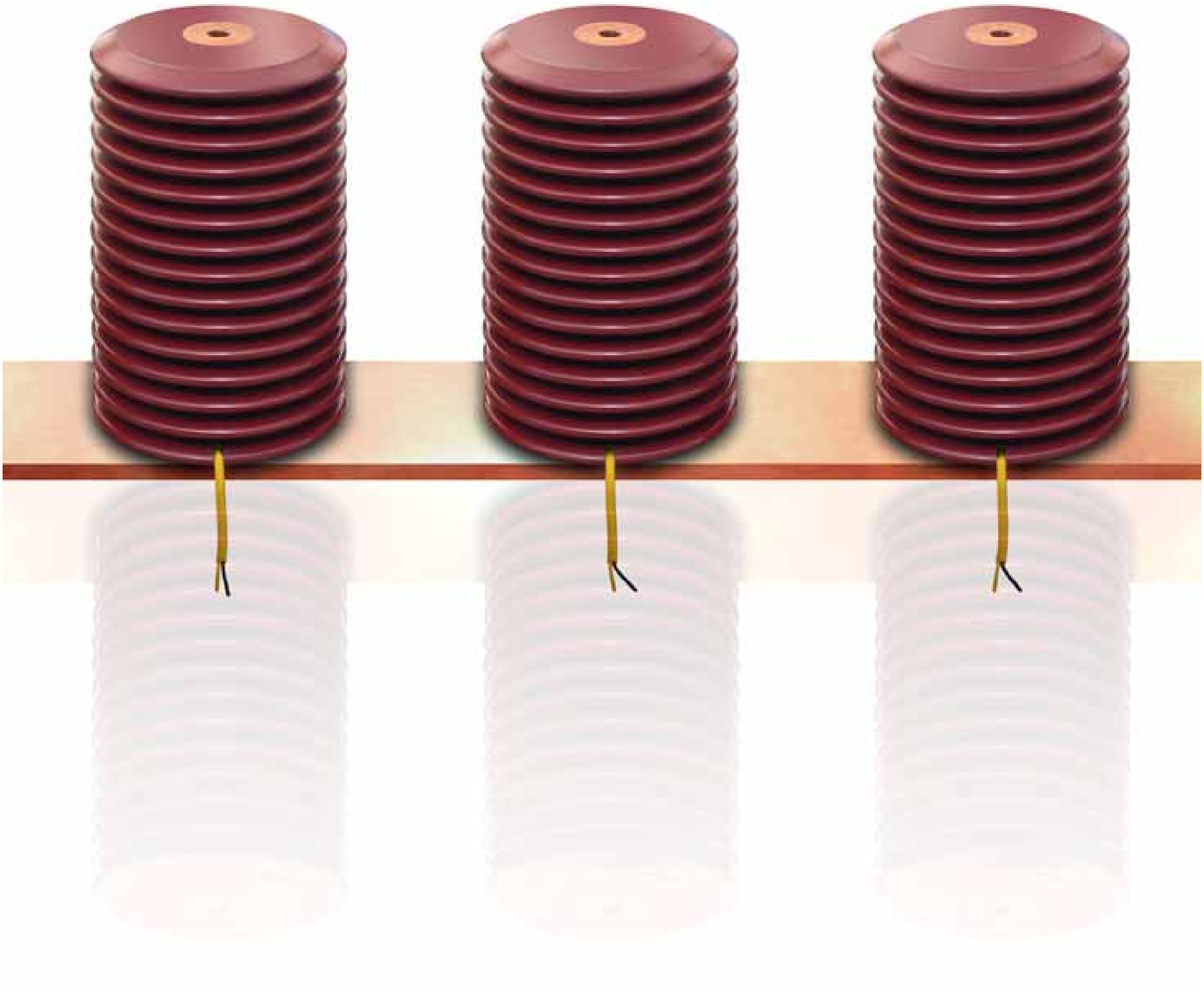


S^3 – Speed, safety and savings

ABB's new ultra-fast earthing switch

DIETMAR GENTSCH, VOLKER GRAFE, HANS-WILLI OTT, WOLFGANG HAKELBERG, ANDREAS BRANDT – ABB's well-known and fast acting vacuum interrupter and the world's fastest limiting and switching device, the I_s-limiter, have been in service for decades. Now the technologies from these devices have been cleverly combined to form an arc-fault protection system for medium-voltage switchgear that operates in the ultra-fast range. As a product, the extremely short switching time of less than 1.5 ms of this special vacuum device combined with the rapid and reliable detection of fault currents and light intensity of a new dedicated electronic unit, will ensure all arcs are almost immediately extinguished. In technical terms, this means that system availability and operator safety are greatly enhanced for rated voltages up to 40.5 kV and rated short-time withstand currents (1s) up to 63 kA. From an economic point of view, downtimes and repair costs resulting from faults will be drastically reduced.

In rare cases, failure inside a switchgear cubicle due to a defect, an exceptional service condition or maloperation may initiate an internal arc, which constitutes a hazard ➔ 1. While the absolute protection of all personnel is by far the most important concern during such an event, users would also like to prevent system components from being destroyed. ABB's new internal arc protection system ensures that this is the case.

The system operates on the principle that the uncontrolled release of energy from an internal arc fault is prevented by rapid metallic 3-phase earthing. Characterized by a significantly low impedance, this type of connection causes the short-circuit current of an arc fault to commutate immediately to the fast-acting earthing switch and extinguish the arc.

The new ultra-fast earthing switch (UFES) contains three complete primary switching elements type U1 (see picture on page 84) and an electronic unit type QRU (quick release unit). Each primary switching element is similar in dimensions (height 210 mm, diameter 137 mm), shape and fastening points to a 24 kV pin-type insulator, and consists of a two-part vacuum chamber embedded in epoxy resin to protect it from the environment. From a dielectric point of view, the chamber actually constitutes two vacuum gaps separated by a membrane. One gap contains a contact pin at earth potential while the other accommodates a fixed contact at high-voltage potential. Each element also features an integrated ultra-fast micro gas generator (SMGG), which is comparable in type and functionality to the gas generators in automobile airbags ➔ 2. The SMGG drives a piston and is designed as a single-shot piston actuator. The electronic unit, based on durable and fast analog technology, is phase independent in structure, and ensures current and light detection and reliable tripping within the shortest possible time.

When an internal arc fault occurs in a switchgear system, the electronic unit detects the fault current (supplied by a current transformer) and the arc light in the compartment (measured by optical sensors). At almost the same time, the gas generator is activated. More specifically, the gas pressure drives the movable piston. This piston slides into the first part of the vacuum chamber and eventually causes the contact pin to penetrate the membrane and engage with the fixed contact permanently and without bouncing to create a solid metal short-circuit to earth. The arc fault can then be short-circuited and extinguished in less than 4ms after it is first detected. The entire sequence, illustrated in ➔ 3, leads to the safe connection of the piston to earth potential via a moving contact system.

Processing that all-important information

The electronic unit has three input channels that enable continuous monitoring of the instantaneous current. The response level, the criterion for detection of a fault current, can be adjusted to suit a wide variety of protection conditions by means of simple controls. With a low input burden of less than 1 VA, the current measurement system can simply be looped into the secondary wiring of the existing current protection transformers.

In addition to current monitoring, nine optical inputs are available for arc-fault detection. The status of the arc-fault protection system is indicated by LEDs and a 7-segment display on the front panel of the unit ➔ 4. Various floating

1 Arc fault duration in electrical systems and the associated consequences.

Using a conventional protection device
- Arc fault duration: 200–300 ms
- Detection by standard relay
- Clearing of arc fault current by the upstream circuit breaker

Possible dramatic consequences include
- Fire/explosion
- Serious injuries to personnel (depending on the switchgear design)

Fast-acting protection relay with supplementary equipment (eg, I_{th}-limiter)
- Arc fault duration: 50–100 ms
- Fast detection by special protection relay
- Clearing of arc fault current by the upstream circuit breaker

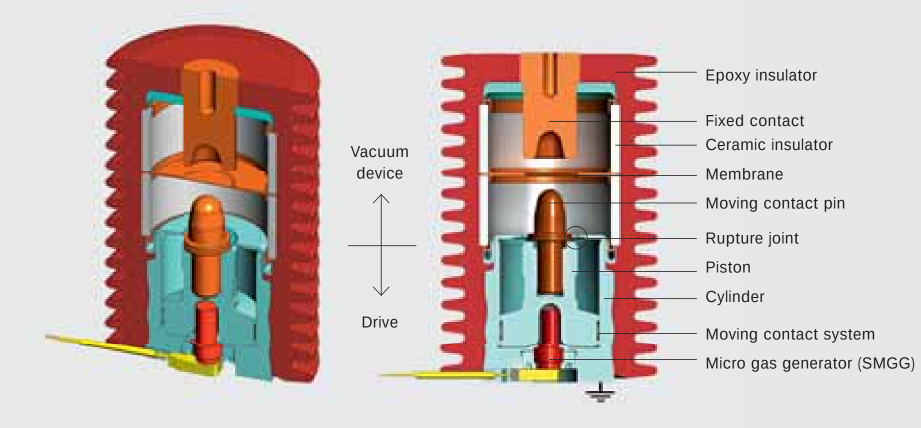
Limited damage to equipment and personnel (depending on the switchgear design)

Ultra-fast earthing switch (UFES)
- Arc fault duration: ≤4ms after detection
- Ultra-fast detection by UFES electronic unit (type QRU)
- Ultra-fast extinction of the internal arc by switching of the UFES primary-element
- Final clearing of fault current by the upstream circuit-breaker

No damage expected

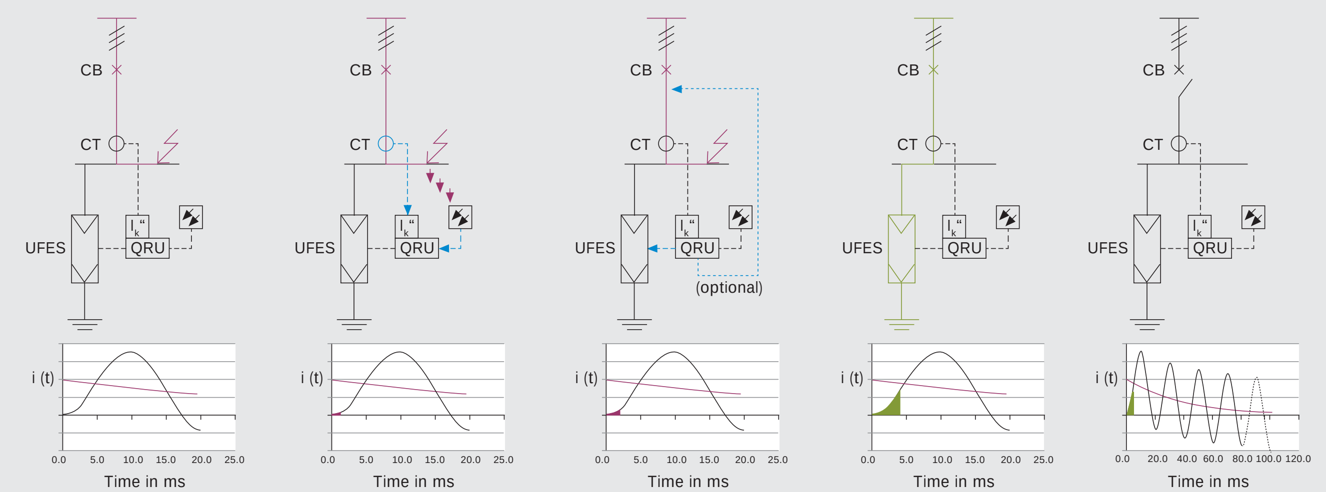
> Technologies from ABB's vacuum interrupter and I_s-limiter have been cleverly combined to form an arc-fault protection system for medium-voltage switchgear that operates in the ultra-fast range.

2 3-D section drawing and sectional view of an UFES primary switching element type U1



4 Electronic unit type QRU1

3 Event sequence description



Internal arc formation.

Arc detection by the electronic device (light and current).

Tripping signal sent to the UFES primary switching elements (optional to the upstream circuit breaker).

Rapid metallic 3-phase earthing by operation of the UFES primary switching elements leading to:
- Interruption of the arc voltage: Immediate extinction of the arc.
- Controlled fault current flow via UFES primary switching elements to earth potential.

Final clearing of the fault current by the upstream circuit breaker.

5 UFES primary switching element type U1

Standard		IEC
Electrical maximum characteristics (different basic types)		
Rated voltage (rms)	kV	40.5
Rated power frequency withstand voltage (rms)	kV	85 / 95
Rated lightning impulse withstand voltage (peak)	kV	170 / (200)
Rated frequency	Hz	50 / 60
Rated short-time withstand current (rms)	kA	50 / (63)
Rated peak withstand current	kA	170
Rated duration of short-circuit	s	3 / (1)
Rated short-circuit making current	kA	170
Mechanical characteristics		
Dimension (diameter x height)	mm	~ 137 x 210
Closing time	ms	< 1.6
Contact bounce duration	ms	0
Lifetime		
Mechanical life operations		1
Number of short-circuit operations		1
Shelf life	years	30
Micro gas generator	years	15

6 Demonstration installation showing UFES primary switching elements on top

ABB's system is an active internal arc fault protection solution for medium-voltage switchgear systems, which greatly increases both system availability and personnel safety.

contacts are provided as interfaces to other units. These can be used:

- To transmit the status of the electronics to a remote control room
- To send commands to a circuit breaker feeding into the arc fault
- As an interlock to block the reclosing of a circuit breaker directly after tripping.

Together with the electronic watchdog function, the functional capability of the SMGG-igniter is also continuously monitored. The electronic unit can be switched to test mode in which all the response criteria for the switchgear can be simulated and checked by the user, and the corresponding trips displayed but not transmitted to the SMGG's.

In combination with the TVOC light detection system, up to 54 compartments in a switchgear system (three compartments per panel) can be monitored using one electronic unit. The TVOC extension modules, each of which contains nine optical inputs, can be directly connected to the five interfaces provided. Because detection of an arc fault by these modules is also monitored by the electronic unit, at least 18 panels in a switchgear system are provided with active protection. As each compartment is individually monitored, the location of the fault can be easily determined.

The power to protect

ABB's system, suitable for rated voltages up to 40.5 kV and rated short-time withstand currents up to 63 kA (1s) → 5, is an active internal arc fault protection solution for new internal arc classified medium-voltage switchgear as well as for existing older generation switchgear. It helps to avoid serious damage to the switchgear, the equipment and the direct environment. Therefore, it greatly increases both system availibilty and personnel safety in the event of internal arc fault. Furthermore it enables the minimization of pressure relief arrangements in poorly accessible switchgear installation rooms.

The UFES primary switching elements can be installed in the switchgear cable connection compartments or simply in each separate busbar section to ensure the entire system is covered. The UFES will be available as a complete unit in a type-tested ABB service box for simple installation in existing switchgear systems → 6 and later as a "loose device" (ie, the electronic unit and three primary switching elements).

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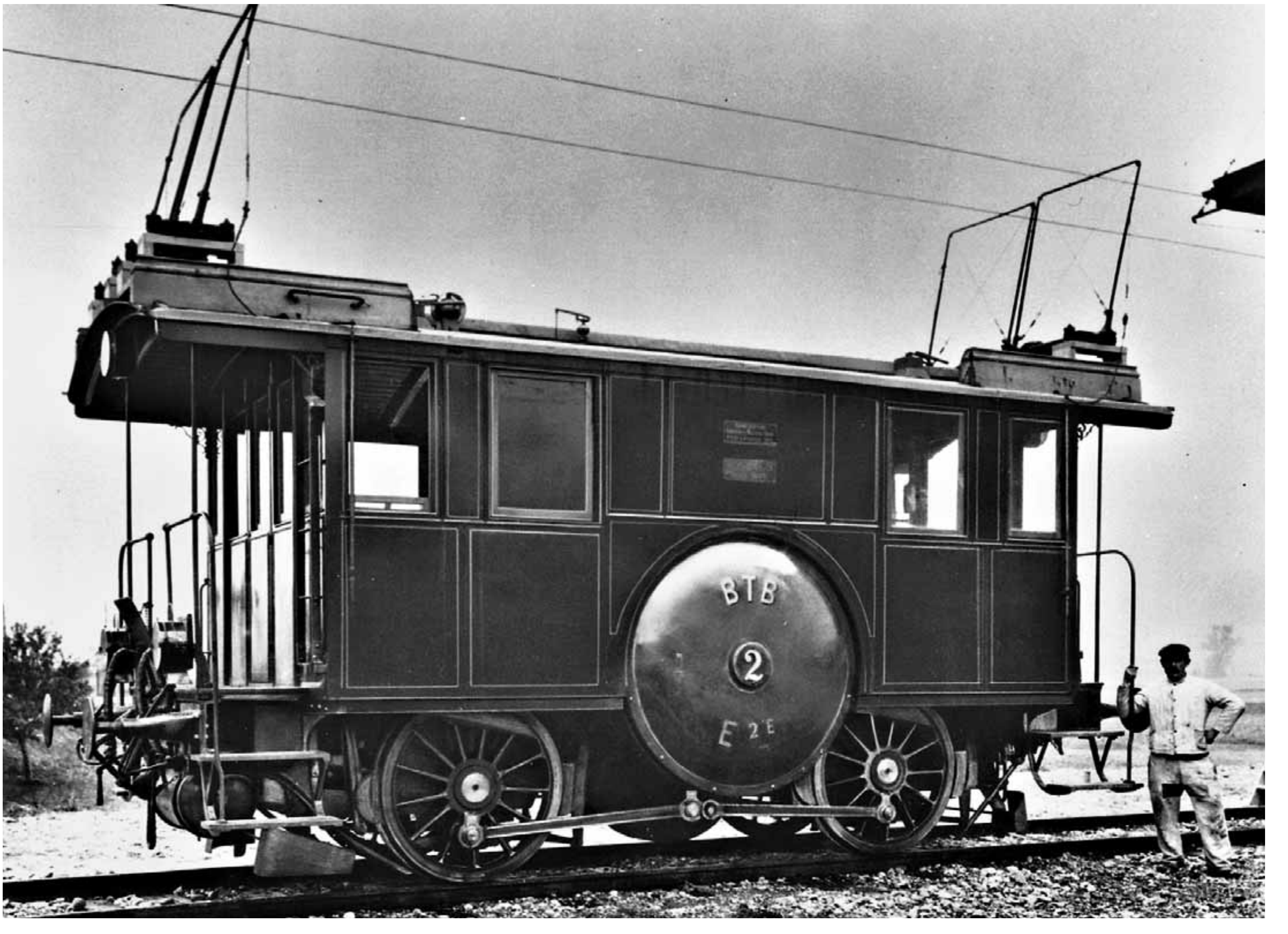


Historical perspective

Electrifying history

A long tradition in electric railway engineering

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

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

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

Electrification with different power systems

It is a little known fact that it was Charles Brown Sr. (1827–1905), whose name lives on as one of the B's in ABB, who founded SLM ➔ 2 in 1871. The company produced steam and mountain railway locomotives and for many decades was to supply the mechanical part (ie, body, frame and running gear) of practically all Swiss electric locomotives. Brown's two sons, Charles E. L. and Sidney Brown also worked on equipment for electric locomotives (It was Charles Brown who later cofounded BBC.) Together the two sons designed the first mainline electric locomotive for the 40 km Burgdorf–Thun railway (picture on page 88). This was a freight locomotive with two fixed speeds (17.5 and 35 km/h) powered by 40 Hz three-phase AC. The transmission used straight-cut gears and had to be shifted during standstill. Two large induction motors drove the two axles via a jackshaft and coupling rods. The overhead line voltage was limited to a maximum of 750 V by law.

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

MFO: Single-phase alternating current

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

1 Early milestones

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

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

BBC: Electric power for the Simplon tunnel

In late 1905, BBC decided to electrify (at its own cost and risk) the 20 km single-

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

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

2 Abbreviations of railway and manufacturing companies

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

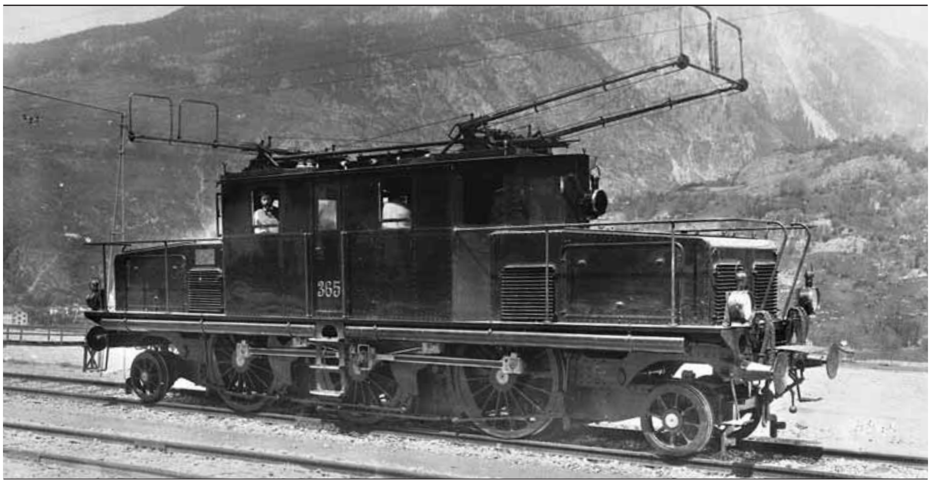
track Simplon tunnel under the Alps between Brig (Switzerland) and Iselle (Italy), which was then approaching completion. An important argument for electrification was the risk that carbon monoxide from steam locomotives could present to passengers should a train break down in the long tunnel. However,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

At the time it was already realized that asynchronous AC motors offered several advantages for traction applications, including robustness and simpler maintenance due to the absence of a commutator. Disadvantages, however, included the coarse speed graduation resulting from pole switching and the double-wire overhead line of the three-phase supply, which added to the complexity of turnouts. Three-phase motors were thus to remain relatively rare in traction applications until recent times when power electronic converters were able to alleviate their shortcomings without compromising their strengths.

In 1908, SBB took over this installation. In 1919 two further locomotives were added and the electrification extended to Sion. A second tunnel bore was completed in 1921. The three-phase era on

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

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



6 Determining the optimal electrification system

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

the Simplon ended in 1930 when the line was converted to the standard single-phase 15 kV / 16 ⅔ Hz ➔ 6.

Electrification of the Lötschberg railway

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

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

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

Electric operation on the Gotthard line

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

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

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

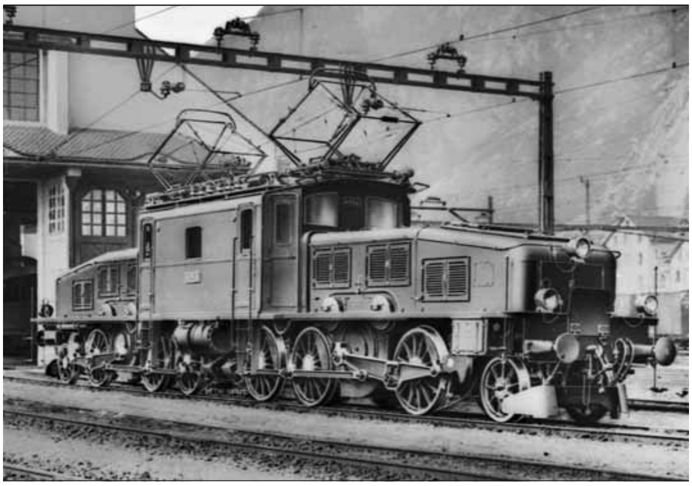
The electrification of the Gotthard line progressed so rapidly that there was virtually no time to adequately test the trial locomotives. Orders had to be placed quickly. BBC/SLM supplied 40 passenger train locomotives (1'B)(B1'), and MFO/SLM supplied 50 freight locomotives (1'C)(C1'). Both types were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

Contributions by Sécheron

In 1921/22 ABB's predecessor company, Sécheron, supplied six Be 4/7 locomotives (1'Bo 1') (Bo') for the Gotthard railway. They were equipped with four individually driven axles with Westinghouse quill drives ➔ 9. Despite their good running characteristics, no further units were ordered as SBB was initially wary of the single-axle drive. For its less mountainous routes, SBB ordered 26 Ae 3/5 (1'Co 1') passenger locomotives with an identical quill drive and a top speed of 90 km/h. Weighing 81 t, these machines

7 Trial locomotive for the Lötschberg railway, 1910

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



were considerably lighter than other types. Ten similar units with a 2'Co1' wheel arrangement (Ae 3/6 III) followed later. These three types were generally referred to as Sécheron machines and were mainly used in western Switzerland. The last were still in operation in the early 1980s when they were mostly to be found on the car transporter trains of the Gotthard and Lötschberg tunnels.

ASEA's activities in the railway sector

Similarly to Switzerland, electrification of the Swedish state railways started before the first world war. From 1911 until 1914, the 120 km long so-called Malmbanan or "ore line" was electrified. Its main purpose was to transport magnetite ore from mines in Kiruna to the port of Narvik (Norway), a port that remains ice-free all year due to the Gulf Stream. Sweden has huge hydropower resources. The Porjus hydropower plant supplies the power for this railway, which is operated with single-phase 15 kV at 16⅔ Hz (initially 15 Hz). By 1920, the electrification had been extended via Gellivare to Lulea on the Gulf of Bothnia. The Norwegian section of the line was electrified in 1923. The mountains traversed are of medium height, and the gradients of 1.0 to 1.2 percent are considerably lower than those on Swiss mountain railways. However, the heavy ore trains placed high demands on the locomotives. ASEA supplied the electrical equipment for 12 1,200 kW articulated locomotives (1'C)(C1') with side-rod drive, as well as for two similar 600 kW express locomotives (2' B 2'). 10,650 kW four-axle locomotives for express goods services were later added, and mainly operated in pairs. In 1925 the 460 km long SJ mainline between Stockholm and Gothenburg was electrified, with ASEA supplying the 1,200 kW 1'C1'locomotives.

Successful single-axle drive

After commissioning the electric service on the Gotthard line, SBB extended its railway electrification onto the plains and into the Jura mountains. By 1927, continuous electric operation was possible from Lake Constance in the east to Lake Geneva in the west. BBC/SLM developed the Ae 3/6 II (2'Co1') passenger locomotives that incorporated a new single-axle drive. This drive concept, named after its inventor Buchli, consisted of a double-lever universal-joint arrangement in a single plane that acted between the frame-mounted motor and the sprung driving axle → 10. 114 locomotives of this type entered service on SBB. The design proved so satisfactory that the initial speed limit of 90 km/h could be raised to 110 km/h. The type was a huge success for Swiss industry and led to export orders and license agreements for similar locomotives for Germany, Czechoslovakia, France, Spain and Japan. In total, some 1,000 rail vehicles with Buchli drives must have been built.

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

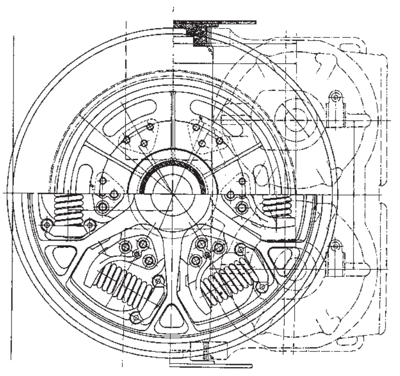
Post-war trends: bogie locomotives

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

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

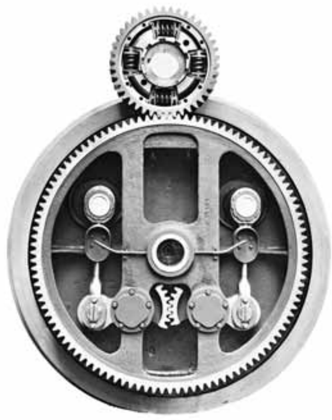
ASEA also turned to the development of bogie locomotives. The first Bo'Bo' type Ra was introduced in 1955 → 11. With its beaded side panels, the "porthole" windows and its round "baby face" the machine reflected American design trends. Like its Swiss counterparts, it was equipped with two traction motors per

9 Sécheron type single-axle quill drive (Sécheron)



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

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



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

bogie. Weighing only 60 t, it was capable of a top speed of 150 km/h. These locomotives proved highly satisfactory and remained in service until the 1980s. In 1962, the first type Rb rectifier locomotives were introduced, followed by the type Rc thyristor locomotives in 1967. The latter were also supplied to Austria (type 1043) and the United States (type AEM-7, built under license by General Motors).

From rectifier to converter technology

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

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

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

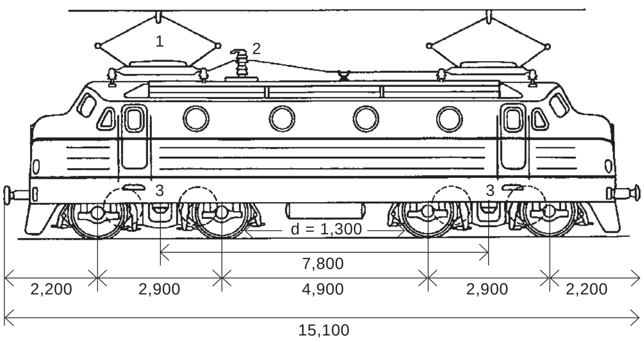
High-speed trains

Between 1989 and 1992, German railways (DB) commissioned 60 ICE (Intercity Express) trains, which were based on the technology of the E120. ABB was involved in their development. The trains consisted of two power cars with converter-controlled three-phase induction motors and 11 to 14 intermediate passenger cars. During a trial run on the newly completed high-speed line between Hamburg and Frankfurt, one of these trains reached a speed of 280 km/h.

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

In 1990, ABB supplied the first of 20 X2000 tilting high-speed trains to SJ for express service between Stockholm and Gothenburg. They use GTO converters and induction motors and can reach

11 ASEA type Ra bogie locomotive of the Swedish State Railways



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

200 km/h. The type is now also used on other lines in Sweden, enabling reductions in journey times of up to 30 percent.

Streamlining the railway business

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

The ABB railway business today

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

Since 2002 ABB has maintained a close strategic cooperation with Stadler Rail. Stadler is an internationally operating rolling stock manufacturer that emerged from a small Swiss company, which originally produced diesel and battery-electric tractors for works railways and industrial lines. The company is now an important international supplier of multiple unit passenger trains. In recent years ABB has developed new components for different overhead line voltages and frequencies as well as for diesel-electric traction applications. ABB supplies the transformers, traction converters, onboard power supply systems and battery chargers used on Stadler trains. Starting in 2011, 50 new Stadler double deck trains will enter service on SBB.

Today, ABB also has strategic agreements with other rolling stock manufacturers and supplies strategic components to Alstom, Siemens and Bombardier. Although the company no longer operates as a manufacturer of complete trains, ABB's involvement with and commitment to railways remains strong.

Norbert Lang
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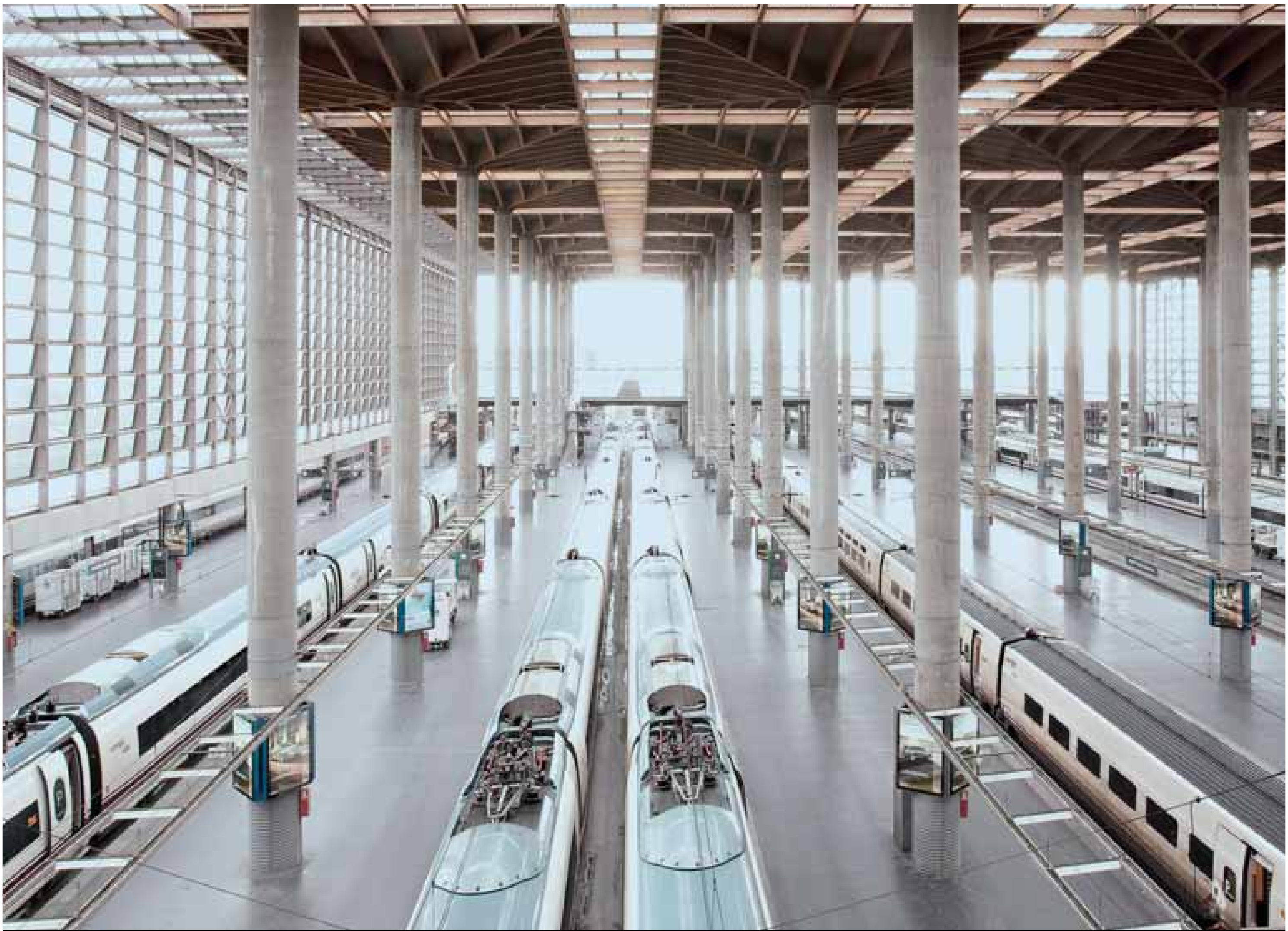
Green perspectives

ABB has numerous technologies that enable production and processes to become more efficient, both in terms of energy usage and of productivity. The company's variable-speed drives, for example, permit huge energy savings to be made in comparison to the more traditional method of using throttling elements to control speed. Not only is less energy input required to do the same work (environmental benefits) but costs are also saved thanks to short pay-back times. Typical applications for such variable-speed drives include fans, pumps, belts and conveyors. They can also be found in more unorthodox situations: for example powering the retractable roof of the Dallas Cowboy's football stadium.

Variable speed drives are just one application of ABB's expertise in power electronics. Power electronics permit current and voltage to be modified to virtually any desired waveform and frequency. Issue 3/2010 of *ABB Review* will look at some of these applications, and also the components at the heart of power electronics: solid state switching devices.

Continuing with the topic of saving energy and boosting productivity, the journal will also look at a building of the future, the latest developments in wind energy and a way to reduce emissions from ship's engines.



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