

ABB

4 | 16
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review

Charging a bus in 15 seconds 8

A long tradition in electric railways 16

World's longest rail tunnel 35

Remote service at sea 44

The corporate
technical journal

Transportation



125

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Transportation and its infrastructure form one of the more visible and tangible applications of technology. The front cover shows the portal of the Gotthard base tunnel, which opened this year. The present page shows the TOSA electric bus. Both projects are discussed in articles in the present issue of ABB Review.



Transportation focus

- 6 Cities take charge**
Making the case for the electrification of urban public transportation
- 8 Charged in a flash**
Optimization of batteries for a flash-charged bus
- 13 Green park**
Krka national park, Croatia, is the first national park in the world to install ABB Terra 53 fast DC/AC chargers
- 16 Electrifying history**
A long tradition in electric railway engineering
- 25 Weight loss program**
ABB's Efflight® traction transformer delivers less weight and losses and needs up to 70 percent less oil
- 30 Efficiency that climbs mountains**
Cutting the energy consumption of the Allegra trains
- 35 Peak power**
ABB's ZX0 medium-voltage switchgear and PMA cable protection for the Gotthard Base Tunnel
- 40 Record breaker**
ABB to provide power, propulsion and automation for the world's most advanced port icebreaker
- 44 Improving remote marine service**
A concept for the next generation ABB customer and service portal

Event

- 50 Connect. Collaborate. Outperform**
Automation & Power World returns to Houston in March 2017

Simulation

- 51 Loss prophet**
Predicting stray losses in power transformers and optimization of tank shielding using FEM

Switching and safety

- 57 Wind protection**
Low-voltage switching and protection strategies in wind turbines
- 63 Arc angel**
Arc flash prevention measures increase safety
- 67 Switching the subject**
A look at recent advances in IGCT technologies for high-power electronics

Up-time and productivity

- 72 Grid4EU**
Laying the groundwork for the development of tomorrow's electricity grids
- 79 Cloud robotics**
Smart robots leverage the Internet of Things, Services and People from edge to cloud
- 84 A combined future**
Microgrids with renewable power integration

Index

- 90 2016 Index**
The year at a glance

Transportation



Bazmi Husain

Dear Reader,

The portion of the world's population living in cities is forecast to rise from 54 percent in 2014 to 66 percent by 2050. The relentless growth of urban centers is bringing with it numerous societal and environmental challenges. Not least among these is that of transportation. With both urban populations and their affluence on the rise, more and more vehicles are competing for limited road space while contributing to pollution. On a local level, emissions from vehicles can have a detrimental impact on both human health and quality of life. On a global level, transportation contributes to about one quarter of global anthropogenic emissions of carbon dioxide. Governments are increasingly recognizing these challenges and implementing measures to make transportation greener.

Besides pollution, transportation is also linked to congestion. Further to its nuisance aspect, congestion is an economic liability as people spend time unproductively and the delivery of goods is disrupted.

Fortunately, there are many ways to meet these challenges, ranging from hybrid or electric cars to high-capacity metros.

The electrification and energy efficiency aspects of such developments are core elements of ABB's portfolio, but the company's abilities are far from limited to these.

For example, ABB is also at the forefront of the digitalization that enables assets and systems to share data, perform more effectively and be serviced and diagnosed remotely.

Further areas that the company is perhaps less commonly associated with include marine transportation, service offerings and the charging of electric vehicles. The latter category includes the "flash charging" of electric buses. This technology involves automatically connecting and topping up a bus's batteries at intermediate points along its route, thereby reducing the weight of batteries and thus making the system more economically competitive. Following a successful test operation, ABB recently signed a contract to deliver the world's first commercial "flash-charged" bus project to the Swiss city of Geneva.

I trust this issue of ABB Review will raise your awareness of and kindle your interest in the challenges of electric transportation and highlight ABB's involvement in its ongoing development.

Bazmi Husain
Chief Technology Officer
ABB Group





Cities take charge

Making the case for the electrification of urban public transportation

TIMOTHY PATEY, RETO FLUECKIGER, ALESSANDRO ZANARINI, JAN POLAND, DAVID SEGBERS, PHILIPPE NOISETTE, BRUCE WARNER – The sustainable development of cities is pivotal for the Earth's future. The UN forecasts the percentage of people living in cities will rise from 54 percent in 2014 to 66 percent in 2050, [1]. During the same period, global population is forecast to reach 9.7 billion. And this population will place demands on mobility. Urban transport is already a cause of congestion and pollution today. Only an increased emphasis on sustainability in transport infrastructure can ensure tomorrow's cities safeguard their ecology, economy, and quality of life.

sions standards for particulate matter from 0.648 g/km in 1992 (Euro I) to 0.018 g/km in 2013 (Euro VI) for transit vehicles [6]. This trend has improved air quality over the past 20 years, and will continue to do so in the years to come. But if public transportation is ever to achieve zero local emissions of particulate matter, full electrification of the system is needed.

Moving back to the global perspective, such a drive for full electrification of public transportation will at the same time contribute to climate change mitigation (assuming the power grid is powered with a significant portion of renewable power in its mix).

This combined drive for carbon neutrality and clean air becomes increasingly pressing with advances in urbanization and population as well as traffic challenges. Rather than building only highways, cities are increasingly developing metros, trams and electric buses.

TOSA future

The city of Geneva, Switzerland, has taken a key step towards full electrification of their public transportation network. The “TOSA” bus line which is presently being delivered is fully electric despite not featuring overhead lines. “Flash” or opportunity charging [7] is used to top up the batteries at intermediate points on the route, meaning the dead weight of large batteries can be reduced, saving on both space and weight. Also, charging time is reduced at the ends of the route, which is especially important during time-constrained rush-hour operation. The flash charging is done safely in only 15–20s, during the time that the bus is stopped anyway to allow passengers to embark and disembark.

The absence of overhead lines is not only less visually disruptive, but also saves on installation costs by avoiding extensive construction work for the overhead line and allows for more flexible bus operations during road works. It also saves on maintenance, which accounts for a significant portion of the costs of traditional bus operation using overhead line infrastructure. The TOSA bus and in particular its batteries are discussed in the next article of this edition of ABB Review.

Using TOSA technology, diesel-powered bus fleets can be replaced with electric bus fleets, without the need to install overhead lines. The technology is realizable today, as has been demonstrated in the city of Geneva.

TOSA is just one example of what ABB has to offer. The company provides electrification of public transportation systems; both on-board the vehicles and off-board at the charging infrastructure. Increased electrification, in whatever form, is key to reducing emissions and achieving carbon neutrality in all modes of transportation. Many examples of this are presented in the present issue of ABB Review.

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Today, transportation contributes nearly one quarter of global CO₂ emissions [2]. Climate change mitigation is being driven by treaties including the Kyoto Protocol (1997), the Copenhagen Accord (2009), and the Paris Agreement (2016). Policy makers have agreed that the average global temperature rise should not exceed 2°C above the average global temperature of pre-industrial times [3]. It has been postulated that in order to assure a 50 percent probability of global warming below this limit by the end of the 21st century, the CO₂ emissions between 2011 and 2050 have to be limited to 1,100 gigatons [4].

The challenge is huge. The potential atmospheric CO₂ emissions from the combustion of existing fossil fuel reserves would outweigh this limit by a factor of more than three [5]. Climate change mitigation policies are urgently required.

On a local level, the desire of many cities for cleaner air is also motivating change. The European Union has promoted cleaner air in cities by tightening emis-

Title picture

Electrification of transportation systems contributes both to clean air in cities and to reducing carbon emissions.



Charged in a flash

Optimization of batteries for a flash-charged bus

TIMOTHY PATEY, RETO FLUECKIGER, JAN POLAND, DAVID SEGBERS, STEFAN WICKI – With its six trolleybus and four tram lines, transportation in the Swiss city of Geneva already makes extensive use of electric traction. As a further step towards making its public transportation system carbon-neutral, the city has announced it will replace the diesel buses used on line 23 by a battery-powered electric bus fleet.

1 TOSA



Taking charge

Flash charging is just the ticket for clean transportation.

ABB's new battery-powered electric bus (BB) is just the ticket for clean transportation. The bus is equipped with a 600 kW flash charging station that can charge the battery in just 15 seconds. This is a significant improvement over traditional charging methods, which can take up to 30 minutes. The bus is also equipped with a regenerative braking system that recovers energy when the bus brakes, reducing energy consumption. The bus is expected to be deployed in Geneva, Switzerland, in 2016.

ABB's new battery-powered electric bus (BB) is just the ticket for clean transportation. The bus is equipped with a 600 kW flash charging station that can charge the battery in just 15 seconds. This is a significant improvement over traditional charging methods, which can take up to 30 minutes. The bus is also equipped with a regenerative braking system that recovers energy when the bus brakes, reducing energy consumption. The bus is expected to be deployed in Geneva, Switzerland, in 2016.

ABB Review 4/2013 featured an article on the TOSA bus demonstration in the Swiss city of Geneva.

Following a successful conclusion of the demonstration, Geneva's public transportation operator, TPG, decided to convert its route 23 to the mode. The order for 12 TOSA buses and 13 charging stations was confirmed in July 2016. ABB's scope of delivery includes converters, motors and the charging stations.

2 Bus stop with flash charging station. The bus' batteries receive a 15 second 600 kW boost while at the stop.



ABB was recently awarded orders totaling more than \$16 million by Geneva's public transport operator, Transports Publics Genevois (TPG), to provide flash charging and on-board electric vehicle technology for 12 TOSA (Trolleybus Optimisation Système Alimentation) fully electric buses → 1. Their operation can save as much as 1,000 tons of carbon dioxide per year (compared with the existing diesel buses).

ABB will deliver and deploy 13 flash-charging stations along the route → 2, as well as three terminal and four depot feeding stations. The flash-charging connection technology used will be the world's fastest: It will take less than one second to connect the bus to the charging point. The onboard batteries can then be charged by a 600 kW boost lasting 15 seconds using time that the bus is at the bus stop anyway. A further four to five minute charge at the terminus will enable a full recharge of the batteries.

Title picture

Geneva (Switzerland) is to replace a presently diesel operated bus line by flash-charged battery buses. In this view the bus is receiving its 15 second top up charge at a flash charging station similar to that which will be installed at 13 intermediate stops of route 23.

ABB will deliver and deploy 13 flash-charging stations along the route, as well as three terminal and four depot feeding stations.

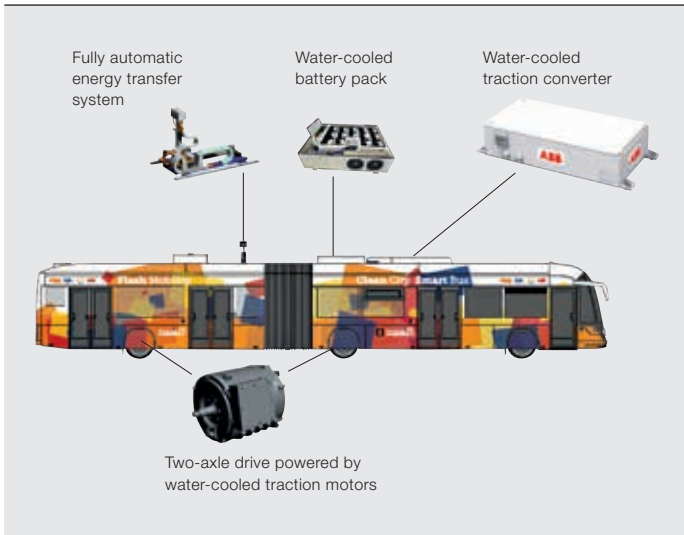
ABB solutions for the electrification of public transportation

ABB has developed a modular platform for the electric drive train of city buses → 3. This caters to all e-bus applications ranging from the traditional trolleybus to DC fast-charged or flash-charged battery buses. At the heart of this are ABB's highly efficient water-cooled permanent-magnet traction motors as well as the extremely compact BORDLINE

CC200 → 4 traction and auxiliary converter. The converter can drive up to two traction motors and all the auxiliary consumers of the bus.

On a flash-charged bus, the converter also handles the flash and opportunity charging at bus stops and the DC fast-charging at the end of the line. On an electric trolleybus, it is supplemented by a double-insulated DC-DC input converter. Adding a battery to this drive train enables the bus to operate free of catenary lines (overhead lines).

3 Key technology components of the TOSA bus.

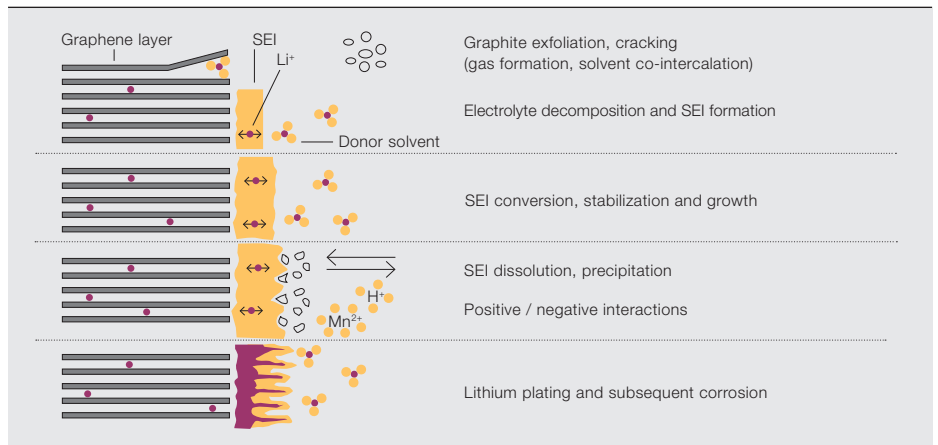


4 ABB's BORDLINE CC200 traction an auxillary converter.



As every mobile phone user knows, availability of battery power is essential if the device is to fulfil its function.

5 Physical and chemical degradation mechanisms of graphite within a Li-ion battery¹.



SEI is the solid electrolyte interphase formed as a consequent of electrolyte decomposition and related side reactions.

Charging matters

As every mobile phone users know, availability of battery power is essential if the device is to fulfil its function. The same applies to an electric bus or tram. However, after a certain time and usage, a battery needs to be replaced. A challenge for ABB engineers is to predict when this will occur, and to create specifications that ensure availability of power through the product and system's life.

A model informed by experiments

A battery "dies" because it fails to deliver the power required for the specified timespan. More specifically, the decline in capacity (Ah) and rise in internal resistance (Ω) are simultaneous processes that compromise the battery's ability to deliver power. This is due to chemical and mechanical decomposition of the materials inside the battery (exam-

ple of graphite degradation are shown in → 5).

A key challenge in battery integration lies in predicting the rate at which the battery will degrade. One approach is to test the batteries: The batteries are charged and discharged under various conditions to quantify the decline in capacity and rise in resistance. However, this method alone cannot cover all the use cases of the electric bus. There are too many variables, including temperature, state of charge, depth of discharge / charge, and current. The time and sheer number of experiments required to cover all the use cases is simply too high.

The solution to estimating battery lifetime is to make a model informed by experimental results and a fundamental understanding of the key physical and chemi-

cal processes of the battery. This approach is semi-empirical, in that it relies partly on empirical/experimental results. Models based purely on physics are not suitable as the high number and complexity of the various physical and chemical interactions are too numerous to run computations efficiently. It is more time efficient to conduct a series of well-designed experiments and use the results to create a model. The key to building a good model is to design the right experiments.

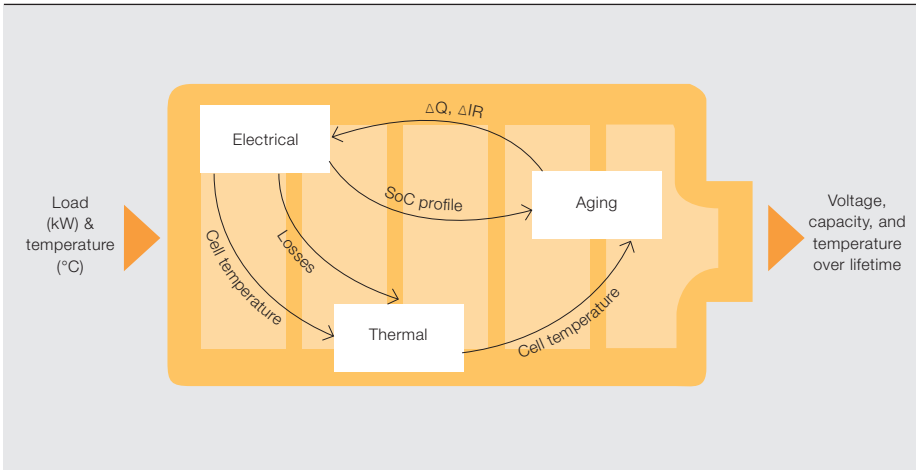
Step 1: Design the right experiments

In this phase, the temperatures, depth of discharge, state of charge, and current are varied in a series of battery tests. The

Footnote

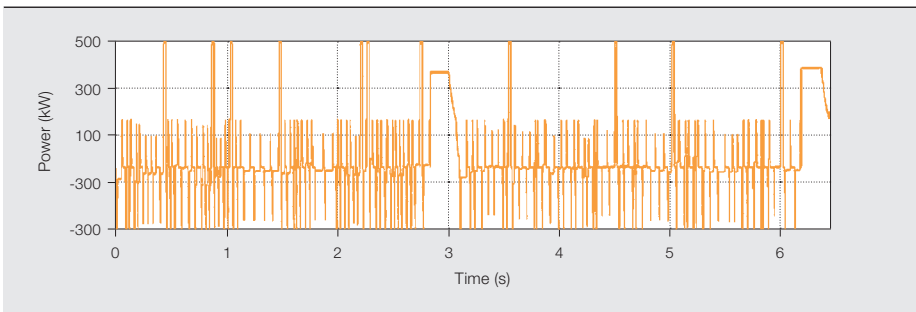
¹ Vetter, J., et al., *Ageing mechanisms in lithium-ion batteries*. Journal of Power Sources, 2005. 147(1-2): p. 269-281.

6 Simple representation of an electrical, thermal, aging model of a Li-ion battery



Key operation concept is the interplay of variables between models: e.g. change in capacity (ΔQ) and internal resistance (ΔIR) modify the electrical model, which varies the state of charge (SoC) profile that modifies the aging model.

7 Example of a battery load profile for one return trip of a 12km route with 13 flash charging and 2 terminal charging sections



A key challenge in battery integration is predicting the rate at which the battery will degrade.

capacity decline and resistance rise are measured. This will later enable a prediction of how certain charge/discharge events of the battery would impact the battery aging over time and use.

Step 2:

Develop an electric, thermal, aging model

The internal electrical architecture of a Li-ion battery is complex, but electrical response is approximated with a number of resistive and capacitive components. Heat and age modify these components, as informed by the thermal and aging models.

As electric buses are power applications, Joule heating (i^2R) is the dominant type of energy loss and dictates the battery cell's wall and core temperatures during

operation. These temperatures are essential for accurate electrical and aging models.

The aging model is based on the results of experi-

ments, and quantification of the decline in capacity and rise in resistance expected from the many possible charge / discharge events.

The resulting battery model combines the electric, thermal, and aging sub-models. The interplay of these sub-models enables the prediction of the change in capacity and resistance under a given load and temperature over time → 6.

Step 3: Verify the model

Experiments at cell level inform and verify the model using realistic load profiles. This is an iterative process involving further refinement.

The key to building a good model is to design the right experiments.

Step 4: Apply the model

Once the model has been generated and verified, it becomes an important tool in scenario analysis. The battery's temperature, voltage, energy, and peak power all affect how a battery system should be dimensioned. While this process is not the final say in how big a battery should be, modelling informs decision makers and designers on how key variations in battery size and cooling influence bus performance.

Scenario analysis

The following scenario analysis considers a 25 ton articulated bus with a maximum passenger capacity of 80 people. There are 13 flash charging stations distributed along the route of 12 km length, providing a charging power of 600 kW for 20 seconds. The terminal charging uses 400 kW and takes four to five minutes. A typical load profile of such a bus is shown in → 7.

Key battery requirements for this electric bus include:

- 10 year lifetime
- minimum charge voltage of 600 V (to assure sufficient power is available for the motor and auxiliary systems and to match the charging infrastructure)
- cell temperature of max. 60 °C (to ensure safe operation, as the electrolyte evaporates above 80 °C)
- charging power of 600 kW for 20s (to allow for rapid charges), and 400 kW for 5 minutes
- an energy of 46 kWh (to complete a journey in one direction, with backup power for exceptional circumstances).

Parameters for three configuration scenarios are presented in → 8.

8 Overview of three possible battery designs for a 12 km urban route (with flash charging)

Design criteria	"Small energy"	"Strong cooling"	"Large energy"
Cell chemistry	LTO	LTO	LTO
Max. C-rate permitted (continuous)	6	6	6
Max. C-rate permitted (for 20s)	8	8	8
Cells in series / in parallel	314 / 4	314 / 4	375 / 4
Energy content [kWh]	58	58	69
Minimum voltage [V]	630	630	750
Nominal cont. power [kW]	400	400	480
Nominal 20s power [kW]	580	580	690
Battery weight incl. cooling system [kg]	~1600	~1600	~2000
Coolant temperature [°C]	25°C	15°C (active)	25°C

C-rate is the rate at which a battery discharges, with 1 C-rate equal to a complete discharge in 1 hour, and 10 C-rate 1/10th of 1 h, (ie, 6 minutes).

9 Overview of the model calculation for the three possible battery designs for a 12 km urban route (with flash charging). BOL = beginning of life, EOL = end of life

	"Small Energy"		"Strong Cooling"		"Large Energy"	
	BOL	EOL	BOL	EOL	BOL	EOL
EOL	-	6 y	-	12 y	-	10 y
Capacity	100%	83%	100%	80%	100%	80%
Resistance	100%	200%	100%	170%	100%	185%
Energy content	58 kWh	48 kWh	58 kWh	46 kWh	69 kWh	55 kWh
Voltage range	690 - 850 V	590 - 850 V	690 - 850 V	630 - 850 V	840 - 1010 V	770 - 1010 V
C-rate terminal (continuous)	5.3	6.2	5.3	6	5.4	5.6
C-rate flash (for 20 s)	8	8.5	8	8.3	6.8	7
Peak core cell temperature	57 °C	86 °C	43 °C	58 °C	44 °C	57 °C
Battery efficiency	90%	80%	90%	85%	92%	86%

The three battery scenarios were analyzed using the thermal, electric and aging battery model to forecast the lifetime and the end of life (EOL) properties. Here the EOL is defined as 80 percent of the initial capacity or 200 percent of the initial resistance. The results of the model analysis shown in → 8.

For the case of the "small energy" battery, flash charging the battery at 600 kW would not be possible at end of life as it is beyond the power limit of the battery pack (with a C-rate limit of 8). It would be able to power the bus for some time using terminal charging only, but the rise in resistance would be too great (210 percent), resulting in an eventual unsafe temperature ($T > 80^{\circ}\text{C}$, internal to the cell) and as well as minimum voltage of less than 600 V, which is insufficient to power the motor and auxiliary systems.

For the case of the "strong cooling" battery, the battery would be fine for terminal charging only. However the flash charging of 580 kW is beyond the limits of the battery pack. The lower coolant temperature, however, is sufficient to maintain healthy voltage and temperature ranges throughout the battery's lifetime of 12 years. This is a clear demonstration that battery temperature matters for system lifetime performance.

The "large energy" battery is the only one of the three considered that could fulfill both the flash-charging and terminal charging requirements. For flash-charging, the additional cells in series is simply needed to raise the voltage and lower the current to meet the power requirements throughout the battery's life. Additionally, this configuration (375s4p) would ensure healthy temperature window for the entire 10 years of the required battery life.

Use of the battery model on these three battery cases is a simple means to demonstrate battery design impact on maintaining a reliable system performance at end of life. Further design iterations would be done to find the optimum solution, while mitigating all risks through system analysis.

Furthermore, the battery model informs the public transportation operator on the battery design impact of choosing flash charging or terminal charging. The bus line operators know their cities and its needs, and are in the best position to decide whether terminal or flash charging is most suited. The battery model is a support tool to inform them of the battery design consequences of their system choices.

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Green park

Krka National Park, Croatia, is the first national park in the world to install ABB Terra 53 fast DC/AC chargers

ALEKSANDAR RADOSAVLJEVIC, MERSIHA VELIC HAJDARHODZIC, MICHELLE KIENER – Krka National Park, situated in Šibenik-Knin county in Croatia, is a world famous natural phenomenon with its seven waterfalls of the Krka River. On the park's territory there are many historical and cultural monuments, one of them is the remains of the hydro power plant Jaruga, the oldest power generating facility in the world, built in 1895. That was the first alternating current (AC) power system in

Croatia, the first in Europe and the second in the world, coming online only two days after the Niagara Falls AC plant. To protect its nature and heritage Krka National Park has invested in five electric vehicles and four ABB DC electric vehicle fast-charging stations: Terra 53 CJG. The first unit is already installed and it is operating every day at Lozovac, nearby the town of Šibenik and the hydro plant Jaruga.



Krka National Park (Krka NP) is home to numerous endemic plants, geomorphological forms of rocks and animal species and covers a total area of 109 km². It is challenging to maintain and preserve natural rarities and therefore the park managers undertake constant efforts in order to keep the high level of conservation of these natural treasures. One aspect of this work has been the initiative to use electric and hybrid plug-in vehicles within the park and to provide fast DC charging stations. The first charging station is already in operation in Lozovac → 1. The next charging station will be installed as part of the new information center at Laškovića above Roški slap and the remaining stations will be strategically placed at a variety of locations within the park.

An even greener park

The missions of Krka NP include reducing CO₂ emissions, as well as reducing noise, fuel consumption and maintenance costs. To invite all park visitors to be part of the efforts to protect the environment, the charging stations will be available for all visitors with electric cars.

Title picture

Krka National Park lies within Šibenik-Knin County, and covers a total area of 109 km²

The stations are set to charge two cars at the same time and charging lasts for a duration of 0.5 to 1.5 hours, depending on the capacity of the vehicle battery. The ABB chargers are equipped with internet based connected services and allow users to easily connect to different software systems and payment platforms. The connectivity also enables remote monitoring, maintenance and functionality add-ons. The working temperature of the charging stations is from -35 °C to +50 °C.

Green line

The initiative is part of the "Green Line" program, launched by the Ministry of Environmental and Nature Protection and

"This is a step forward in nature conservation, and we are particularly proud that the Public Institution of Krka National Park joined the Green Line project, which provides protected areas the opportunity to serve as a model for the introduction and broader user of electric vehicles. We hope that the project will continue to develop, to allow greater numbers of citizens to become direct contributors to environmental protection through the purchase of electric vehicles," stressed Krešimir Šakić, director of the Public Institution of Krka NP.

The electric vehicle charging infrastructure is a Terra DC 53 multi-standard 50 kW modular station with one, two or three

The electric vehicle charging infrastructure is a Terra DC 53 multi-standard 50 kW modular station with one, two or three plugs for the rapid charging of electric vehicles.

plugs for the rapid charging of electric vehicles. The flexible design enables multi-protocol charging, ie, CCS, CHAdeMO and fast charging AC standards, to meet the individual needs of each customer. The stations are designed

for super-rapid charging and are ideal for use at petrol stations and in urban city areas with high vehicle traffic.

for super-rapid charging and are ideal for use at petrol stations and in urban city areas with high vehicle traffic.

Park first

The first station came online in September 2016 and is particularly special be-



cause it's the first ABB fast electric vehicle charging station installed in any national park in the world. In addition, Krka NP is one of the first European parks to install electric vehicle charging stations.

The local area has a history of firsts. The park is close to the town of Šibenik, which was the first town in the world to have street lights powered by electricity. In 1895 some houses in the town were electrified and 340 street lights installed, made possible, of course, by the nearby Jaruga hydro-power plant → 2. Yet more poignant is that the birthplace of Nikola Tesla, Smiljan, is only 100km to the north of the park.

One can only wonder what Tesla's thoughts would be on seeing these new DC installations. But it would be nice to think that he would see the bigger pic-

The station is special because it's the first ABB fast electric vehicle charging station installed in any national park in the world.

ture and appreciate the work being done to conserve a national park, as well as the wider environment. In Krka NP there is no war of the currents. Simply a motivation to provide sustainable infrastructure, where the quiet hum of an EV en-

gine is no distraction to the gentle sounds of nature, undisturbed by man-made emissions.

The authors would like to thank the team from Krka NP, especially: Krešimir Šakić, Joško Baljkas and Katia Župan.

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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.

to supply the mechanical part (ie, body, frame and running gear) of practically all Swiss electric locomotives. Brown's two sons, Charles E. L. and Sidney Brown also worked on equipment for electric locomotives (It was Charles Brown who later cofounded BBC.) Together the two sons designed the first mainline electric locomotive for the 40 km Burgdorf–Thun railway → [title picture](#). This was a freight locomotive with two fixed speeds (17.5 and 35 km/h) powered by 40 Hz three-phase AC. The transmission used straight-cut gears and had to be shifted during standstill. Two large induction motors drove the two axles via a jackshaft and coupling rods. The overhead line voltage was limited to a maximum of 750 V by law.

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

MFO: Single-phase alternating current

Between 1905 and 1909, MFO tested a single-phase 15 kV/15 Hz electrification on a section of the former Swiss "Nationalbahn" railway between Zurich-Seebach and Wettingen (now part of the Zurich suburban network). The first locomotive used was equipped with a rotary converter and DC traction motors → [3](#). In 1905, a second locomotive was added → [4](#). This used the same axle arrangement (B'B'), but the bogies both had a 180 kW single-phase series-wound motor fed directly from the transformer's tap changer. (Tap-changer control was in later years to become the standard control method for AC locomotives and was not to be displaced until the advent of power electronics.) The axles were driven via a speed-reduction gear, jackshaft and coupling rods. The maximum speed was 60 km/h. The motors used salient stator poles and phase-shifted field commutation. This locomotive performed so well that the earlier locomotive was adapted accordingly. Between December 1907 and 1909 all regular trains on this line were electrically hauled. Because over-

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 Jungfrau railway to the summit of the Jungfraujoch at 3,500 m above sea level.
- 1901: ASEA supplies electrified tramcars to the city of Stockholm.

head 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 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

the electrification was removed after completion of the trial and the line reverted to steam operation (it was finally electrified in 1942). However, experiences gained were to have far-reaching consequences.

For most manufacturers, the development of electrification technology started with tramways. In 1890, a predecessor of ABB's business in Sécheron, Switzerland, supplied France's first electric tramcars to Clermont-Ferrand → [1](#). These were soon followed by the world's first electrically operated mountain rack railways. In 1898 another ABB predecessor, BBC, equipped several mountain railways, including the world-famous Jungfrau railway 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

Title picture

The first mainline electric locomotive for the 40 km Burgdorf–Thun railway (1899).

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



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



Walter Boveri objected to the operation of utility and railway grids at different frequencies. Among others, his intervention led to the compromise of using $16\frac{2}{3}$ Hz for railways.

2 Abbreviations of railway and manufacturing companies

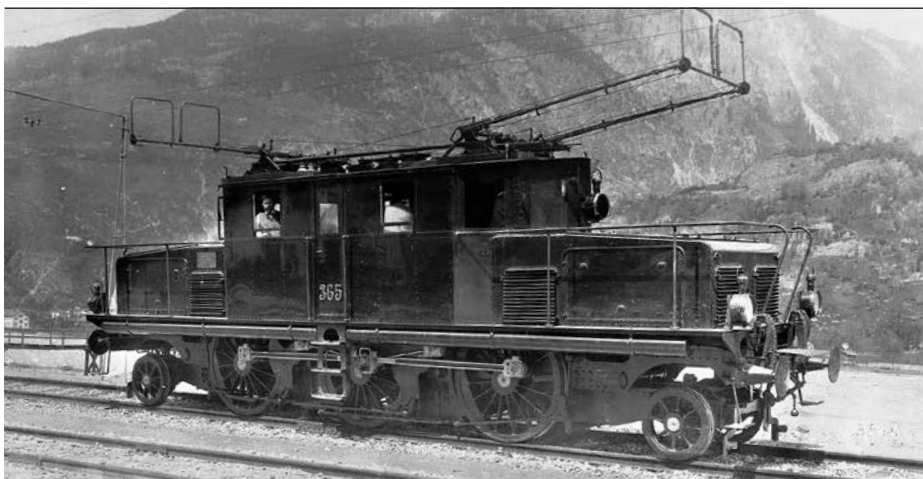
ASEA	Allmänna Svenska Elektriska Aktiebolaget, Västerås, Sweden (1983–1987). In 1988, ASEA merged with BBC to form ABB.
BBC	Brown, Boveri & Cie. AG, Baden, Switzerland (1891–1987)
BLS	Bern-Lötschberg-Simplon Railway, Spiez, Switzerland
CIEM	Compagnie de l'Industrie Electrique et Mecanique
DB	Deutsche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

BBC: Electric power for the Simplon tunnel

In late 1905, BBC decided to electrify (at its own cost and risk) the 20 km single-track Simplon tunnel under the Alps between Brig (Switzerland) and Iselle (Italy), which was then approaching completion. An important argument for electrification was the risk that carbon monoxide from steam locomotives could present to passengers should a train break down in the long tunnel. However, only six months remained until the tunnel's inauguration. Electrification was carried out using a three-phase supply at $16\frac{2}{3}$ Hz / 3 kV fed from two dedicated power stations located at either end of the tunnel. The same power system was also adopted on the Valtelina railway in Northern Italy, the Brenner and the Giovi lines as well as the line along the Italian Riviera. The initial fleet comprised two locomotives of type Ae 3/5 (1'C 1') → 5 and two Ae 4/4 (0-D-0), all using induction motors. Speed was

controlled using switchable stator poles. The low-mounted low-speed motors drove the axles via multi-part coupling rods. The locomotives had an hourly rating of 780 kW and 1,200 kW respectively and a top speed of 75 km/h. Until all locomotives were completed, three locomotives of a similar design were rented from the Valtelina railway.

At the time it was already realized that asynchronous AC motors offered several advantages for traction applications, including robustness and simpler maintenance due to the absence of a commutator. Disadvantages, however, included the coarse speed graduation resulting from pole switching and the double-wire overhead line of the three-phase supply, which added to the complexity of turn-outs. 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, the SBB took over the installation. In 1919 two further locomotives were added and the electrification extended to Sion. A second tunnel bore was completed in 1921. The three-phase era on the Simplon ended in 1930 when the line was converted to the standard single-phase 15 kV/ 16 2/3 Hz → 6.

Electrification of the Lötschberg railway

With gradients of 2.2 to 2.7 percent and curve radii of 300m, the railway from Thun via Spiez to Brig operated by BLS and completed in 1913 has a distinct mountain railway character. From an early

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

Electric operation on the Gotthard line

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

BBC's cofounder Walter Boveri vehemently objected to the operation of national utility and railway grids at different frequencies. Among others, his intervention led to the compromise of using 16 2/3 Hz (= 50 Hz → 3) for railways.

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.

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

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

Contributions by Sécheron

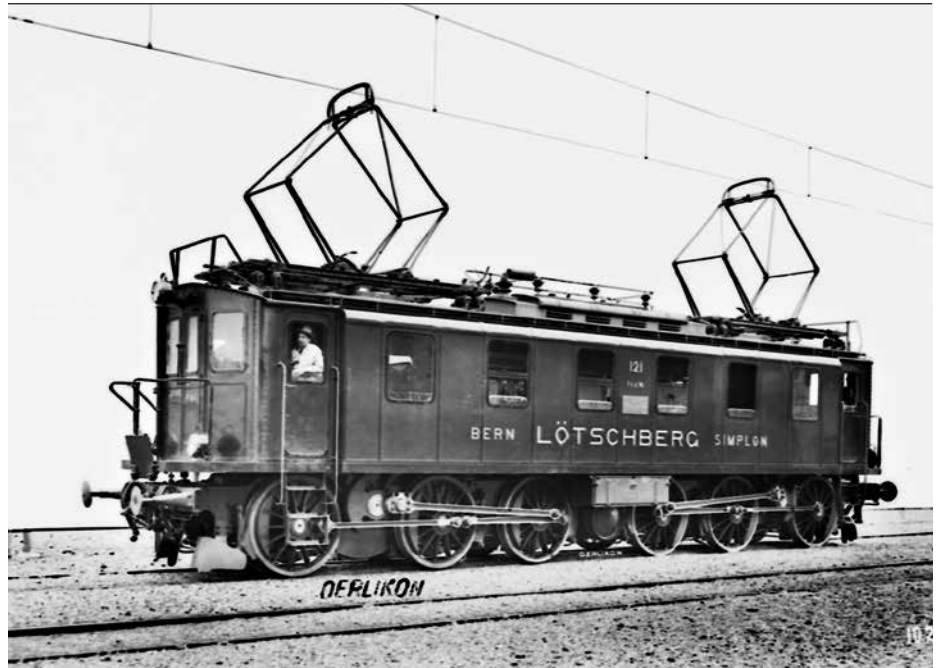
In 1921/22 ABB's predecessor company, Sécheron, supplied six Be 4/7 locomotives (1'Bo 1') (Bo') for the Gotthard railway. They were equipped with four individually driven axles with Westinghouse quill drives → 9. Despite their good run-

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

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 2/3 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.

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

7 Trial locomotive for the Lötschberg railway, 1910



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

ASEA's activities in the railway sector

Similarly to Switzerland, electrification of the Swedish state railways started before the first world war. From 1911 until 1914, the 120 km long so-called Malm-banan 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 hydro-power plant supplies the power for this railway, which is operated with single-phase 15 kV at 16 2/3 Hz (initially 15 Hz).

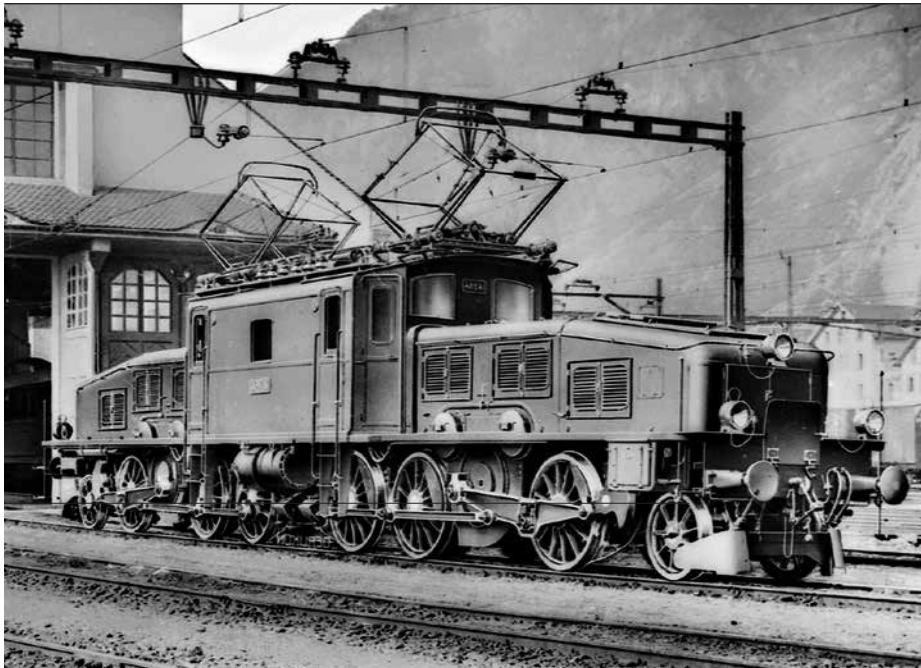
By 1920, the electrification had been extended via Gellivare to Lulea on the Gulf of Bothnia. The Norwegian section of the line was electrified in 1923. The mountains traversed are of medium height, and the gradients of 1.0 to 1.2 percent are considerably lower than those on Swiss mountain railways. However, the heavy ore trains placed high demands on the locomotives. ASEA supplied the electrical equipment for 12 1,200 kW articulated locomotives (1'C)(C1') with side-rod drive, as well as for two similar 600 kW express locomotives (2'B 2'). 10,650 kW four-axle locomotives for express goods services were later added and mainly operated in pairs. In 1925 the 460 km SJ mainline between Stockholm and Gothenburg was electrified, with ASEA supplying the 1,200 kW 1'C1' locomotives.

Successful single-axle drive

After commissioning the electric service on the Gotthard line, SBB extended its

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

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



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

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

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

Post-war trends: bogie locomotives

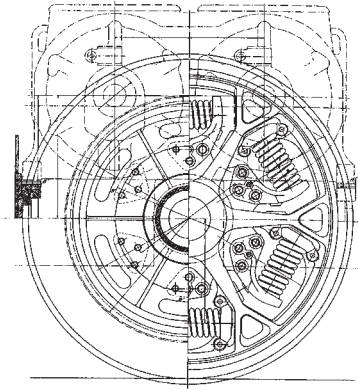
Most locomotives described so far had combinations of carrying axles and pow-

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

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

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

9 Sécheron type single-axle quill drive (Sécheron)



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

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 single-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 loco-

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



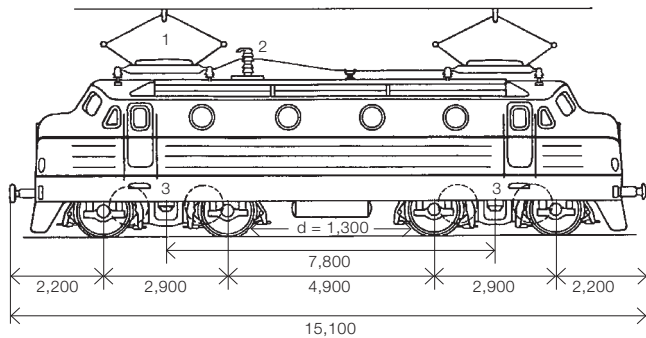
The motor shaft attached to the upper cog and the axle to the lower.

motives 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 (Inter-city 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.

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

Streamlining the railway business

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

The ABB railway business today

Following the merger of ASEA and BBC to form ABB, the respective transportation system businesses were formed into an independent company within the ABB Group. In 1996, ABB and Daimler Benz merged their railway activities under the name ABB Daimler-Benz Transportation

(Adtranz). Adtranz also acquired the Swiss companies SLM and Schindler Waggon in 1998. In 1999, ABB sold its stake in Adtranz to DaimlerChrysler which later sold its railway sector to Bombardier. Thus today, ABB no longer builds complete locomotives, but continues to supply different high-performance components for demanding traction applications.

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

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



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

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Weight loss program

ABB's Effilight® traction transformer delivers less weight and losses and needs up to 70 percent less oil

TOUFANN CHAUDHURI, MARIE-AZELINE FAEDY, STEPHANE ISLER, MICHELLE KIENER – Traveling across Europe by train is already faster than by plane right now [1], and just last year a Japanese train reached 601 kph (374 mph) on a test track, covering 1.77 km in 10.8 seconds and setting a new world record. While speed records make great headlines and public reading, for designers and innovators, the weight of the train is just as important. ABB's new Effilight traction transformer is up to 20 percent lighter than a classic traction transformer. It is also up to 50 percent more efficient when the saved weight is reinvested in additional core and winding material, therefore significantly reducing energy costs for the operator. ABB's new Effilight traction transformer is up to 20 percent lighter than a classic traction transformer. When a celebrity loses weight, the news travels faster than a new train speed record. The remaining challenge for Effilight is for the traction transformer weight loss news to be as widely known.

Title picture

Effilight was launched to the market at InnoTrans, in Germany, in September 2016.

Traction transformers take up valuable train space and add weight to the train, so the motivation to reduce their size and weight is strong. However, the constraints applied by the law of physics are also strong. The transformer core must have certain dimensions in order to accommodate the magnetic field. In addition, weight constraints make traction transformers less efficient because the amount of copper and iron must be limited. On traditional trains pulled by locomotives, the heavy transformer is not necessarily a disadvantage as it contributes to adhesion: the maximum force that the locomotive can apply to pull a train without losing adhesion on the rails is limited by the weight of the locomotive. In modern passenger trains, however, there is a tendency toward multiple unit trains where the traction equipment is not concentrated

in the locomotive but distributed along the length of the train in the same vehicles which passengers travel [2]. This brings considerable benefits in terms of adhesion and acceleration, but also requires

that the size and location of the installed transformers is carefully considered. Space in the passenger vehicle must be maximized and noise must be at a minimum.

Proven technology improved

Effilight was introduced to the market at the beginning of 2016 → 1 and the public launch was in September 2016 at InnoTrans → Title picture. The key technological differentiator between Effilight and a classic traction transformer is that in a classic transformer the active part is fully immersed in oil. This means oil volume is far from ideal and the whole assembly is penalized by the large oil tank and the

ABB has developed a hybrid transformer concept where there is a small oil tank around the winding, while the core remains in the air.

resulting constraints. However, for Effilight, ABB developed a hybrid transformer concept where there is a small oil tank around the winding, while the core remains in the air.

Over a period of about three years the concept was developed from the idea to the physical testing stage.



Weighty matters

Weight is a pivotal concept for traction transformers. The maximum admissible weight is imposed by the train manufacturer, who in turn must reach the axle load constraint imposed by the railway infrastructure operators. If the weight is exceeded, the train simply cannot be homologated and therefore cannot run.

It was the initial desire to reduce the weight of the equipment which drove the development of what was to become Effilight. ABB oil insulation traction transformers have a proven lifetime record with more than 40,000 units in operations. Building on this experience ABB researchers started brainstorming how their weight could be reduced. During continued discussions and research, an idea started to emerge: what if only the parts that actually need to be immersed in oil, were immersed? A concept for a radical redesign began to develop. Work started on how to realize the idea of separating the active part of the transformer, from the core.

Over a period of about three years the concept was developed from the idea to the physical testing stage. Small prototypes were built at first and as refinements took place were scaled up to building and testing large prototypes. The biggest challenges that were overcome were mainly to do with mechanical integration, dielectric constraints and magnetic field issues.

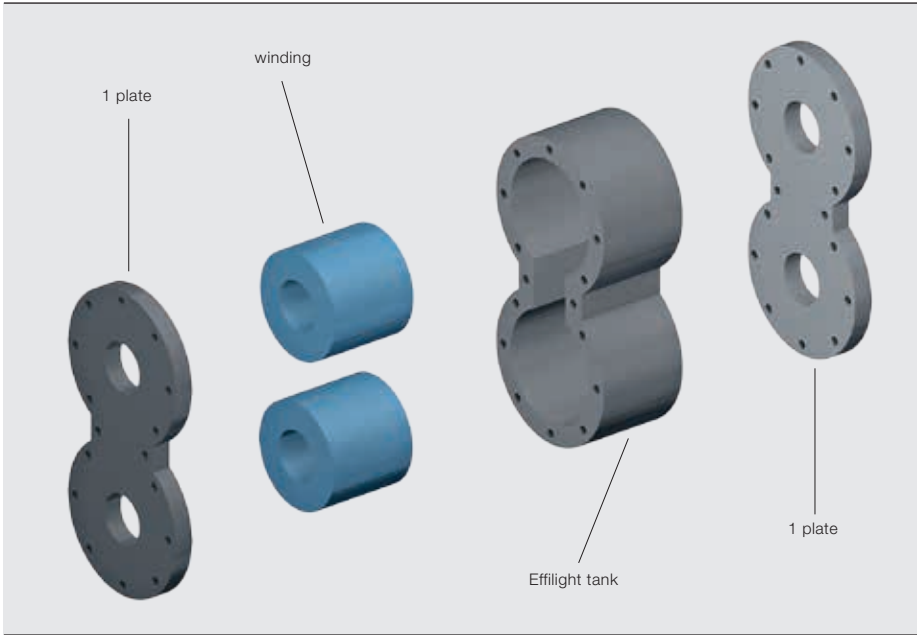
The biggest challenges that were overcome were mainly to do with mechanical integration, dielectric constraints and magnetic field issues.

Full type testing, including two shock and vibration tests, were performed, followed by environmental testing that was carried out over a number of months. The prototype transformer was subjected to frequent daily fast switch-ons and warm-ups and performed extremely well. Thanks to the weight saving, the efficiency of the transformer can also be increased because more copper can be added to reduce the winding resistance. The losses of the transformer can be halved while keeping the weight unchanged.

Oil tight

Effilight is a typical example of a solution or product where once it exists, it suddenly strikes people as an incredibly obvious solution. A classic moment of

2 Expanded product view of how the cell is fully sealed and protected from leaks



Now that only the windings are immersed in oil, for cooling and dielectric purposes, the oil volume can be reduced by up to 70 percent when compared to a classic transformer.

3 Effilight study prototype – parameters and savings

Parameters	Prototype 1.1 MVA – 15 kV	Base transformer 1.1 MVA – 15 kV	Savings
Total weight	3150 kg	3450 kg	- 9 %
Losses (75°C)	57.2 kW	84.5 kW	- 33 %
Oil weight	200 kg	573 kg	- 65 %
Length	1944 m	1995 m	-
Width	2500 m	2524 m	-
Height	851 mm	834 mm	-

“of course, how obvious, why did no one think of that before?”. The answer

in reality. A key solution to develop was, how is it possible to ensure that

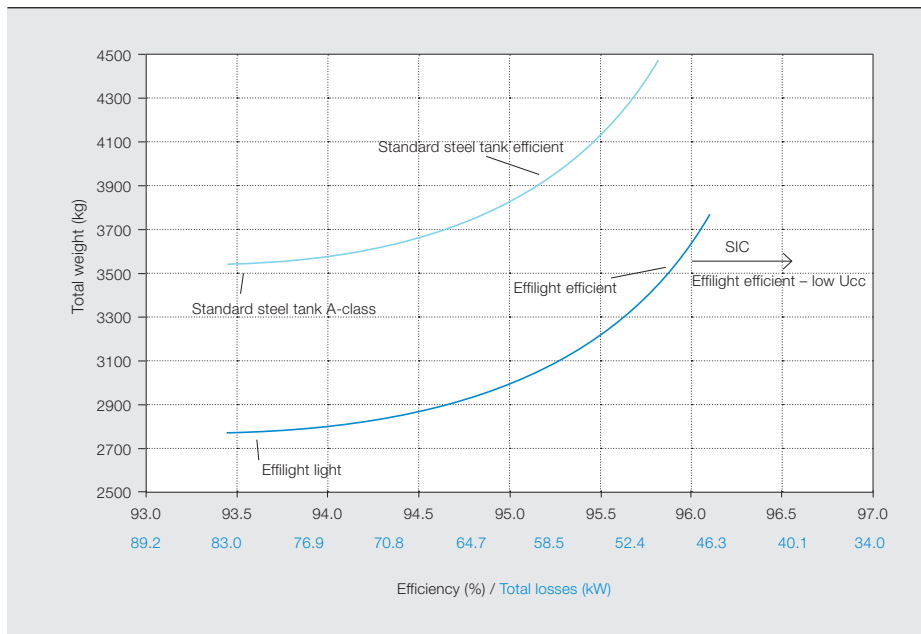
Full type testing, including two shock and vibration tests, were performed, followed by environmental testing that was carried out over a number of months.

is that, as can often be the case, the technology needed to catch up with the ideas. Once the idea of removing the core from the oil had been conceived, the challenge was how to achieve that

the “cell” (enclosure of the active part) is fully sealed and immune from leaks, when the core is now external? The answer was a form of “tank in tank” concept, where the cell is sealed separately within another enclosure → 2.

O-ring gaskets ensure tightness using a time proven solution.

4 Weight and efficiency trade-off



The “active part” windings and the enclosure require no redesign to adapt them for different mounting positions, be that roof-mounted, underframe or in a machine room.

Now that only the windings are immersed in oil, for cooling and dielectric purposes, the oil volume can be reduced by up to 70 percent when compared to a classic transformer. The new approach also brings a reduction of up to 20 percent in weight. The weight saving can then be reinvested in heavier windings using thicker copper wiring that improve the energy efficiency of the transformer by 50 percent, cutting electrical losses in half → 3.

A place for everything...

For high-power transformers, the amount of oil is not as significant as the amount of copper or steel used, which means there are high-power cases where Effilight does not provide a significant weight reduction advantage. The full benefit of Effilight is achieved in the lower power ratings. The reason for this is the filling factor (the ratio between the weight of copper and steel versus the total transformer weight) tends to decrease when power decreases → 4-5.

... and everything in its place

The prototype has been built and tested for roof-mounting, however the Effilight traction transformer has been designed to be modular. This means that the “active part” windings and the enclosure require no redesign to adapt them for different mounting positions, be that roof mounted, underframe or in a machine room → 6-7. Naturally this brings economies of scale and repetition advantages for train man-

5 Effilight's benefits

Power	15 kV / 16.7 Hz	25 kV / 50 Hz
1.0 MVA	Up to - 20 %	-
2.0 MVA	- 10 to - 15 %	- 20 %
3.0 MVA	Up to - 10 %	- 15 %
4.0 MVA	-	Up to - 10 %

5a Average weight benefit

Power	15 kV / 16.7 Hz	25 kV / 50 Hz
1.0 MVA	Up to + 50 %	-
2.0 MVA	+ 20 to + 30 %	Up to + 50 %
3.0 MVA	Up to + 20 %	+ 20 to + 40 %
4.0 MVA	-	Up to + 20 %

5b Average efficiency benefit

ufacturers and easier maintenance for operators. It means that a variety of different equipment can be fitted with the same transformer, resulting in reduced training costs by using the same transformer across their fleet.

Maintenance and protection functions are the same for Effilight and classic transformers, which means an existing transformer can be replaced by an Effilight without affecting existing maintenance and protection systems or processes.

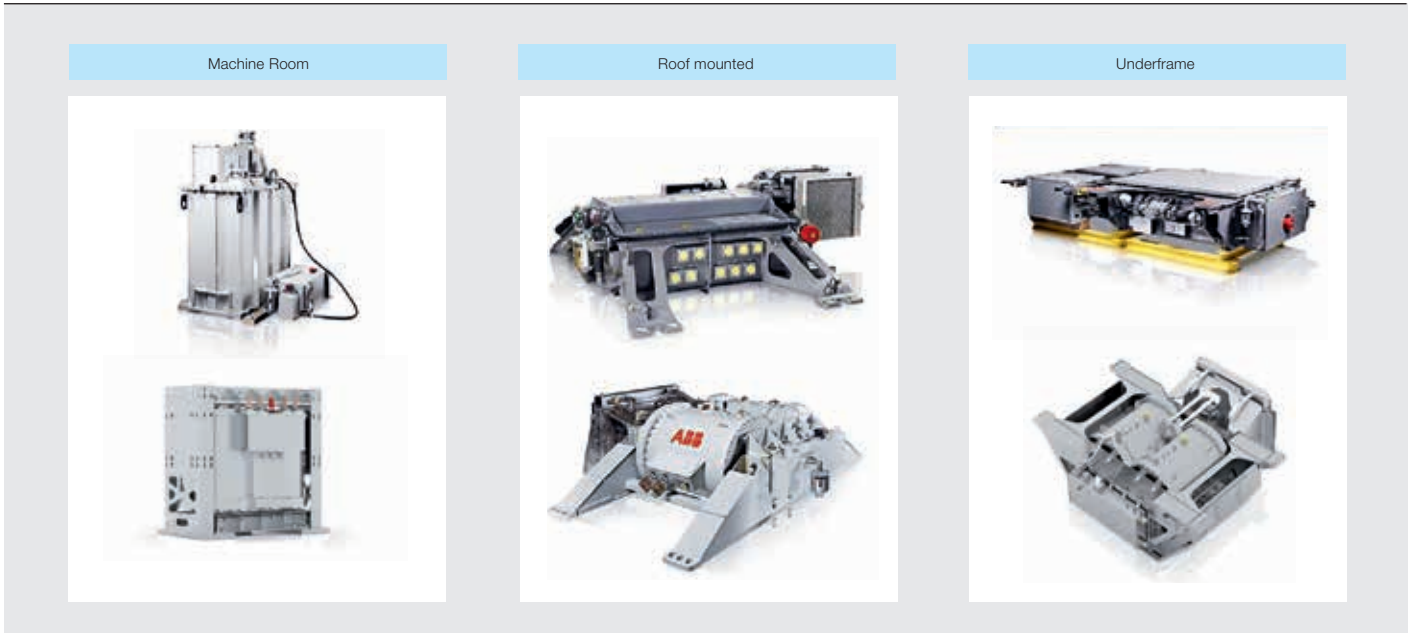
Future on track

Today, more than half the world's trains are powered by ABB traction transformers, and most of the world's train manu-

An existing transformer can be replaced by an Effilight without affecting existing maintenance and protection systems or processes.

facturers and rail operators rely on them. Effilight is the latest member of this illustrious family. That Effilight's design still

6 Efflight is suitable for all the different assembly positions



7 Efficient traction transformers – comparing technology and application

Parameters	Classic	Efflight®
Lightweight variant		✓
25 kV option	✓	✓
Wind speed cooling possible		✓
Roof mounted	✓	✓
Machine room mounted	✓	✓
Underfloor mounted	✓	✓
Lifetime	40 years	40 years

includes oil insulation, continues the guarantee expected from an ABB transformer of a 40 year lifetime. Achieving substantial weight reduction through the Efflight technology allows ABB to deliver to its customers a new degree of freedom which was not previously existing: a choice of weight reduction and energy efficiency increases. It is possible to tailor the solution to specific needs for specific train platforms, allowing for instance the weight to be reduced by 10 percent while still increasing the efficiency by 20 to 30 percent. Efflight may currently be a young upstart, but its future looks sparkling. Light it may be, but in terms of lifetime, efficiency and delivery, a lightweight performer it is not.

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Efficiency that climbs mountains

Cutting the energy consumption
of the Allegra trains

BEAT GUGGISBERG, THOMAS HUGGENBERGER, HARALD HEPP – Railways are among the most energy efficient forms of transportation available, but that is no reason not to advance their efficiency further. A recent project focusing on the Allegra trains of Switzerland's RhB (Rhaetische Bahn) has made these already efficient trains even more frugal.

Title picture

An Allegra train on the Albula railway, a UNESCO world-heritage site.





1 RhB provides a year-round service.



The railway network of RhB (Rhaetische Bahn) extends over 384 km in the Alps of south-eastern Switzerland. The railway serves such popular tourist resorts as Davos, Klosters and Sankt Moritz, and carries around 10 million passengers per year. Parts of the system, featuring breathtaking sequences of twisting tunnels and elegant viaducts, are classified as UNESCO world heritage sites → [title picture](#). Besides RhB's function serving tourism, the system assures local transportation and carries freight all year round. In some locations, where roads are regularly closed due to winter snowfall, the railway provides the only viable alternative transportation.

Commencing in 2010, RhB began modernizing its fleet by introducing a new family of multiple unit trains branded Allegra. These 20 trains are supplied by Stadler with compact electrical equipment by ABB including traction transformers and converters → [2](#). The Allegra units were designed to fulfill highly demanding requirements imposed by the tight curves, steep gradients and challenging climatic conditions → [1](#) of RhB's network as well as the long and heavy trains they are required to pull.

As is often the case in engineering, the power requirements were dimensioned to meet the toughest possible conditions under which they were required to operate. The greatest traction power is required, for example, when moving a heavy train up a steep slope. For much of the time the units work under less demanding conditions (lighter loads, level track). Efficiency under such conditions may thus be suboptimal. A project was launched to investigate and implement ways of improving overall energy efficiency.

Motors

The power delivered by a traction motor is the product of the magnetic flux and the torque-forming current in the stator. Both of these factors contribute to losses. As the current-dependent losses dominate at high power, the motor is typically operated at the maximum flux with the current being used to control output. However, at smaller power levels it can actually be more efficient to operate at a lower flux. Every speed / torque value pair has an optimum dependent on the motor parameters.

DC-link

Normally, when a traction converter varies its power output, this is achieved by

maintaining the DC-link voltage as constant as possible and varying the output current. As the full DC-link voltage is only actually required at full power, it is viable to permit this voltage to sink to lower values when operating at lower power. Optimums were identified for different scenarios including power, tractive effort and variations in catenary voltage. These calculations did not consider the converter in isolation, but included losses in the transformer and motors resulting from converter switching patterns.

Disconnecting traction motors

When the train is required to operate at a high power output, all traction motors are required. For lower power output however, it is more efficient to selectively

A project was launched to investigate and implement ways of improving overall energy efficiency.

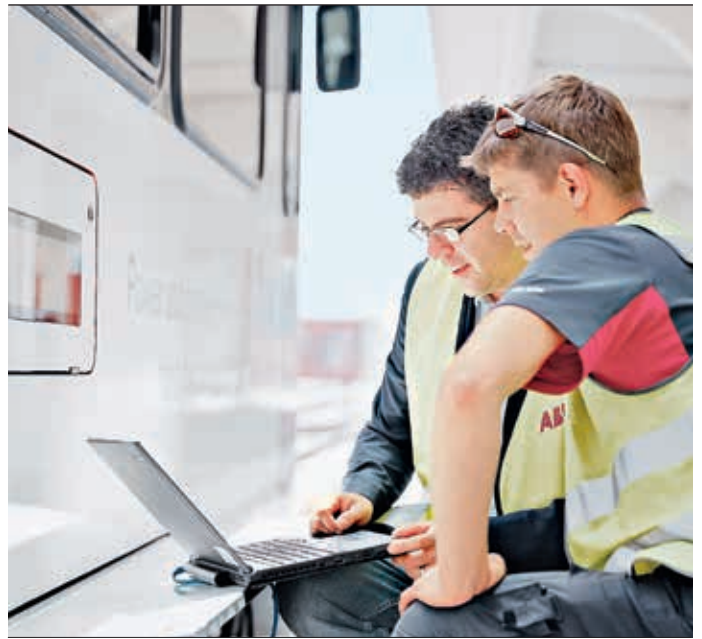
use a reduced number of motors (and the associated inverters) and disconnect the others.

In view of the abundance of curves, considerations over maintaining a good dynamic behavior of the unit meant that both axles on a bogie should always exert

2 One of the Allegra trains was specially painted to mark the 125th anniversary of ABB in Switzerland.



3 The software changes were implemented between September 2014 and September 2015.



the same tractive or brake forces. Optimized control is thus implemented on a bogie by bogie rather than axle by axle basis.

Implementation

The software implementation concerned both the vehicle-level control system and the PEC (power electronic controller) that controls individual bogies and the associated traction converters.

Further to the improvement of traction energy usage, the measures taken also considered effects on the unit's adhesion, and optimized this appropriately.

DC electrification

Most of the RhB system is electrified at 11 kV / 16.7 Hz. However, the 62 km line from Sankt Moritz to Tirano (Bernina line) is electrified at 1,000 V DC. Whereas some Allegra units are designed to operate on the AC lines only, others are equipped for dual-voltage. The measures described in this article largely concern AC operation. Improvements delivered in DC mode are more modest. Under DC operation, the DC-link voltage cannot be optimized in the manner described as it is directly fed from the catenary.

Calculations showed that a conversion of the DC section to AC would not improve the energy balance. The steeper gradients of the Bernina line (up to 7 percent) mean the units are operated at full power

more extensively, leaving less room for the optimization to yield real gains.

Savings

The software changes were implemented and tested between September 2014 and September 2015 → 3.

The implemented software modifications have led to energy savings of 950 MWh per year for all 20 units combined. This accounts for around 2 percent of the RhB's overall electricity consumption. A tangible sign that the measures are leading to greater efficiency can be seen in the observed reduction of motor temperature in operation.

In addition to the electricity saved, the more benign operating conditions for components and materials, including converters, motors, semiconductors and isolation should extend their operational lives and reliability.

This article is based on "Reduktion des Traktionsenergiebedarfs der Allegra-Triebwagen der RhB" by Markus Meyer, Andreas Heck, German Walch and Matthias Muri, *Schweizer Eisenbahn Revue* 2/16.

The implemented software modifications have led to energy savings of 950 MWh per year.

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Peak power

ABB's ZX0 medium-voltage switchgear and PMA cable protection for the Gotthard Base Tunnel

ANDREAS BEINAT, FELIX INGOLD – Launched in 1993 with preliminary geological test bores, the Gotthard Base Tunnel – the longest rail tunnel in the world – opened in June 2016, a year ahead of schedule. ABB's contribution to this monumental construction project came in many forms – such as over 800 medium-voltage (MV) switchgear units that power the tunnel infrastructure and the many kilometers of robust PMA cable protection for the lighting system in the tunnel.

Title picture

Costing over \$10 billion and with two parallel tubes, each of 57 km long, the Gotthard Base Tunnel relies on an intelligent and reliable electrical infrastructure to ensure safe operation.

1 The tunnel will carry trains only. Shown is the Faido track changeover.



After 20 years of construction, the world's longest railroad tunnel opened in June 2016. In addition to increasing freight capacity along the Rotterdam-Basel-Genoa corridor, the Gotthard Base Tunnel also includes regular passenger services that significantly cut travel time between the north and south of Switzerland. Up to 250 trains a day will use the tunnel when all services are running → 1. It is a testament to the professional engineering and efficiency of those involved in the project that the tunnel was brought into operation a year ahead of the schedule foreseen in 2008.

At that time, ABB was contracted by Balfour Beatty Rail to provide the MV switchgear needed to power the Gotthard Base Tunnel's infrastructure. This 50 Hz technology supplies power for systems that include air conditioning, ventilation, lighting, signaling, communications and safety. Balfour Beatty Rail belongs to the Transtec consortium, which was assigned to install the rail infrastructure by the tunnel builder, Alp-Transit Gotthard AG.

ABB was able to complete this massive order in just six years. The completion of the delivery of 875 units of MV switchgear was celebrated at the installation

site in Schattdorf, Switzerland in August 2014 by representatives of both Balfour Beatty Rail and ABB.

Adapting to on-site conditions

Every 325 m along the twin tunnels, there is a passageway between them → 2. These are also designated as escape routes and every other one is equipped with electrical power. To deliver this power, ABB supplied ZX0 MV gas-insulated switchgear (GIS), which had to be adapted to the difficult on-site conditions. Railroad tunnels come with a myriad of challenges, not least of which is the fine, powdery dust abraded from the train tracks each time a train speeds over them.

ZX0 GIS

Given the importance of switchgear and circuit breakers in ensuring the safe and flexible operation of the endeavor, ABB had to make sure its switchgear fitted the bill under the special conditions encountered in the tunnel complex. ZX0 GIS was the ideal solution for the Gotthard Base Tunnel as it has a modular and compact structure that delivers and distributes energy without interruption at the highest level of availability. With the ZX0, ABB has delivered switchgear

that is reliable, low-maintenance, and easy to configure and operate.

The fact that the ZX0 is gas-insulated brings with it many advantages. It offers the highest level of safety for railway employees, for example, as all live parts are completely touchproof, which means that inadvertent contact with live parts

ABB's MV switchgear supplies power for systems that include air conditioning, ventilation, lighting, signaling, communications and safety.

is impossible and the switchgear can be handled safely during installation and commissioning. No gas handling is necessary on-site because all MV parts are inside a sealed tank, protected from external influence, with no maintenance necessary for the parts inside the tank. This minimizes accidents and danger to human life.

The gastight enclosure protects all components against aging, thus reducing the total cost of ownership and making the ZX0 a cost-effective solution with a low overall lifetime outlay.



Photo: Alp Transit Gotthard Ltd.

ZX0 GIS was the ideal solution for the Gotthard Base Tunnel as it is modular and compact.

Intensive testing

Given the special challenges faced in the Gotthard Base Tunnel, steps were taken to enhance the ZX0's integrity. For example, ABB designed the ZX0's accompanying local control cubicle in accordance with the IP65 protection rating and also made it dust-tight and resistant to water jets. The design was also able to withstand the pressure variations caused by passing trains.

With the inter-tunnel passageways also being used as escape routes, there were much stricter requirements for arc-fault protection and arc resistance than is the case even for restricted-access areas. The ZX0, therefore, includes a special pressure relief system to eliminate all risk to human safety.

Suitable monitoring

To protect, control, measure and monitor the network throughout the entire tunnel system, ABB provided 500 units of the REF542plus feeder terminal. The REF542plus ensures a stable, uninterrupted energy supply by quickly locating any fault and immediately transmitting the fault type and location information to the tunnel control system.

The feeder terminal also offers remote services, providing access to stored programs and protection data via Ethernet LAN. The REF542plus can execute remote protection in a multistage way so that any faulty parts within the net-

work can be switched off individually. For ease of use, remote access can be handled using a standard Web browser – operators can log on to the feeder terminal from any place at any time, with the appropriate security precautions.

The SMS feature in the new REF542plus release offers operators even more freedom of movement. If the REF542plus registers an event, it can send a notification via text message (SMS) to the operator's mobile phone. The operator can then log on via the Internet to the switchgear, access the REF542plus, remotely analyze the fault and determine how to correct it.

To reduce the occurrence of faults in a power distribution network, it is necessary to analyze how often faults happen. For this, the REF542plus uses GPS (global positioning system) in an innovative way. Instead of using GPS as a geolocation tool, the REF542plus takes advantage of the precise time signal provided by GPS to continuously synchronize its own embedded clock. Faults are time-stamped with a sub-millisecond precision and forwarded to a central location for analysis. These time stamps help to evaluate the causes of faults.

Scope of delivery

ABB has supplied more than switchgear to the Gotthard Base Tunnel. Among other things, the company also supplied the power supply and drive systems for the strongest ventilation system in the world, with a power rating of 15.6 MW. The entire ventilation control system itself – comprising activation and control units for the fans and the tunnel sensors, as well as fire location detection – was also supplied by ABB. A scenario manager provides the corresponding control of the airways for a variety of predefined events.

All live parts are completely touchproof, which means that inadvertent contact with live parts is impossible and the switchgear can be handled safely.

Meeting high reliability demands

All of the tunnel equipment described above is wholly dependent upon a reliable power supply. However, within such long and deep tunnels, exceptional climatic conditions prevail. Air temperatures can exceed 40°C while regular medium-pressure washdown procedures contribute to a relative humidity of up to 70 percent. Moreover, excellent



Alpiq Burkhalter Bahntechnik needed a flexible, easy-to-install, completely closed cable-protection solution that could also withstand the tunnel environment.

fire-safety characteristics are essential for all products used in tunnel infrastructure applications. However, many products currently available on the market are unable to meet the very high safety and reliability standards required.

Alpiq Burkhalter Bahntechnik AG, a partner in the Transtec Gotthard consortium, consulted PMA (a member of the ABB Group and one of the market leaders for high-specification cable protection) regarding a complete, high-specification, end-to-end cable protection system with excellent fire-safety characteristics (flammability, smoke density and toxicity) and high ingress protection (IP68 and IP69K) to withstand the medium-pressure cleaning process.

Although Alpiq Burkhalter Bahntechnik had used ABB's PMA cable protection systems for tunnel projects before, the Gotthard Base Tunnel project presented new challenges and the company needed a flexible, easy-to-install, completely closed cable-protection solution that could withstand the tunnel environment.

Polyamide protection

High-grade, specially formulated polyamide has excellent resistance to ultra-violet (UV) rays and weathering, and offers good impact strength. Polyamide products have outstanding fire-safety characteristics regarding low flammability, smoke/gas emission and toxicity in the event of a fire, all of which are especially important for this tunnel project.

At first, smaller installations under bridges and in tunnels were fitted with PMA products for extensive testing. The results were so convincing that Alpiq Burkhalter Bahntechnik chose PMA products for this world-famous project.

ABB was asked to deliver 21 km of VAMLT conduit along with over 21,000

ABB designed the ZX0's accompanying local control cubicle in accordance with the IP65 protection rating and also made it dust-tight and resistant to water jets.

BVNZ strain relief fittings and BFH-0 conduit fixation clamps for the lighting system in the 57 km long railway tunnels. More than 10,000 emergency guidance lights and 450 emergency exit



light systems were subsequently equipped with ABB's PMA cable protection products → 3-6.

A strong tunnel system

PMA polyamide-based cable protection systems possess high mechanical strength characteristics such as compression strength and resistance to high-energy impact, combined with high flexibility. They are corrosion free with high ingress protection against water and dust – important in the Gotthard Base Tunnel. They demonstrate high resistance to numerous environmental influences such as chemicals (particularly cleaning agents) and UV, are immune to attack by rodents and have a broad operating temperature range. ABB's PMA cable protection systems have a long lifetime and come with the assurance of dedicated customer service.

The scope of this world-renowned project presented unique technological challenges and as such represents an excellent global reference for ABB's products.

PMA polyamide-based cable protection systems possess high mechanical strength combined with high flexibility. They are corrosion free with high ingress protection against water and dust.

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Further reading

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Record breaker

ABB to provide power, propulsion and automation for the world's most advanced port icebreaker

ANTHONY BYATT – To make sure the maximum amount of power possible can be derived from marine engines such as those used in icebreakers, they are fitted with turbochargers. ABB has a wide range of turbocharger solutions for marine craft and are now to supply the new Power 2 800-M turbocharger for the most advanced port icebreaker ever built, which is currently in planning for construction by the Vyborg Shipyard in Russia.



Title picture

ABB's Power2 turbocharging solution provides the power icebreakers need.



All these additional features mean that an icebreaker is much heavier than a normal ocean-going ship of similar size.

Moreover, due to the immense strength and often unpredictable nature of ice, icebreakers are equipped to deal with a plethora of potential dangers. For example, pressurized air and heated water jets may be forced out of the ship under the ice to help break it or ballast water may be pumped rapidly around the vessel to rock it a further assisting ice breaking.

Clearly, icebreakers have to have powerful engines.

To make sure the maximum amount of power possible can be derived from the marine engines such as those used in icebreakers, they are fitted with turbochargers. ABB has a wide range of turbocharger solutions for marine craft and are now to supply turbochargers for the most advanced port icebreaker ever built, which is currently in planning for construction by the Vyborg Shipyard in Russia. ABB will also provide the power and automation capabilities for the vessel.

The main engine will be fitted with Power2 800-M, the most advanced two-stage turbocharging system in the industry, enabling highest efficiency turbocharging performance.

Power2 800-M

Power2 is ABB's dedicated two-stage turbocharging system. Power2 800-M, the second generation of Power2, is the

When John Franklin searched for the North-West Passage in the mid-1800s, he could scarcely have imagined by just how much polar sea ice would retreat in the following 150 years. Now, large ocean-going ships regularly ply sea routes along the north of Canada and Russia. These shipping lanes almost halve the time it takes to voyage between the Atlantic and the Pacific oceans and the routes are remaining ice free for ever-longer periods, thus lengthening the shipping season.

With this increased shipping presence comes the increased need for icebreakers. Due to the nature of the job they do, icebreakers have to be of solid construction: Thick ice is not often broken by ramming it, but by lifting the ship above the ice and breaking it from above. Lifting an icebreaker is no easy matter as icebreakers have very heavy and robust strengthening cross-members to protect the vessel against the pressure of pack ice → 1. Further, an icebreaker's hull differs from a normal hull in thickness, shape and material: The bow, stern and waterline are reinforced with thick steel specially chosen for its low-temperature performance and the hull's shape is designed to assist the ship to rise above the ice before falling and breaking through it.

The main engine will be fitted with Power2 800-M, the most advanced two-stage turbocharging system in the industry.

most compact turbocharger solution of its kind. Space is at a premium in a ship's engine room and with this in mind, ABB designed the turbocharging system to



take up minimal space: This two-stage turbocharging system is 20 percent more compact than conventional two-stage turbocharging solutions. Space saving is especially critical in an icebreaker as the extremely strong hull construction of the vessel leaves less internal space than would be available on an equivalent, regular ship.

The Power2 800-M's extractable cartridge enables service to be completed in just two steps instead of the previous six, making maintenance easy and reducing downtime and service costs.

On the icebreaker's engine, the Power2 800-M will enhance fuel efficiency and flexibility of operations. With up to 60 percent less NOx emissions, the Power2 800-M also substantially cuts discharges to the atmosphere – an important aspect for operation in the pure Arctic environment.

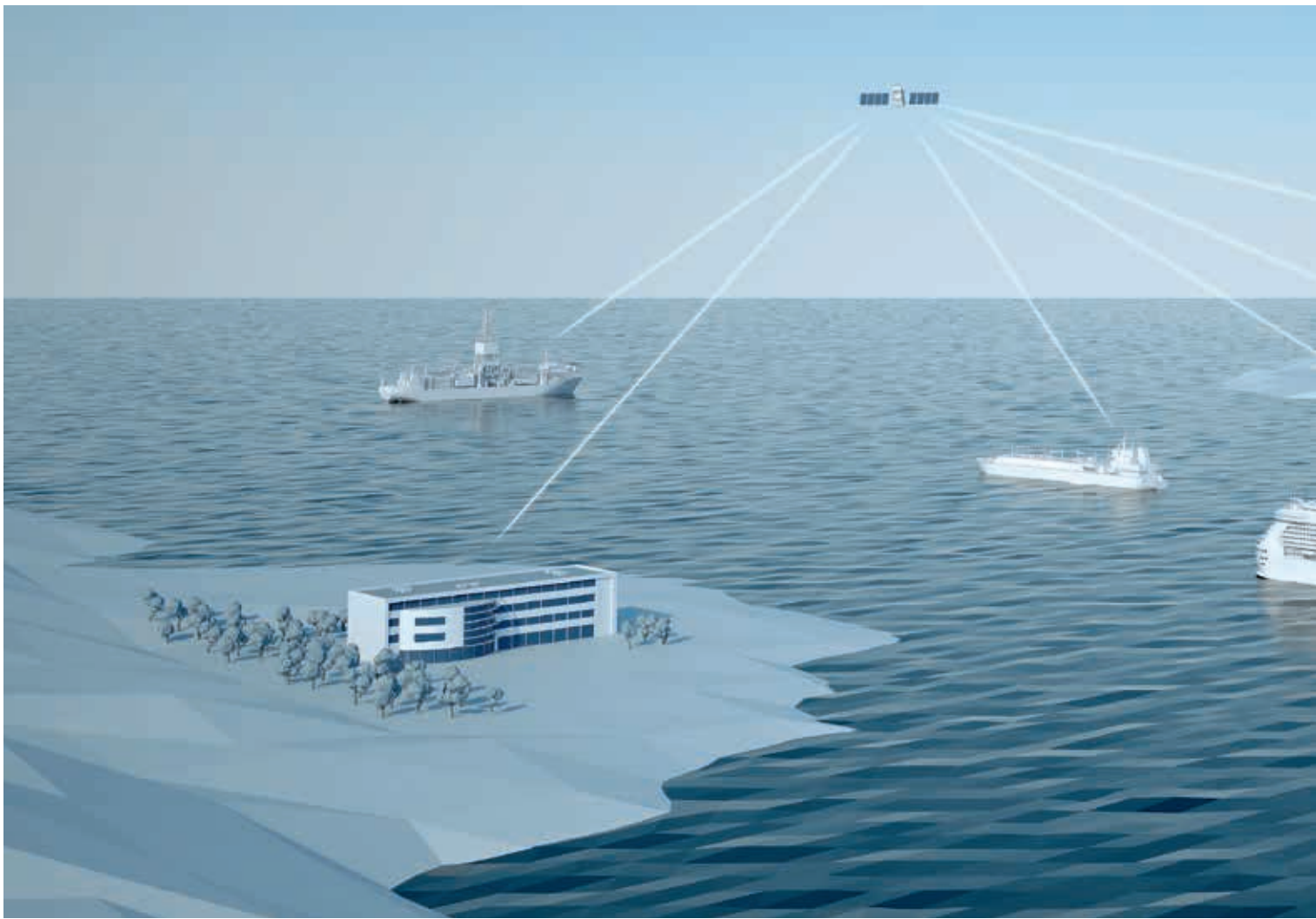
With a low-pressure and high-pressure stage, the Power2 800-M provides higher air pressure ratios – up to 12 from eight in the previous generation. A single-stage turbocharger can operate at around 65 to 70 percent efficiency; Power2 800-M exceeds 75 percent efficiency and is the only system currently available across the large-engine industry with this capability.

The Power2 800-M responds to the need for new marine engine technology to offer consistency of performance across conventional and newer marine fuel options. This application will demonstrate the advances in efficiency and power density now available for four-stroke engines that operate over a wide range of load profiles and that face added demands from various bodies who regulate emissions. Once the icebreaker is constructed, commissioned and operating in iced-up port waters, the capabilities of the Power2 800-M will prove to be invaluable in providing the power to keep waters ice-free for shipping.

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Power2 800-M is the most compact turbocharger of its kind.



Improving remote marine service

A concept for the next generation ABB customer and service portal

MARIA RALPH, VERONIKA DOMOVA, PETRA BJÖRNDAL, ELINA VARTIAINEN, GORANKA ZORIC, RICHARD WINDISCHHOFER, CHRISHOPHER GANZ – The level of remote automation, remote monitoring, and remote control have continuously increased over the decades in key industries. Military, power utilities, nuclear, rail, port authorities, highway authorities, emergency services, mining, oil and gas, aviation, and space industries are heavy users of remote technologies and operational centers to manage their operations, fleets of assets and emergency services. This industry trend confirms what has been recently coined the 4th Industrial

Revolution by World Economic Forum founder Klaus Schwab [1] and is closely related to Zuboff's three laws [2] which are 1) everything that can be automated will be automated, 2) everything that can be informed is informed (the process of digitizing information) and 3) every digital application that can be used for monitoring and control will be used for monitoring and control. ABB is building on this operational concept to develop smarter solutions that more effectively support its remotely connected marine customers.



ABB is building on this operational concept to develop smarter solutions that more effectively support its remotely connected marine customers.

Traditionally, diagnosing and troubleshooting problems for marine customers have been activities ABB engineers have done in person at customer sites. However, with the introduction of advanced sensors, cloud services and satellite communication technology, the service and support tools of remote diagnostics and troubleshooting – which have been sporadic for the past decade – are now becoming a common work practice. ABB engineers are now in a position to offer marine customers more timely issue resolution due in large part to the ability to remotely connect to customer equipment onboard and collect data from sensors installed onsite. As a result, ABB engineers are able to support not just one customer but many customers at the same time since they may not need to travel to the site. The customer's technical staff are involved in the resolution

ABB engineers are able to support many customers at the same time since they may not need to travel to the site.

process as well. In fact, when a problem occurs, a virtual team of all required experts is quickly formed to share relevant information and rectify the situation. This allows marine customers to get back online more quickly than in the past.

With this approach to remotely support customers, both changes in work practices and an improvement of the tools supporting engineers are required. Just some of the changes needed for effective support are: providing engi-

neers with quick and easy access to colleagues worldwide, enhancing how customer data is visualized to ensure engineers have a complete picture of the problem and ensuring relevant material is at each engineer's fingertips. To this end, ABB Marine has developed a cloud-based fleet portal. This portal provides engineers working remotely with a more effective way to analyze the important information necessary to diagnose and troubleshoot customer issues. It provides the most critical information required to obtain an overview of an individual situation as well as a fleet of assets, helping them establish context and, in turn, the possibility of more timely resolutions of customers' cases.

Customer and supplier needs

Within any type of service support role, time is a critical factor. Being able to diagnose and efficiently resolve issues with customers' equipment is the primary focus for ABB support engineers. As such, the tools used to support them need to be as effective as possible.

Title picture

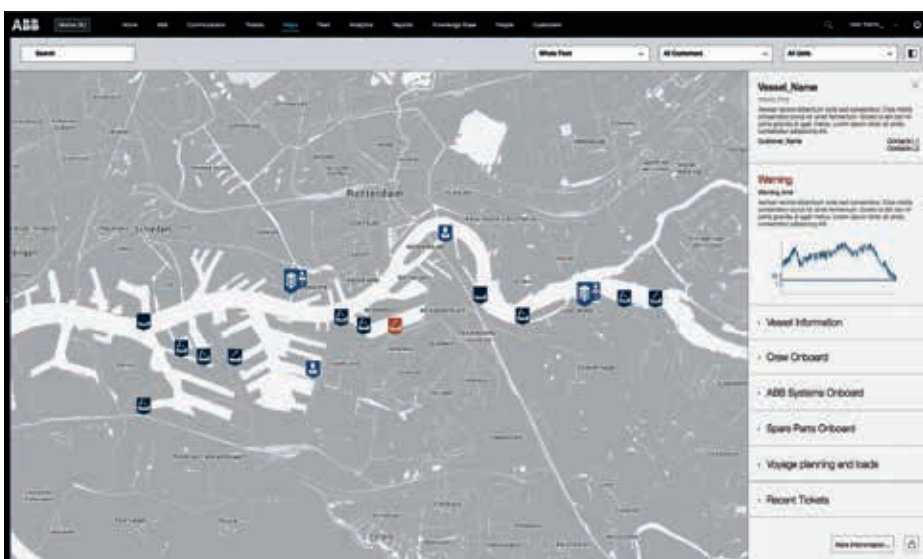
Remote connectivity from shore to ship.

The customer's technical staff are involved in the resolution process as well.

1 The Dashboard tool



2 The Map tool



Designing effective support solutions requires an in-depth understanding of how support engineers work. Interviewing and observational approaches are used to gain valuable insights into real work practices and to assess goals, needs and concerns. In turn, this information provides the key design considerations for the creation of the new HMI (human-machine interaction) solution. The prototype developed took into account the following key outcomes of the interviews and observations:

- Establishing the context for troubleshooting:

- 1) In order to understand all possible solutions, remote support engineers need to gather as much relevant information as possible about the problem.

- 2) There is no easy way for technical crew members to easily and quickly transfer context information such as video or images to the remote support engineer handling the case.

- 3) There is also no easy way for the remote support engineer to give suggestions to the technical crew located onboard.

- Information is distributed. Not all information for diagnosing and troubleshooting a problem is in one easily accessible location. Engineers therefore spend a lot of time searching for relevant material.
- Locating and coordinating with a local field engineer, who is both adequately qualified and who is in close physical proximity to the customer's vessel, to go onsite for a hardware fix can be challenging.

3 Fleet details

The screenshot displays a web application interface for fleet management. At the top, there are navigation tabs for 'Home', 'Map', 'Dashboard', 'Fleet', 'Map', 'Analytics', 'Reports', 'Inventory', 'Users', 'Help', and 'Logout'. The main content area is titled 'Fleet details' and contains a table with columns for 'Vessel Name', 'Status', 'Location', 'Type', 'Company', 'Year', 'Capacity', 'Status', 'Color', 'Vessel Name', 'Status', 'Location', 'Type', 'Company', 'Year', 'Capacity', 'Status', 'Color'. The table lists several vessels with their respective details.

The tool provides reset information including locations for local support centers, port locations and airports.

4 Fleet details drilled down

The screenshot shows a detailed view of a vessel, titled 'Vessel_Name'. The interface includes a sidebar with navigation options like 'Dashboard', 'Map', 'Fleet', 'Analytics', 'Reports', 'Inventory', 'Users', 'Help', and 'Logout'. The main content area is divided into several sections: 'Vessel Info' (Vessel Name, Vessel Key, Vessel Company, Vessel Status), 'Vessel Details' (Vessel Name, Vessel Key, Vessel Company, Vessel Status), 'Vessel Status' (Vessel Name, Vessel Key, Vessel Company, Vessel Status), and 'Vessel Data' (Vessel Name, Vessel Key, Vessel Company, Vessel Status). The 'Vessel Data' section includes a map of the vessel's location and a table of vessel details.

Design concepts

Based on these identified needs, a new prototype of a fleet and service coordination portal was developed, comprised of four main components: Dashboard, Map, Fleet details and Analytics. The prototype was developed using contemporary web technologies such as HTML5, JavaScript, Angular JS, D3.js, bootstrap, CSS, Google Maps open API.

The Dashboard tool enables engineers to customize their view according to what information is important for them based on their role → 1. The information on the dashboard can be rearranged to suit the user with information being added or deleted as they require for their work. Engineers can also filter information displayed in this view according to a certain customer or vessel.

The Map tool provides users with an interactive map that enables users to pan and zoom as well as filter information → 2. Vessel locations are shown and individual vessels are color-coded to indicate those vessels with issues (ie, has active alarms) in red. This enables the engineers to stay informed about the current state of all vessels they are responsible for monitoring at any one time. Zooming into the vessel enables the engineer to see a more detailed map view with the ship's planned route outlined. Additional information is also provided when zoomed into a specific vessel including locations for local support centers (ie, where local field engineers may be available), port locations, airports, as well as a night/daytime visualization to indicate under what time of the day the vessel is operating.

Being able to diagnose and efficiently resolve issues with customers' equipment is the primary focus for ABB support engineers.

5 The Analytics tool



The Fleet tool provides engineers with more detailed information about the vessels under their watch. Vessels can be grouped (filtered or sorted) into certain categories that can be filtered further, such as vessels with active alarms. Selecting a vessel from this list takes the engineer to a more detailed information page about that vessel with a breakdown of data such as systems onboard, equipment maintenance history, planned route and spare parts onboard → 3, 4.

Finally, the Analytics tool provides engineers with a customizable workspace whereby they can arrange the layout of information in a way that works best for them. Engineers can add or remove information, and can annotate data on-screen. This workspace can also be used to collaborate with other remote service engineers to get further assistance on cases. The analytics concept provides engineers with a way to dig deeper into data, using pattern matching and data tagging to find commonalities and relationships between key signals. This capability allows them to make better data comparisons and therefore more informed decisions → 5.

Production management benefits

The prototype developed provides remote service support engineers with an overall awareness of the state of the vessels they are monitoring and supporting. Providing these engineers with the right information in an intuitive and easy to understand format enables them to more effectively and quickly understand the current vessel's state and any issues

associated with that vessel. Providing a way to effectively identify issues with customers' vessels, as well as competent support for understanding the problem at hand, enables engineers to use their advanced skill set to resolve customer issues in a timely manner.

Wave problems goodbye

ABB's solution provides remote service support engineers with information in a more intuitive and easy to understand format, supporting them in their decision-making. The solution further demonstrates ABB's commitment to producing high quality solutions targeting key domains and to improving processes for industry-leading service.

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Connect. Collaborate. Outperform.

Automation & Power World returns to Houston in March 2017

STEPHANIE JONES – Since 2009, ABB Automation & Power World has brought together professionals from the utility, industry, and transportation and infrastructure sectors for the company's premier educational and collaboration event in North America. In 2017, the event will return to the George R. Brown Convention Center in Houston, Texas, on March 13–16.

Automation & Power World offers four days of training, networking opportunities and the chance to see firsthand the widest range of technologies available from one company in one location → 1. Together with thousands of customer attendees, ABB technical experts, industry leaders, ABB management and business partners will take a focused look at how all stakeholders can succeed together in a changing business environment.

Attendees can choose from hundreds of educational workshops, daily keynotes by industry leaders, panel discussions and hands-on training courses to create a customized learning experience. Workshops focus on topics to help achieve business goals, and are presented by technical experts, end users and industry specialists.

The Technology & Solution Center will house the largest portfolio of ABB products, solutions and services in North America. Visitors will have hands-on access to the latest power and automation software and technology. Plus, ABB experts will be available to explain what is on display, answer questions and share their insights.

The conference also features multiple collaboration opportunities. From hosted peer-to-peer roundtable discussions to industry-specific plenary sessions to daily networking events, attendees can meet peers in their own industry as well as those with similar responsibilities in other industries to exchange information on what has worked – and what has not – when facing comparable issues.

Not only is the Automation & Power World experience priceless, so is event registration. There is no conference fee for ABB customers and other industry professionals to attend. So mark your calendars for March 13–16, 2017, and visit the event website for full event details and to register: <http://new.abb.com/apw>.

1 The chance to see first-hand the widest range of technologies available from ABB in one location



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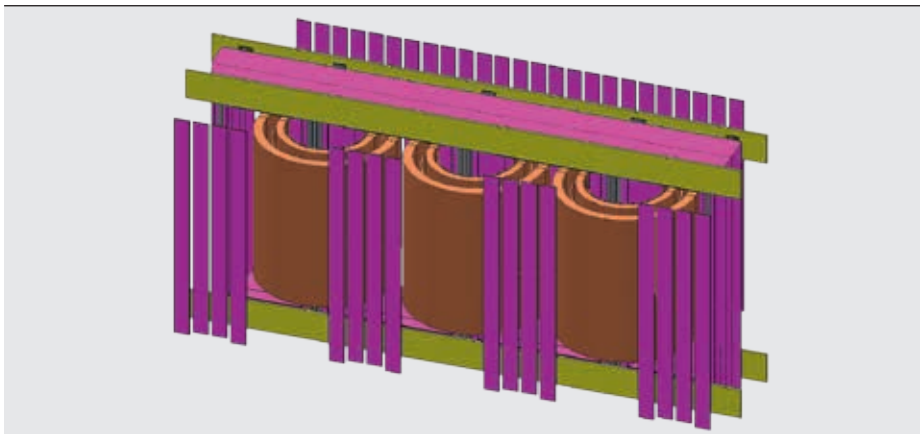
Loss prophet

Predicting stray losses in power transformers and optimization of tank shielding using FEM

JANUSZ DUC, BERTRAND POULIN, MIGUEL AGUIRRE, PEDRO GUTIERREZ – Optimization of tank shielding is a challenging aspect of design because of the need to reduce stray losses generated in the metallic parts of power transformers exposed to magnetic fields. The simulation methods now available allow the evaluation of more explorative designs that would otherwise not have been considered. FEM methodology is applied to calculate losses and temperature distribution, and several configurations of transformer shielding were considered during the research. The benefit of applying computer simulations is not only limited to cost and time savings for a single transformer unit, but also results in a better understanding of the physical processes occurring during operation. The results obtained from 3-D simulations were in close agreement with measured values. This experience, reinforced by increased trust in the applied methodology, can be applied by ABB in the design of future devices.

FEM is a sophisticated tool widely used to solve engineering problems.

1 Simulation model of transformer (tank walls are not shown)



Power transformers are important components of an electrical network [1]. The reliable and energy-efficient operation of transformers has a considerable economic impact on transmission and distribution systems [2] and great effort is spent to make the design optimal [3].

In the case of transformers, increasing efficiency often means reducing losses. Load losses in transformers occur in conductors and magnetic parts. In windings and bus bars there are two components of the losses: resistive and eddy-current. Metallic parts of transformers exposed to magnetic fields, such as the tank and core clamping structures, also produce stray losses [4].

The procedure described here is commonly used by engineers in ABB factories manufacturing large oil-immersed power transformers.

Practical solutions can be efficiently determined using the finite element method (FEM). The simulation parameters are statistically fitted based on dozens of tested units of small, medium and large power transformers produced around the world by ABB. A material library dedicated to such calculations was developed by ABB scientists using laboratory measurements. The methodology gives the highest accuracy, compared to other tools and analytical methods available for stray losses estimation.

Electromagnetic simulations

FEM is a sophisticated tool widely used to solve engineering problems. It is utilized in new product development as well as in existing product refinement to verify a proposed design and adapt it to the client's specifications [5]. The method requires the creation of a discretized model of an apparatus with adequate material properties.

Simulation software resolves basic electromagnetic field distribution by solving Maxwell's equations in a finite region of space with appropriate boundary conditions. Simulations described in this article were performed using a commercially available FEM software package.

Skin effect

The thickness of steel plates is much larger than the depth to which magnetic fields will penetrate them. In order to properly represent the small penetration of the magnetic field in a numerical model, a huge number of small elements must be used in the vicinity of a surface

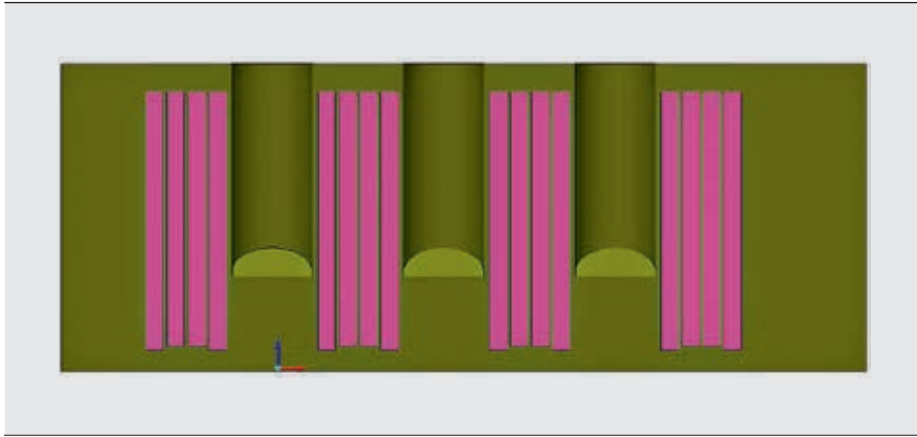
FEM requires the creation of a discretized model of an apparatus with adequate material properties.

of each component made of magnetic material. This requires computational power far exceeding the capabilities of modern workstations.

Title picture

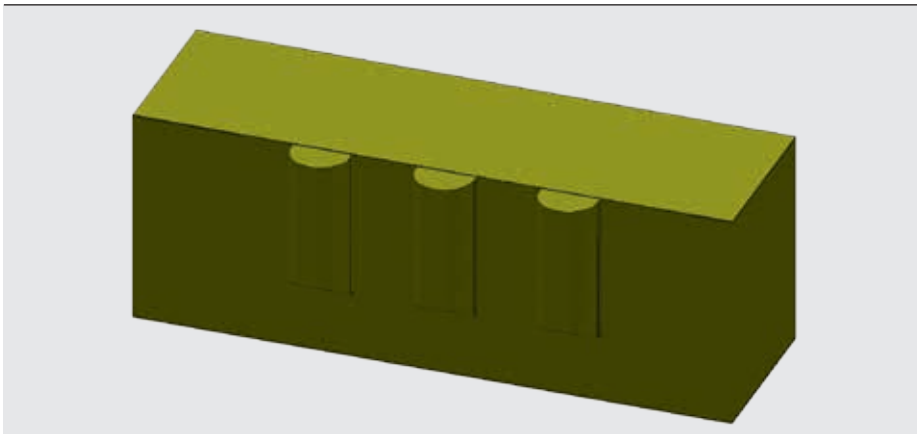
502 MVA transformer completely ready and assembled (tank, bushings, conservator and cooling system) in the test room of the ABB factory in Córdoba, Spain.

2 Magnetic shielding of the tank from HV side for the original design of investigated transformer



Surface impedance boundary condition enables calculations of stray losses in transformers, using a significantly reduced number of finite elements.

3 Simulation model of transformer (tank walls are shown)



A solution to this limitation has been implemented in many FEM software packages. In a first approximation, it can be stated that all eddy currents, and therefore losses, are generated close to the surface of the magnetic conductive materials. Therefore, the phenomenon can be treated as a boundary condition rather than a volume calculation.

Surface impedance boundary condition

Surface impedance boundary condition (SIBC) is a particular case of a general approximate boundary condition relating to electromagnetic quantities at a conductor/dielectric interface. It enables calculations of stray losses in transformers, using a significantly reduced number of finite elements [6].

Surface impedance boundary conditions were assigned to magnetic and conducting components of the transformer such as flitch plates, tank and clamps.

Electromagnetic simulations of power transformers

A MVA three-phase 380/110/13.8kV auto-transformer, produced by ABB, was used

for this research. The results concern the unit's stray losses and temperature distribution. For simulation purposes, a simplified 3-D model was created including only the major components of the transformer. The model includes a core, windings, flitch plates, clamps, a tank and magnetic shields on high- (HV) and low-voltage (LV) walls → 1.

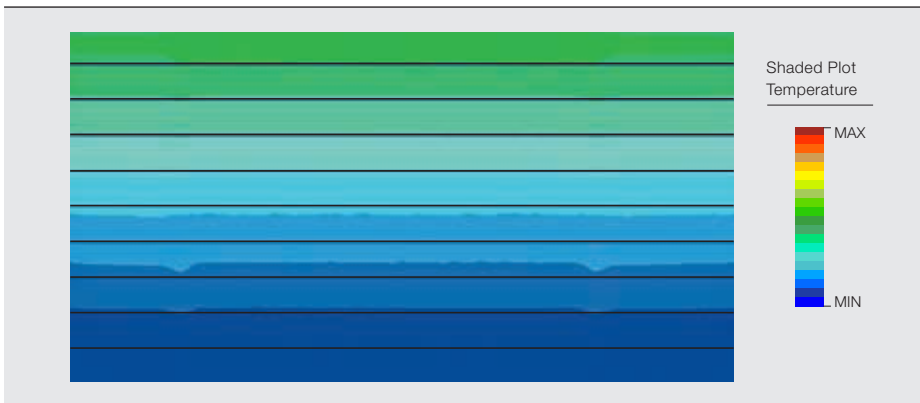
Magnetic shielding

When loaded with full current, transformer windings produce high amounts of stray flux and losses, which translate into temperature rises in metallic parts. To avoid overheating, magnetic shunts are mounted on the tank walls → 2. Shunts are ferromagnetic laminated steel elements that guide the flux emanating from the transformer winding ends and work as shields.

In this particular case, the tank has three embossments on the HV wall → 3 to make room for the three HV bushings. Only the optimization procedure for the shunts on the HV wall is considered here because no hot spots are detected from the LV side → 4.

During the project, coupled magneto-thermal simulations were performed. This type of calculation is very useful for the analysis of electrical machines such as transformers and motors.

4 Temperature distribution for tank LV wall for the original model of investigated transformer



5 Stray losses for the original design of investigated transformer

Element	Relative losses [%]
Core	41.1
Clamps	19.1
Flitch plates	4.2
Tank (HV wall)	25.6 (16.2)
Shunts	10.0
Total	100.0

Stray loss calculations

Preliminary calculations were carried out for a single frequency of 60 Hz, including the initial design of the shielding → 2. The percentage distribution of the stray losses can be seen in → 5. The losses generated in the tank HV wall are about 16 percent of the total stray losses in the constructional components obtained for the presented model.

for bottom oil temperature, the highest value for top oil temperature). The temperature of the air was defined as constant over the tank’s height, with uniform distribution.

The highest temperatures obtained for the initial design are observed in the regions below the embossments in the HV wall.

Temperature distribution calculations

During the project, coupled magneto-thermal simulations were performed. This type of calculation is very useful for the analysis of electrical machines such as transformers and motors.

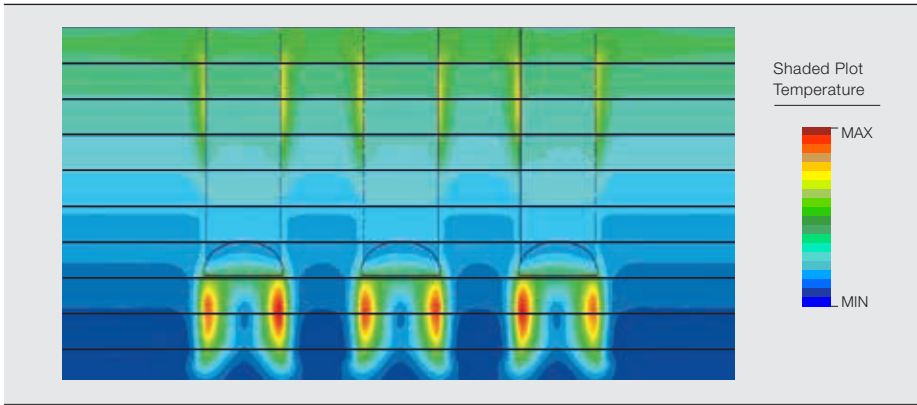
The highest temperatures obtained for the initial design are observed in the regions below the embossments in the HV wall → 6. The results obtained show that these regions should be shielded as the temperature rises exceed the permissible limit. However, the maximum values of temperature distribution for the LV wall are acceptable → 4.

For the evaluation of component temperature, appropriate values of convective heat transfer coefficients between components and their environment must be defined for each surface of interest in the model. A linear distribution of the oil temperature was assumed for the internal surfaces of the tank (the lowest value

Optimization of tank shielding

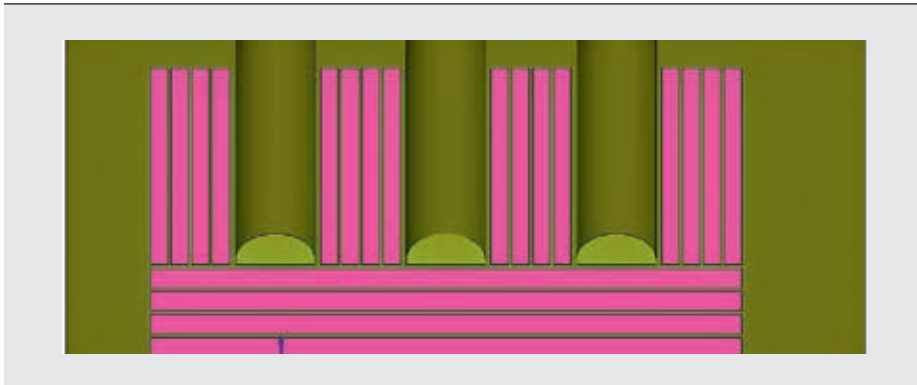
The optimization of magnetic shielding was a process guided by experienced engineers. Several possible arrangements of the shunts were calculated in

6 Temperature distribution for tank HV wall for the original design of investigated transformer



Total stray losses were decreased by 11.3 percent. The losses in the shunts themselves were also reduced by about 24 percent.

7 Magnetic shielding of the tank from HV side for the optimal design of investigated transformer



8 Stray losses for the optimal design of investigated transformer

Element	Relative losses [%]
Core	41.2
Clamps	18.9
Fitch plates	3.6
Tank (HV wall)	17.4 (7.8)
Shunts	7.6
Total	88.7

order to select the version that would protect the wall best, while keeping losses to a minimum. The vertical shunts

The temperature rise test confirmed the tank temperatures predicted by 3-D analysis.

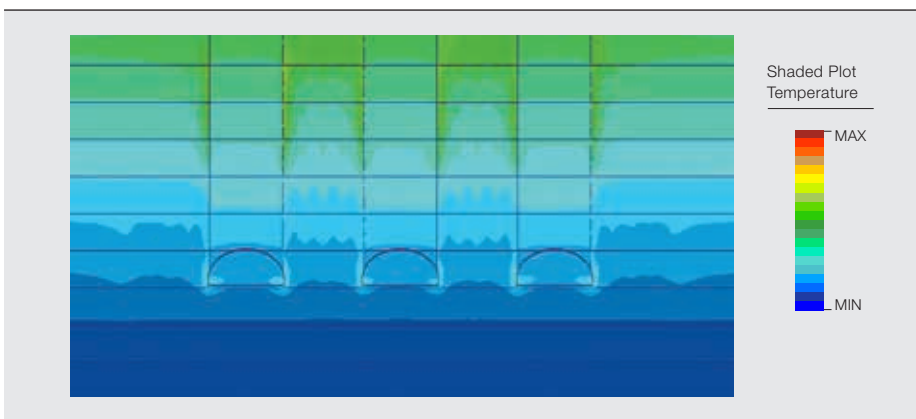
were shortened and horizontal shunts were introduced to protect regions where hotspots were predicted → 7.

The results obtained for the final design of the magnetic shielding are presented in → 8 (total stray losses obtained for the original design were assumed to be 100 percent). Total stray losses were decreased by 11.3 percent. The highest reduction is observed in the HV wall (52 percent). The losses in the shunts themselves were also reduced by about 24 percent.

The design changes have a significant impact on the temperature obtained in the transformer tank. As illustrated in → 9, the highest temperatures are located near the vertical edges of the embossments near the top of the tank. Previously observed hotspots were eliminated.

Electromagnetic simulations of power transformers have proven to be a very powerful tool applicable in the development and design stages.

9 Temperature distribution for tank HV wall for the optimal model of investigated transformer



Test results

During the final acceptance tests, the load losses came out within 1 percent of the losses estimated by the internal ABB tool. Final measured stray losses (the difference between measured load losses and estimated winding losses) were 5 percent above those calculated by FEM analysis.

The temperature rise test confirmed the tank temperatures predicted by 3-D analysis. No excessive gasses in the oil were reported as a result of the test, indicating no local overheating inside the tank.

Power to the simulator

Electromagnetic simulations of power transformers have proven to be a very powerful tool applicable in the development and design stages. Different alternative shielding solutions could be compared using FEM software and appropriate numerical models. Stray losses were predicted accurately, well within the uncertainty of measurements.

The applied methodology of tank shunts optimization is practical, inexpensive and easy to follow.

Magneto-thermal coupled analysis provides important information on the electromagnetic and thermal behavior of transformers.

To conclude, a design engineer would have probably never dared to use this shielding configuration without the insight obtained from 3-D simulations. Therefore, such an approach brings multiple benefits in terms of the opportunity to run simulation tests of different solutions and result in improved designs with lower stray losses and greater efficiency.

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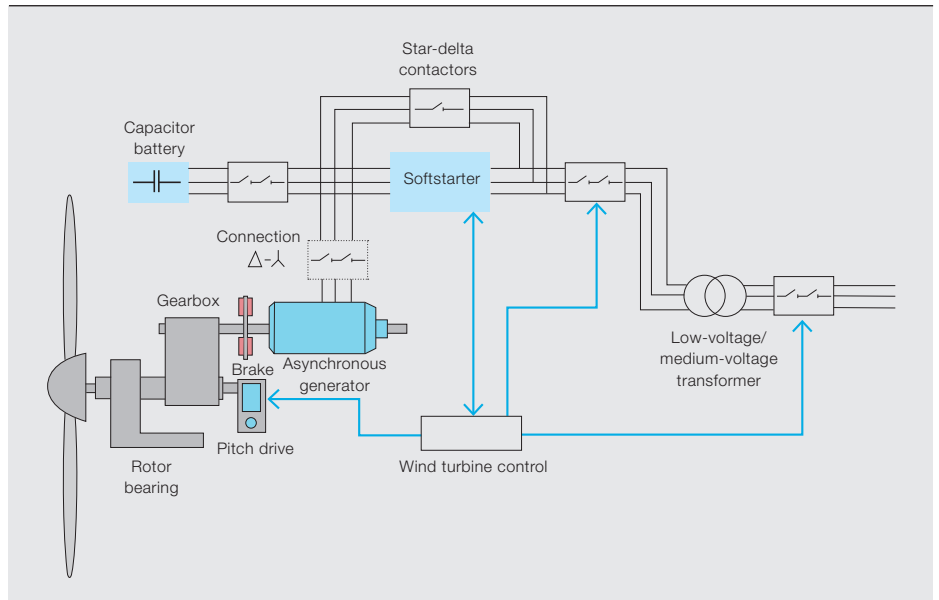
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Wind protection

Low-voltage switching
and protection strategies
in wind turbines

ANTONIO FIDIGATTI, PAOLO BARONCELLI, MARCO CARMINATI, ENRICO RAGAINI – Wind turbines come in different designs, each with its own electrical behavior that needs a unique approach when it comes to switching and protection. A review of the three most common turbine designs reveals the important factors to be taken into consideration in the choice of switching and protection components.



More than 150,000 wind turbines are currently installed worldwide. Over 90 percent of these generate electrical power at low voltages ($\leq 1,000$ V).

Challenges for wind turbine protection and control

The electrical protection and control systems that are so critical to keeping wind turbines running safely present conflicting requirements related to conversion efficiency, production continuity, fault disconnect, climatic and mechanical constraints, compactness and the need to reduce the effects of faults in the tight space inside the nacelle.

Conversion efficiency

Wind speed and direction can change rapidly or the wind can drop altogether so the turbine's mechanical and electrical configuration must be capable of rapid adaption. This causes frequent operation of control actuators (eg, for pitch adjustment), which, in turn, produces repeated connection and disconnection of the power circuit, with the attendant risk of component overheating.

Title picture

A critical factor in any wind turbine is the choice of switching and protection devices. How does turbine design influence this choice?

Power production continuity

Power production continuity requires high reliability during the entire lifetime of the wind turbine. The difficulty of physical intervention makes high reliability even more desirable. A good strategy here is to use components for their main function only (eg, circuit breakers for protection, contactors for switching, etc.) rather than trying to squeeze secondary functions from them. Generous tolerances are also obligatory.

Fault-disconnect behavior

The need to guarantee linear behavior even during network disturbances has led to the definition of grid codes, compliance with which is mandatory. In many cases, the control of reactive power flow under standard service conditions as well as under disturbed conditions requires a high number of operations by the connection devices of capacitor banks and filters.

Climatic and mechanical constraints

The environmental stresses suffered by a wind turbine can be severe: Vibrations can be of several millimeters' amplitude and thermal conditions can range from below -25 °C when heating and de-icing functions are switched off during inactivity to $+50$ °C when power-dissipating

components are operating in overload conditions. The aging effects of this operational environment as well as the effects of frequent switching, salt air, humidity, pollution, etc., must be taken into account in lifetime calculations.

Compactness

Further mechanical constraints are linked to the requirements for compactness and low weight because of the limited

Protection systems must work in a wide range of electrical conditions while at the same time correctly and quickly discriminating between normal and fault conditions.

space available in the nacelle and the need to minimize mechanical stresses on the structure. These factors necessitate trade-offs with the overdimensioning required for high efficiency and service continuity.

Faults in the nacelle

Faults in the nacelle are a particularly critical issue: The protection and control system, besides preventing and limiting the catastrophic effects of faults in the reduced space available, should ensure electrical transients do not damage the valuable mechanical system (which rep-

2 Requirements for switching/protection devices with FSIG

	Main power circuit	Main auxiliary circuit
Load current (A)	≤ 1,800	≤ 320
Voltage (V)	≤ 690	≤ 690
Frequency (Hz)	50-60	50-60
Prospective short-circuit current (kA)	≤ 35 @ 690 V	
Type of load classification according to [2]	Resistive	Induction motor or transformer
Presence of inrush current	No	Yes
Life time (years)	20	20
Number of mechanical operations with electrical isolation from the voltage sources (maintenance or out of service)	100-1,000	< 1,000
Number of generator-to-network or reconfiguration connect/disconnect mechanical operations (or electrical operations at low current)	10,000-100,000	Not applicable
Number of electrical operations	< 100 (trips or emergency stop)	< 100 (trips or emergency stop)
Protection against overload and short circuit	Yes	Yes
Optimum solution	Circuit breaker plus contactor	Circuit breaker

A good strategy is to use components for their main function only rather than trying to squeeze secondary functions from them.

resents about 80 percent of the turbine cost). This translates into several requirements that sometimes conflict with each other, such as:

- Avoid unwanted tripping but also dangerous overvoltages.
- Operate rapidly to reduce mechanical stress and strain on the drivetrain, as well as fire risk.
- Detect the small short-circuit current contribution from the generator.
- Correctly identify the faulty feeders on the auxiliary circuits after a noncritical electrical fault in order to increase power generation availability.
- Limit the fault energy (and trip fast at low current) in order to protect weak components like the brushing system.
- Isolate faulty sections safely.
- Isolate safely during maintenance, while providing the energy required by the auxiliary systems.

The key characteristics, then, for the control and protection components are, in order of importance:

- high switching reliability
- reduced maintenance
- compactness and reduced weight
- cost

These four requirements are often incompatible with each other and trade-off choices regarding protection and switching have to be made. Optimal strategies in this trade-off can be explored by examining the three main wind turbine technologies:

- An asynchronous generator directly connected to the grid: fixed-speed induction generator (FSIG)
- An asynchronous generator with its rotor excited at a variable frequency, directly connected to the grid: doubly-fed induction generator (DFIG)
- A permanent magnet synchronous (or asynchronous) generator connected to the grid through a full-scale frequency converter (FSFC)

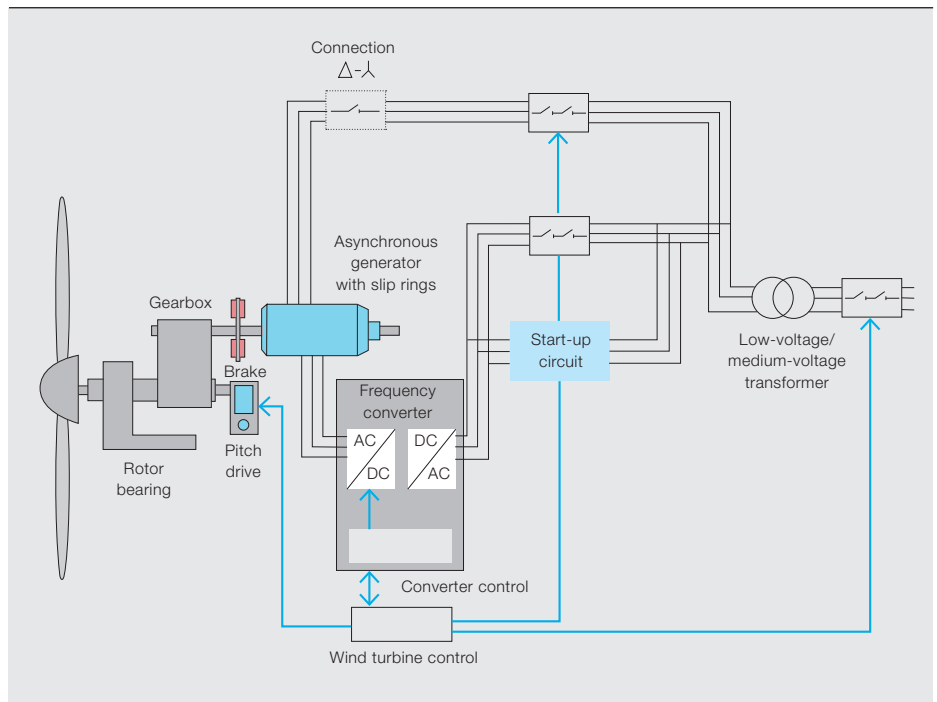
Fixed-speed induction generator

In the FSIG configuration, with a brushless asynchronous generator directly connected to the grid, only very limited deviations from the synchronism speed are possible. Reactive power is, therefore, delivered by capacitor banks, the switching of which is relatively frequent [1]. The start-up phases of the generator are managed by a softstarter equipped with parallel-connected contactors, which are closed once the steady state has been reached. Star-delta connection to the winding(s) of the generator is generally employed for the proper management of different wind regimes. Also, the generator can have multiple poles to extend the working range → 1-2. This electrical configuration is simple and highly efficient, but:

- The reduced production speed range is unsuitable for variable wind areas.
- A long-time overload condition has to be withstood, so the main circuit components have to be oversized.
- The contactor-based step control on the capacitors could produce overvoltage effects; in many such cases

The aging effects of the operational environment as well as the effects of frequent switching, salt air, humidity, pollution, etc., must be taken into account in lifetime calculations.

3 Simplified diagram of wind turbine with a DFIG



- interaction with the softstarter could be problematic.
- The system is unable to follow fast grid perturbations without disconnection.

Therefore, this configuration is only suitable for small- to medium-sized wind turbine sizes that are installed on a network with a low wind energy production penetration (<5 percent).

Doubly-fed induction generator

This configuration employs a slip-ring induction generator, the rotor circuit

of which is powered at a variable frequency → 3–4. Wider variations in the rotation speed of the system are possible compared with the FSIG approach since the excitation frequency of the rotor allows displacements from the synchronism speed to be compensated for [1]. Generally, the excitation circuit, where power can flow in both directions (European approach), is sized at 20 to 30 percent of the rating of the main circuit. The converter is used to control the generator speed and power factor, allowing a wider speed range for power production as well as the ability to feed reactive

power to support the grid. In some cases, star-delta connection to the generator is used for the proper management of different wind regimes with rotor current values optimized in term of slip-ring and brushing system life. The advantages compared with constant speed turbines are:

- Variable-speed operation increases kilowatt-hour production.
- Utilization of a small converter, sized at up to one-third of the nominal power, allows reactive power to be supplied to the grid in normal and abnormal conditions with a good voltage and power factor control.
- Total system efficiency is high.

On the other hand, some disadvantages have to be considered:

- The direct connection between the grid and the generator transfers network perturbations to the mechan-

The protection and control system should ensure electrical transients do not damage the valuable mechanical system – which represents about 80 percent of the turbine cost.

4 Requirements for switching and protection devices with DFIG

	Main power circuit	Main excitation circuit	Start-up circuit
Load current (A)	≤ 4,000	≤ 630	≤ 5
Voltage (V)	≤ 1,000	≤ 690	≤ 690
Frequency (Hz)	50-60	50-60	50-60
Prospective short-circuit current (kA)	≤ 30 @ 1,000 V	≤ 50 @ 690 V	≤ 50 @ 690 V
Type of load classification according to [2]	Resistive	Induction motor	Induction motor
Presence of inrush current	No	No	Yes
Life time (years)	20	20	20
Number of mechanical operations (or electrical operations at low current) with electrical isolation from the voltage sources (maintenance or out of service)	100-1,000	< 1,000	Not applicable
Number of generator-to-network or reconfiguration connect/disconnect mechanical operations (or electrical operations at low current) with electrical isolation from the voltage sources	10,000-100,000	1,000-10,000	Not applicable
Number of electrical operations	< 100 (trips or emergency stop)	< 100 (trips or emergency stop)	< 10,000 (excitation circuit insertion)
Protection against overload and short circuit	Yes	Yes	Yes
Optimum solution	Circuit breaker if < 1 operation/day or circuit breaker plus contactor if more*	Circuit breaker coordinated with contactor in parallel with the start-up circuit	Circuit breaker plus contactor

* The speed of wind turbine generators is more often in the lower range than in the rated range, resulting in frequent switching on and off at typically 2,000-5,000 cycles per year (depending on wind turbine generator type), which makes contactors the best technical solution

ical drive chain, reducing the ability of the system to stay connected.

- The slip-ring brush rotor is a high-maintenance weak point.

Full-scale frequency converter

With an FSFC design, rotation speed may vary over a wide range because frequency variations can be compensated for by a drive placed between generator and network [1]. In the full converter concept, the converter decouples the generator and the mechanical drivetrain from the grid → 5–6. All the generated power flows through the converter to the grid. The converter provides generator torque and speed control. There are three main full converter concepts: high-speed, medium-speed and low-speed. These use different gearbox and generator solutions. The advantages of an FSFC design compared to constant-speed turbines are:

- There is no direct electrical connection between generator and grid. This reduces mechanical shocks on the turbine during grid faults and increases grid code compliance.
- A full speed range is enabled with increased annual power yield.
- Full control of active power is possible, with full reactive power production.

In the FSFC configuration, circuit breakers are often employed for multiple purposes:

- To safely disconnect and isolate for normal operation or maintenance.
- To protect: In a fault involving the inverter or the sections between the generator and the inverter (eg, cable connection section), the circuit breaker is the only device able to detect safely the short circuit and disconnect from the power source. This requires protection releases (trip units) specifically designed for variable-frequency operation that can work in the specified environmental conditions.
- The circuit breaker provides generator disconnection redundancy.

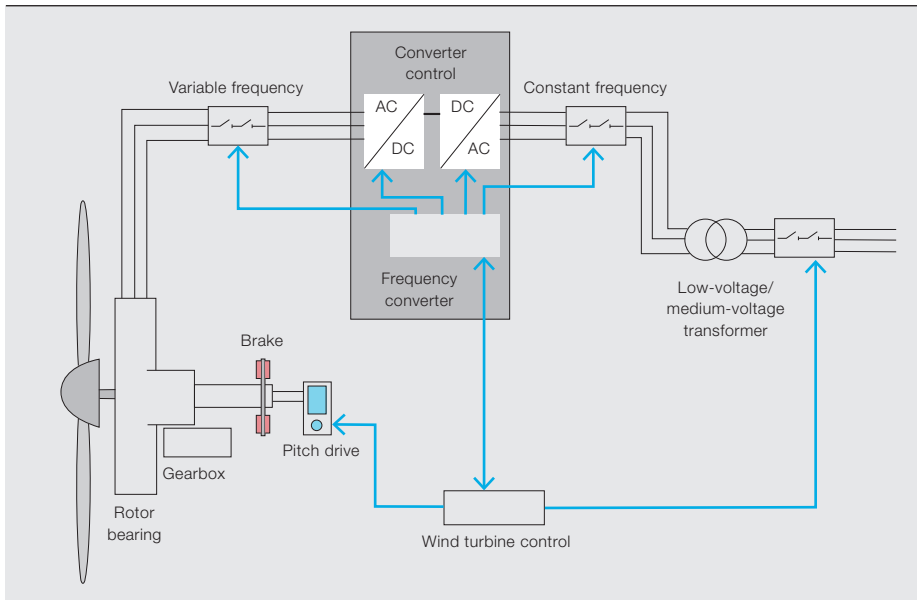
Breaking news

A choice of switching and protection components appropriate to a particular wind turbine design is essential for smooth operation and the minimization of the effects of faults.

The protection of wind turbines and other renewable generators is an area of intense research and development in which ABB is heavily involved. In recent years, ABB has released a series of solutions that protect plants with variable frequency in the wind, mini-hydroelectric, wave and traction power sectors – a prominent example of which is the Tmax

Equipment has to be compact and light because of space constraints and the need to minimize mechanical stresses on the structure.

5 Simplified diagram of wind turbine with FSFC



6 Requirements for switching/protection devices with FSFC

	Main power circuit on the variable-frequency side	Main power circuit on the grid side	Main auxiliary circuit
Load current (A)	≤ 5,000 or n x 700-1,600	≤ 5,000 or n x 700-1,600	≤ 250
Voltage (V)	≤ 1,000	≤ 690	≤ 690
Frequency (Hz)	1-16, 30-80, 40-140	50-60	50-60
Prospective short-circuit current (kA)	≤ 15 @ 1,000 V*	≤ 50 @ 690 V	
Type of load classification according to [2]	Resistive	Resistive	Induction motor
Presence of inrush current	No	No	Yes
Life time (years)	20	20	20
Number of mechanical operations (or electrical operations at low current) with electrical isolation from the voltage sources (maintenance or out of service)	100-1,000	< 1,000	< 1,000
Number of generator-to-network or reconfiguration connect/disconnect mechanical operations (or electrical operations at low current) with electrical isolation from the voltage sources	Not available (in general, the generator remains connected to the drive)	1,000 - 100,000 (according to the control strategies)	Not applicable
Number of electrical operations	< 100 (trips or emergency stop)	< 100 (trips or emergency stop)	< 100 (trips or emergency stop)
Protection against overload or short circuit	Yes	Yes	Yes
Optimum solution	Circuit breaker if protection is required for connection cables or inverter switch. Switch disconnecter and external protection system is present.	Circuit breaker if < 1 operation/day or circuit breaker plus contactor if more	Circuit breaker

* Depending on the power and the configuration of the plant

VF and Emax VF circuit breakers that can operate in the range from 1 to 200 Hz.

The major benefits of this new range of circuit breakers for variable frequency applications are: Compatibility with all types of generators – even in overspeed conditions – thanks to the high rated voltage of the circuit breakers (up to 1,000 V); standardization of switchboard design, regardless of the end market; and optimization of stock management thanks to dual IEC/UL circuit breaker marking. This new family of trip units, together with optimized current sensors, ensures high-precision protection over an extended frequency range. Whilst improved arcing chamber and contacts guarantee high breaking capacity over the whole frequency range, the dimensions are the same as standard circuit breakers.

Developments in protection and switching devices are ongoing – for example, to harness the power of the Internet and the cloud to allow remote optimized power control at any time and from anywhere.

This article is based on the following IEEE paper: A. Fidigatti, P. Baroncelli, M. Carminati and E. Ragaini, "Selection of low voltage switching and protection devices in wind power generators," Industry Applications Society Annual Meeting (IAS), © 2011 IEEE, Orlando, FL, 2011, pp. 1-5.

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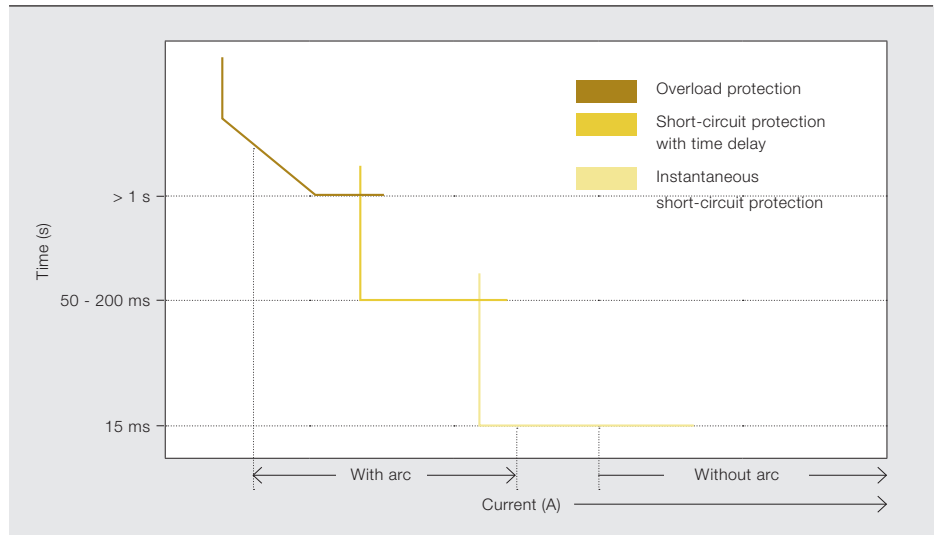
Arc angel

Arc flash prevention measures increase safety

PAVLO TKACHENKO, ANDREAS VON LAKO – An arc flash is one of the most serious incidents that can occur in an electrical installation. Arc-flash temperatures can reach 20,000°C and the energy and shrapnel produced in the arc blast can cause death, injury and serious damage. Normal short-circuit measures are too slow to protect against arcing events like this. ABB has released a new version of its well-established 110 to 240V AC/DC Arc

Guard System™ that has been protecting people and electrical equipment from dangerous electrical arcs for over 35 years. The TVOC-2-48 now makes the Arc Guard System available for equipment in the 24 to 48V DC range. In addition to Arc Guard, rigorous testing according to the guidelines contained in the IEC 61641 Technical Report further ensures the safety of ABB electrical cabinets under conditions of internal arcing.

1 Usual short-circuit protection methods are much too slow to prevent arcing events



by a factor of 67,000:1 when changing from a solid to a vapor (water: 40,000:1) and the molten metal and shrapnel produced by the arc can reach velocities of 1,600 km/h. An intense, high-energy radiation with a temperature of up to 20,000 C is produced that is capable of vaporizing nearby materials. This radiation can also be absorbed by metal objects worn by people in the vicinity, heating the objects and causing severe burns to the wearer.

A full 65 percent of switchgear arc flash incidents occur with an operator working on the equipment.

Because fatalities and serious injury are often classified as burn victims by hospitals, statistics on arc flash casualties are hard to come by. However, even one arc flash incident is one too many.

In incidents that lead to arc flash, the usual methods of short-circuit protection is inadequate. This is because the arc itself acts as a resistor that limits the overcurrent. This, in many cases, will lead to such a delay that by the time the load protection kicks in, it is far too late → 1.

Arc Guard

ABB has long recognized the hazards of arcing accidents and, nearly 40 years

ago, developed its Arc Guard System – a product that significantly reduces the damage resulting from an arcing accident by quickly disconnecting the switchgear, with the help of the installed breaker, after an arcing fault. The latest ABB Arc Guard System TVOC-2-48 extends the operating regime of the product from 110 to 240V AC/DC to the 24 to 48V DC range.

Arc Guard employs light sensors that detect the start of the arc flash → 2. On detection, a signal is sent directly to the breaker trip mechanism. The total time from detection to trip signal being sent is less than 1 ms and, with a modern breaker, the entire disconnect sequence can be reduced to under 50 ms.

Arc Guard employs light sensors that detect the start of the arc flash and send a signal via a fiber optic cable directly to the breaker trip mechanism.

Fiber optic communication is used not only for its speed but also because it is immune to the EMI that may be present, especially in the event of an electrical fault. This also means that cables can be retrofitted without concern about cross-talk or electrical conductivity safety issues.

Though rare, an arc flash is an extremely serious and dramatic event. An arc flash is the heat and light produced by an arc caused by a fault in electrical equipment. Most arc flashes arise from human error – eg, conducting materials inadvertently left in assemblies during manufacture, installation or maintenance; faults in materials or workmanship; failure to put measures in place to exclude the entry of small animals such as mice, snakes, etc.; use of an incorrect assembly for the application, resulting in overheating and, subsequently, an internal arcing fault; inappropriate operating conditions; incorrect operation; or lack of maintenance.

Arc flashes can produce earsplitting noises that surpass 160 dB; the United States OSHA (Occupational Safety and Health Administration) limit is 115 dB for a maximum of 15 mins. Copper expands

Title picture

ABB's Arc Guard System TVOC-2-48 extends arc flash protection to the 24 to 48 V DC range. Electrical cabinet safety is further enhanced by following the guidelines contained the IEC 61641 Technical Report.



The new ABB Arc Guard System TVOC-2-48 extends the operating regime of the product from 110 to 240V AC/DC to the 24 to 48V DC range.

Up to 10 light sensors can be connected to one Arc Guard System TVOC-2. Also, two extension units with additional 10 sensors each can be connected and TVOC-2 units can share current sensing information. Sensors are calibrated to have equal light sensitivity and their positioning is not critical as their fish-eye lens design can observe a large angle. Overall, the system is very easy to install.

To avoid false tripping due to camera flashes or sunlight, the arc monitor can be combined with a current sensor and set to activate only when an overcurrent is also registered.

The Arc Guard System ensures the safety of personnel even when the cabinet door is open and a functional safety SIL-2 classification makes the TVOC-2 one of the most reliable arc mitigation products available on the market.

Because they reduce downtime cost and damage, some insurance companies recommend the use of such systems and may take this into account when setting premiums. Also, many countries legislate for protection against arcing accidents and regulations such as The Low Voltage Directive of the European Union stipulate that measures to prevent damage by excessive heat, caused by arc flashes, for example, are to be taken.

System pro E power

The IEC 61439 series of standards sets out rules and requirements for interface characteristics, service conditions, construction, performance and verification

of low-voltage switchgear and controlgear assemblies. The main objective of these standards is to achieve safe operation under normal operating conditions as well as under abnormal operating conditions, eg, occurrence of overvoltage, overload or short-circuit currents. However, no requirements are set out dealing with the case of an arc fault inside the assembly.

ABB has long since recognized the hazards of arcing accidents and, nearly 40 years ago, developed its Arc Guard System.

Instead, manufacturers turn for guidance to IEC Technical Report 61641, officially titled, "Enclosed low-voltage switchgear and controlgear assemblies – Guide for testing under conditions of arcing due to internal fault." This is not a standard, but a technical report and is not a compulsory test. The criteria it uses to assess the protection afforded by the assembly are:

1. During an arcing event, correctly secured doors and covers do not open and remain effectively in place, and provide a minimum level of protection in accordance with the requirements of IP1X of IEC 60529.

Fiber optic communication is used not only for its speed, but also because it is immune to the EMI that may be present, especially in the event of an electrical fault.

This criterion minimizes the risk of severe injury to persons by impact from doors, covers, etc. and ensures a minimum level of protection for persons against accidental contact with hazardous live parts.

2. No parts of the assembly are ejected that have a mass of more than 60g except those that are dislodged and fall between the assembly and the indicators. This minimizes the risk to persons from ejecta.

By using the ABB System pro E power switchboard solution and the Arc Guard System, the danger of arc flash can be reduced to a minimum.

3. Arcing does not cause holes to develop in the external parts of the enclosure below 2 m, at the sides declared to be accessible, as a result of burning or other effects. This minimizes the risk of severe injury to persons by direct burning from the arc.
4. The indicators do not ignite (indicators ignited as a result of paint or stickers burning are excluded from this assessment).
5. The protective circuit for the accessible part of the enclosure is still effective in accordance with IEC 61439-2.

6. The assembly is capable of confining the arc to the defined area where it was initiated, and there is no propagation of the arc to other areas within the assembly. Effects of hot gases and sooting on adjacent units other than the unit under test are acceptable, as long as only cleaning is necessary.
7. After the clearing of the fault, or after isolation or disassembly of the affected functional units in the defined area, emergency operation of the remaining assembly is possible. This is verified by a dielectric test according to IEC 61439-2:2011, 10.9.2, but with a test voltage of 1.5 times the rated operational voltage for 1 min. Bending or bowing of doors and covers of the unit under test and adjacent units is acceptable providing the unit can be readily restored to a minimum level of protection in accordance with IPXXB of IEC 60529. With the exception of the tested zone as declared by the manufacturer, all other units should remain fully operable both mechanically and electrically and remain essentially in the same condition as before the test.

Personnel protection is achieved when the criteria 1 to 5, above, are fulfilled; personnel and assembly protection is achieved when criteria 1 to 6 are fulfilled; and personnel and assembly protection with limited operation capability is achieved when criteria 1 to 7 are fulfilled.

System pro E power is ABB's main distribution switchboard solution. With rated current up to 6,300A and short-circuit current up to 120kA, System pro E power complies with the test requirements IEC TR 61641. In the official language of

IEC TR 61641, ABB's System pro E power has arcing class B classification, ie, under arcing conditions, criteria 1 to 6 are fulfilled. The addition of the TVOC-2 Arc Guard allows all criteria up to and including 7 to be achieved.

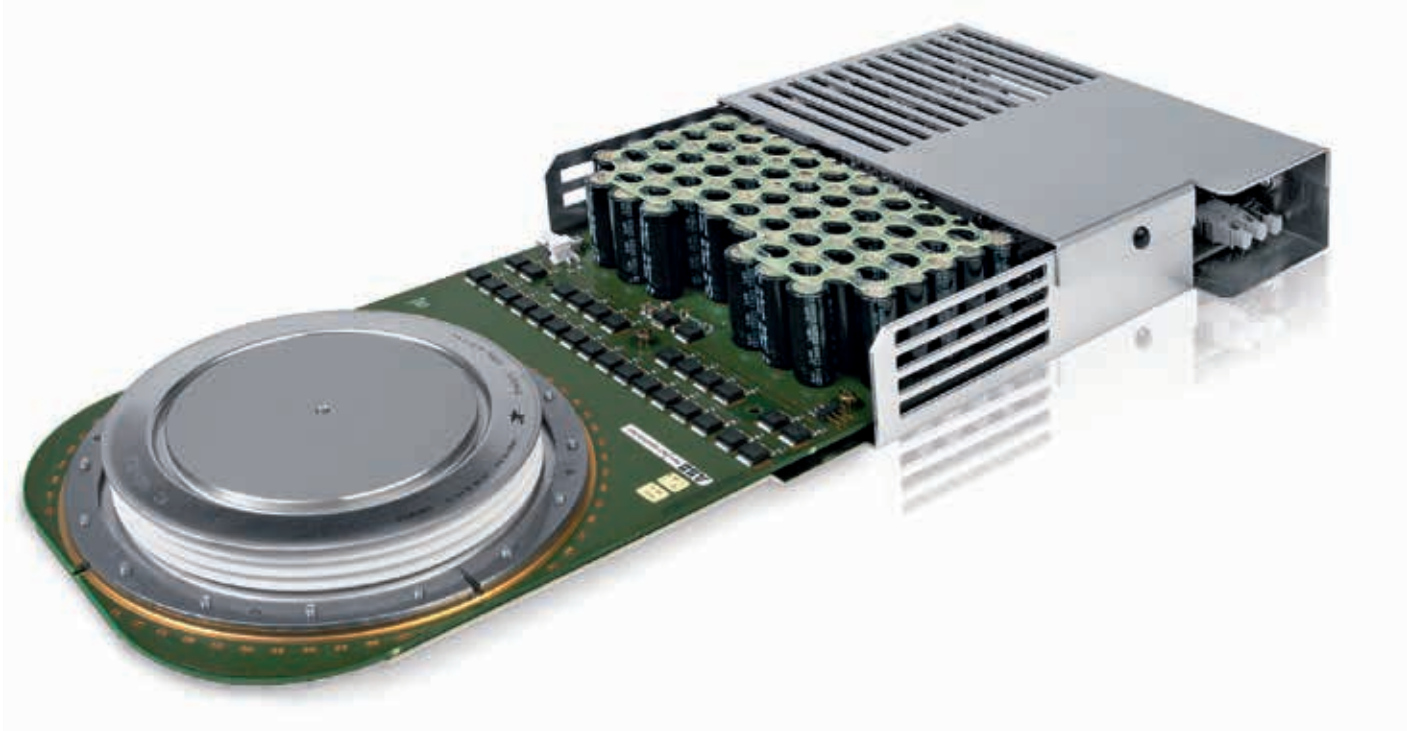
Arc flashes pose a serious hazard to personnel and equipment in electrical installations. However, using a well-designed and well-tested switchboard solution such as the ABB System pro E power, and a fast and effective arc mitigation product such as the Arc Guard System, the danger of arc flash can be reduced to a minimum.

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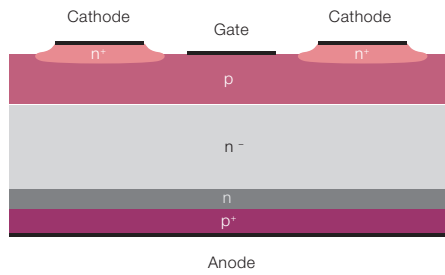


Switching the subject

A look at recent advances in IGBT technologies for high-power electronics

UMAMAHESWARA VEMULAPATI, MUNAF RAHIMO, MARTIN ARNOLD, TOBIAS WIKSTRÖM, JAN VOBECKY, BJÖRN BACKLUND, THOMAS STIASNY – In the mid-1990s, ABB introduced a new member of the power electronics family – the integrated-gate commutated thyristor (IGCT). Like the gate turn-off thyristor (GTO) from which it evolved, the IGCT is a fully controllable semiconductor switch that can handle the high currents and voltages prevalent in high-power electronics applications. The IGCT has a better performance than the GTO regarding turn-off time, size, the degree of integration, power density, etc. and this superiority has helped it become the device of choice for industrial medium-voltage drives (MVDs). It has also found use in many other applications such as wind-power conversion, STATCOMs and inertias. IGBT technology development has made rapid progress over the past decade.

1 IGCT device



1a Schematic cross-section of an asymmetric IGCT



1b Top view of a 91 mm IGCT wafer



1c The IGCT wafer in a hermetic package and with its integrated gate unit

In many ways, an IGCT is similar to a GTO. Like the GTO, the IGCT is basically a switch that is turned on and off by a gate signal. However, IGCTs have advantages over GTOs: They can withstand higher rates of voltage rise (so no snubber circuit is needed); conduction losses are lower; turn-off times are faster and more controllable; cell size on the silicon wafer is smaller; and the solid gate connection used by IGCTs results in lower inductance. Furthermore, the IGCT drive circuit is integrated into the package [1] → 1.

In the past couple of decades, IGCTs have become ubiquitous in high-power electronics and are now available in voltage ratings ranging from 4.5 kV to 6.5 kV and in three main types: asymmetric, reverse-conducting (RC-IGCT) and symmetric or reverse-blocking (RB-IGCT).

- Asymmetric IGCTs cannot block reverse voltages of more than a few tens of volts. Consequently, they are used where such a voltage would never occur – for example, in a switching power supply – or are equipped with an appropriate anti-

parallel diode to conduct currents in the reverse direction. Asymmetric IGCTs have the highest power level for a given wafer size.

- RC-IGCTs have a diode integrated into the same GCT wafer to conduct currents in the reverse direction, but this uses wafer area that could otherwise be used for switching function capacity.
- Symmetrical IGCTs are inherently able to block reverse voltages, but conduct currents only in the forward direction.

The hermetic press-pack design of the IGCT has for years proven its reliability in the field with respect to power semiconductor device protection and load cycling capability. Consisting of a few layers of well-designed materials there are no issues with solder voids or bond liftoff, as is experienced by other technologies.

IGCT performance trends

In the past ten years, IGCT technology has seen major advances, especially regarding lower conduction losses and higher power densities → 2. Power in-

creases have come from achieving lower losses and/or higher operating temperatures, chiefly enabled by an increased device safe operation area (SOA) that allows higher turn-off current. Absolute power has been increased by enlarging the state-of-the-art 91 mm diameter wafer to 150 mm and integration concepts that provide full functionality with a single wafer device instead of employing two devices (IGCT and diode).

Increased margins: high-power technology

The main limiting factor in conventional IGCTs relates to the maximum controllable turn-off current capability and not losses or thermal constraints. Therefore, the introduction of the high-power technology (HPT) platform [2] has been hailed as a major step forward in improving IGCT

The hermetic press-pack design of the IGCT has for years proven its reliability in the field.

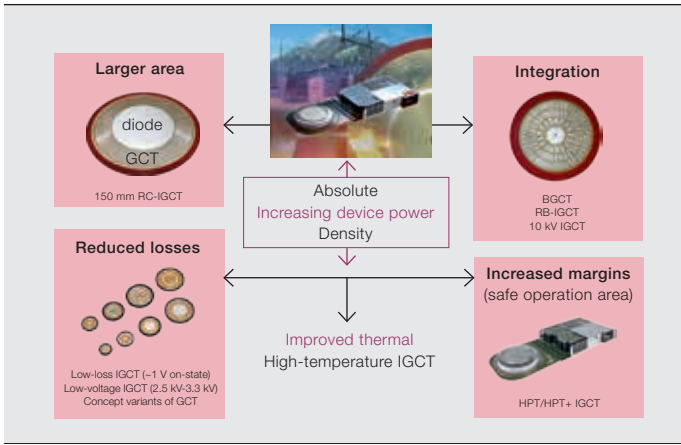
SOA performance while providing an enabling platform for future development.

An HPT-IGCT gives an increase in the maximum turn-off current of up to 40 per cent at 125 °C. HPT-IGCTs incorporate an advanced corrugated p-base design – compared with a standard uniform p-base junction – that ensures controlled and uniform dynamic avalanche operation with better homogeneity over the diameter of the wafer during device turn-off → 3. The HPT has been proven for IGCT products with voltage ratings of up to 6.5 kV. In tests, 91 mm, 4.5 kV HPT-IGCTs have turned off currents in excess of 5 kA, withstanding extreme conditions with a large stray inductance.

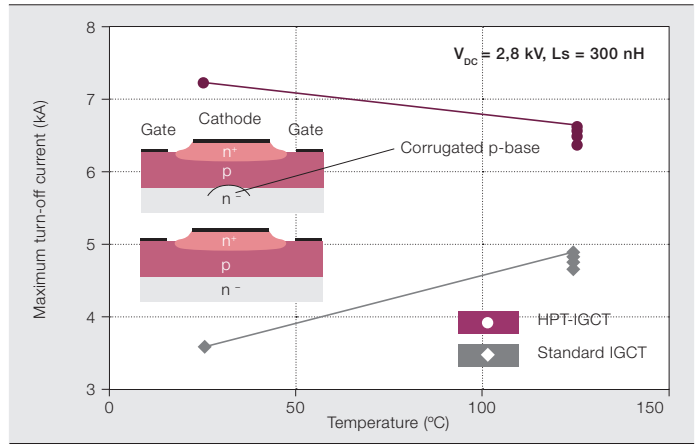
Title picture

The invention of IGCTs has changed the rules in the power electronics landscape. Pictured is an ABB IGCT with gate unit.

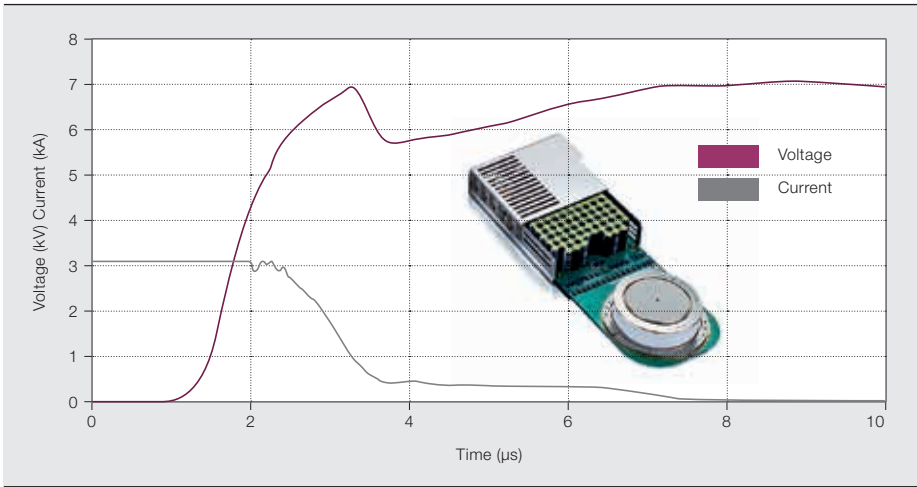
2 IGCT development trends for achieving lower losses and/or higher power handling capabilities



3 Experimental results of the HPT-IGCT maximum controllable turn-off current capability against a standard IGCT



4 91 mm, 10kV IGCT and its measured turn-off waveforms at 3.3kA, 5.5kV and 125°C



In the past ten years, IGCT technology has seen major advances, especially regarding lower conduction losses and higher power densities.

Integration: RB-IGCT

In some cases – such as with a solid-state DC breaker, in AC applications or in current source inverters (CSIs) – a symmetrical blocking switching device is required. Although this could be accomplished by using an asymmetric IGCT connected in series with a fast diode, the preferred solution is a symmetric IGCT in a single wafer. Since the required performance and some modes of operation are different from other IGCTs, device design optimization is needed to achieve the reverse-blocking performance along with low losses and robust switching performance. Both 6.5kV RB-IGCTs for CSI applications and 2.5kV RB-IGCTs for bi-directional DC breaker applications have been developed. A 91 mm, 2.5kV RB-IGCT, for example, has been demonstrated with an on-state voltage drop as low as 0.9V at rated current (1 kA) at 125 °C and a maximum controllable turn-off current capability up to 6.8kA at 1.6kV, 125 °C [3].

Integration: high voltage ratings (10 kV IGCT)

It would be possible to make a three-level inverter without series connection for line voltages of 6 to 6.9kV if IGCTs with a voltage rating in the range of 8.5 to 10kV were available. Such a device offers simple mechanical design, less control complexity and high reliability compared with the series connection of two 4.5 or 5.5kV devices for line voltages of 6 to 6.9kV. To prove the feasibility of this approach, devices rated at 10 kV have been manufactured using the HPT platform and the concept has been shown to work [4] → 4.

Improved thermal performance: high-temperature IGCT (HPT+)

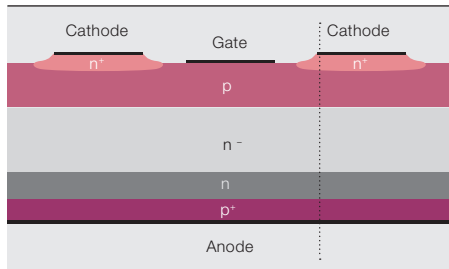
One way to increase the output power of an existing converter design is to increase the temperature rating of the power semiconductor device used. For continuous operation, however, the cooling system capabilities may limit this increase. For intermittent high-power operation, though, a temperature increase

can be a valid option and the HPT-IGCT can be improved to accommodate this. Accordingly, the corrugated p-base doping profile was further optimized to allow a full SOA in the whole temperature range up to 140 °C. Also, the internal interfaces, such as the metallization on the wafer, were improved to reach a higher thermomechanical wear resistance. The verification of these improvements has started and the first results look promising. Also, this so-called HPT+ technology has a clearly improved technology curve compared with HPT-IGCT due to its optimized corrugated p-base design [5].

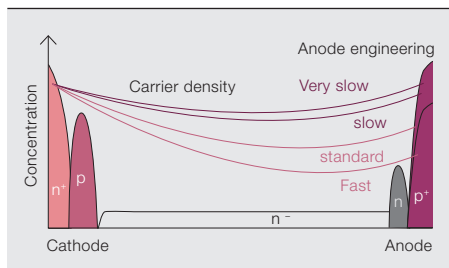
Reduced conduction losses: toward a 1 V on-state, 3.3 kV IGCT

In recent years, there has been a clear trend toward using multilevel topologies in many power electronics applications. Such products often operate at fairly low switching frequencies but at the same time require high current-carrying capabilities and/or high efficiency. Due to its inherent low-conduction-loss thyristor

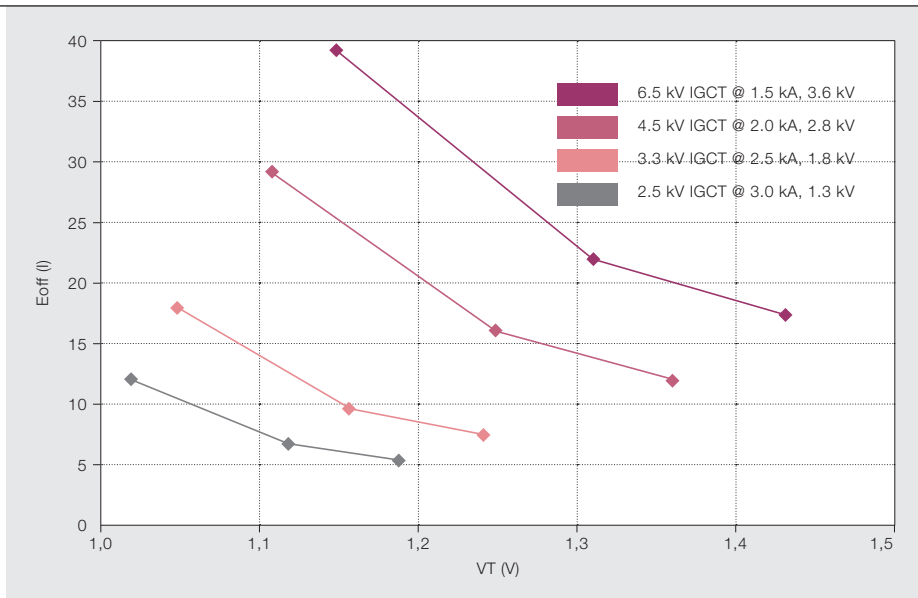
5 IGCT anodic engineering



5a IGCT structure



5b IGCT doping and anode engineering carrier profiles along the section a'-a



5c Technology curves of different voltage class 91 mm IGCTs at 125°C achieved through anode engineering

Power increases have come from achieving lower losses and/or higher operating temperatures, chiefly enabled by an increased device SOA that allows higher turn-off current.

properties and hard-switched functionality, the IGCT is predestined for these applications. Therefore, further optimization is required to achieve very low on-state voltages (~ 1 V) through anode engineering while maintaining good overall performance \rightarrow 5.

Since there is a certain amount of freedom in selecting the device voltage for a multilevel system, a number of simulations and experiments have been performed for a wide range of voltage classes to see what performance can be achieved [6]. The available results are summarized in \rightarrow 5 and give input to the designers of multilevel converters to see how the systems can be optimized with respect to the minimum total inverter losses for a given topology, voltage rating and current rating.

Furthermore, first prototype samples of 3.3 kV RC-IGCTs were manufactured to verify the simulation results. Three different anode injection trials were carried out (A1, A2 and A3) to ensure the potential of 3.3 kV RC-IGCTs to achieve very low conduction losses even at higher currents with reasonable switching losses [7].

Larger area: 150 mm RC-IGCT

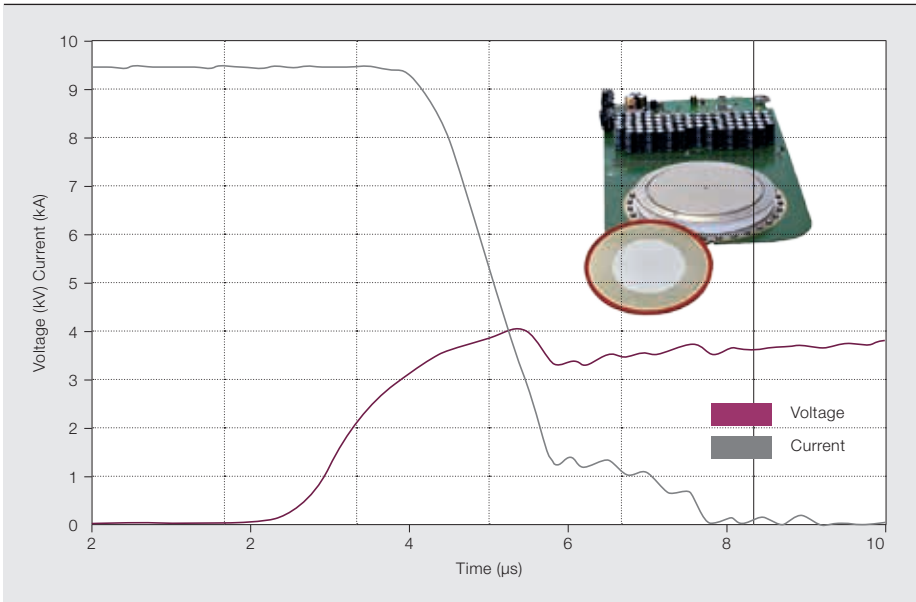
The quest for ever-greater power ratings makes larger silicon diameters inevitable. Compared with the previous technology, HPT has an improved scalability that enables the design of devices beyond the standard 91 mm wafer size. The

first 150 mm, 4.5 kV RC-IGCT prototypes based on HPT+ technology have recently been manufactured. With these devices, it will be possible to make three-level inverters up to about 20 MW without the need for series or parallel connection of power semiconductor devices [8] \rightarrow 6.

Future trend: Full integration with bi-mode gate-commutated thyristor

The conventional RC-IGCT enables better component integration in terms of process and reduced parts count at the system level, and therefore improved reliability. As explained above, in an RC-IGCT the GCT and diode are integrated into a single wafer, but they are fully separated from each other as shown in \rightarrow 2. Consequently, in the RC-IGCT, the utilization of the silicon area is limited in the GCT region when operating in GCT mode and in the diode region when operating in the diode mode. Therefore, a new fully integrated device concept (interdigitated integration) was developed that resulted in the bi-mode gate-commutated thyristor (BGCT), which integrates IGCT and diode into a single structure while utilizing the same silicon volume in both GCT and diode modes [9] \rightarrow 7. Each segment acts either as GCT cathode or diode anode.

This interdigitated integration results not only in better usage of the diode and GCT areas but also better thermal distribution, softer reverse recovery and lower leakage current compared with conven-



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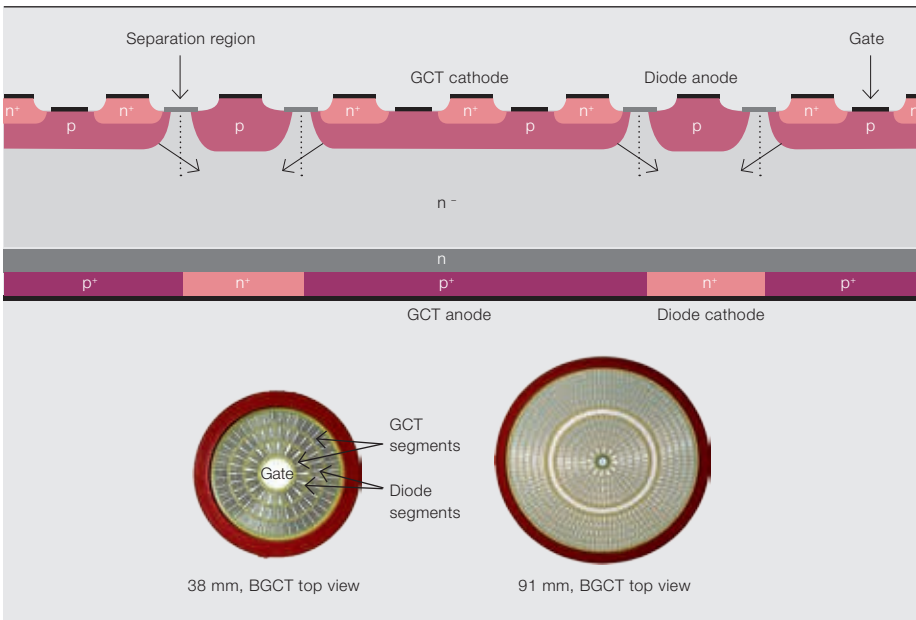
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7 Schematic cross-section of the BGCT and fabricated 38 mm and 91 mm, 4.5 kV BGCT prototypes



The introduction of the HPT platform has been hailed as a major step forward in improving IGCT SOA performance.

tional RC-IGCTs. The BGCT concept has been demonstrated experimentally with 38 mm, 4.5 kV as well as 91 mm, 4.5 kV

prototypes [10] and the results confirm the potential advantages of the BGCT over conventional RC-IGCT.

This review of recently introduced IGCT technologies with improved performance and functionalities provides only a glimpse of the promising field of IGCT technology. Power electronics systems designers face an exciting future of further device improvements, with the prospect of devices with even higher operational temperatures, even better reverse blocking and reverse conducting functionalities, lower losses delivered by a 1 V on-state, a wider range of voltage ratings and larger areas up to 150 mm and beyond.



Grid4EU

Laying the groundwork for the development of tomorrow's electricity grids

GUNNAR BJÖRKMAN, PETER NOGLIK, ERIK HAMRIN, JIRI NEDOMLEL – Grid4EU was an innovative, smart grids project proposed by a group of six European distribution system operators (DSOs) and carried out in close partnership with a set of electricity retailers, manufacturers and research organizations.

Running from November 2011 to January 2016, the project adopted a systematic approach to testing, in real size, some innovative concepts and technologies. It aimed to highlight and help overcome some of the barriers – whether they be technical, economic, societal, environmental or regulatory – to smart grids deployment.



Growing penetration of renewables across Europe’s distribution grid over the past few decades has led to growing challenges in maintaining the stability and reliability of the grid. Looking ahead, the European Commission (EC) has a goal to meet at least 40 percent of the continent’s demand for electrical power with renewables by 2030. To achieve this ambitious target, DSOs will need to make major changes to the way they run their networks.

Recognizing this, the EC brought together six major DSOs along with 21 specialist technology firms and academic partners under the Grid4EU project. It was the largest smart grid project funded by the EC to date and one in which ABB played a major role as an equipment provider and system developer. Grid4EU is shorthand for a “large-scale demonstration of advanced smart grid solutions

with wide replication and scalability potential” and its ultimate goal was to test the potential for smart grids in Europe and lay the foundations for large-scale roll-out of smart grid technology.

During the project, each of the six DSOs worked with partners to evaluate the real-life performance of different smart grid technologies in a variety of climates, grid topologies, population densities and regulatory conditions but also to assess issues like scalability, replicability and cost benefits.

The project adopted a systemic approach to test, in real life and size, how DSOs can dynamically manage electricity supply and demand. Such control is crucial for the integration of large amounts of renewable energy and empowers consumers to become active participants in their energy choices. Ultimately, tested solutions should increase the network’s efficiency, reliability, flexibility, and resilience → 1.

The project was structured to take into account the following limitations:

- Existing networks consist of long-life assets and equipment that cannot be removed or easily upgraded.

- In Europe, the technical, economical, societal and regulatory contexts for distribution grids vary significantly from country to country.

The following provides a technical description of the three demonstrators in which ABB was involved. In addition, three other demonstrators were undertaken – under the leadership of Iberdrola, ENEL and ERDF – in which other technological aspects were implemented. In addition, the project included a number of general work packages where issues like scalability, replicability and cost benefits were investigated. For more information on these,

The EC brought together six major DSOs along with 21 specialist technology firms and academic partners under the Grid4EU project.

and details of the ABB demonstrations and the general work packages, please refer to the Grid4EU website (www.grid4eu.eu) and the Grid4EU Final Report.

Demonstrator 1

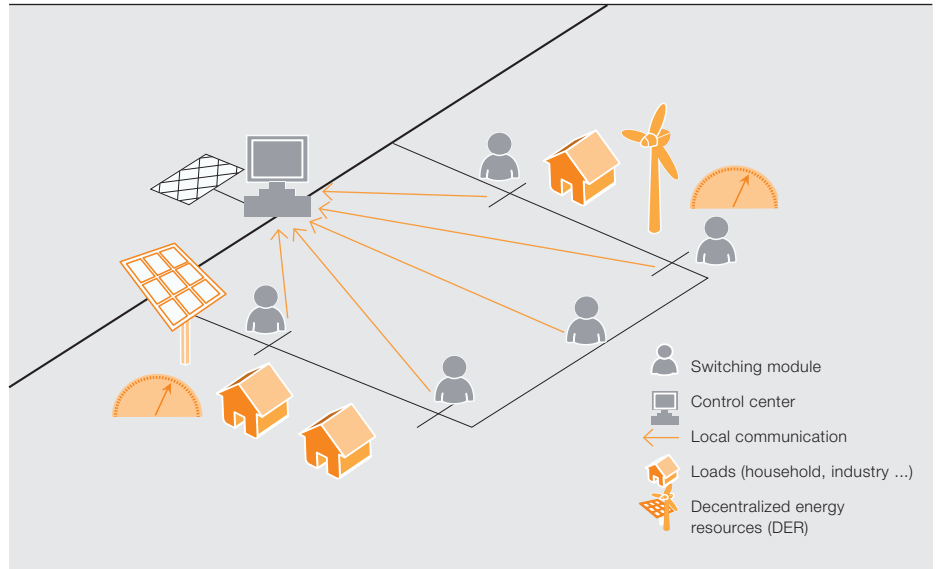
The principle behind Demonstrator 1 was that by increasing automation on the medium-voltage (MV) network, the grid will be able to reconfigure itself to optimize operations.

Title picture

The Grid4EU project helped the participants better understand the challenges associated with the future evolution of the European power grid.

The project adopted a systemic approach to test, in real life and size, how system operators can dynamically manage electricity supply and demand.

2 Project topography



Demonstrator 1 was led by RWE Deutschland AG with the support of ABB and the Technical University of Dortmund (TU Dortmund). The objectives were:

- To improve automation on the MV grid while enabling growth of distributed energy resources (DERs)
- To achieve higher reliability on the grid through faster recovery from outages while avoiding overloads and maintaining voltage stability
- To reduce network losses

Demonstrator 1 was located in Reken, a small city in North Rhine-Westphalia that was selected because the renewable energy generation there already exceeds the maximum load by around 20 percent, with further growth in renewables expected. Also, there was very little monitoring or automation already in place. Together, these aspects made Reken typical of the issues faced by many grid operators across Europe.

The basic idea of the project was to extend the automation level of the MV networks based on an autonomously acting multi-module system (MMS). In this scheme, decentralized modules provide measured values and a forecast of the load situation for the next few hours. Some of these modules are equipped with switching gear. The central module, in primary substations, collects all needed data and generates switching actions to move the sectioning point to fulfill the objectives. The possibility of autonomous switching allows dynamic topology reconfiguration, which is a new concept of operation → 2.

In this demonstration, ABB was responsible for developing the secondary equipment and providing a secured communication. As a basic component, the remote terminal unit (RTU) RTU540 family was used, supported by the measurement units 560CVD11 and 560CVD03 → 3.

These modules were built into several types of secondary substation, beginning with a new compact station over a walk-in station using special cabinets containing the switchgear → 4. The corresponding lean control center, in the primary substations, consists of five RTU560CMU05s in a rack configuration.

The software for the MMS was developed – with support from ABB – by the TU Dortmund. To be as flexible as possible, the whole software was programmed using a programmable logic controller (PLC). One important aspect of the development was that the functionality had to be tested before first tests were carried out in the field. Therefore, a “hardware-in-the-loop” simulation was established containing the same number of modules as in the field and connected to a complete grid simulation.

First results showed that the MMS can delay the expansion of the Reken grid for a minimum of three to four years, and reduce the losses by 28 percent. Due to these positive results, RWE is considering a second installation of the MMS.



First results showed that the MMS can delay the expansion of the Reken grid for a minimum of three to four years, and reduce the losses by 28 percent.

Demonstrator 2

The main focus of Demonstrator 2, led by Vattenfall, was to improve the monitoring of a low-voltage (LV) network. To do this, the solution uses the ABB MicroSCADA Pro platform with the ABB DMS600 and the ABB SYS600 Historian. This software stack collects and displays data from RTUs located in secondary substations as well as from smart meters on customer premises.

Combining this information, the system can provide functionalities such as power quality reporting, outage detection, and evaluation of technical and non-technical losses. The system also has the possibility to include customer meter notifications in the DMS600, making it possible for operators to get instant information about incidents at customer sites. The RTUs communicate with built-in GPRS modems and use the IEC 60870-5-104 protocol to send data to the control center.

During the demonstration, over 100 stations were retrofitted with ABB's RTU cabinets. They have been designed to be robust, cheap and easy to install. In this context, "easy" means that one type of cabinet is made to fit a range of different types of substations. A range of compact RTU cabinets was specially designed as part of the project.

For an operator monitoring LV networks, it is important that all information presented is meaningful and easy to grasp. In Demonstrator 2, the operators of the DSO were involved in the process of

identifying the functionality that was of highest interest to them → 5. Among these functions, the outage detection function that provides data on the status of stations, groups and even the individual phases of the groups in a substation, is notable → 6. Functionality to compare energy billed with energy supplied and a basic framework for power quality data evaluation is also provided.

With Demonstrator 2, the partners proved that it is possible to develop and deliver cost-efficient tools for LV network monitoring. The cost/benefit analysis performed by the DSO shows that the system actively helps reduce the system average interruption duration index (SAIDI) values for the DSO by 5 to 12 percent.

The findings of Demonstrator 2 will form a basis for ABB's involvement in the upcoming smart grid project, Upgrid, and will contribute to ABB's grid automation portfolio in Sweden.

Demonstrator 5

Demonstrator 5, led by ČEZ Distribuce of the Czech Republic, was designed and implemented to demonstrate the management of island operation, power quality measurement and failures on MV and LV grids. Demonstrator 5 also examined the influence of electric vehicle charging on a distribution network. This was achieved mainly by the installation of remote-controlled devices, introduction of infrastructure enabling fast communication and modifications in the SCADA (supervisory control and data



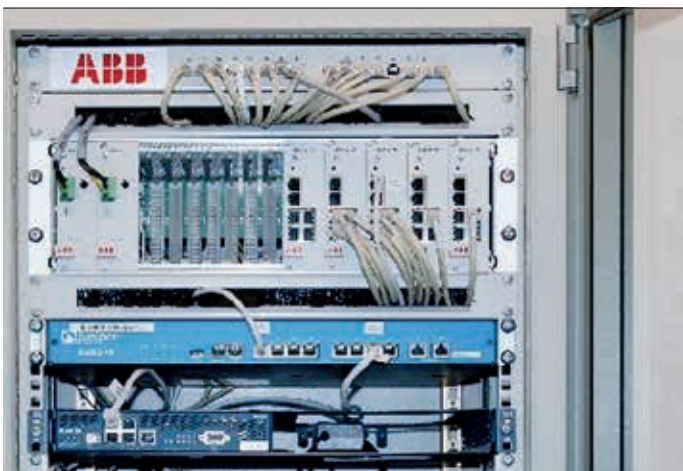
4a New intelligent compact substation



4b Dedicated cabinet solution containing new switchgear and "intelligence" added to existing substation



4c Replacement of existing switchgear in a walk-in substation



4d Master RTU in the primary substation

With Demonstrator 2, the partners proved that it is possible to develop and deliver cost-efficient tools for LV network monitoring.

acquisition) system to support automated operation. Balancing power supply and power consumption during island operation and switching to/from island operation was performed by an automated system.

Automated MV failure management minimizes impact on customers by using new equipment installed in distribution transformers (DTs), namely six units in Vrčlabí equipped with circuit breakers, RTUs and IEDs (disconnection points). Other "non-disconnection" DTs are equipped with load-break switches, RTUs and fault current indicators on MV outgoing feeders. MV-level automation required implementation of communication routes and logic in the local SCADA. In total, 27 newly reconstructed DTs were equipped with components to enable Demonstration 5 functionalities.

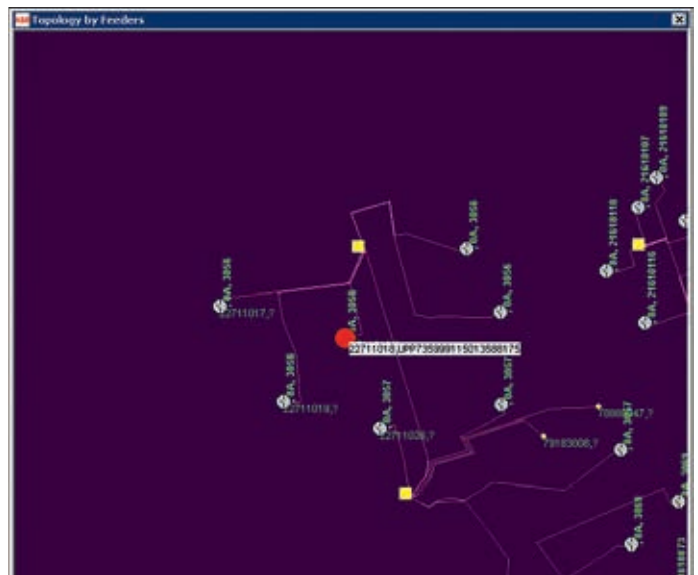
The implemented functionality results in the smallest possible number of customers being impacted by failures. Ideally, the new functionality will eliminate power outages completely and significantly reduce the time needed for fault localization and isolation. The reduction in time required for fault localization and isolation, according to simulation tests based on 18 months of fault data, amounted to 85 percent.

Islanding functionality was selected as a solution for areas prone to failures because of climatic or geographical conditions. Islanding was tested at the 10kV level and, after network unification, also on the 35kV MV network in the urban area of Vrčlabí. The power supply during island operation was provided by a CHP (combined heat and power) unit of 1.56 MW capacity installed within the island area. The aim of island operation was to test the capability of a predefined network to disconnect from the surrounding MV grid in the

5 The event interface allows the operator to navigate through meter alarms and sort events

Code	LV customer code	LV network	State	Time Stamp
UPF73599115013691647	2259932	<S5000075	Meter down	2015-11-09 21:46:4
UPF73599115014105909	72493181	<S5000085	Meter down	2015-11-09 21:59:3
UPF73599114971957874	70303073	<S5000014	Meter down	2015-11-09 22:01:2
UPF73599114971958475	70303073	<S5000014	Meter down	2015-11-09 22:04:3
UPF73599115013649844	72494950	<S5000010	Overcurrent phase 1	2015-11-09 22:12:0
UPF73599114971888959	72494969	<S5000038	Overcurrent phase 2	2015-11-09 22:33:0
UPF73599114971957981	70303073	<S5000014	Meter down	2015-11-09 22:36:3
UPF73599115014105145	72501790	<S5000017	Meter down	2015-11-09 22:36:3
UPF73599114971910985	72228362	<S5000007	Overcurrent phase 1	2015-11-09 22:40:2
UPF73599115013799999	72497238	<S5000032	Overcurrent phase 1	2015-11-09 22:45:2
UPF73599115013660315	72494073	<S5000073	Overcurrent phase 3	2015-11-09 23:15:3
UPF73599114972173625	75634105	<S5000038	Overcurrent phase 3	2015-11-09 23:24:2
UPF73599115013580175	22711018	<S5000064	Meter down	2015-11-09 23:50:1
UPF73599115014236457	22711018	<S5000064	Meter down	2015-11-09 23:51:5
UPF73599115013660802	72493969	<S5000073	Overcurrent phase 3	2015-11-09 23:58:11
UPF73599114972141900	74819495	<S5000058	Meter down	2015-11-09 23:58:4
UPF73599114971958452	70303073	<S5000014	Meter down	2015-11-10 00:00:3
UPF73599115014127237	72493156	<S5000017	Overcurrent phase 2	2015-11-10 00:14:4
UPF73599115014130695	72493154	<S5000015	Overcurrent phase 3	2015-11-10 00:21:2
UPF73599115013777005	72504450	<S5000013	Device tampering	2015-11-10 00:25:11
UPF73599115013992215	72496006	<S5000132	Overcurrent phase 1	2015-11-10 00:29:4
UPF73599114971864090	71704430	<S5000075	Meter down	2015-11-10 00:39:5
UPF73599115013886629	22893309	<S5000070	Phase loss phase 2	2015-11-10 02:33:4
UPF73599114972141900	74819495	<S5000058	Meter down	2015-11-10 02:53:9
UPF73599114972141909	74819495	<S5000058	Meter down	2015-11-10 04:02:5

6 The DMS600 view of individual customer meters, with one event indicated by a red dot



case of failure on the higher voltage level and to maintain balanced operation in the island. Preconditions for a successful island operation are: connection of sufficient power generation, adaptation of protection settings, existence of a communication infrastructure and deployment of automation equipment. The equipment must then be able to undertake three tasks:

- Disconnect the predefined (island) area
- Balance power production and consumption in the island during the failure duration
- Reconnect the islanded area to the standard MV grid

Island operation was proven by two successful functional tests, the first of which took place in June 2014 at the 10kV voltage level and the second in June 2015 at the 35kV voltage level (after reconstruction of the grid and voltage unification within Vrchlaby).

The Grid4EU project has shown, in real-life installations, that smart grid technology is available and can function under many different grid and climatic conditions throughout Europe. Moreover, the project focused not only on new smart grid functionalities but also on larger-scale deployment. However, the project has also shown that many challenges around scalability, replicability and cost benefits remain to be solved. In the panel discussion at the final event in Paris in January 2016, the general managers

of the participating DSOs stated that “this is the time to be brave and make investments in the smart grid. The major challenges for us are the economics and the attitude of the personnel involved. However, these challenges will be overcome and the investments will and must start.”

The work was characterized by very good cooperation between the DSOs and the other players. This might have been one of the goals of the EC when initiating Grid4EU. For ABB, the investments made in the smart grid domain and relations created within the project will bring increased business volumes. ABB has already seen follow-up orders directly connected to its participation in the project.

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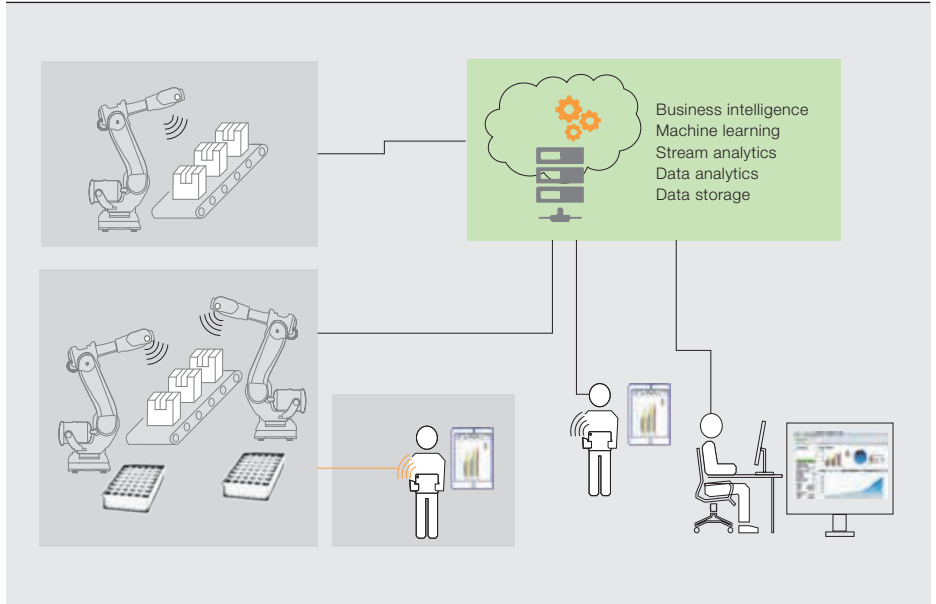
Cloud robotics

Smart robots leverage the Internet of Things, Services and People from edge to cloud

HONGYU PEI-BREIVOLD, KRISTIAN SANDSTRÖM, LARISA RIZVANOVIC, MARKO LEHTOLA, SAAD AZHAR, ROGER KULLÄNG, MAGNUS LARSSON – Few doubt that, in the near future, robotics will fundamentally change production systems and dramatically increase their level of automation. To bring this transformation about, the human effort required to set up automated tasks needs to be greatly reduced. In other words, robots will have to figure out for themselves how to solve problems and adapt to dynamic environments. This step forward can be made by exploiting the Internet of Things, Services and People (IoTSP). The IoTSP facilitates the creation of new technology and novel business models that make large-scale data propagation, stream analytics and machine learning a reality.

Title picture

The IoTSP will enable robots to be used in a much wider variety of tasks than is currently the case.



The importance of IoT and cloud technologies

With commercial Internet of Things (IoT) and cloud technologies, it is currently possible to transport large amounts of sensor data and other information from devices to data centers. Within the data center, stream analytics can be used to process the device information in real time for filtering, selection and aggregation.

The processed information can be fed into different cloud services such as business intelligence (BI) tools that turn raw data into tables and graphs – giving instant insight into production situations. The information can also be used by machine-learning packages to make predictions – for process optimization or predictive maintenance, for example. Many such highly scalable and cost-effective services that can analyze large quantities of data in data centers are already available.

It is, of course, imperative that such analysis is done safely, securely and with full data integrity. Also, reliability and availability levels must be maintained.

By increasing robot capabilities using IoT and cloud technologies, and by locating most storage, analysis and large-scale

computation in data centers, future requirements on robot intelligence can most likely be met without any increase in the cost or physical size of controllers.

Motivation example

The ways in which the IoTSP can help improve operational performance in robotic production scenarios can be illustrated by considering an example: In a small-part assembly cell, two robots are working collaboratively. Small parts come in on two separate feeders. The robots pick parts from their respective feeders, assemble them and put the assembly on a conveyor belt. An operator

There are many manufacturing or assembly scenarios that would benefit from robotic automation, but that are challenging to automate.

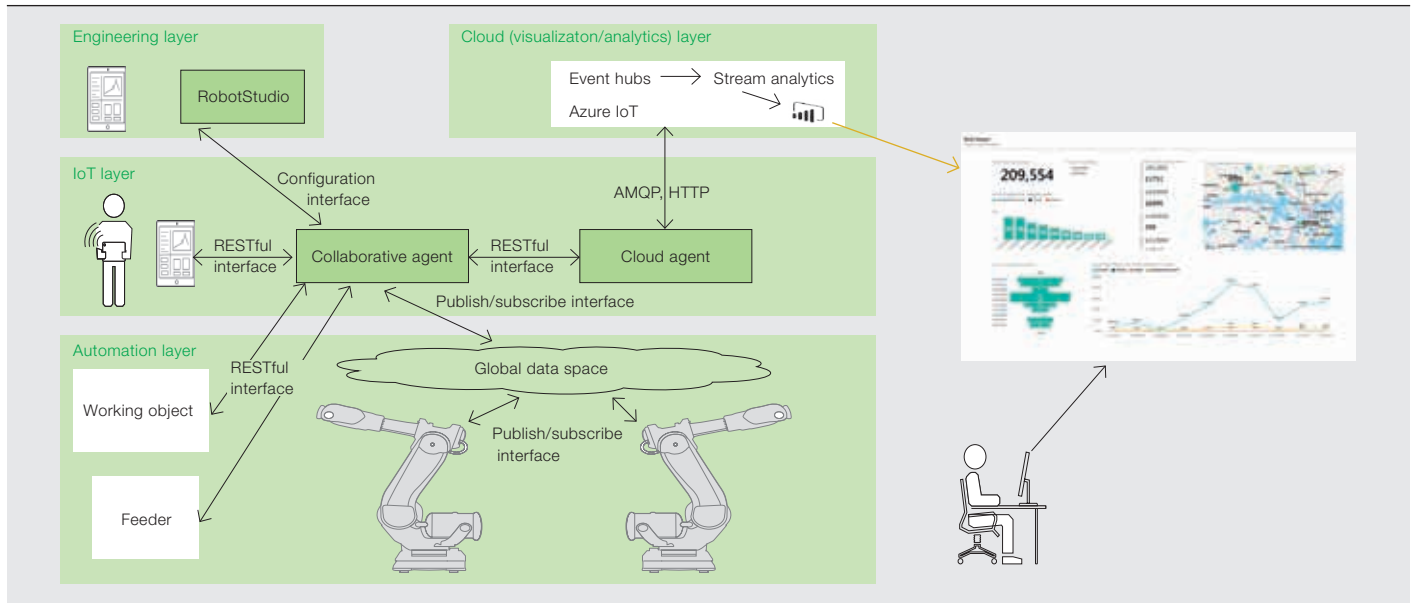
or a production manager can use a mobile device to monitor the production status and obtain information about the devices in the production cell at any time and from any location. Device predictive KPIs (key performance indicators) can also be checked so that maintenance decisions can be made.

In the case of a sudden disturbance – such as one feeder slowing down due to an assembly part supply problem – infor-

It is predicted that the use of robotics in manufacturing and automation will increase significantly in the near future and that this growth will drive a major expansion of the industrial robot market [1]. These expectations are predicated on industrial robots finding their way into many more automation scenarios than is currently the case.

Today, industrial robots can tirelessly repeat complex tasks with high precision – for example, welding, painting, automobile production and certain types of assembly. However, there are many other manufacturing or assembly scenarios that would benefit from robotic automation but that are challenging to automate. This can be due to, for example, short production runs or environments that are not well enough controlled. In many of these cases, humans currently play an important role. If the use of robots is to be extended to these challenging scenarios, robots have to become more flexible, easier to program and more autonomous. Further, at the same time as robots need to more intelligently use information provided by humans and the environment, robots also need to channel information to humans in a more intelligent way. They can do this by analyzing known information, extracting knowledge from it and making that knowledge easily accessible also to non-experts.

2 A scalable collaboration platform: system architecture



If the use of robots is to be extended to more challenging scenarios, robots have to become more flexible, easier to program and more autonomous.

mation is exchanged between the robots, feeders and conveyor belt, which all adapt their rate of operation to accommodate the new circumstances. The operator is notified of the situation via his mobile device. If operational performance is within a certain tolerance, he may decide not to interrupt the production process. Or, in the case of a faulty feeder, he may check the KPIs of the devices and find out that a service technician is shortly due to replace some parts on that feeder. This may mean the system can be run in its current state until the service occurs, meaning a possibly costly immediate production shutdown can be avoided.

Solution strategy

The scenario just described involves industrial robotics control, networks of sensors and actuators that demand real-time and predictable temporal behavior

of the robot control system. A further requirement is a set of intelligent robot service features that can be deployed using IoT technologies to improve operational performance on the factory floor. One way to make this constellation of requirements a reality is to:

- Enable data sharing among connected robots and other devices within a production cell
- Host real-time robot applications that require very low and predictable latency at the network edge or in the robot controllers.
- Connect to a remote data center for large-scale BI and data analytic capabilities

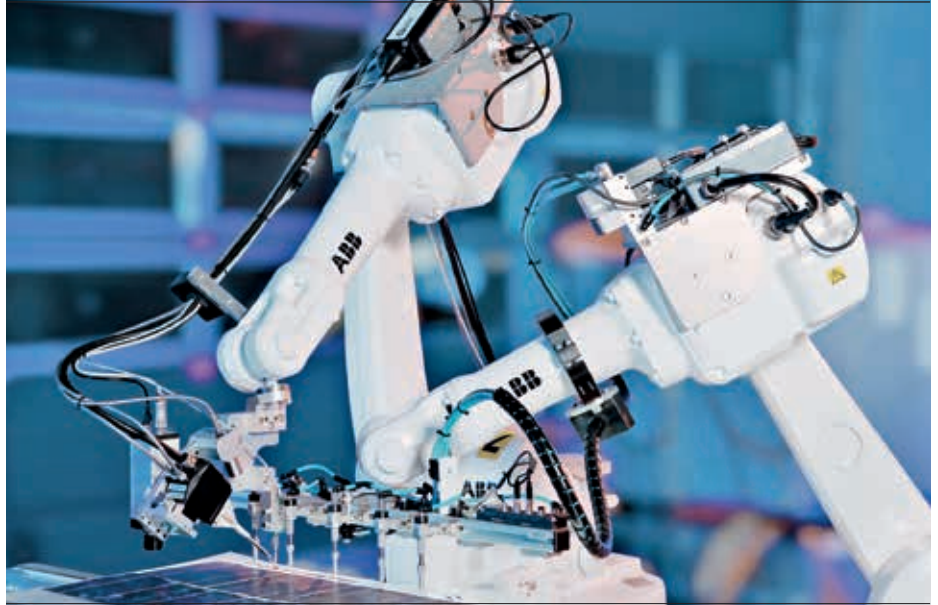
In this way, additional cloud-based service solutions can be offered to customers, eg, easy access to, and visualization of, production data in the cloud. Moreover, by utilizing cloud infrastructures that can provide elastic computation resources and storage, new intelligent robot services centralized on BI and data analytics can be developed → 1. Examples of these are machine learning and advanced analysis of large datasets of robot information collected during operation life cycles.

End-to-end concept and technical solution

To realize the solution strategy just described, ABB has designed a scalable collaboration platform that enables information sharing between connected industrial robots, other industrial devices in

Using IoT technology to connect things, services and people will change the everyday life of users and enable intelligent industrial operations.

3 The platform makes it easy to configure robotic setups



a production cell and people → 2. The platform, when it becomes a final product, will offer ease of use with respect to configuration, eg, discovery of robots, connecting robots for collaboration and service provision → 3.

In the platform's automation layer, real-time data exchange between robots is enabled through publish-subscribe middleware technology, eg, the data distribution service (DDS) framework. One device publishes information on a topic and other interested devices can subscribe to receive it. Subscriber devices do not need to know where information comes from as context data is also provided to tell the subscriber devices what to do with the information.

The devices exchange information through a virtual global data space. The robots and the feeder mentioned in the example above could, for instance, exchange information (current position, speed, etc.) through this global data space.

Not all devices in a production cell may be suitable for participation in a publish/subscribe framework. This can be due to, for example, accessibility limitations of third-party devices or finite computing power. Such devices can, however, in-

teract with robots and other devices through a lightweight RESTful interface, which is provided by a collaborative agent in the IoT layer. RESTful interfaces are based on REST (representational state transfer) – a Web architecture that takes up less bandwidth than other equivalent architectures and that simplifies connection of diverse clients. The collaborative agent can be deployed on any device (including the robot controller) on which the published/subscribe framework can be installed. The RESTful interface is also employed by the differ-

IoTSP is providing a new way of realizing business agility and a faster pace of innovation.

ent mobile devices that are used for production cell monitoring, as well as by a cloud agent. The cloud agent, deployed on a robot controller or some other device in the production cell, uses AMQP (advanced message queuing protocol) and HTTP as an interface to send data to or interact with the cloud layer.

The proposed cloud layer in the architecture enables increased service opportunities by connecting the devices in the production cell, or the production cell itself, to the cloud. For this particular robot collaboration platform, Microsoft Azure IoT Suite [2] is used, which offers a broad range of capabilities – eg, data

The proposed cloud layer in the architecture enables increased service opportunities by connecting the devices in the production cell, or the production cell itself, to the cloud.

collection from devices, stream analytics, machine learning, storage and data presentation. In particular, ABB has exploited Azure IoT Suite to provide a production data visualization and monitoring service. The solution consists of an IoT client, an event hub (which acts as an event ingester),

stream analytics and Power BI (a self-service BI solution). The cloud agent sends robot data to the event hub. The stream analytics ser-

vice consumes that data and enables stream processing logic (in a simple SQL-like language) to be run. The results of this processing are sent to Power BI, which carries out the monitoring and visualization of the production data.

In the engineering layer, two types of applications are distinguished: Web-based simplified configuration applications and RobotStudio-based applications for advanced configuration of the robots and the rest of the production.

Grasping the future

Using IoT technology to connect things, services and people will change the everyday life of users and enable intelligent industrial operations. Imagine that the small parts in the example scenario described earlier have attached to them

smart tags that allow, via wireless communication, the transmission of certain types of information – for example, CAD drawings, item description and handling instructions – to robots and operators. The dissemination of such information could, for example, allow the adjustment

By using IoT and cloud technologies, future requirements on robot intelligence can most likely be met without any increase in the cost or physical size of controllers.

of robot grasp planning with the available grippers when there are changes in the types of small parts. At present, this is an offline and manual task.

The key idea of IoTSP is to obtain information about devices and the environment, analyze data from the physical and virtual world for optimized operations, and provide enhanced services to users. By delivering new end-customer software services and experiences that are based on information extracted from multiple connected devices, IoTSP is providing a new way of realizing business agility and a faster pace of innovation.

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A combined future

Microgrids with renewable power integration

CRAIG BLIZARD, ZOHEIR RABIA – Photovoltaic-diesel (PVD) hybrid solutions represent a key market segment that is discernibly influenced by the reduction in the manufacturing costs of the photovoltaics (PVs). In response to recent PV module price drops and diesel price increases over time, PV diesel hybrid solutions are beginning to gain acceptance around the world as an economically attractive alternative to grid extension and mini-grid systems that operate solely on diesel.



The high cost of and strong reliance on diesel fuel in countries belonging to Sub-Saharan Africa, Latin America and Southeast Asia, as well as their geographic remoteness, insular distribution and topography are key factors that make PVD solutions ideal for customers in these locations.

The ABB PVD solution, which includes the PVD automation and solar inverters, can be setup as an additional source of energy in these locations thereby maximizing fuel savings and reducing running time costs. The current low prices of PV systems are an added bonus that result in a quick return on investment.

The PVD energy solution provides customers with a compelling alternative to the sole use of diesel-powered mini-

grids. Worldwide there are tens of gigawatts (GW) worth of power in isolated diesel-based microgrids that would lend themselves to be retrofitted through the integration of renewable energy technologies such as the PVD. This existing

either connected to the main power grid or in “island” mode where they neither draw power from the main grid nor supply power to it. Microgrids are a general classification of small, self-sufficient power networks that serve consumers.

Using the knowledge and benefits of the microgrid plus system, PVD 1.0 has been designed with a focus on cost effectiveness as well as engineering simplicity.

The microgrid concept is not new and yet its commercial significance today is only now becoming apparent. During the age of industrialization, centralized grids that served a large number of consumers from a

diesel mini-grid market represents an enormous economic potential for years to come.

single primary power source made more economic sense than did microgrids. It was not feasible for most municipalities, colleges, or other such entities to build and manage their own small power plants and distribution networks. Microgrids weren't a cost-effective solution for everyday energy needs. Reliance on

Title picture

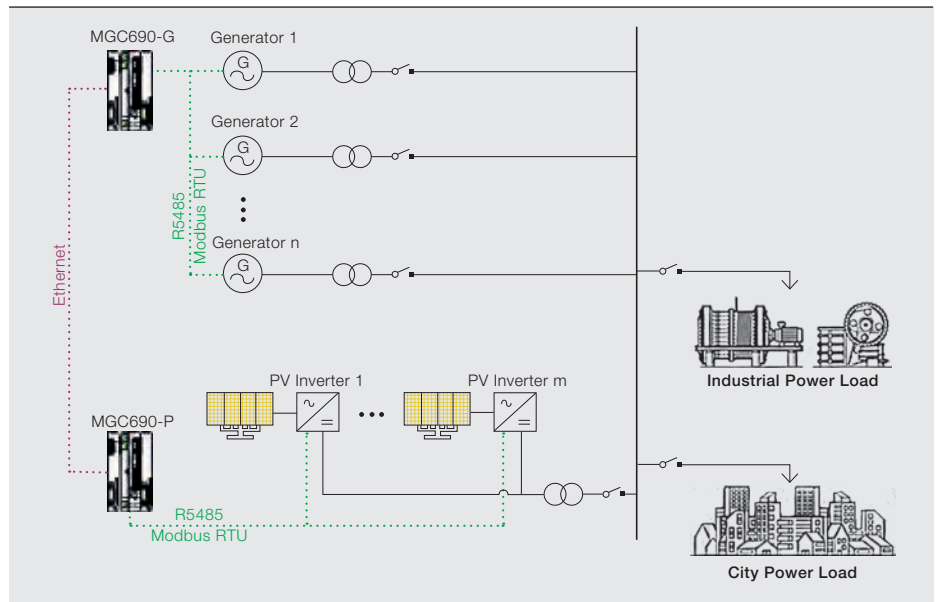
ABB's photovoltaic-diesel hybrid system is ideal for reliable power generation in remote geographic locations.

Microgrids

Microgrids refer to distributed energy resources and loads that can be operated in a controlled, coordinated way

Peak solar penetrations of around 30 – 50 percent are typically achievable, corresponding to net renewable energy and fuel offsets of up to 15 percent during a year.

1 Conceptualized hybrid plant design for municipalities and commercial industries



power sources such as diesel generators was deemed suitable during mission critical situations such as during energy disruptions. Today however, microgrids that focus on the integration and effective management of renewable energy resources are gaining significance. Their potential as a sensible commercial solution to everyday power needs can be beneficial under many different circumstances.

ABB microgrid expertise

ABB is an expert on microgrids, having accumulated more than 25 years of knowledge and experience and having successfully executed more than 30 projects. ABB's commitment to microgrids has been demonstrated through ongoing research and development, investment and product innovation. This work has been applied to the field of plant automation for conventional and modern power generation technologies, as well as power system technologies such as grid-stabilization and energy storage systems.

Photovoltaic diesel

ABB's microgrid plus product line is a dedicated automation platform designed to manage power generation systems characterized by different combinations of conventional and renewable energy technologies such as diesel, gas, geothermal, hydro, wind, solar and energy storage systems. Microgrids can be effectively managed through the incorporation of the Microgrid Plus product line. The result is the ultimate balance of power

quality and security, while ensuring ideal renewable energy utilization.

ABB's PVD is the newest addition to the microgrid automation product palette. PVD has been created by ABB specifically for the automation of hybrid plant solutions comprising solar PV and fossil fuel generators. Using the knowledge and benefits of the Microgrid Plus system, PVD has been designed with a focus on cost effectiveness as well as engineering simplicity. This design philosophy has resulted in a reduction in the number of components and drastically simplified the project delivery model.

Because minimizing costs is at the forefront of PVD design, the end user can deploy a complete automation solution out of the box. Pre-engineered libraries and minimal site commissioning costs as well as a low component count mean that no specialized skills are required and additional engineering development costs are unnecessary.

In terms of performance, PVD has been designed with medium penetration renewable technologies in mind. Peak solar penetrations of around 30 – 50 percent are typically achievable. This corresponds to net renewable energy and fuel offsets of up to 15 percent during a year, a clear performance benefit.

In addition, the PVD offers a consistent deployment method and setup for control systems ranging from one to 16 genera-



tors and one to 32 inverters in order to accommodate various plant configurations in a simple and effective manner thereby meeting an array of customer needs → 1.

ABB inverters

Both string inverters and central inverters can be used in a PVD application and ABB has developed products to manage solar generators. Two types of ABB inverters have been combined with the PVD: the three-phase string inverter

Equipped with extensive electrical and mechanical protection, central inverters are engineered to provide a long and reliable service life of at least 20 years.

(TRIO) for string inverters and inverters of the PVS class for central inverters. Both inverters have been tested and verified on interface maps with PVD.

These inverters have been selected from the full range of products and services that ABB offers for the generation, transmission and distribution of solar energy –



in both solar panel systems connected to the grid and hybrid systems – operating along the entire solar value chain.

ABB string inverters

The TRIO 20.0 and 27.6 are part of the TRIO family of inverters that represent the most efficient solution for both commercial PV applications and large-scale ground-mounted PV plant energy harvesting solutions → 2. These string inverters are ideally suited for small and medium industries, hotels and resorts and warehouses and commercial buildings located in remote areas.

Furthermore, the TRIO's high dependability, thanks to the natural convection cooling and IP65 environmental protection rating, make it resistant to extreme environmental conditions and therefore ideal for external use.

In addition to proven reliability, high efficiency (up to 98.2 percent) and broad input voltage range, the TRIO inverters are advantageous for the aforementioned locations due to their design configuration flexibility, which allows them to fit in a variety of solar park layouts. TRIO inverters also offer two independent maximum power point trackers (MPPT), which guarantee optimal energy output from two sub-arrays, characterized by different orientations. Furthermore, this inverter solution offers customers rapid installation due to the presence of an easily detachable wiring box.

As of today TRIO inverters with a cumulative power rating of approximately 4 GW have been shipped all over the world, making these inverters a valuable tool to drive energy needs for customers in isolated communities.

ABB central inverters

For multi-megawatt plants especially in the mining and heavy industry segment, central inverters are highly rated by both system integrators and end-users who require high performance solar inverters for utility-scale PV power plants and a maximum return on investment over the life cycle of a power plant.

The PVS 800 central inverter consists of proven components and has a long track record of performance excellence for both demanding applications and harsh environments → 3. Equipped with extensive electrical and mechanical protection, the inverters are engineered to provide a long and reliable service life of at least 20 years.

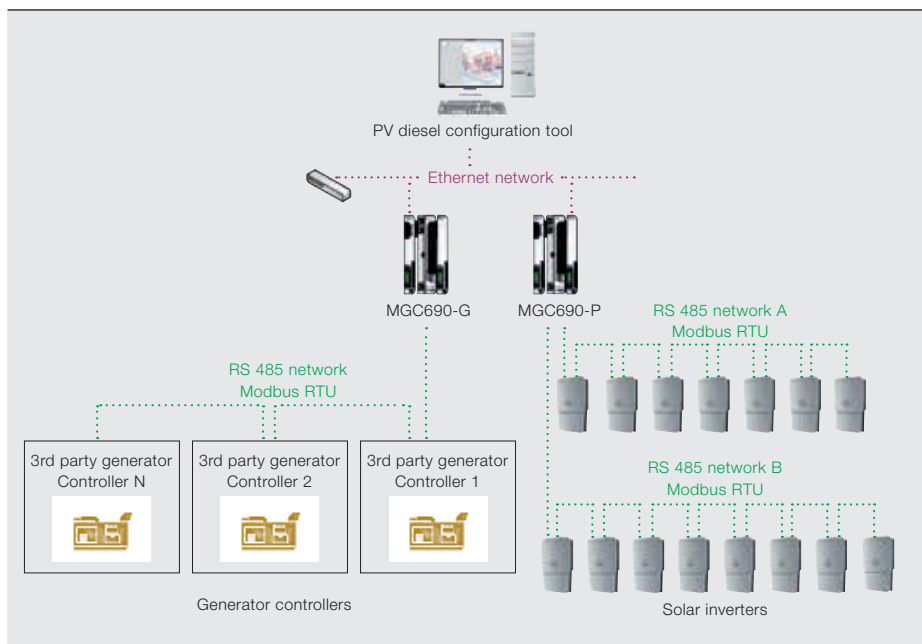
In addition, ABB central inverters provide high total performance based on high efficiency, low auxiliary power consumption, verified reliability and ABB's experienced worldwide service organization. The inverters are available from 100 kW up to 1,000 kW, and are optimized for use in multi-megawatt PV power plants.

PVD package solution

PVD consists of dedicated controllers packaged as a complete kit solution designed to facilitate integration into new and previously developed industrial installations → 4. The controllers have been classified according to two distinct functions, firstly the G (or generator) controller responsible for automation of fossil fuel generators and the P (or PV) controller responsible for managing the PV generation.

For the purposes of site configuration and commissioning duties, a dedicated tool is included as a key component of

4 ABB's control system network is a complete automation solution.



the package → 5. The tool allows the user to carry out basic functions such as setting parameters and making controller mode changes. In addition, the user can implement high-level, real-time system status checks and view key performance indicators, without the need to install a dedicated Supervisory Control and Data Acquisition (SCADA) package. Nonetheless if the customer requires a SCADA system, the PVD can be easily tailored with a SCADA solution to the customer's needs.

At its core, the PVD solution utilizes MGC690 controllers, which consist of control hardware and software designed to be robust and reliable and to meet the stringent requirements of total plant automation. Microgrid systems based on MGC690 feature high-density DIN-rail packaging, a flexible system architecture, high performance, real-time control, and fast Ethernet-based network communications.

To facilitate device-to-device communications within PVD, messages between the generator and PV controllers are transmitted via a dedicated 100MB Ethernet connection. This configuration alleviates the need to interact with or interrupt existing site communication infrastructure. Downstream communications between the controllers and the field are serviced by dedicated Modbus RTU links pre-terminated into the controller.

ABB's PVD system utilizes MGC690 controllers, which consist of control hardware and software designed to be robust and reliable and meet the stringent requirements of total plant automation.

The MGC690 controller's industrial grade embedded system architecture allows the PVD solution to execute the entire plant automation logic rapidly, in under 100ms. The low power consumption coupled with the extended operating temperature range enables the MGC690 to be installed in sealed enclosures without the need for fans, louvers, air filters or other forced cooling equipment. This eliminates maintenance requirements associated with cooling systems and significantly reduces operating costs associated with control system equipment, which is particularly advantageous for microgrid customers.

5 Packaged key components ensure optimal automation.



ABB's PVD solution with the PVD controller and choice of string or central solar inverters provides a reliable, efficient and cost-effective alternative to mini-grids and grid extensions that operate solely on fossil fuels. The engineered design and flexibility of configuration make these two different power solution products highly suitable for small to mid-size industries, geographically isolated areas or in utility-scale power plants. The MGC690 and the PVD provide consumers with the benefits of rapid, accurate and uninterrupted control of their microgrid systems enabling a stable and reliable power supply. This in combination with the low price of photovoltaics, fuel savings and low running time costs of implementing a PVD solution lead to a quick return on investment and value for customers.

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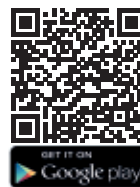
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Innovation

A technological breakthrough has its greatest impact when it enables people to do things they could not do previously, or permits them to improve the efficiency of what they already do. This can mean they achieve the same or a better result with greater ease, fewer resources, lower costs or while improving the safety or environmental footprint or flow of information.

The first issue of ABB Review in 2017 will be dedicated to the company's recent and ongoing innovations – breakthroughs that will improve the operations, ease, environmental balance or safety of the businesses of its customers. Topics covered range from a leakage detector for pipelines to wireless sensors for home automation, and from a new eco-friendly alternative to SF₆ for gas-insulated switchgear to a new series of robots.

Read about these stories and more in ABB Review 1/17.



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Innovation



- 6 Innovation highlights**
ABB's top innovations for 2016
- 12 Small wonder**
Station service voltage transformers for small power requirements
- 18 A flexible friend**
ABB's flexible tank concept for transformers mitigates rupture risk
- 23 Protect and survive**
Fault protection analysis in low-voltage DC microgrids with photovoltaic generators
- 30 Test drive**
ABB's new test laboratory lets customers optimize motor/drive combinations
- 34 Driving force**
Rare-earth-free electric motors with ultrahigh efficiencies deliver sustainable and reliable solutions
- 41 Twist off**
Damping torsional oscillations at the intersection of variable-speed drives and elastic mechanical systems
- 49 Visionary**
3-D visualization enhances production operations
- 53 Pulp mill optimization no longer pulp fiction**
Producing high-quality pulp consistently with advanced process control
- 60 Alarming discoveries**
Improving operator effectiveness through alarm life-cycle support
- 65 From paper to digital**
A research project for extracting object-oriented descriptions of piping and instrumentation diagrams
- 70 Our readers have spoken**
Presenting the results of our readership survey

Food and beverage



- 6 A healthy choice**
ABB's close relationship with the food and beverage industry is getting closer
- 9 When bytes meet bites**
What the Internet of Things, Services and People means for the food and beverage industry
- 14 Mix and MES**
An ABB manufacturing execution system raises productivity for DSM Nutritional Products
- 17 Assembling flavors**
Industry 4.0 based on IoTSP enables Automation Builder to rapidly virtualize discrete production processes and machinery in the food industry and beyond
- 20 A safe investment**
Food-safe components in washdown applications
- 24 Palletizing for the palate**
Selecting ABB's IRB 460 robot stacks up
- 28 An ingredient called innovation**
Innovations for the food and beverage industry
- 30 Fish tale**
ABB maintenance and operational services for Marine Harvest
- 34 Recipe for success**
Simultaneous mass flow rate and density measurement for the food and beverage industry
- 37 Same again?**
Consistent flavor is essential in any distilling or brewing operation
- 40 The whey forward**
Reliable and accurate instrumentation for the dairy industry
- 45 Food power**
ABB's rugged UPS PowerLine DPA ensures food and beverage production facilities keep running
- 50 Stirred, not shaken**
Ultralow harmonic drives keep harmful harmonics out of food and beverages
- 52 125 years**
ABB celebrates 125 years in Switzerland
- 55 Power semiconductors**
The past and present of power semiconductors at ABB
- 61 Integrating IT and OT**
Leveraging operational technology integration with Decathlon Services
- 68 AirPlus™**
An alternative to SF₆ as an insulation and switching medium in electrical switchgear
- 73 Putting a damper on resonance**
Advanced control methods guarantee stable operation of grid-connected low-voltage converters

Two anniversaries



- 7 125 years and a centennial**
ABB celebrates 125 years' existence in Switzerland and 100 years of corporate research
- 13 Brainforce one**
100 years of ABB's first Corporate Research Center
- 16 Driving ideas**
Electric motors represent a field rich in ABB innovation
- 17 Digital variable speed drives**
- 19 Softstarters**
- 21 The leading edge of motor development**
- 23 A direct link**
HVDC technology for better power transmission
- 24 Efficient power transfer with HVDC Light®**
- 27 Ultrafast disconnecter for hybrid HVDC circuit breaker**
- 29 Sophisticated HVDC extruded cable technology**
- 31 Transforming and changing**
Transformer insulation science and innovative tap changers for high-power applications
- 32 Vacuum-based OLTCs**
- 35 Fundamental research in UHVDC converter transformers**
- 38 Microgrids**
How microgrids can cut costs, emissions and enhance reliability
- 41 Robot bio**
The life and times of the electrical industrial robot
- 45 A stirring history**
Sustained innovation sums up the history of ABB's electromagnetic products
- 49 Sense of ore**
Mining 2.0 – Automation solutions for the mining industry
- 55 A new compact HVDC solution for offshore wind**
HVDC offshore wind compact solution with half the weight and AC platforms eliminated
- 57 Local savings**
Energy storage leads the way for accessible solar in the home
- 62 Unlocking value in storage systems**
A large-scale case study of a battery/diesel grid-connected microgrid

Transportation



- 6 Cities take charge**
Making the case for the electrification of urban public transportation
- 8 Charged in a flash**
Optimization of batteries for a flash-charged bus
- 13 Green park**
Krka national park, Croatia, is the first national park in the world to install ABB Terra 53 fast DC/AC chargers
- 16 Electrifying history**
A long tradition in electric railway engineering
- 25 Weight loss program**
ABB's Effilight® traction transformer delivers less weight and losses and needs up to 70 percent less oil
- 30 Efficiency that climbs mountains**
Cutting the energy consumption of the Allegra trains
- 35 Peak power**
ABB's ZX0 medium-voltage switchgear and PMA cable protection for the Gotthard Base Tunnel
- 40 Record breaker**
ABB to provide power, propulsion and automation for the world's most advanced port icebreaker
- 44 Improving remote marine service**
A concept for the next generation ABB customer and service portal
- 50 Connect. Collaborate. Outperform**
Automation & Power World returns to Houston in March 2017
- 51 Loss prophet**
Predicting stray losses in power transformers and optimization of tank shielding using FEM
- 57 Wind protection**
Low-voltage switching and protection strategies in wind turbines
- 63 Arc angel**
Arc flash prevention measures increase safety
- 67 Switching the subject**
A look at recent advances in IGBT technologies for high-power electronics
- 72 Grid4EU**
Laying the groundwork for the development of tomorrow's electricity grids
- 79 Cloud robotics**
Smart robots leverage the Internet of Things, Services and People from edge to cloud
- 84 A combined future**
Microgrids with renewable power integration
- 90 2016 Index**
The year at a glance



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Our contribution to the future: putting bold ideas solidly on track.

Deep beneath the Swiss Alps, the world's longest tunnel, stretching 57 km, is nearing completion. By the end of this year, the Gotthard base tunnel will be traversed daily by 260 freight and 65 passenger trains at speeds of up to 250 km/h, dramatically shortening journey times through the Alps. To help make this engineering feat possible, ABB experts developed custom infrastructure, energy-efficient power distribution, and the largest fresh-air ventilation system ever built.

