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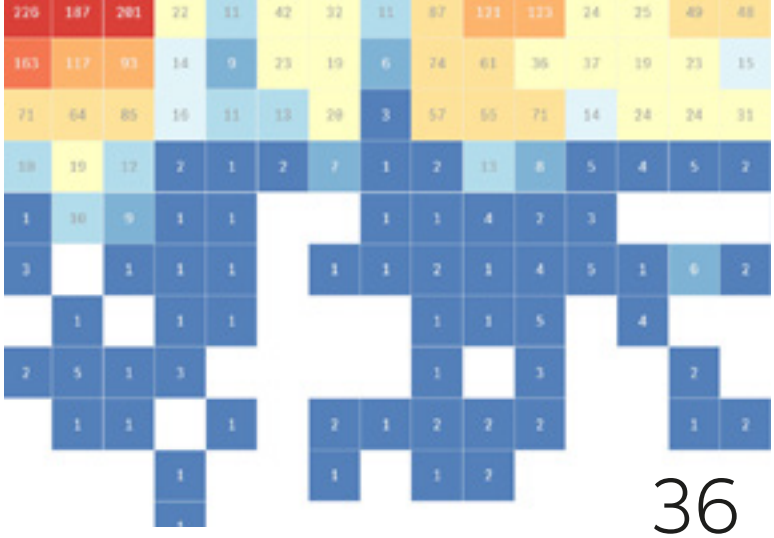

New software quality analytics app

Evolution of HVDC Light®

Partnership with Soft Robotics

Digitization on track

Large 33/66 kV wind turbine transformer

Factory 2.0

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ABB Becomes title sponsor of electric racing

Capable of producing enough power at a moment's notice. Reliable in extreme conditions. Systems that are secure and safe to use and, above all, sustainable and do no harm to the environment. This description could apply to ABB's business, or to the dynamics of ABB FIA Formula E Championship electric car racing, of which the company is now title sponsor.

EDITORIAL

Innovation

Dear Reader,

The world of technology is evolving rapidly. Being successful requires a committal to continuous innovation. Besides the numerous breakthroughs created in ABB's own labs, the company also pursues what is known as open innovation. We are scouting for, investing in and forming partnerships with innovative startup opportunities around the world, especially in emerging fields in areas such as machine learning, distributed energy and intelligent buildings. This activity is the focus of a series of articles in the Technology Ventures section of this journal.

The present edition of ABB Review is also packed with numerous examples of successes and breakthroughs from the company's own labs, many connected to ongoing digitization and the use of smart tools.

I would also like to draw your attention to a logistical matter. Whether you read ABB Review online, in the app or in print, you can ensure you never miss a new edition by signing up for an email alert on www.abb.com/review.

Enjoy your reading.

Bazmi Husain
Chief Technology Officer

Technolo ventures

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Artificial intelligence, blockchain, and autonomy are just some of the buzzwords emerging from the explosion of new technologies and disruptive business models impacting industry today. To remain competitive in this fastchanging, increasingly digital world, large incumbents have to be more agile than ever, proactively engaging with external players to increase the pace and effectiveness of their own innovation programs. How does ABB do it? ABB Review presents an introduction to ABB Technology Ventures (ATV), ABB's venture capital group, and highlights some examples of how ATV helps bring outside innovation into ABB.

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TECHNOLOGY VENTURES

In search of strategic innovation and collaboration

Accelerating digitization is forcing enterprises to reassess how they capitalize on new technology. Previous innovation models are often inadequate and companies have to look beyond their own walls to engage with a dynamic, partnership-driven innovation ecosystem.

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As ubiquitous as it is, few people realize that the Apple iPhone is a decade old. When it came on the market in 2007, it joined stalwarts such as BlackBerry and Palm as the latest “smart” gadget promising convenience and connectivity. Fast forward to 2018 and the impact of near-universal connectivity and computing is just starting to be seen. The last decade has witnessed an explosion of new technologies and disruptive business models and technology is now touching almost every aspect of our lives, at work and home.

The last decade has witnessed an explosion of new technologies and disruptive business models.

As digitization begins to impact traditional businesses like power utilities and manufacturing, entirely new – and often highly digital – markets are opening up and the rules of the game are changing. In order to tap into these opportunities and address the challenges this new world brings, existing business models, strategies and operations have to be re-evaluated. Companies must reassess the way they adopt new technologies and keep up with their peers.

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01 A constantly shifting and continually accelerating technology world is forcing large companies to look outside their own boundaries.

Open Innovation – now more than ever
In the 1980s, some of the best innovations came from government research labs. In the 1990s, when businesses started deploying personal computers, local area networks and Internet connectivity, they took over the lead in technological development. Since the early 2000s, technology innovation has moved to the consumer space. The rapid adoption of technologies and platforms such as cellphones, social networks and streaming media has led to dramatic improvements in computation, storage and connectivity. Those technologies and their functionalities are now spilling over into other markets and are generating a massive opportunity for new value creation, especially in industrial settings. As author Gary Hamel put it in his book, “Leading the Revolution” [1], “if you want to see the future coming, 90 percent of what you need to learn you’ll learn from outside your industry.”

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In order to tap into these opportunities and address the challenges this new world brings existing business models, strategies, and operations have to be re-evaluated.

Traditionally, new business development processes and the marketing of new products took place within a firm’s closed environment. However, in the last decade, overcoming a not-invented-here mindset and the need for outside-in-innovators have become widely discussed topics, with the result that more companies now look outside company boundaries as part of an innovation strategy →**1.**

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One prominent way to do this is Open Innovation. Endorsed by Henry Chesbrough in 2003, Open Innovation is the process of also looking outside a company's walls and beyond its industry for ideas that will keep the enterprise well ahead of its competitors. Especially considering today's environment where companies are increasingly

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Open Innovation is the process of searching outside a company's walls for technology and solutions that will keep the enterprise well ahead of its competitors.

dependent on technologies that are coming from the consumer space and the line between the consumer and industrial sphere is blurring, Open Innovation has gained further importance. More recently, the emphasis has been placed on not only looking outside of an organization's walls but also proactively engaging with external players by creating partnerships and working in an innovation ecosystem. According to a recent article in Harvard Business Review "in order to seize the opportunity and belong to the winners of the game, collaboration across the economy must become universal" [2].

Engagement in an interconnected, dynamic innovation ecosystem can take many forms, ranging from co-creating groups where the ideation phase of a new product is outside the company, over lean startup approaches such as experimenting, incubating and failing fast to corporate venture capital (CVC). However, the common denominator in all of these is cooperative interaction with the relevant stakeholders.

ABB Technology Ventures

Innovation is at the core of ABB and many of the technologies that underpin modern society were pioneered by ABB since its founding over 130 years ago. The super-twisted liquid-crystal display, self-blast circuit breakers for high-voltage switchgear, the electronic gas meter, optical current and voltage sensors, high-voltage DC technology, the world's first truly collaborative industrial robot as well as many advances in power electronics are just a sampling of the fundamental breakthroughs and innovative product technologies created by ABB. With seven research centers worldwide and an annual investment of approximately $1.5 billion, ABB's R&D engineers and scientists continue to develop breakthrough technologies that change the way the world works and industries do business.

02 Much technological impetus can be gained from idea injection from partner companies.

Being a pioneering technology leader, ABB has long embraced a decentralized approach to innovation. ABB's global research centers and business units cooperate with leading universities around the world and other external partners in a fully networked environment.

Part of ABB's R&D organization is ABB Technology Ventures (ATV), the company's strategic venture capital investment arm. Headquartered in Switzerland, with offices in Silicon Valley and India, ATV identifies startups that have the potential to be leaders in their sector and thus drive strategic value for ABB. Once ATV has mapped out how the startup can be beneficial to ABB, it will invest equity in the startup, purchasing up to 20 percent of the company with investments ranging from $250,000 to $20 million. The average check size is $4 million.

ABB Technology Ventures is the company's strategic venture capital investment arm.

Founded in 2009, ATV has deployed over $190 million into 26 startup companies and four venture capital funds. The team's portfolio currently has 18 active companies. Aligned with ABB's goal to write the future of industrial digitization, these companies span a range of sectors – including robotics, industrial IoT (Internet of Things), machine learning, distributed energy and smart buildings – and are spread across North America, Western Europe, Israel and China. While these partner companies should promise best-in-class financial returns, it is more important that investments offer strategic value to ABB. This can come through enhanced understanding of a new technology like additive manufacturing or blockchain, delivering to ABB an early glimpse of a new sector – such as drones – where ABB may want to participate, challenging internal thinking, driving product pull-through, or simply filling a portfolio gap and helping ABB get to market faster →2.

Delivering market intelligence, identifying trends and acting as something of an early warning system for ABB are functions of ATV. By picking the most interesting and promising of the startups to invest in, ATV complements ABB's internal R&D activities by taking calculated risks in the development of "may breakthrough" innovations that potentially fall outside of the purview of traditional corporate technology development. ATV can act as a test lab for emergent, higher-risk technologies or business models, testing them with a fraction of the money and resources that would be needed for a comparable venture involving ABB's in-house R&D.

While ATV is a key pillar of ABB's approach to Open Innovation, according to René Cotting (Head of Operations, Innovation and R&D at ABB, and as Chairman of ATV) working with startups has to be complemented by a strong focus on ABB's R&D competencies, partnerships and M&A (mergers and acquisitions) activity. "Our goal is to create marketable products that are able to meet rapidly changing customer requirements in new ways, and can be introduced onto the market in a lasting, exciting and sustainable manner," says Cotting. "In order to do so, our world-class R&D organization, as well as other parts of the organizations such as our business units and M&A teams, have to work together to enable a holistic perspective on innovation management."

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03 PointGrab is another company that has benefited from collaboration with ATV. PointGrab's vision sensor, equipped with an integrated deep-learning algorithm, is able count and track people without using CCTV.

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References
[1] Hamel G., "Leading the Revolution: How to Thrive in Turbulent Times by Making Innovation a Way of Life," Plume Printing, August 2002. ISBN 1-57851-189-5 (hardback), ISBN 0-452-28324-8 (paperback).

[2] Gnanasambandam C. Uhl M., "Innovation Is as Much About Finding Partners as Building Products," Harvard Business Review, July 20, 2017.

A good example of ABB's synergistic approach to R&D is ATV's investment in Bonsai AI. Bonsai is a small company based in Berkeley, California, just across the bay from San Francisco and in the same high-rise building as the University of California, Berkeley's own startup accelerator, Skydeck. The company has raised money from Microsoft, Samsung and New Enterprise Associates – the largest VC fund in the world – and is attacking the problem that artificial intelligence, and in particular reinforcement learning (RL), is relatively difficult to understand, debug and implement.

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A good example of this synergistic approach to R&D is ATV's investment in Bonsai AI.

"If you're Google, Facebook, Amazon, that's fine, you're okay," Bonsai CEO Mark Hammond explains. "But it's less than ideal if you're a company in manufacturing, retail, or anything that involves real-world logistics, where you might not have those same engineering resources and those prepackaged services don't meet your needs."

Bonsai's technology – aimed at helping companies in these more traditional spaces, including companies like ABB who are looking to make their robots and other hardware easier to program and safer to interface with – abstracts away the complexity of programming and managing AI models. At its core, Bonsai's technology is based on TensorFlow – a popular tool created by Google that helps the user build so-called machine learning systems. TensorFlow is an alternative to Microsoft's Cognitive Toolkit but with a highly visual and intuitive implementation. ABB's researchers in the United States immediately saw the value of providing a higher-level AI language and compiler.

In conjunction with its investment, ATV has facilitated collaboration with Bonsai to adapt their graphical interface from the robot simulation tool Gazebo to ABB's RobotStudio and is now working with the company to make the jump to simulations using live robots such as ABB's two-armed YuMi robot and then go after real-world use cases.

The Bonsai relationship is a good example of how ATV can identify the most suitable partners for collaboration and how such collaborations can provide a mutually advantageous outcome for both parties →3. The interview with Grant Allen, Managing Director of ATV and the description of the partnership with Soft Robotics in the following pages reinforce the lesson that it is essential for a company to look outside its boundaries and proactively engage with suitable external players to increase the effectiveness of its innovation processes. ●

03

INTERVIEW

Interview with the Managing Director of ABB Technology Ventures

Grant Allen

Corporate venturing has become a key component of ABB's quest for growth. To understand better how ABB works with startups and how investment decisions are made, ABB Review met with Grant Allen, Managing Director and Head of Ventures at ABB Technology Ventures (ATV). Grant is based in ABB's new Silicon Valley headquarters in San Jose, CA.

ABB Review (AR): Can you please describe the innovation ecosystem at ABB and how it has changed in the last few years?

Grant Allen (GA): A robust and forward-leaning R&D function is the foundation for ABB's pioneering technology leadership. It's what I point to most frequently as our sustaining competitive advantage and the number of true breakthroughs we've had as a company over the years is remarkable. Every time I meet with ABB's researchers, I'm impressed by the capacity we have internally to develop new products and progress the state of the art in our industry. However, as in any large company, there can be a bias towards improving the known, rather than exploring – even clumsily – the unknown. This can lead to patterns of incrementalism and optimizing towards the evolutionary rather than the revolutionary. In practice, this means that a large percentage of development resources are spent on improving and optimizing the current portfolio, often at the expense of risk-taking and investigation of new breakthroughs. We view this as a search for local rather than global maxima that will, over time, build shareholder value. I clearly see the need for any large company to have a search party function to identify and capitalize on breakthrough technologies and business models that go beyond the core and help the parent company find entirely new offerings for their customers. This is the search for the new white space and ultimately the global maxima. And this is where I believe corporate venturing functions like ATV can be a good tool.

AR Where do you see corporate venture capital (CVC) five years from now? What are the biggest trends in terms of corporate startup engagement?

GA Corporate venturing is more prevalent today than it has ever been. It is a clear trend that large companies are looking outside their walls for disruptive innovations. Now, whether they are simply looking to track those innovations or take them seriously, engage with them, perhaps even challenge their own existing models, that's the real trick. I don't think many of these corporate venture capitalists are doing this well – they're window shoppers in the sense that they're looking at and talking with a lot of startups and bringing their executives through Silicon Valley for what we call the technology petting zoo but they are not investing big checks or meaningful business unit calories. That's when CVC activities become hard because while we all like to make money on our investments, the real measure of our success is how much it moves the strategic needle for our parent company.

In five years, I see CVC still going strong but with about half – if not more – of the groups investing today having pulled back from the market. These are the groups who have dabbled but have either failed to produce strategic value for their parents or have lost too much money, or both. History dictates that CVC groups have a short shelf life; often the simple turnover of an executive sponsor can trigger a strategic review and bring about the end of the venture capital arm. Thus, we have to be especially vigilant that at every stage of our platform life cycle we are delivering strategic value and doing so in the context of a durable financial returns mechanism.

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AR Tell us a bit more what role ABB Technology Ventures plays in this market environment?

GA When I first moved to Silicon Valley three years ago, I met with many of the big-name financial venture capitalists: Andreesen Horowitz, Greylock, Kleiner Perkins, Lightspeed. There was generally muted interest in the ABB-relevant topics such as renewable energy, factory automation – even robotics. The hardware investment trend had not taken off yet and there was still a hangover from the cleantech boom of the early 2000s in which most funds investing in energy tech lost their shirts. Fast forward to today, and AI and robotics are two of the hottest topics in tech investing, deep tech is highly en vogue, and in spite of the longer ramps, many funds have turned to hardware investing. Other funds like Eclipse Ventures and Andy Rubin's Playground Global have been created solely to invest in hardware! Now, some of these same top venture capitalists seek ABB out because we are experts in these fields, particularly robotics and industrial IoT. We are happy to play the role of technical advisor and as we leverage that to add value to the other investors in the ecosystem, we can then get into the very best deals and bring to the table the other things that make ABB such a great investing partner: ABB's brand, a deep R&D bench, a global supply chain and channel access, market knowledge and decades of experience producing some of the most precise, rugged and functional products on the planet.

AR What is your investment footprint and style?

GA Since we were founded, ATV has invested directly into 26 startups. One of our most recent investments was a Chinese company, but the rest are spread between North American, Western Europe and Israel. The pace has been about four new investments per year and today we have 18 active portfolio companies in which $88 million is invested.

To maximize our value-add to the companies in which we invest and to give us downside protection, we like to take an active role in each investment. In practice, this means ATV takes either a voting seat on the board of directors or one or more non-voting observer seats. We often get asked if we need right of first refusal or other special considerations and the answer is "no."

— 01 TaKaDu's AI solutions complement ABB's products.

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AR How do you find the appropriate startup to invest in?

GA We talk to over 2,000 startups per year that we identify through many different channels. We are continually running market and technology sector studies and mapping companies in segments of interest – understanding the key startups in the food and beverage automation space was one of our recent projects – and we have a full-time team member helping with market analytics and driving competitor insights. We also are developing a tool to help us track all of these companies and allow a common, Web-based means for R&D and the ABB businesses to uncover relevant startups on their own.

AR What does a typical startup collaboration look like?

GA Once the ATV investment committee, which includes ABB's CTO, to whom I report, approves an investment and that company becomes part of the active portfolio, ATV, together with our counterparts in the sponsoring business unit, supports and mentors them. We assist, as most good VCs do, with technology roadmapping, refinement of business model, finding product/market fit, recruiting and follow-on financing. We go beyond the "typical" VC value add, though, and assist directly with deeper technology development, giving the startup access to ABB's R&D bench, and making introductions to ABB customers and partners. We drive them quicker to commercial viability and the interaction the startup has with the ABB business units is critical to begin this catalysis. From the outset of working with potential investments, ATV acts as a bridge between the startup and the key ABB players: global business and technology managers, any of ABB's seven corporate research centers, as well as local and global business units, sales groups and product groups. This ensures that there is a full alignment of expectations and goals and maximizes the ease with which a smaller company can tap into ABB's global network of ABB expertise and resources. With 135,000 employees and

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02 Pointgrab's vision sensor counts and tracks people without using CCTV but with similar accuracy.

being the largest supplier of industrial motors and drives, the largest provider of generators to the wind industry and the largest supplier of power grids in the world, the ABB network is a formidable asset for a startup at any stage. ABB helps companies in rapidly accelerating their paths to the commercialization of products and services through access to ABB's R&D manpower and labs, global sales channels and wide-ranging partnerships.

AR Is there a concrete example where working with a startup has created direct value for ABB's customers?

GA In each of our investments, we look for the win-win synergy where there is value for the startup and for ABB. When we unlock this combination, by definition we are providing more ultimate value for ABB's customers. One example is TaKaDu, an Israel-based startup providing a Software-as-a-Service (SaaS) solution for water utilities. Their software enables the utilities to detect, analyze and manage network events and incidents via an automated cloud-based service. Whereas ABB is a supplier of instrumentation and control systems, and hardware components such as sensors and measurement products, TaKaDu delivers an AI-based solution to provide early warning of the most likely leakage scenarios in the system and to tell the customer the optimal placement of the minimal number of pressure sensors. This approach saves costs and maximizes reliability. ABB together with the TaKaDu expertise is a clear symbiotic relationship →**1**. Again, a win-win in our eyes.

AR Tell us a bit about one of your latest investments.

GA For the past few years, we've been trying to figure out how ABB can participate in the aerial inspection and drone services space. We initiated an external study on drones and have been tracking a number of UAV companies and how they are deploying value-add services for field operations, logistics and security. One company, Kespry, emerged as a clear leader in the space, with a unique focus on the data ingest and workflow capabilities as well as the ease-of-use so that field workers can very quickly deploy their drone solution on the job site. Kespry is using a high-resolution aerial camera to do volumetric estimations of mining aggregates and device estimations are ±1 percent accurate. This is a huge leap forward from the current practice and we see significant applications for this technology within ABB. For instance, with our marine and port operations, we could use the drones from this particular company to do high accuracy counts of shipping containers and to automate many other aspects of port operations. And that's just the beginning.

AR Can you give us some concrete examples of technologies that are bound to cause disruption?

GA Let's take the example of PointGrab, an Israel-based company. PointGrab developed a vision sensor with an integrated deep-learning algorithm for home and building automation. The sensor is not a video sensor – no video signal is produced, though the sensor is able to count and track people with an accuracy you would usually get only with a CCTV camera →**2**. This solution is cyber-safe and no-one can look into the room. It represents a completely new generation of sensors that overcome physical barriers by using artificial intelligence.

AR Thank you for the interview. ●

TECHNOLOGY VENTURES

Transforming robotics with Soft Robotics

ABB Technology Ventures (ATV) is ABB's strategic venture capital investment arm. ATV finds the startup partners from which ABB can best benefit, both strategically and financially. ABB's partnership with Soft Robotics provides a perfect example of how proactive engagement with a startup can make all the difference when it comes to improving innovation processes.

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Who says a robot has to be made of metal? For the past decade, Harvard's George Whitesides and his army of post-doctorate fellows have been rewriting the rules on what constitutes a robot. Through a collaboration between Harvard and DARPA, the innovation arm of the Department of Defense, the Whitesides Group at Harvard University has been focused on a new breed of biologically inspired "soft robots." The challenge was initially to create a robot that could make its way underneath a pane of glass just 20 mm above a surface [1]. While most robotic engineers attempted to solve this problem with traditional, rigid robots, Dr. Whitesides drew inspiration from nature to create a new class of soft robots made entirely of elastomeric polymers. It was that challenger mindset that made way for a breakthrough in the field of robotics.

SOFT ROBOTICS

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Soft Robotics is born
The earliest applications of the technology to come out of the DARPA collaboration were in surgery and other biomedical applications. But a major unmet need and opportunity in industrial automation were recognized: The majority of robotic solutions today are based on hard linkages, making it difficult for them to pick up soft and variable objects, like fresh produce, or interact safely with humans. If the new robot technology could safely manipulate and transport organs and soft tissue without damage, it could easily grasp

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The underlying design for Soft Robotics' technology was inspired by the octopus's tentacle.

delicate and variable products that had previously been off-limits to automation, like fresh produce or consumer goods. This premise resulted in the foundation, in 2013, of Soft Robotics as a spin-off from the Whitesides Group →**1.**

Getting the upper hand
The underlying design for Soft Robotics' technology was inspired by the octopus's tentacle – a dramatic shift away from the traditional robotics approaches involving hard linkages, sensors and servo motors. This inspiration led to the invention of soft robotic actuators made entirely of polymers that do not require sensors or other electromechanical devices for operation. Soft Robotics' novel approach solves the problem through material science, not through higher levels of cost and complexity. The computational power of the system is built into the gripper itself – a proprietary blend of materials with microfluidic channels that, when actuated, mimic the soft tissue of the human hand.

Prof. Whitesides' work at MIT spawned an entirely new area of research, with soft robotics becoming a focus at Harvard University and the associated Wyss Institute, Cornell, Stanford, MIT and numerous other institutions. While there is now significant academic work in this area, Soft Robotics Inc. has been the pioneering force in developing the first and only commercial applications. The commercial need is driven by the fact that only 12 percent of non-automotive industries are automated by robots today because solutions for tasks that are either unstructured or that call for dexterous manipulation of variable product have not been available →**2.**

By leveraging the properties of soft and compliant materials, Soft Robotics has been able to build a fundamentally new set of adaptive and dexterous robotic hands and automation systems that open up completely new applications. Labor-starved industries such as food and beverage, advanced manufacturing and e-commerce can now realize the power of robotic automation. Soft Robotics' technology can now manipulate objects that vary in shape, size and weight, and that are easily damaged →3. The most immediate need for this type of technology was seen to be in food and agriculture, advanced manufacturing and e-commerce, where automation is needed not only to meet increasing market demand and labor scarcity but to manipulate the variable and fragile nature of the product.

ABB is a pioneering force in industrial automation and the company's decades of experience have proved invaluable to the Soft Robotics team.

Productization challenges

While Harvard and DARPA had grown a robust foundational IP platform over nine years of development, Soft Robotics was faced with the challenge of moving an academic technology from the bench into the market – and designing it to meet the highest automation standards of Fortune 100 customers. DARPA and Harvard had built the grippers, but Soft Robotics needed to solve the challenge of how to control them and evolve the technology into a solution that could operate reliably, repeatedly and at high speeds for customers in food and beverage, advanced manufacturing and e-commerce. The company advanced the grippers and incorporated FDA-compliant materials to meet the food handling sanitation guidelines as outlined in the Food Modernization and Safety Act. An electro-pneumatic control system enabled by proprietary firmware was designed and developed to give customers full command over grip parameters including speed, force, gripper spacing and opening width.

The power of pairing the system with AI and machine learning was recognized: Once one solves for the human hand in robotics, machine learning can be used to train robots on how to grasp and manipulate a wide range of other things. Human-supervised automation of highly unstructured tasks like bin picking, sorting and even harvesting are now a reality. This vision for a "robotic-human alliance" has manifested itself into version 2.0 of the technology: SuperPick – designed specifically for the unstructured environments in e-commerce and logistics.

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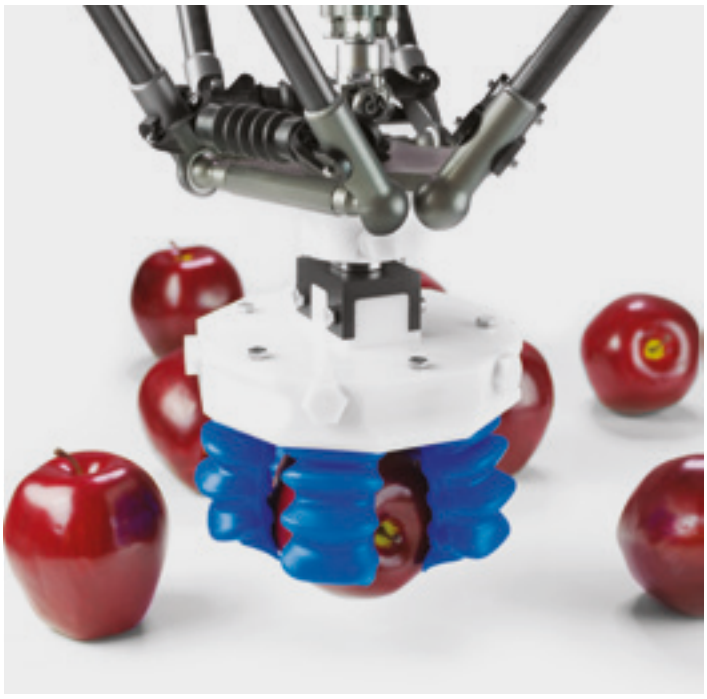

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01 Soft Robotics was spun out of the Whitesides Group in 2013.

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02 Soft Robotics has the first commercial solution to robotic gripping of delicate items.

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03 Soft Robotics' technology mimics the human hand, thus allowing easy gripping of objects that are delicate and that vary in size, shape and weight.

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Reference
[1] https://www.youtube.com/watch?v=QpnLj-rzjIo&

Robotic synergies

ABB is a pioneering force in industrial automation and the company's decades of experience have proved invaluable to the Soft Robotics team as they scale their technology to meet the demands of automation customers. ABB is both a partner and investor in Soft Robotics and ABB's robotic systems bring the highest level of speed and accuracy to the Soft Robotic solutions. When the Soft Robotics gripping systems are combined with ABB technologies like the IRB360 FlexPicker, entirely new pick and place applications are opened up. In partnership, the two companies have built solutions for the food and beverage industry, helping to solve top industry challenges such as food safety, productivity and regulatory compliance.

For example, one of the largest global pizza retailers and e-commerce companies ships its dough fresh to its retail locations around the world. Due to the variable and delicate nature of the dough balls, the company had been trying for two years to automate the manipulation and packaging of the end-product. Soft Robotics was able to develop a customized solution to automate this customer's challenge in under a week. The automation solution combines Soft Robotics' gripping system with ABB IRB360 FlexPicker robots to dexterously grasp and maneuver the dough at high speeds. Today, this system is being deployed at this customer's manufacturing facilities around the world.

A partnership for the future

A core premise of Soft Robotics is that the company is not looking to re-invent anything ABB is already doing; the startup is simply adding on functionality to ABB's existing robots and enhancing the value ABB can deliver to its

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In partnership, the two companies have built solutions for the food and beverage industry.

customers. At the vanguard in the fast-moving field of agile, automated manipulation, Soft Robotics presented a compelling opportunity for ATV to take an equity position in the startup and accelerate the business partnership with ABB. As Grant Allen, Managing Director and Head of Ventures at ABB Technology Ventures has said: "ABB is one of the leading corporate investors in the robotics space and we saw a critical need in markets such as food processing, agile manufacturing and logistics for an adaptable soft gripping mechanism. Soft Robotics has delivered a compelling solution – and, frankly, gone well past that."

Buoyed by this endorsement from ABB, Soft Robotics' engineers continue to break new ground in the area of intelligent grasping. They are now looking to broader automation challenges and are currently rolling out a solution for e-commerce fulfillment centers where robots can identify objects in a bin and not only identify the correct object for packing, but reach in, grab the correct object and complete the packing task. This "bin picking" task has been a classic problem in robotics. Soft Robotics' solution will help write the future of increased autonomy and customer efficiency in warehouse operations, all thanks to a dynamic young startup out of Cambridge, Massachusetts. ●

Innovatio highlight 2018

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Successful innovation marries what's possible with what's necessary, thereby yielding the greatest business value. ABB focuses on identifying those needs, and transforming them into opportunities, especially in energy and other mission-critical industries that want to work faster, and more flexibly, responsibly, and profitably.

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WindSTAR – World's first 33 and 66 kV large offshore wind turbine transformer

By 2020, 65 percent of new wind farm installations in Northern Europe will work at 66 kV. This boost in voltage level, from 33 kV, will significantly reduce losses, make generation systems more efficient, deliver life cycle benefits and enable significant cost-efficiency gains to be made.

In mid-2017, ABB announced its latest innovation in transformer technology with the introduction of the 66 kV WindSTAR transformer. WindSTAR has been designed to fit into the small space available within the turbine by passing through the tower or nacelle door and will thus enable a new generation of powerful offshore wind turbines to operate at the world record voltage of 66 kV.

The WindSTAR design is robust, reliable and safe. For example, to reduce the risk of fire, the transformer uses aramid high-temperature insulation paper and the insulation liquid is made from an environmentally friendly and high-flashpoint ester.

Space is valuable and restricted inside the turbine so WindSTAR's design is compact and lightweight, with a minimal footprint – all of which also lowers transport and tower structural costs. A modular design makes it simple to adapt to the customer's specific requirements.

WindSTAR offers a best-in-class solution to withstand sudden variable loading and is available for both 33 and 72.5 kV class applications. Low overall system losses and improved levelized cost of energy ensure the customer has a low total cost of ownership. 128 units of the 33 kV and 16 units of the 66 kV version have already been delivered to offshore wind turbine projects. ●

Agile manufacturing with ABB Ability™ Manufacturing Operations Management

Modern production facilities must manage costs, ensure safety, maintain product quality and meet sustainability goals while also accommodating faster production rates, shorter product cycle times, unexpected changes in the market and special requests for product variants.

These challenges can be met by agile manufacturing. Agile manufacturing is a production philosophy that concentrates on fast reaction to unpredictable and rapid changes in the product landscape by introducing better integration between business-level resource planning and local process controls.

How does ABB Ability support agile manufacturing?
ABB Ability Manufacturing Operations Management is a comprehensive, scalable and modular suite that enables manufacturing to become more responsive and adaptive by connecting the people, assets and systems involved in the production process. It enables effective decision-making and reliable, lean production execution by fully integrated operations.

ABB relies on Manufacturing Operations Management to support lean and agile principles in more than 60 of its own manufacturing plants worldwide. Currently, ABB is implementing a fully flexible production line including automatic guided vehicles (AGVs) and robotics – a real Industry 4.0 solution. This solution supports rapid and configurable implementation of smart logistics scenarios for the interaction of robots and AGVs. The interactive shop floor visualization of Manufacturing Operations Management enables quick responses and intelligent, informed decisions by dashboards displaying real-time order status, alerts, energy consumption, etc. The right information is just a swipe away and can be viewed on mobile or multitouch devices, or desktop computers. ●

eXLent for Fairway Crude Oil Storage Facility

The Fairway Crude Oil Storage Facility – located south of Houston, Texas – has nearly 20 million barrels of storage capacity across five underground salt cavern systems, with the ability to store all crude oil and condensate grades. Operation first commenced in April 2017 in three of the cavern systems. A twin 24-inch bidirectional pipeline connects the storage facility to a major delivery and receipt point for Eagle Ford shale and Canada/mid-continent crude oil flows, and serves refiners and terminals in the Texas City and Baytown market areas. The system is capable of simultaneously receiving and delivering over 15,000 barrels per hour per pipeline.

ABB, together with local channel partner CRT Services, delivered the digital measurement solution for the optimal operation of the facility. Products delivered to and received from customers are accurately tracked in the pipelines and the caverns. At any time, customers can remotely schedule, view and report product transfers and inventory.

The solution is built with ABB's eXLent platform, which uses cutting-edge technologies such as Node.JS, TypeScript and React to provide a user-friendly, secure and scalable foundation for centralized (oil and gas) measurement applications. State-of-the-art practices in development – like fully automated unit, functional and end-to-end tests combined with detailed code coverage reports – ensure a very high level of quality while retaining development speed and short release cycles. This enables the team to provide new feature releases to the customer every few weeks and respond quickly to feedback. ●

Encapsulated stainless steel motors come clean

Food and beverage plants operating in Europe typically use shrouded motors in washdown areas where food safety and hygiene is crucial. Such motors, especially when fan cooled, can become contaminated with airborne particles – a safety risk. To clean equipment, the shroud must be removed – a difficult and time-consuming process that increases operating costs. ABB's new IEC encapsulated stainless steel motor is a better alternative for the European and Asian food and beverage industry.

Stainless steel motors produced by the Baldor Electric Company (a member of the ABB Group) have been a reliable standard in the North American market for more than 20 years. To ensure food safety, hygiene and low maintenance costs, ABB's new encapsulated stainless steel motor has multiple key features. These motors withstand harsh washdown conditions – even high temperature (80 degrees Celsius) and high pressure streams (100 bar). The IP69K ingress protection ensures robustness. The stainless steel motors are compatible with clean-in-place methods – reducing the time needed to clean equipment. And, of paramount importance, the motors are totally enclosed and non-ventilated (TENV) up to 1.5 kW. The motor's smooth surface ensures a contaminant-free surface and improved safety. The availability of a range of motor efficiency levels and presence of encapsulated windings result in superior reliability and extended lifetime – with motors lasting up to five times longer than standard motors.

The use of ABB's stainless steel encapsulated motors that can withstand high pressure sprays, can give operators in the food and beverage industry an upper hand. This ingenious product improves food safety, maximizes uptime and reduces overall operating costs thereby lowering the total cost of ownership. ●

Digitization on track

Breakthrough innovations in mechanical design and motion control hardware are at the heart of ACOPOStrak. This revolutionary design of this intelligent product-transport system enables adaptive manufacturing and promises a new era in flexible and efficient production. ACOPOStrak – developed by B&R, a company recently acquired by ABB – delivers true mass customization and batch-of-one production.

Like some industrial-scale version of a child's slot racing track, ACOPOStrak's design flexibility allows it to morph into many different configurations of open and closed layouts by arranging its segments appropriately. The core of the track system is a linear motor assembled from four types of modular segments: a straight segment, a 45° segment and two 22.5° segments – one curved to the right, the other to the left.

ACOPOStrak adapts perfectly to any production site and opens up completely new machine designs that have never before been possible.

The most important element of ACOPOStrak is the diverter. The diverter is 100 percent electromagnetic and, therefore, entirely free from mechanical wear. Like a highway junction, the ACOPOStrak diverter allows product flows to diverge and converge. The diverter allows shuttles to switch tracks at full speed with no compromise in productivity: The product flow can be divided, pass through multiple processing stations and then converge further down the line. This way, production speed is no longer throttled by the station with the slowest processing time. Individual track segments and processing stations can be added in response to changes in demand.

Mass-produced items such as bottled beverages can be grouped on-the-fly into custom six-packs – three of one flavor, two of another and one of a third – without any changes to the hardware. The diverter also allows defective products to be sorted out as soon as they are identified, rather than continuing on to the end of the line as they would in a conventional system. This has a positive effect on overall equipment effectiveness.

The hot-swappable shuttles can be replaced tool-free and on-the-fly for unprecedented availability. With switching products, all the operator has to do is place the wheels of the new shuttle on the guides. The shuttles are held on the track purely by permanent magnets. Changeover and service can be made even more efficient by including a pit lane in the track layout.

The intelligent transport system is also unmatched in performance: The system is capable of 5 g acceleration and reaches top speeds in excess of 4 m/s with a minimum product pitch of only 50 mm. Such performance statistics, combined with the benefits of the diverters and the extreme design flexibility, represent an unprecedented generational leap in productivity and accelerated return on investment (ROI).

B&R provides an extensive range of software functionality to get ACOPOStrak up and running with minimal time and effort. The same application code can be executed in simulation as on the actual hardware, with no limitations, so that developers can switch back and forth between simulation and real hardware as often as necessary, which shortens development and commissioning times.

B&R's ACOPOStrak makes flexible, modular manufacturing systems highly profitable to operate. ACOPOStrak enables high overall equipment effectiveness, high ROI and a short time to market. And with that, the industry is on the fast track to true mass customization. ●

Magnos28 with microwing technology

ABB can look back on 75 years of innovation in the field of continuous gas analysis – working to improve production efficiency and measurement performance. Introduced in 2017, ABB's new Magnos28 paramagnetic oxygen analyzer with its patent-pending microwing technology, is the all-in-one sensor device leveraging ABB's technology leadership. It is the newest product in the palette of the Advance Optima and EasyLine continuous gas analyzer series.

Form follows function
The Magnos28, takes advantage of automation technology to revolutionize paramagnetic oxygen analysis. The microwing technology using a silicon sensor replaces the conventional sensor consisting of the traditional glass dumbbell and its circuit path, mirror, mounting and taring weights. Ideally suited, ABB's microwing sensor reacts accurately to changes in oxygen concentration changes thanks to its very low mass, high width-to-thickness ratio and optimized magnetic field distribution in the measurement position. These absolutely reproducible silicon sensor elements are at the heart of the Magnos28 analyzer. Sub-micrometer precision, achieved during production, improves reliability and performance – ensuring that ABB's customers can make successful measurements rapidly under challenging process conditions.

Adopting new production technology
Sub-micrometer precision is achieved by incorporating the latest digital manufacturing technology to produce the microwing. Applying semiconductor-based production technologies, multiple sensors can be manufactured on a wafer slice – a completely new approach to magneto-mechanical oxygen sensor production.

By avoiding the manual yet critical production tasks, ABB turns what was once a complex, time-consuming and labor-intensive task into an elegantly simple and super-efficient process. Under absolutely clean conditions, the microwing is automatically positioned and bonded to a platinum wire with manufacturing tolerances of less than one micrometer. Each production step is tightly controlled and verified during assembly, securing the production of each sensor with optimized and reproducible quality.

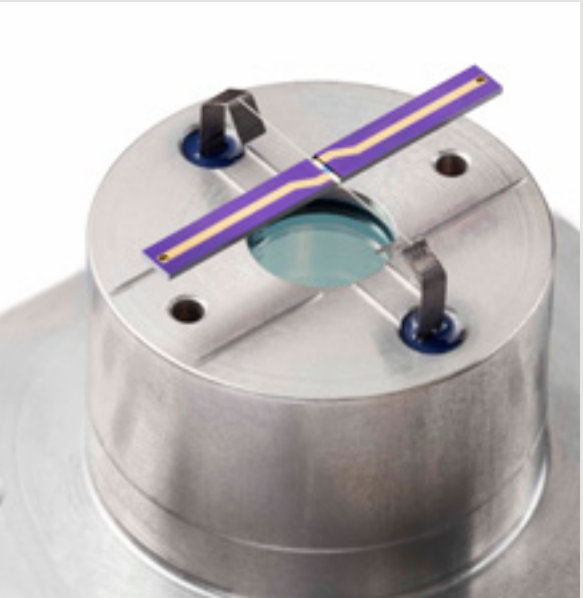
Using a patent pending sensor balancing process, laser ablation removes miniscule amounts of the wafer coating, perfectly aligning the microwing within the center of the magnetic field.

Measure for measure: setting new limits
The Magnos28 oxygen analyzer can measure rapid changes in the concentration of the sample gas and yet it is characterized by long term stability. Calibration of the zero-point with ambient air or nitrogen is usually only required once a month. Moisture influence is drastically reduced and no longer restricts sensitive measurement tasks at very low oxygen concentrations – as low as 0.5 volume percent. At typical gas cooler temperatures (3 °C), the influence of moisture on the measurement is within the detection limits of the instrument (50 ppm). The new sensor measures the pure magnetic properties of both diamagnetic and paramagnetic gases – matching the theoretical and physical values practically without deviation.

An internal gas flow management system directs sample gas to the microwing which, responds instantly. Compared to its predecessor, the Magnos28 internal chamber volume is lower by a factor of three. The rapid gas exchange translates to a 15 percent increase in response time. These features make the ABB Magnos28 gas analyzer perfect for threshold monitoring or for any situation characterized by rapidly varying conditions. Neither external factors such as pressure and temperature, nor internal signal noise have relevant influence on the resulting measurements.

The Magnos28 state-of-the-art design allows super-precision in severely challenging environments. The innovative microwing sensor technology enables reliable oxygen measurement of a wide variety of solvents and corrosive gases. A careful selection of inert materials reduces drift substantially and practically eliminates the adverse effects of solvents. Sensitive parts of the Magnos28 internal chamber such as the pole shoes are protected by specially selected coatings. Excellent measurement properties are achieved with improved drift stability even in the presence of corrosives such as sulfur compounds. The new technology avoids glue or lead solders, which, in the traditional glass dumbbell design could react with the gas matrix and interfere with the reliability of the measurement.

The improved drift stability and ability to measure at very low oxygen concentrations provides customers with enhanced sensitivity and reliability. The robust Magnos28 with the revolutionary silicon-based microwing technology sets the stage for the future of paramagnetic oxygen measurement. ABB's rigorous design standards and use of innovative automation production techniques make this possible. ●



New 38 kV circuit breaker

An innovative design of medium-voltage indoor vacuum circuit breaker actuated by servomotors is under development by ABB. The main target of the servomotor actuation is a dramatically increased mechanical life of the breaker – delivered thanks to the intrinsic ultralong life of the motors themselves and the optimized travel curve for the vacuum interrupters. The servomotor actuation also brings superior circuit breaker performance in terms of mechanical operation compared with competitors' offerings based on either traditional spring mechanisms or magnetic actuators. This breaker will be rated for 38 kV 2,500 A with a 31.5 kA short-circuit current.

Ultra-durable circuit breakers are highly appreciated by steel manufacturers – who can switch the breakers that protect their electric arc furnaces up to 100 times a day. A pilot installation was agreed with one of the world's biggest steel manufacturers, NUCOR, and at the start of 2017, the new ABB breaker became operational in NUCOR's steel plant in Seattle, United States. The rich experience delivered by validation of the solution within a real application and the deep engagement with the customer will be key contributors to a successful product launch early in 2018. ●

Connected atomizer

A paint atomizer is a spraying device used to paint car bodies. Atomization of the paint takes place in a so-called rotary bell atomizer, which has a bell cup that rotates at up to 60,000 rpm. Once atomized and electrically charged by a 100 kV electrostatic field, the paint is transported towards the (grounded) object to be painted. This process transfers up to 85 percent of the paint to the target and produces a good paint finish.

Until now, atomizers have had a common design: a high-speed, high-precision air motor to rotate the bell cup, a shaping air ring for pattern adjustment, a high-voltage generator as well as some valves for the trigger and cleaning. ABB has now further improved the quality and reliability of its atomizer by adding smart sensors (with integrated CPU) and RFID tracking tags. This innovation delivers better control of the paint application and the ability to recognize incipient failures.

- Improved reliability: An ultracompact inertial motion sensor with a 3-D accelerometer, 3-D gyroscope and temperature sensor monitors the behavior of the atomizer during production. High-bandwidth (6.7 kHz) data from the sensors is combined with internal data processing, including angle conversion and frequency analysis, to provide real-time data analysis and feedback that keeps the atomizer within a safe performance envelope.
- Secure quality: RFID tags on the critical components deliver the data that can ensure that the right part is in the right place when starting production or restarting after a manual cleaning. RFID tags also enable tracking of component life histories so that spares can be ordered in good time, before production is disrupted.

This new, connected atomizer also enables the customer to have a better closed process loop, which will improve his ability to put the right thickness of paint on the right area and thus guarantee the coating's lifetime.

The connected atomizer is only the start: ABB's ambition is to have much better control of the complete paint line by also adding analytics tools and by sharing all available information via the cloud so that the power of algorithms and big data can be used to improve the quality and efficiency of the client's production. The data collected will also go towards constant design improvement. ●

TruONE™ – the world's first true ATS for critical power

When power to a critical application – in a hospital, data center or telecommunications installation, for example – is lost, an automatic transfer switch (ATS) immediately brings in the backup generator. Installing an ATS is a non-trivial task involving various sensors, controllers, switches and operator interfaces that all have to be wired up. ABB's TruONE all-new ATS removes all this complexity as it requires just a single wire and uses standard enclosures.

TruONE is the world's first true ATS to package all the necessary sensors, controllers, switches and operator interfaces into a single, easy-to-install device that helps improve protection and makes installation simpler, more reliable and 80 percent faster. Ergonomic studies indicate that TruONE cuts cabling and commissioning times and costs by up to 90 percent.

TruONE, which surpasses IEC and UL test requirements, is also setting new industry safety standards as the detachable HMI is completely isolated – so potentially dangerous line voltages no longer need to be connected to the door.

With seven communications protocols providing all-round connectivity, the TruONE ATS is part of the ABB Ability™ portfolio of solutions that boost customer productivity. TruONE is the first ATS with a built-in condition monitoring and predictive maintenance functionality that ensures the device is available when it is needed. To make system integration even easier, the device has the same user interface and software environment as the ABB Emax 2 smart air circuit breaker.

The new device features a host of design and engineering advances, including an ingenious contact construction that uses new materials and geometries to make load transfer more reliable. ●

ABB's Ability™ Smart Sensor keeps pumps flush and efficient

ABB Ability Smart Sensor developed for rotary motors is shown.

ABB Ability™ Smart Sensor is already available as a condition monitoring offering that brings predictive maintenance functionality to low-voltage motors. In an innovative step, it has now been modified and applied to pumps. In cooperation with the Swiss producer of centrifugal pumps, Egger Pumps Technology AG, ABB has advanced Smart Sensor to allow the advanced monitoring of pump conditions and exploit digital industrial opportunities.

Pumps, like motors, depend on rotating components and are omnipresent in diverse industries ranging from pharmaceuticals to the chemical industry – including water treatment facilities. High-quality centrifugal pumps that operate in wastewater plants must deal with specific challenges like sensitive fluids with a high solid content. The pumps must deliver low life cycle costs and a long service life. Problems such as clogging and cavitation occur, requiring pumps to be checked every week by an experienced operator. This is labor intensive and recruiting personnel for this type of physical effort is difficult. Without these maintenance checks, failures can occur – posing a safety risk for operators and higher costs.

The Smart Sensor

The ABB Ability Smart Sensor is a ground-breaking product developed for monitoring and analyzing condition parameters on rotating motors. The sensor, introduced at the Hanover Fair in 2016, can be used on almost all low-voltage motors whether new or already installed. The ABB Ability Smart Sensor enables motor operators to detect problems early and analyze their efficiency through advanced signal processing and data analytics in the cloud. The solution can reduce downtime by 70 percent, extend motor lifetime by up to 30 percent and reduce energy consumption by up to 10 percent.

The cooperation

What if the Smart Sensor solution for motors was available to improve downtime and extend the lifetime of pumps, improving maintenance conditions and increasing safety for personnel? With these challenges in mind, Egger Pumps Technology AG, Cressier, sought a partner to collaborate on a solution for pumps. This medium-sized company had experience with ABB's Ability Smart Sensor for motors. Egger approached ABB with the goal of co-developing a smart sensor for centrifugal pumps for use in wastewater treatment plants.

Developing smart sensors for pumps is complex and cannot be accomplished by experts working solely on motor technology. Various pump technologies, such as the patented radial flow or axial flow centrifugal pumps, exist to solve specific hydraulic challenges in sewage treatment plants. Because pump technology is not at the core of ABB's expertise, engineers and scientists at ABB and Egger Pumps Technology AG worked together, and with the ABB Ability team, to ensure the success of the development.

The cooperation began with meetings between technical teams in Switzerland, gathering data at end customer sites in Germany. ABB pulled in resources (Germany, India and Switzerland) to provide essential scientific expertise. Egger provided access to end customers and testing facilities in Cressier, where a joint test campaign was run in July 2017. In November 2017, end customer tests were completed at the wastewater treatment company, AVA, in Altenrhein, Switzerland, to gather further practical data to meet future customer needs.

Testing the Smart Sensor

ABB's unparalleled experience in developing smart sensors that know just when a motor needs service has allowed the team to adopt an agile and expert approach. Crucial to the success of this lighthouse product, ABB delivered pump sensor prototypes early on to test and gather data in a defined real-world industrial setting.

The test phase focused on monitoring four operational challenges for wastewater treatment industries: rotational speed of the pump, imbalance, cavitation and clogging.

During the test phase, the sensor recorded data for all parameters; health indicators and key performance indicators were sent to the ABB Ability cloud through either a gateway device or a smartphone. Hence, operators and users could access the data via an app on their smartphone or via a browser.

More extensive analysis is planned to detect trends to enable cloud-based services. This future step will allow data transmission and analysis and further reduction in maintenance costs, yet guarantee safety. In partnership, ABB and Egger are successfully developing advanced monitoring solutions to bring active information on a pump's condition – reducing downtime and increasing performance – lowering overall costs and maintaining safety. This advantageous synergy promises results that can be applied in the future to other industrial applications that rely on pump technology. ●

— Sensor test-site at a wastewater treatment plant.

Software virtualiza

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and tion

The next frontier for digitization reaches beyond development of digital tools to reveal new ways to model, structure, and operate entire systems, hardware included. ABB is innovating at the edge of this juxtaposition of virtual and real. What has already been accomplished suggests what's to come.

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SOFTWARE AND VIRTUALIZATION

New app visualizes a path to long-term software quality

ABB has developed a software engineering analytics application for the kind of long-lived software found in the company's industrial and grid automation product lines. The app, which is used by globally-distributed ABB software development teams to improve software quality and development efficiency, supports the visualization of defect and code histories, as well as code ownership.

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Managing and improving the quality of source code is important for long-lived products such as those in ABB's industrial and grid automation product lines. Such products are expected to operate in customer environments for many years. In support of these products, ABB manages their associated software maintenance over multiple releases, thereby continuously enhancing their performance.

To help foster a long-term overview of a product's software maintenance history, ABB has developed a visual analytics app that tracks source code changes. The app allows ABB software development teams to take a data-driven approach to improving their verification strategies.

The app's visualizations are built into ABB's Metrics Portal. The portal and its associated analytic capabilities support over 3,000 software development professionals in all of ABB's globally distributed business units and provides access to data from many sources used for research. For example, the portal analyzes over four million distinct work items extracted from the company's application life cycle management (ALM) systems – thus providing assistance with the product lifecycle management (governance, development, and maintenance) of computer programs. Data from the systems is refreshed on a nightly basis so that fresh analytic reports are available to team members throughout the organization.

> The app allows software development teams to take a data-driven approach to self-improvement.

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01 Code heat map with defects.

The Metrics Portal makes it possible to integrate data from many sources. Data loading tasks are allocated by data sources and by data flow layers. Each layer is responsible for a specific function such as data extraction and transformation, data loading, and information display through

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The Metrics Portal delivers visualization applications for managing projects, development, testing and software maintenance activities.

dashboards. Using these data sources, the Metrics Portal delivers visualization applications for managing projects, development, testing, and software maintenance activities. The visualizations provided by the Metrics Portal allow development teams to review historical performance, propose changes and gauge the efficacy of the resulting improvements.

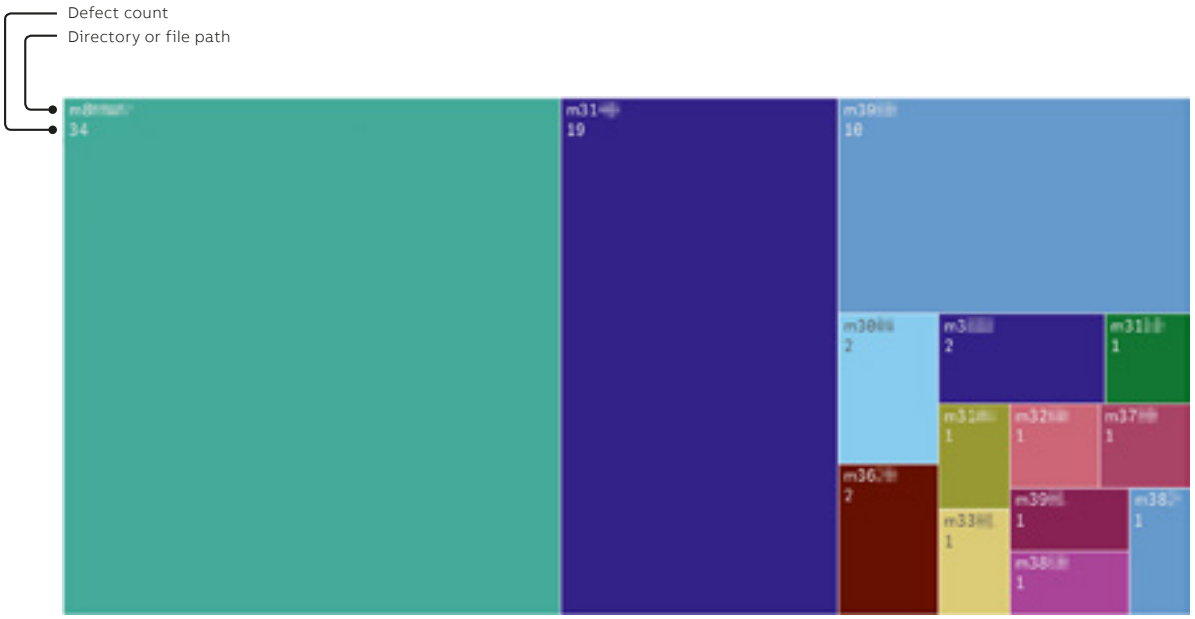
This article describes some of the advanced software maintenance visualizations in one of many applications that are delivered via the ABB Metrics Portal. For each visualization, a description of the key use cases and their presentation is provided.

Defect heatmap

One of the major benefits of business intelligence systems is that they allow users to combine disparate data sources. Taking advantage of this principle, data on defect counts is combined with commits and file paths from ABB's source code configuration management system.

The system stores each version of the code created or modified by developers as distinct commits. ABB also uses an application life-cycle management tool to track new features and defect fixes as items in an agile process work flow. The Metrics Portal makes it possible to combine data from both of these systems.

A mash-up of commits and defects is illustrated in →**1.** Each file path is shown, along with the number of defects it received updates for in its change history. The size of blocks indicates the relative portion of defects in the system that are attributable to the path. Colors are randomly generated to better distinguish parts of the system.



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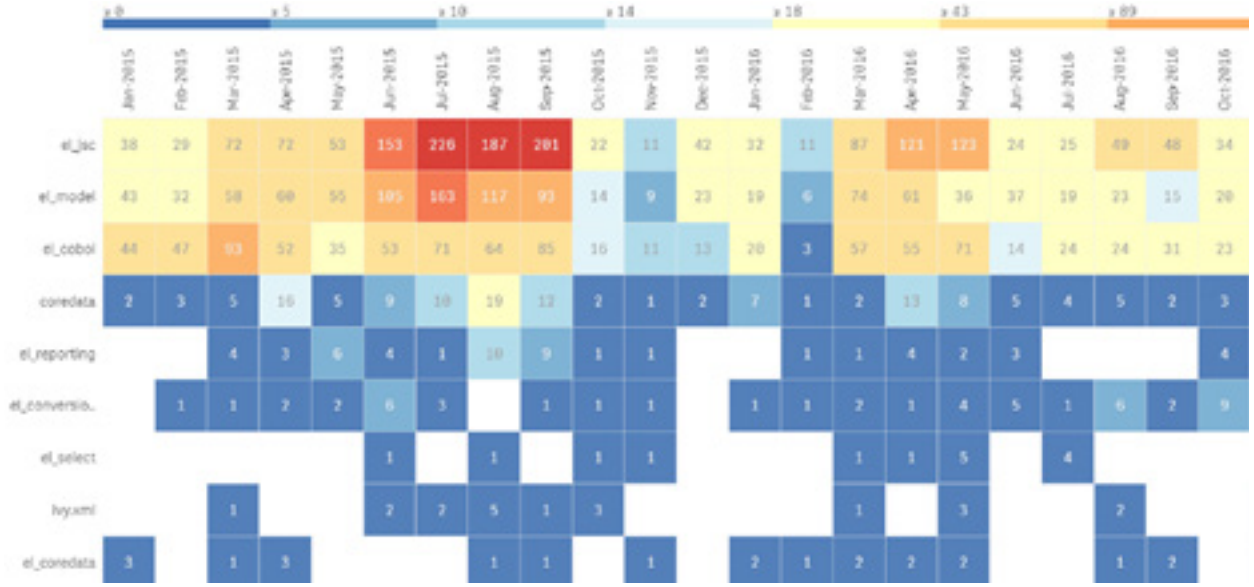

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This view helps product owners and architects to find the most defect-prone parts in the code base by allowing them to access the data on a component level, then drill down through the file path hierarchy to the specific files that are the most defect prone. They can use this to target refactoring and other architectural improvements and then measure the efficacy of those improvements. →2 shows a heat map of change frequency for each component for each month. Each square shows the number of changes for the component in a particular month and is colorcoded such that the higher the number of changes, the hotter the colors. Users can expand each component, directory level by directory level, until they sufficiently isolate the change frequency to specific files of interest.

A code ownership heat map addresses issues such as globally distributed teams and knowledge transfer.

Development teams use this form of visualization to determine the most frequently changing components in a system over time for a given release. Many recent changes to components indicate the need to regression-test the functions associated with that component. The result provides an indication of where a team needs to focus its quality assurance efforts.

Code ownership map

An illustration of the usefulness of combining different data sources to help identify code owners is provided in →3.

One of the challenges of having globally distributed teams is that developers often do not know who to contact for guidance when modifying an unfamiliar part of a project. Teams also have to worry about owners of particular parts of the code departing the company. However, these issues can be addressed by means of a code ownership heat map that shows all of the files for a code base →3.

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02 History of changes by component.

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03 Code ownership heat map.

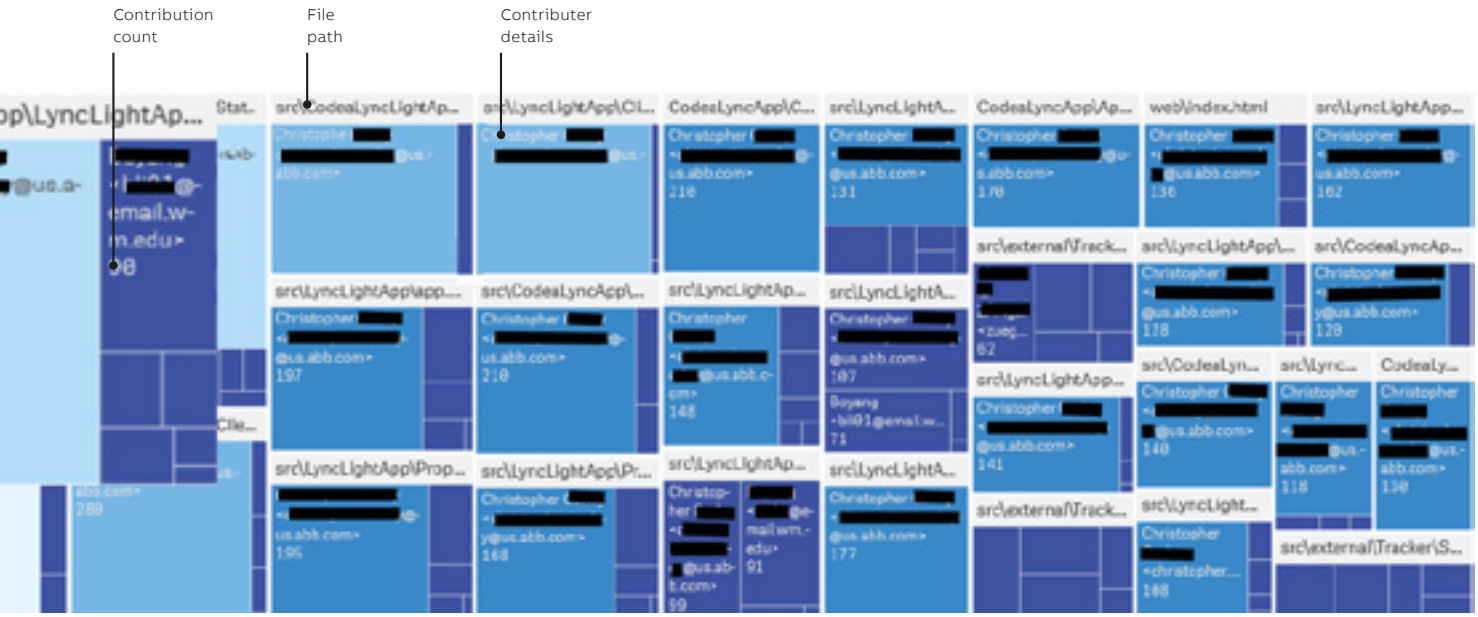
This view can be filtered from the root of a repository all the way down to individual files. The heat map shows each file as a rectangle. Within each file, individual contributors are represented proportionally to the number of commits they have made to a given path. This map makes it easier to identify the primary contributors for a file. Although the commit history in the configuration management system provides author information, it does not differentiate between someone who has made numerous changes to a file and someone who has made only one.

The code ownership map can also be combined with the company's internal Lightweight Directory Access Protocol (LDAP), which makes it possible to identify parts of the code base where primary contributors have changed roles or departed the company.

Key points

All in all, ABB has built a software engineering analytics application that indicates the best ways to manage the code base of long-lived products. The app combines disparate sources of data to produce new and useful visualizations, including defect history, code change history, and code ownership. In addition, by combining multiple sources of data (such as source code and personnel data), the app provides analytics to solve issues that teams previously struggled with. Thanks to these developments, ABB teams can use the resulting visualizations to better manage their software quality and development efforts. ●

— By combining multiple sources of data (such as source code and personnel data), the app provides analytics to solve issues that teams previously struggled with.



SOFTWARE AND VIRTUALIZATION

Dynamic QR Code speeds service response

“DQR Code assistance for analyzers” is an ABB service product that provides comprehensive diagnostics and a real-time health check of an analytic system without any need for training or remote connectivity. This innovative application expedites service response, so ABB-manufactured assets stay online and customer production keeps running →1.

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In today’s global economy, customers are constantly striving to improve on their own – but they also depend on suppliers like ABB to come up with novel ideas that will increase asset utilization and enhance the services they provide.

It was this spirit of collaboration that drove ABB developers to design DQR Code assistance for analyzers (“DQR Code” for short). This innovative application expedites ABB’s service response to customer issues to make sure ABB-manufactured assets stay online and the customer production line keeps running. Initially, DQR Code has been used to enhance service response for ABB’s continuous gas analyzers as ensuring high availability of these devices is crucial: Every minute of missing data can significantly impact plant productivity, resulting in lost revenues. Continuous gas analyzers are also used to meet regulatory compliance – device downtime could lead to a failure to monitor and report plant emissions to regulatory agencies, which can result in significant fines and even plant shutdown.

From QR to DQR

Until now, when issues with ABB’s continuous gas analyzers arose, most customers – through lack of on-site expertise to quickly troubleshoot problems – had to contact their local ABB office for help. While effective, this approach is not as efficient as it could be, nor does it lead to problem resolution as quickly as the digital age demands. This is where DQR helps out.

DQR Code assistance for analyzers expedites ABB’s service response to make sure ABB-manufactured assets stay online and production keeps running.

Traditional QR (quick response) codes are ubiquitous bar-code-like squares that can be scanned by mobile devices such as smartphones to access information resources, such as a website, instantly. DQR (dynamic QR) is an evolution of the QR code.

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01 DQR Code enhances service response for a range of ABB equipment by providing comprehensive diagnostics and a real-time health check.

Normally, QR codes are static, often printed on a poster or advertisement, for example, and can only display a limited amount of predefined, hard-coded information. In contrast, DQR code generation reflects the real-time status of the device in question: Every time a new DQR code is requested by the user, the DQR software pulls updated data and status information from the central unit, which can be in control of several separate ABB gas analyzer modules. The DQR codes combine with the interactive display on the continuous gas analyzer systems to give operators a real-time analysis and health check of their gas analyzer's performance history and to provide them with direct and quick access to important device serial number information that ABB's service professionals require to access a device's history and ideal-state status.

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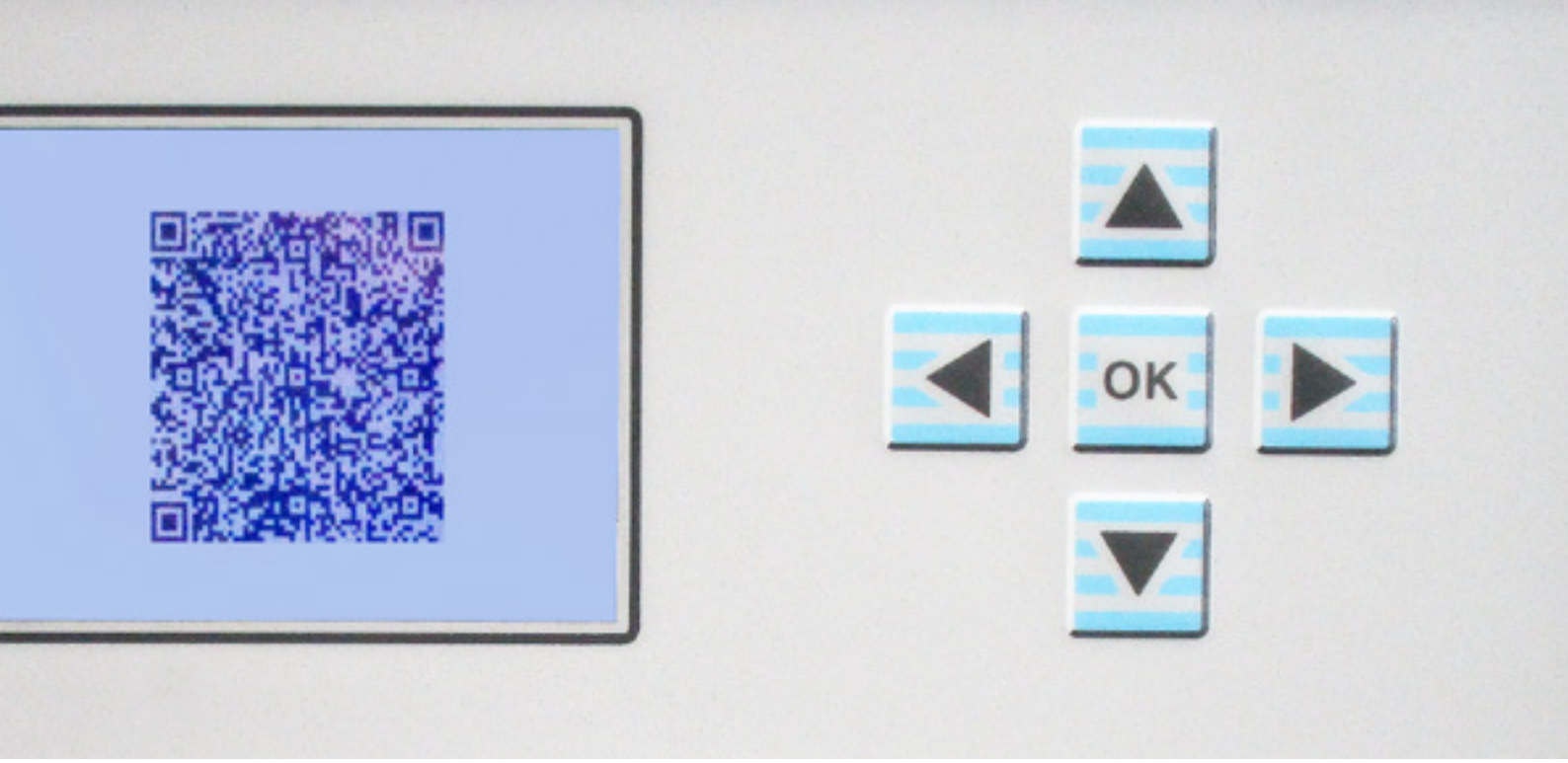
The DQR code generated reflects the real-time status of the device in question.



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The operator must simply scan the code on the analyzer display with any QR code reader app (such as on a smartphone) or ABB's myInstalledBase app (myIB), which is available for download from the Apple Store and the Google Play Store. If needed, the code can be forwarded via e-mail to the local ABB office for fast access to advice and guidance on the ABB product or even that specific unit, including repair history, parts requirements, etc. →**2-4.** Operators do not need training or remote connectivity to utilize DQR Code.

Operators do not need training or remote connectivity to utilize DQR Code.

The DQR value proposition

It is no secret that a digital transformation is sweeping the industrial world. As part of the "Industry 4.0" transformation, ABB's DQR Code assistance for analyzers introduces a new way to increase measurement data availability for customers who have analyzers installed in remote locations, have strict remote connectivity policies, are looking to reduce the burden of operator knowledge needed to run advanced analytical systems or are seeking competitive advantage that speed can provide.

The goal of this technology is clear: To simplify service delivery without complex installations or procedures in order to improve mean time to repair (MTTR), operator efficiency and plant uptime.

Simple to use and effective in troubleshooting, DQR Code belongs to a generation of customer support solutions designed to enhance collaboration between customers, equipment and ABB. That is why all of ABB's continuous gas analyzer systems for emissions monitoring (AO2000, EL3000, EL3010-C, EL3060, ACX and ACF5000) now come with DQR Code as a standard feature.

ABB's continuous water analyzers for consumer applications, the Aztec 600 chlorine analyzer series and silica analyzers for process control in industrial applications (the Navigator 600 series) will also be DQR Code enabled. ABB's RVG200, SM500F, SM300 and RDM500 paperless data recorders will also come equipped with DQR Code as a standard feature. And every Advanced Top Works platform will also have DQR Code.

DQR Code is backward compatible, so it can be added to equipment retroactively for customers with existing installations.

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02 The DQR code can be scanned by the operator using any common QR code reader app.

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03 Getting the right information to the right people: DQR Code provides comprehensive diagnostics and a real-time health status without any need for training or remote connectivity.

From data to intelligence

ABB chose QR codes because they are fast, familiar and easy to use. Almost anyone who has a smartphone or tablet knows how to scan a QR code. Combined with mobile devices, DQR Code represents an innovative way to communicate with customers, allowing, for instance, improved case-specific support by ABB that results in increased availability of analyzer assets. Once established, this type of familiarity opens up a host of new ways for operators to interact with devices that improve the users' experience by allowing them to work with more information more effectively.

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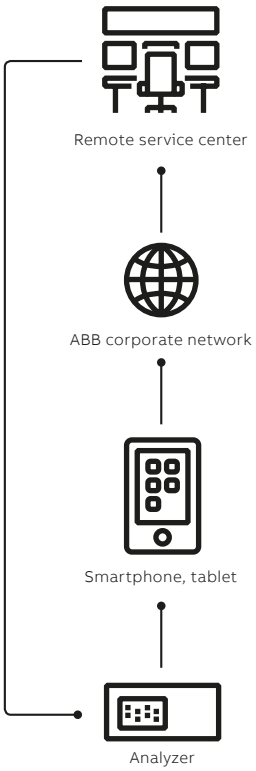
Users can automatically synchronize the summary report with their ABB ServIS installed base management system to create a recommended service action.

In order to turn QR data into actionable intelligence, ABB developed a software tool called ABB Ability™ Verification for Measurement Devices that reads the QR code text file and prepares a summary report detailing system status and any issues the unit may be having. Users can then automatically synchronize the summary report with their ABB ServIS installed base management system to create a recommended service action, such as a workshop repair, site repair or telephone assistance. An e-mail notification can also be sent with the recommended service recommendations.

ServIS is ABB's system for storage and management of the installed base information of the products a particular customer is using. The ServIS tool is used by ABB personnel and customers to find customer and installed-equipment information. Using mobile devices such as tablets, smartphones or laptops, service engineers can access life cycle status, technical data and documentation, service reports of previous maintenance, recommended services and other customer data.



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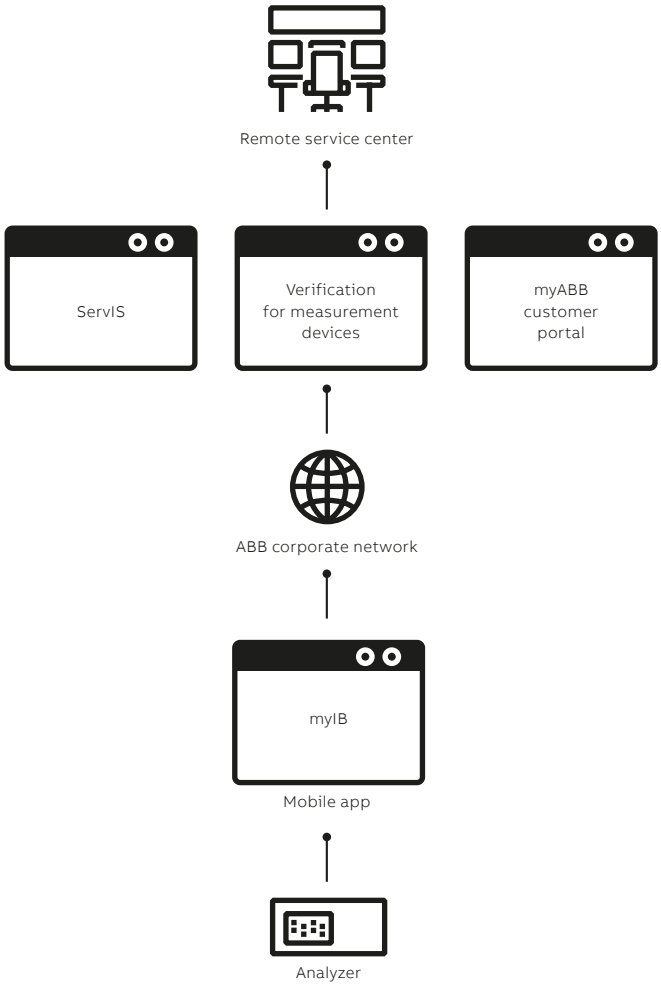

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After a service action is complete, this data is updated by a service engineer and uploaded to the system. The data is also sent to myABB, a 24/7 customer portal for viewing installed base and related information, including features such as the ABB library, training material and service agreement details.

Cyber secure

Despite all the attention devoted to Industry 4.0 and the Industrial Internet of Things (IIoT), there is still reluctance among many plant operators to allow smart devices into their plants. In this age of heightened concerns regarding cyber-security, this makes sense.

That is why DQR Code is a noninvasive technology designed to transfer information from device to user securely. DQR Code information is read-only. Operators cannot write any data to, or run any software on, the device via the DQR Code interface. And QR codes, in general, are a low-tech and well-established technology that is reliable and easy to read under difficult conditions, a common occurrence in the harsh environments in which ABB's continuous gas analyzers are often found.

DQR Code is a safe entry point into service processes and has the potential to significantly speed up the entire service delivery process by

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DQR Code is a noninvasive technology designed to transfer information from device to user securely – and DQR Code information is read only.

providing operators and engineers with the safe, reliable, convenient and quick access to information they need to make critical real-time decisions.

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04 DQR overview.

—
05 The benefits of DQR Code to customers.

Without a system, it's just a feature
Incorporating this new feature into the way ABB collaborates with customers requires integration into operating procedures, as well as into the ABB Measurement Care service agreement a standardized contract structure that matches a specific service scope to customer needs.

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The future trajectory of DQR Code will see it move from the enhanced troubleshooting and improved human-machine interactions available today to predictive maintenance.

ABB Measurement Care has three service levels:
- Rapid response
- Life cycle management
- Performance improvement

DQR Code assistance for analyzers has been incorporated into the rapid response level, fulfilling the goal of accelerating service response to ensure maximum asset and process uptime →**5.**

Looking ahead
The future trajectory of DQR Code will see it move from the enhanced troubleshooting and improved human-machine interactions available today to predictive maintenance. By coupling DQR Code data with the cloud, analytics and artificial intelligence (AI), ABB will be even better placed to solve customer problems remotely.

Although just beginning to make a significant impact, AI is set to change much about how the world functions and how resources are conserved, consumed and utilized. By combining the forward-looking capabilities of AI with advanced diagnostic algorithms, ABB will be able to both troubleshoot continuous gas analyzer issues more effectively and efficiently, and will also be able to

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By coupling DQR Code data with the cloud, analytics and AI, ABB will be even better placed to solve customer's problems remotely.

prevent problems before they start, helping plant operators increase productivity, reduce downtime and improve resource utilization.

Put plainly, DQR Code is a simple elegant solution to a complex problem. ●

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Increased asset and process availability
Case-specific information and individual support
Faster communication enabled by complete information package
Faster issue resolution due to case-specific service recommendations and better preparation of service calls
Higher operator efficiency
A standardized, platform-independent feature
Easy, reliable data transfer
No additional hardware or working steps required
Simple access requiring no detailed knowledge
Standardized output
Improve life cycle management
Simplified product registration
Better data quality of installed base
Complete product history

SOFTWARE AND VIRTUALIZATION

Blockchain – basics and beyond

In a blockchain, transactions are executed once and immutably recorded in a fault-tolerant and tamperproof manner. These properties make a blockchain ideal for a wide range of uses. However, blockchain technology is in its infancy and has shortcomings that must not be overlooked.

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A blockchain is a database that is replicated across multiple machines and used to maintain a continuously growing list of records. Records are compiled into so-called blocks, which contain a timestamp and a link to the previous block, thus forming a chain of blocks. The current high level of interest in blockchain technology is due to its desirable properties: Transactions are executed exactly once and an immutable record of all transactions is maintained in a fault-tolerant and tamperproof manner. Moreover, if the ledger is publicly available, anybody can verify the correctness of its records →1.

A blockchain is a database that is replicated across multiple machines and used to maintain a continuously growing list of records.

Traditionally, such features are powered through a trusted third party, which hosts multiple databases – for the sake of availability and fault tolerance – and vouches for the integrity of the stored data. The main disadvantage of relying on a third party is that trust is required in this party not to abuse its power and to provide its services faithfully. What is more, there is a risk that a malefactor could gain control over the third party and, for example, delete or modify records. In a blockchain, however, control is distributed, which makes the system much more resilient to malicious or inadvertent manipulation →2.

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01 Blockchain transactions are executed just once and an immutable and tamperproof record of all transactions is maintained. This makes blockchain ideal for a wide range of applications in today's digital world. Probably the best-known application of blockchain technology is its use as a basis for cryptocurrencies, of which there are many.

Origin

The original blockchain is the foundation of Bitcoin, the world's first successful incarnation of a so-called virtual currency [1]. Bitcoin was proposed, in 2009, by "Satoshi Nakamoto" – a pseudonym. Satoshi's real identity is unknown and the name may even refer to several people. The blockchain that underpins Bitcoin is described in Satoshi's seminal work.

Unlike traditional currencies, virtual currencies are not controlled and regulated by banks and governments. Instead, control is decentralized and anybody in the world is free to join and dedicate (computational) resources to uphold the integrity of the system. Building a robust virtual currency is no small feat: If there is no centralized authority, such as a bank, who can prevent a malicious user from spending his or her virtual money multiple times? How can a seller be certain that a buyer has sufficient funds to purchase a chosen item? How can nonrepudiation of transactions be guaranteed? These questions hint at some of the crucial problems that any virtual currency must solve.

The Bitcoin blockchain addresses these issues by providing global consistency and serialization of transactions, ie, it defines for any two transactions which transaction occurred first. The additional key property of the Bitcoin blockchain is that the records are immutable, ie, recorded transactions cannot be altered or deleted →3.

02

Despite what some analysts claim, the blockchain concept is rather simple. In fact, the blockchain is of interest because it is simple yet offers several properties that are essential for many distributed applications. In short, the blockchain has the potential to simplify and automate processes for a wide range of use cases.

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The current high level of interest in blockchain technology is due to its desirable properties.

Potential future use cases

The main difference between using a third party and a blockchain lies in the claim that the blockchain removes the need to trust any particular party. In other words, trust is shifted from a specific party to a distributed system and its embedded protocols. As a consequence, one needs to trust that the majority of the parties involved in maintaining the ledger follow the protocols, ensuring that the ledger operations are carried out as intended and the remaining (malicious) entities cannot corrupt the system.

An entry is submitted to the blockchain

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02 The distributed nature of blockchain control makes it ideal for tracking and verifying all sorts of transactions – for example smart contract execution.

—
03 Blockchain principles.

Since trust is a valuable and crucial commodity in any distributed system, it comes as no surprise that numerous use cases for blockchain technology, other than virtual currencies, have been proposed and are being investigated by ABB as well as many other companies. Most proposals can be classified into three categories, of increasing complexity:

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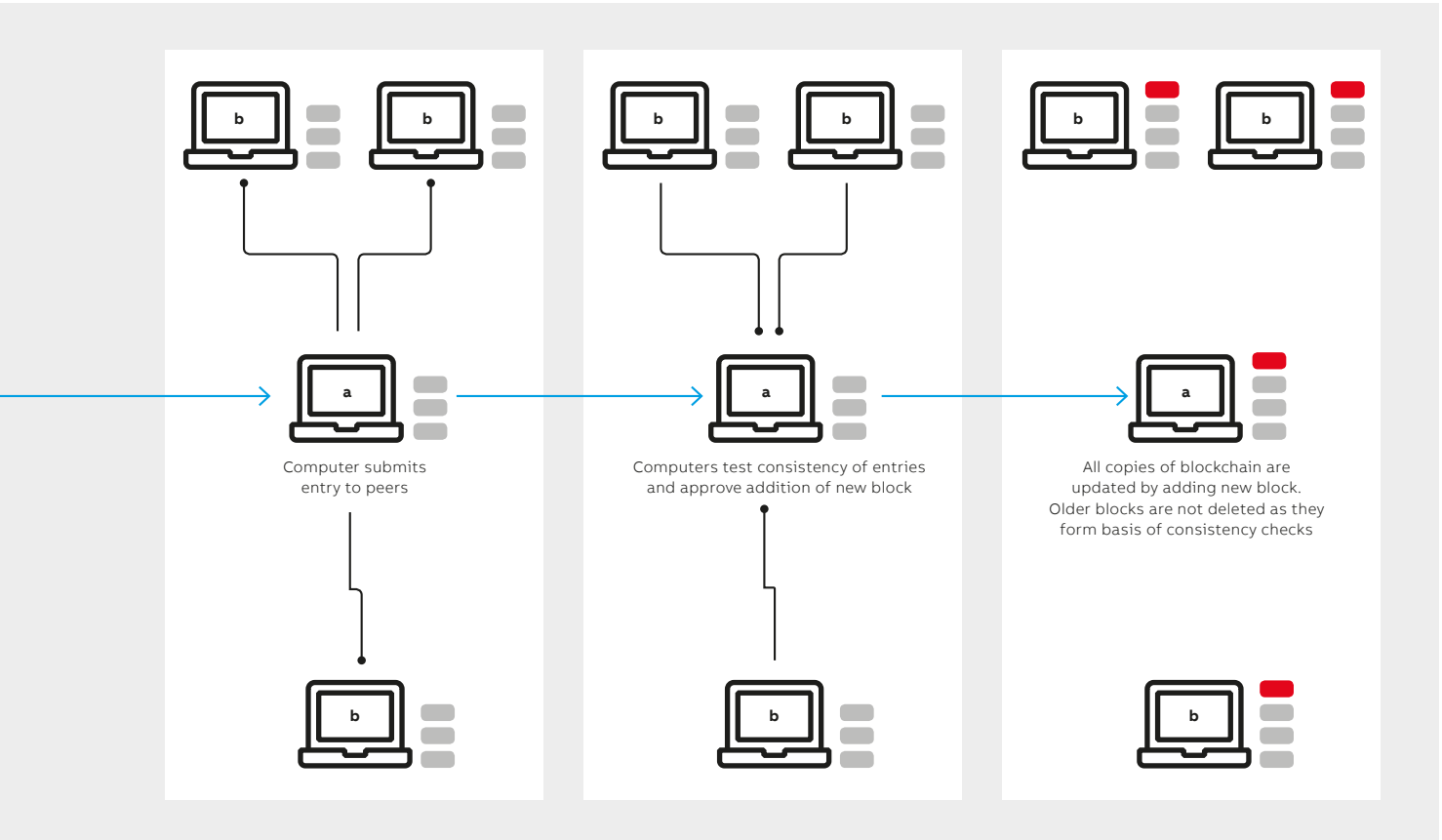
The Bitcoin blockchain provides global consistency and serialization of transactions, as well as record immutability.

1. Registry service:
   Storing digital records in an immutable and auditable distributed ledger.
2. Asset exchange:
   Asset creation and ownership transfer.
3. Smart contract execution:
   Automate business processes through the execution of code.

The information stored in the blockchain can represent physical or digital assets, identities, transactions, or contracts. A protocol governs how entries are created, validated, recorded, and distributed. For the applications belonging to the first category above, the blockchain is used as a ledger to record important facts and events such as births, marriages, deaths, property deeds, intellectual property, election results, legal decisions, financial investments, insurance policies or medical history →**4**. For such registry services, the main appeal is that records stored in the blockchain are immutable and that they can potentially be used across organizational boundaries (with data protection and privacy mechanisms in place). The ability to share records across boundaries is viewed as an especially important prerequisite for digitization in the financial and medical industries as well as for governmental services. This capability could be of great interest for ABB.

In the second category, banks are particularly interested in the exchange of (digital) assets, the facilitation of cross-border payments, and trade in stocks, derivatives and options. In the industrial arena, transactions that change the ownership of, or provide access to, physical goods can be carried out on a blockchain. Use cases being discussed here include tracking parties involved in a supply chain and decentralized approaches to access control.



One step beyond transactions are so-called smart contracts, a distributed protocol that executes the terms of a contract autonomously, with the aim of reducing the risk of error and manipulation. It has been proposed to add support for smart contracts on top of a blockchain: The contract would be stored in the blockchain in the form of executable code. When a smart contract is executed, the blockchain network members run the executable code according to the terms agreed upon in the contract. Since each execution starts with the same initial state, this automatic and distributed execution ensures consensus on the result among all members that execute the contract correctly. Smart contracts offer the potential for new financial instruments, parameterized insurance contracts and other services combining a shared database with the means for verifiable calculations or automated approval processes between two or more participants without trusted third parties. For example, smart contracts are envisioned to facilitate energy exchange and trading – both activities for which ABB supplies solutions →5.

04

While use cases are often described in terms of their potential compared to the state of the art – eg, by outlining potential cost savings – there is little discussion on how well the blockchain fits the given use case. In other words, the discussion as to whether or not a blockchain can be used to transfer trust from key parties to a distributed system is often missing. One needs to analyze carefully if a blockchain approach can resolve trust issues or if other, more traditional methods – eg, distributed databases – can provide the same benefits.

It has been proposed to add support for smart contracts on top of a blockchain. These could facilitate, eg, energy trading.

Challenges and limitations

Apart from the many advantages and great potential of blockchain technology, there are also some challenges that may hinder its adoption. In particular, lack of flexibility is a serious limitation as modifying the underlying protocols and implementations is almost impossible because any change must be adopted universally. If some participants update their protocols and some do not, a so-called fork of the chain is created, essentially creating two (conflicting) realities. Thus, massive coordination is required among all major participants before any change is possible. This limitation even holds for minor implementation bugs – some bugs in the Bitcoin blockchain implementation were identified a long time ago and are still not fixed. In addition to this rigidity, a further drawback is the fact that blockchain approaches suffer from limited scalability possibilities with respect to the number of users and the number of items to be appended per time unit. For example, the Bitcoin blockchain has a new block added every ten minutes, which corresponds to a growth rate of around 8 GB per year. While this number looks small enough in the light of modern computing resources, it also implies that the number of transactions is fixed to about seven per second, which is far too low for a global transaction system.

—
04 A blockchain can reliably register a whole range of important records such as personal, financial and legal data as well as intellectual property information, election results or medical history.

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05 Smart contracts enabled by blockchain technology could revolutionize the world of energy exchange and trading.

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Reference
[1] www.bitcoin.org

05

As mentioned above, any suggested change must find a majority of participants to support it, so there is no quick fix for this issue around the corner. Moreover, the energy consumed maintaining the Bitcoin blockchain is massive – and rising, as it relies on a proof-of-work approach that continually ramps up the computational power needed to compute a new block. The energy consumption is currently estimated to be of the order of the production capability of two nuclear power plants.

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One needs to analyze if a blockchain approach can resolve trust issues or if more traditional methods can provide the same benefits.

While the basic idea behind blockchain immutability is sound, there are many potential modes of attack on the implementation and application sides that require attention. For example, Bitcoin wallets are vulnerable to theft, packets can be sniffed, distributed denial-of-service attacks could be mounted, etc. Furthermore, it is not possible to prevent an attacker who controls more than 50 percent of the blockchain computational power from controlling the blockchain itself. Such an attacker can even undo past transactions.

A significant amount of research is being invested to mitigate these limitations. The lack of flexibility can be addressed by putting control over the blockchain protocols into the hands of a consortium. In this case, the consortium, but no individual party, must be trusted. The expensive proof-of-work mechanism can be replaced with a much more energy-efficient approach based on distributed consensus algorithms (the Hyperledger project is a noteworthy example). It remains to be seen if a blockchain-based system can be implemented that overcomes the most crucial current limitations while preserving the features that make blockchains interesting in the first place.

Blockchain's future

On the application level, the hype around blockchain technology has led to inflated expectations. A closer look at many proposed use cases reveals that trust is a key prerequisite for their success. However, it is not always possible to resolve trust issues with a blockchain-based approach. In general, blockchain technology is no silver bullet. Each use case requires a carefully implemented solution that can benefit from concepts used in Bitcoin or blockchains. Blockchain technology is still in its infancy and has obvious shortcomings that, despite all the hype, must not be overlooked. It is worthwhile for ABB to observe the ongoing development as innovations will most likely bring the blockchain technology to a level of maturity that will unlock its business potential to automate and simplify processes in the industrial domain. ●

Energy transitio

n

Wind farms, extended grids, and smart integration and management present new challenges for generating and distributing electricity in an age of renewable energy, requiring innovation tempered with a commitment to reliability and safety. ABB is working with customers to keep the lights on during this transition.

54 WindSTAR – World's first large 33 and 66 kV offshore wind turbine transformer
60 Evolution of HVDC Light®

ENERGY TRANSITION

WindSTAR – World's first large 33 and 66 kV offshore wind turbine transformer

ABB's new 66 kV WindSTAR transformer can fit into the tower or nacelle of a wind turbine. The boost in wind farm voltage level from 33 kV to 66 kV significantly reduces losses, makes generation systems more efficient, and delivers life cycle benefits and cost-efficiency gains.

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The global uptake of renewable energy continues to exceed expectations. Latest predictions by the International Energy Agency (IEA) have renewables, by 2025, generating over 25 percent of the world's electricity [1], with a quarter of this coming from wind. The recent falls in the cost of wind energy – and the significant potential for further cost reduction – may herald a trend that will result in an even higher level of wind power generation than that currently predicted.

WindSTAR will enable a new generation of powerful offshore wind turbines to operate at the world record voltage of 66 kV.

Along with higher absolute levels of wind energy, there is also a trend toward ever-more-powerful wind turbines. Current maximum power outputs are around 8 to 9 MW and the output of the largest wind turbines is expected to exceed 12 to 14 MW by 2020. To accommodate higher offshore power densities and to reduce the levelized cost of energy (LCoE), wind farms are moving from 33 kV operating levels to 66 kV.

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01 WindSTAR 66 kV transformer – 11 MVA 66/0.69 kV.

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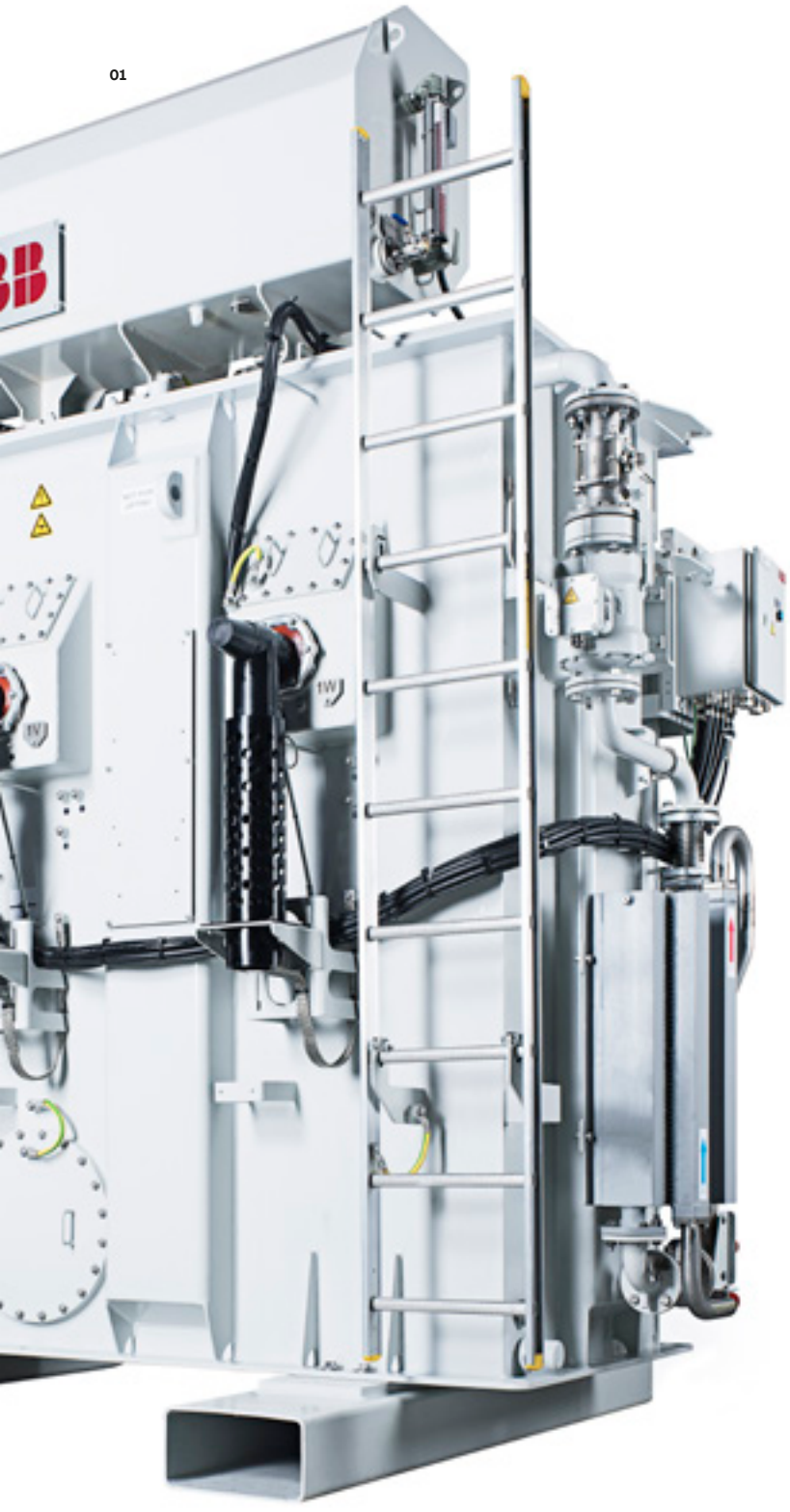

By 2020, 65 percent of the new installations in Northern Europe will work at 66 kV. This boost in voltage level will significantly reduce losses, make generation systems more efficient, deliver life cycle benefits and enable significant cost-efficiency gains to be made.

—

Much thought has been given to the WindSTAR design to ensure that it is as robust and safe as possible.

In mid-2017, ABB announced its latest innovation in transformer technology with the introduction of the 66 kV WindSTAR transformer →**1.** WindSTAR has been designed to pass through the door of a wind turbine tower or nacelle and will thus enable a new generation of powerful offshore wind turbines to operate at the world record voltage of 66 kV →**2.**

WindSTAR concept

By its nature, an offshore wind farm will be in a difficult-to-reach location. Consequently, the cost of repair and maintenance will be correspondingly high. For this reason, much thought has been given to the WindSTAR design to ensure that it is as robust, reliable and safe as possible. For example, to reduce the risk of fire, the transformer uses aramid high-temperature insulation paper. The insulation liquid is made from an environmentally friendly and high-flashpoint ester. Transformers using this ester demonstrate a much-reduced risk of fire initiation and propagation, not to mention outstanding self-extinguishing properties. This makes ester-filled transformers among the safest liquid-filled transformers on the market. Further, by its very nature, the ester is readily biodegradable. This means that any spill need not be treated as hazardous waste, which saves disposal fees and possible regulatory penalties.

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For further robustness, the transformer's tank can be hermetically sealed with a welded-on cover.

To make sure it can cope with the rough and very variable conditions out at sea, WindSTAR's vibration and short-circuit resistant design has been extensively tested in-house, as well as type-tested and approved.

—

WindSTAR's dimensions make it easy to transport to the end location and it will fit through the tower or nacelle door.

The short-circuit testing is especially critical so as to ensure reliability even in the most extreme working conditions and to minimize any possibility of outage – this is very important considering the offshore location of the transformer. Testing is also carried out according to specific customer requirements – for example, XYZ-dimension shake table tests on the no-load tap changer (NLTC) to optimize the positioning of the leads.

Space is valuable and restricted inside the turbine so WindSTAR's design is compact. The design is also lightweight (to lower transport and tower structural costs) with a minimal footprint. For example, forced oil and forced water cooling methods are used to remove heat from the transformer. As these methods remove heat more effectively than, say, forced air cooling alone or convection, the cooling system can be made more compact as can the transformer assembly.

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02 The engineer beside this 66 kV WindSTAR transformer gives an indication of its scale. It can fit through a tower or nacelle door.

—
03 WindSTAR is compliant with international standards and regulations relating to wind turbines.

WindSTAR's dimensions make it easy to transport from factory to end location and it will fit through the door of the turbine tower or nacelle. In fact, the compact dimensions allow the use of a smaller-then-normal door, which strengthens the tower

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The transformer uses high-temperature aramid insulation paper as well as an insulation liquid made from an environmentally friendly and high-flashpoint ester.

or nacelle and reduces turbine structure costs. Further, WindSTAR's safety-conscious design means only a very minimal physical clearance is needed to guarantee the wellbeing of personnel, thus saving more space.

WindSTAR offers a best-in-class solution to withstand sudden variable loading and is available for both 36 and 72.5 kV class applications: 10.8 MVA 33/0.69 kV, 11 MVA 66/0.69 kV. Both products are compliant with international standards and regulations for wind turbine transformers →**3-4.** Low overall system losses and improved LCoE ensure the customer has a low total cost of ownership.

03

Voltage	33 kV	66 kV
KV class	36 kV	72.5 kV
Rated power	> 10 MVA	> 10 MVA
Cooling	KFWF	KFWF
Insulation liquid	Ester	Ester
Insulation material	High-temperature class	High-temperature class
Tapping range	± 2 x 2.5%	± 2 x 2.5%
Low voltage	> 400 V	> 400 V
Frequency	50 or 60 Hz	50 or 60 Hz

04

Further, a modular design makes it simple to adapt the final solution to the customer's specific requirements and features such as plug-in bushings on the high-voltage side make installation and commissioning easy →**5**. A full set of options is available too, to suit the particular implementation requirements – for example, two- or three-winding design, remote monitoring, on-load tap changer or NLTC, an auxiliary transformer that can be internal or external (or dry or liquid), etc.

WindSTAR projects

When it entered service in 2014, the Vestas V164 had the largest installed capacity of any wind turbine. In 2017, the 9 MW version of the V164 set a one-day production record of 216 MWh.

It is for power levels such as these that the WindSTAR has been conceived and 128 units of the 10.8 MVA 36/0.69 kV version have already been delivered to MHI Vestas V164 offshore wind turbine projects: Burbo Bank (UK, 32 units), Walney Extension (UK, 40 units) and Borkum Riffgrund (Germany, 56 units).

WindSTAR offers a best-in-class solution to withstand sudden variable loading.

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04 WindSTAR class 36 and 72.5 kV characteristics.

—
05 The WindSTAR is designed for easy installation and commissioning.

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06 WindSTAR 66 kV transformer – reception at a customer site.

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References

[1] International Energy Agency, "IEA raises its five-year renewable growth forecast as 2015 marks record year." Available: https://www.iea.org/newsroom/news/2016/october/iea-raises-its-five-year-renewable-growth-forecast-as-2015-marks-record-year.html

[2] J. Shankleman, et al., "Gigantic Wind Turbines Signal Era of Subsidy-Free Green Power." Available: https://www.bloomberg.com/news/articles/2017-04-20/gigantic-wind-turbines-signal-era-of-subsidy-free-green-power

[3] J. Hill, "Mammoth 50 MW Wind Turbine Blades Could Revolutionize Offshore Wind In US." Available: https://cleantechnica.com/2016/01/29/mammoth-50-mw-wind-turbine-blades-revolutionise-offshore-wind-us/

Likewise, 16 units of the WindSTAR 11 MVA 66/0.69 kV product have been installed in V164 wind turbines: Five in the Blyth Offshore Demonstrator, a 41.5 MW, five-turbine wind farm – the first 66 kV offshore wind farm in the UK, with the capacity to deliver clean power to 34,000 homes; and 11 to the European Offshore Wind Deployment Centre →**6.** This offshore wind test and demonstration facility

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Modular design makes it simple to adapt to the customer's requirements and features such as plug-in bushings on the high-voltage side make installation and commissioning easy.

is located 2.4 km off the coast, in Aberdeen Bay, in Scotland, and incorporates a 92.4 MW offshore wind power plant with the capacity to meet the annual electricity demand of nearly 80,000 homes.

Which way the wind blows

It is to be expected that turbine sizes will increase yet further – 15 MW [2] is already on the horizon and behemoths of up to 50 MW have been studied [3].

With extensive experience of high-power and high-voltage transformers for variable-speed drive (VSD) applications and a proven capability to design transformers with high quality, low maintenance and compact design for severe marine environments, ABB is ready to face these challenges and help enable a stronger, smarter and greener grid. ●

06

ENERGY TRANSITION

Evolution of HVDC Light®

ABB has been pioneering the voltage source converter (VSC) for high-voltage direct current (HVDC) applications since the first installation of HVDC Light. After more than 20 projects commissioned and the uptake of commercial operation, it is now time to take the next step in power transmission capabilities, using HVDC Light with improved current capacity, compactness and controllability.

01

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ABB's predecessor company, ASEA, started work on HVDC transmission in 1929 with the development of the Classic HVDC product, also known as the line-commutated converter (LCC). In 1954, ASEA constructed the world's first commercial HVDC link – to the island of Gotland, in the Baltic Sea. This pioneering heritage was later expanded to VSCs and, in 1997, ABB laid the ground for the world's first VSC-HVDC demonstration project, in Hällsjön, Sweden, thus introducing HVDC Light. This groundbreaking event marked the advent of transistors as power semiconductors for HVDC transmission, which allows voltage and frequency to be controlled by the converter. Since the introduction of HVDC Light, well over 20 projects have been completed or are under construction.

Since HVDC Light can easily adapt to required grid codes, fast delivery time and additional auxiliary services such as black start and AC voltage support are possible.

HVDC Light technology is being successfully deployed in an increasing number of applications, thanks to the parallel development of higher converter voltage and power ratings, improved semiconductors based on insulated-gate bipolar transistors (IGBTs) and advances in extruded cables with solid-polymer insulation →**1**. By embedding HVDC Light functionalities into an AC network, voltage support, reactive power compensation, black start and the performance of existing grid assets can be reinforced.

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01 Skagerrak 500 kV HVDC Light Hybrid bipole, converter building.

—
02 HVDC Light converter valve in a power-from-shore application.

HVDC Light evolution

The evolution of HVDC Light started in the mid-1990s with the idea being to bring the excellent dynamic performance of VSC that had existed in train drive systems and variable-speed drives over to transmission systems. At this time, vital supporting technologies – such as high-voltage semiconductors and digital control systems – were also rapidly evolving. HVDC Light was launched in 1997 with the Hällsjön pilot after three years of intense research and development dedicated to solving, for example, the problem of how IGBTs could be controlled in series connection, thus enabling a high-voltage IGBT setup that could operate in the kHz range. Technology areas such as system design, valve design, control and protection design and plant design were adopted for the voltage source technology from ABB's knowledge of classic HVDC in order to create HVDC Light.

02

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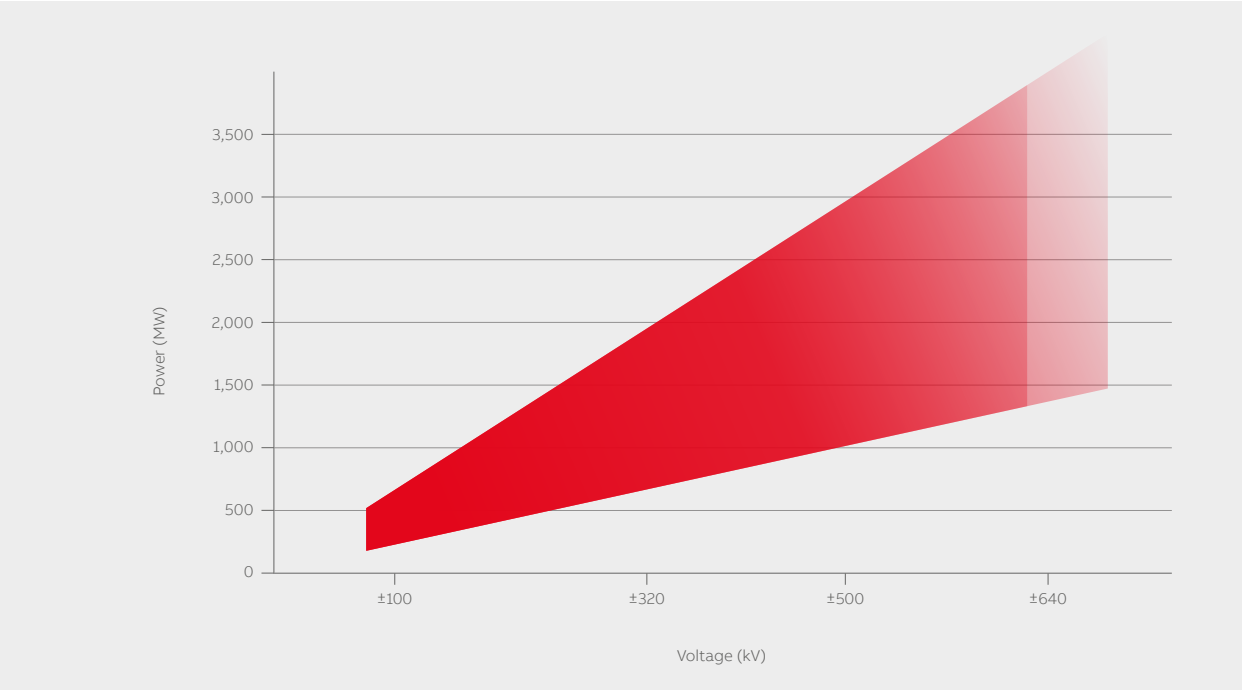
For remote offshore wind generation, HVDC Light enables connection distances above 100 km – a difficult proposition for conventional AC solutions.



03

The first commercial HVDC Light link, on Gotland, was to support the integration of renewable wind power into a fairly weak island grid. The project was a showcase for how HVDC Light can support grid resilience through active and reactive power control with high dynamic performance. The power level was a modest 55 MW at 80 kV.

The increase to 1,400 MW at 500 kV DC has enabled cable interconnectors with lengths of 300 to 700 km to reach the power limit allowed in some European grids.

The next evolutionary step was to introduce HVDC Light as an interconnector between asynchronous grids. Since HVDC Light can easily adapt to required grid codes without any negative effect on existing grid infrastructure, fast delivery time and additional auxiliary services such as black start and AC voltage support are possible. Interconnector projects were installed in Australia, North America and Europe.

HVDC Light has always targeted environmental challenges, resulting in the development of power-from-shore applications for the oil and gas industry as well as for the connection of remote offshore wind generation →**2**.

For the latter, HVDC Light enables connection distances above 100 km – a difficult proposition for conventional AC solutions. In fact, voltage-source HVDC has been a fundamental enabler for remote offshore wind farms. Further, projects in Norway have proven HVDC Light's ability to provide a solution with small physical footprint and weight, and with a performance and availability superior to gas turbine technology.

HVDC Light was originally always combined with high-voltage, extruded XLPE DC cables, which give a high power density with a narrow right of way. Solutions with a mix of overhead lines and cables or only overhead lines have also been deployed. In the Caprivi Link project between Namibia and Zambia, for example, two weak grids are connected by a long HVDC Light overhead line. The Caprivi Link can be expanded from an asymmetrical monopole to a bipole scheme in a later stage – which is possible thanks to HVDC Light's controllability, where control parameter adjustment enables easy adaption to different grid conditions.

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03 Possible power range for HVDC Light systems.

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04 The new BIGT structure.

The increase of the HVDC Light power level to 1,400 MW at 525 kV DC has enabled cable interconnectors with lengths of 300 to 700 km to reach the power limit allowed in some European transmission grids. 3,000 MW at 500 kV is the next step foreseen, which would enable HVDC Light to be employed in many new point-to-point or multi-terminal systems, thus solving many transmission challenges, especially in remote generation applications →3. The combination of modern power semiconductors, the MACH control and protection system, and the system knowledge collected in the ABB HVDC Light experience database will serve the industry well and is a good base for the next step in the evolution of HVDC Light.

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Compact converter designs that reduce valve hall size and deliver efficient valve control, reduced losses and increased reliability are criteria that have driven valve development.

Development of converter valves, systems and plants

Having started with small-scale monopoles and DC cables, VSC systems based on modular multilevel converters now extend HVDC to the whole range of possible applications and configurations, eg, high-power, multi-terminal bipolar transmission with overhead lines, high-power offshore wind farm grids, and system synchronization and stabilization installations.

Advanced control features like black-start capability, islanding, power system stabilization and harmonic suppression have been implemented. System control and protection developments, including hybrid DC breakers, make HVDC Light applications compatible with the HVDC grids of the future.

Plant design focuses on compact solutions – ideal for both for onshore and offshore – that place great emphasis on space, weight, EMC (electromagnetic compatibility) and noise requirements. Footprint has reduced by a factor of two every five years.

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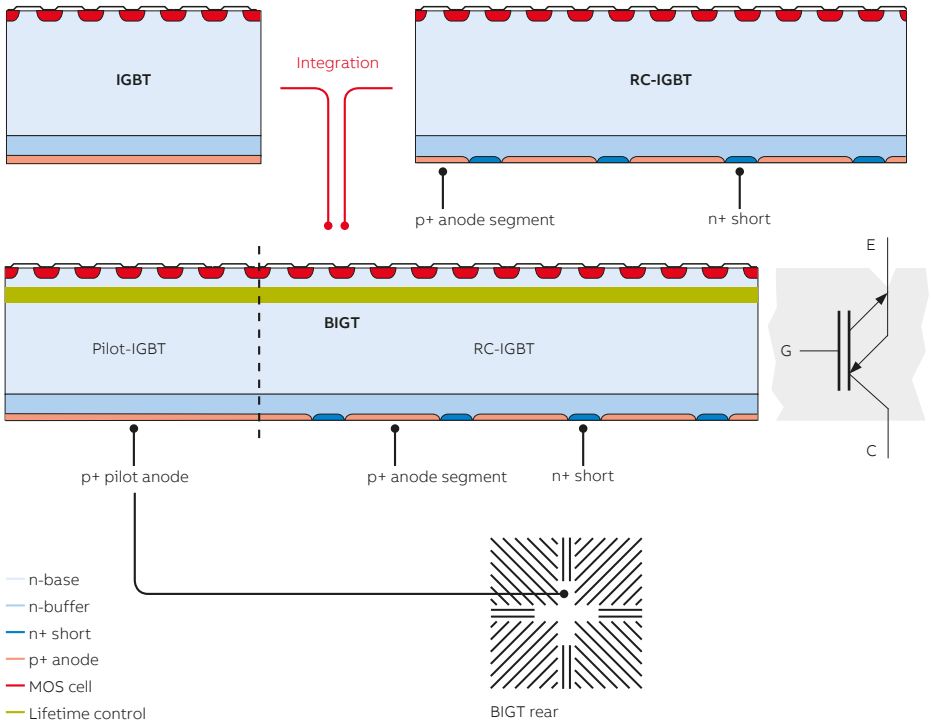

Simple layout and corresponding plant design
Compact converter designs that reduce valve hall size and deliver efficient valve control, reduced losses and increased reliability are criteria that have driven valve development.

Today's HVDC Light converters scale from 80 kV to 800 kV and 100 MW to 4,600 MW, with rated DC currents up to 3,000 A. The use of BIGTs (bi-mode insulated-gate transistors) and advanced switching algorithms allow for increased current density and low converter losses.

Station losses are now under 1 percent per station and in the range of HVDC Classic (LCC-HVDC used for ultrahigh-power transmission).

State-of-the-art test capabilities
With larger HVDC Light converter power ratings, test demands increase. Operational testing, for example, is performed to verify the performance of converter valves under worst repetitive stress (voltage, current and temperature) conditions and to verify the interactions between the valve electronics and power circuits.

A new 2,900 m^2 test facility was recently constructed to verify converter valves with current ratings of 3,000 A and above. In the test setup, power circulates between two single-phase systems representing independent converter stations. Only converter losses are fed into the test circuit. Each valve arm consists of six cells. The equivalent three-phase power of this setup is 31 MW.

5,200 V/3,000 A BIGT Stakpak Modules
Over the past few decades, advances in high-voltage semiconductor devices have led to tremendous improvements in terms of higher power handling capabilities and lower losses. For VSC topologies, a prime development goal was full integration of the active power semiconductor switch and the antiparallel freewheeling diode.

Today's HVDC Light converters scale from 80 kV to 800 kV and 100 MW to 4,600 MW, with rated DC currents up to 3,000 A.

This led to a focus on an IGBT and diode integration solution – referred to as the reverse conducting IGBT (RC-IGBT). The main aim was to obtain higher power densities and more compact systems while improving the diode performance when compared to modern IGBT/diode solutions.

Initially, such a concept was only realized for RC-IGBTs with a lower voltage rating (< 1,200 V), suitable for soft switching applications that have low demand on the diode-mode switching performance. However, despite major challenges with respect to the design and performance trade-offs for a hard switching RC-IGBT, ABB became the first to develop a high-voltage RC-IGBT with voltage ratings up to 6,500 V for mainstream VSC applications such as HVDC Light.

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05 The 3,000 A BIGT StakPak.

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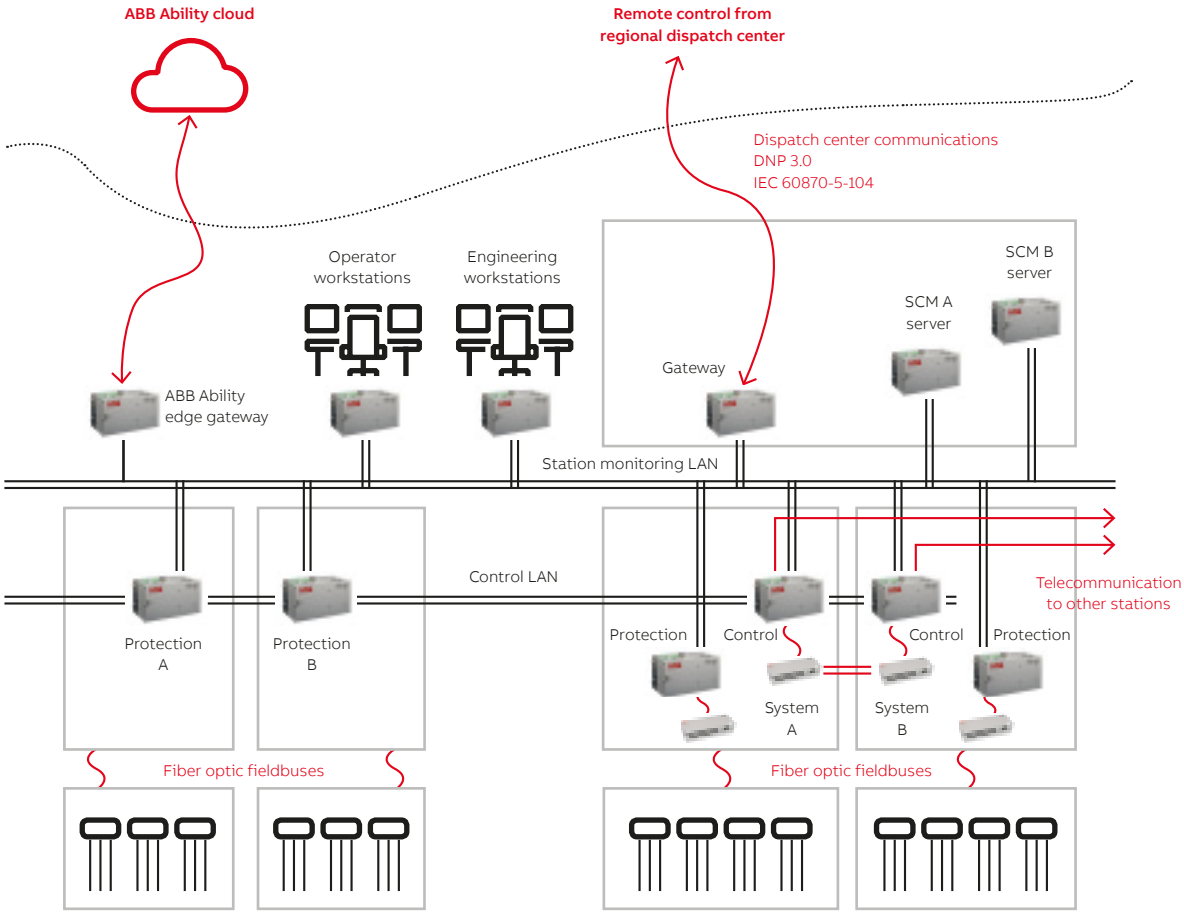
06 Structure of the HVDC MACH 3 control system for one pole.



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The advanced RC-IGBT concept is the BIGT referred to above. The BIGT was designed in accordance with the latest IGBT design concepts while fully incorporating an optimized integrated antiparallel diode in the same structure [1] [2] →**4**.

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A new 2,900 m² test facility was recently constructed to verify converter valves with current ratings of 3,000 A and above.

A 5.2 kV BIGT chip was implemented in a new generation of ABB's press-pack module. This new module is based on the already well-known StakPak™ platform that has proved its outstanding reliability and ruggedness by serving for many years as the principle switching device in ABB HVDC Light applications. The newly designed 5.2 kV Stakpak employs the BIGT chip technology but maintains the same packaging features that made the previous generations successful →**5**.

The new Stakpak module is the first commercially available high-voltage module equipped with BIGT chips [3].

The new module keeps the concept of individual chip contacts through strong press pins, which allow for a better cooling capacity and enable a relaxation of the flatness tolerance on the stacking cooler. All the Stakpak modules consist of a number of standard rectangular submodules; switch power is determined by the number of submodules in the frame. Since the BIGT is an integrated structure, the requirements of different IGBT/diode ratios is no longer an issue and much higher current ratings for the same given footprint can be achieved. The six-submodule version shown in →**5** can be rated up to 3,000 A – making it the most powerful IGBT-type package developed to date as it is capable of both IGBT- and diode-mode operation.

07

MACH™ 3 – the control and protection brain
HVDC transmissions have always been different from AC transmissions in that the power flow on an AC line is solely determined by the voltage and phase angle difference between the endpoints, whereas the power transfer of an HVDC system is fully controllable and the power flow is determined by the control system. This property is what provides many of the outstanding system features of an HVDC system, but it also requires a very fast and reliable control system.

Since the first commercial installation of HVDC Light, power capacity has increased by more than 60 times while equipment has become more compact and converter losses are four times lower.

With the introduction of HVDC Light (VSC) converters in the mid-1990s, the controllability of the HVDC converters took a quantum leap forward, as not just the active power but also the reactive power became fully controllable. The high-performance MACH 2 control and protection system was introduced together with HVDC Light, which allowed the first generation of VSC converters to achieve their outstanding performance.

It is therefore very timely that the evolution of ABB's HVDC Light technology, with higher power handling capacity, higher reliability and even further controllability coincides with the introduction of the latest generation of control and protection systems from ABB, the MACH 3 →**6.**

MACH 3 is based on high-performance 64-bit multicore general purpose processors, eight-core floating point digital signal processors (DSPs) and the latest generation of large FPGAs (field-programmable gate arrays). The DSP alone is capable of an astounding 160 Gflops (160×10^9 floating point operations per second) →**7-8.**

MACH 3 also provides high-speed communication links between the units and to and from the distributed I/O units. Optical fiber cabling eliminates almost all control and protection copper wiring and thus substantially increases reliability and safety in the station.

With its outstanding communication capabilities, MACH 3 is the ideal platform to implement a fully digitalized HVDC station. All time-tagged events and alarms together with all important measured values are immediately available to the control and protection computers – from where they can

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07 PS700, the latest main computer for MACH.

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08 MACH PS935 Digital signal processing unit.

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References
[1] M. T. Rahimo, et al., "The Bi-mode Insulated-Gate Transistor (BIGT) A Potential Technology for Higher Power Applications," ISPSD 2009, Barcelona, June 2009.

[2] M. T. Rahimo, et al., "The Two in One Chip, The BiMode Insulated-Gate Transistor BIGT," ABB Review, 2/2013. pp 19-23.

[3] F. Dugal, et al., "The Next Generation 4,500 V/3,000 A BIGT Stakpak Modules," PCIM 2017, Nurnberg, May 2017.

[4] "HVDC Light (VSC)." Available: http://new.abb.com/systems/hvdc/hvdc-light

be made available to the range of ABB Ability™ services presently being introduced.

Future improvements – introducing ABB Ability MACH 3

Since the first commercial installation of HVDC Light, power capacity has increased by more than 60 times while equipment has become more compact and converter losses are four times lower. This rapid development, combined with unprecedented controllability, underpins the rapid growth of VSC-HVDC worldwide. Further improvements in performance and compactness during the next decade are foreseen.

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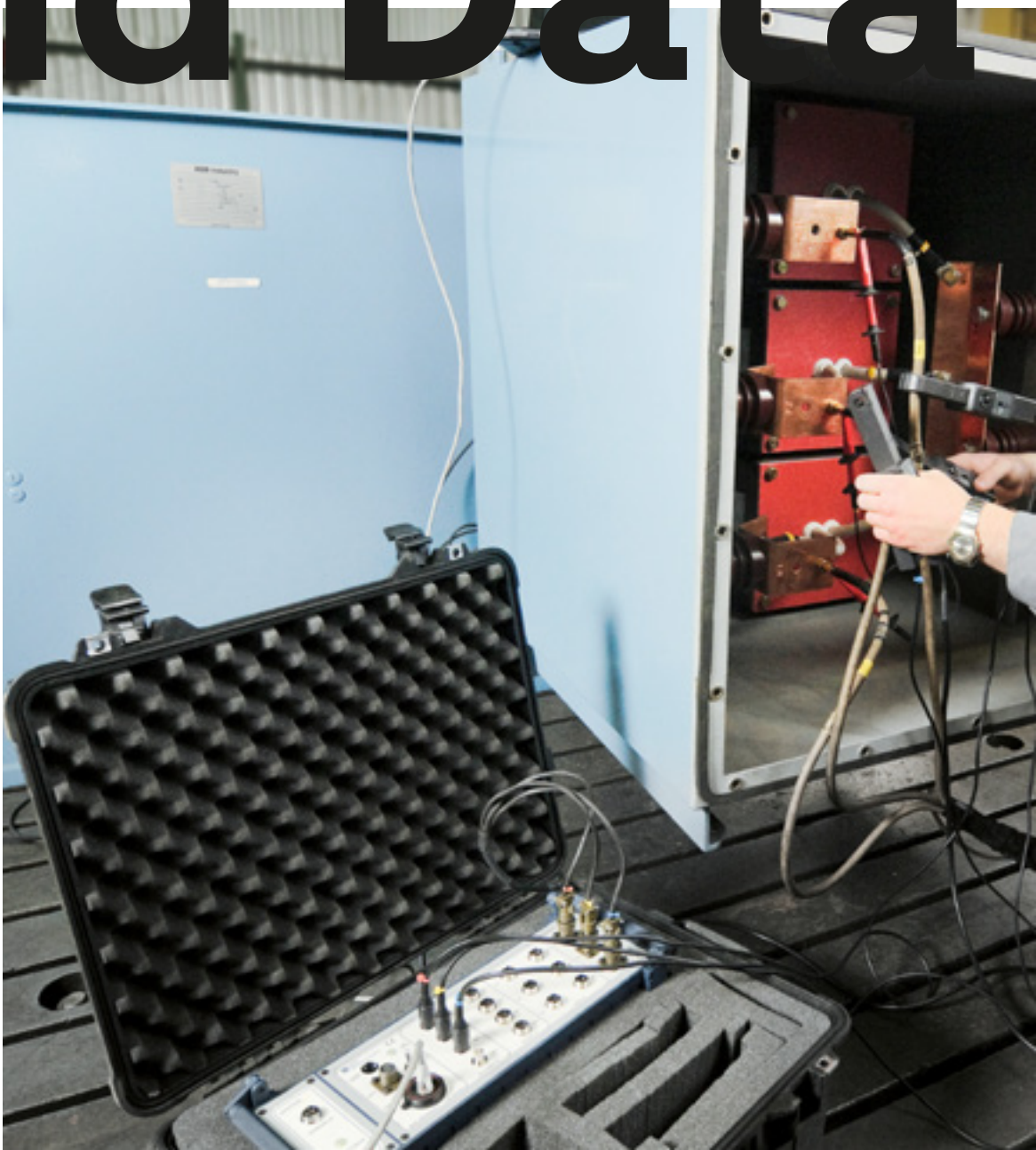
ABB became the first to develop a high-voltage RC-IGBT with voltage ratings up to 6,500 V for mainstream VSC applications.

In parallel to the development of HVDC Light, ABB is taking the next step in connectivity with ABB Ability. ABB Ability is a unified, cross-industry digital capability – extending from device to edge to cloud – with devices, systems, solutions, services and a platform that enable more knowledge of the system, more capabilities and improved performance delivered by connectivity of the grid equipment.

For HVDC, this can be exemplified by improved remote support, enhanced cyber security protection, dedicated support functions and facilities, and asset health systems. Developments and experience of collaboration in large automated systems in other industrial segments suggest coming rapid development in these areas. After all, HVDC stations, or plants, have been digitized for decades and represent some of the most vital grid assets. Digitization will come as a natural next step in the increased use of HVDC in the future grid [4]. ●

08

Diagnost and Data



ics

ABB Ability™ connects customers to the power of the Industrial Internet of Things by using diagnostics and expertise to “close the loop” between data and device operation. Think of it as an added layer of functionality that improves the performance of existing equipment, which also means it’s a creator of added value.

70 Data transmission drives turbocharger to new levels

72 What currents tell us about vibrations

DIAGNOSTICS AND DATA

Data transmission drives turbocharger to new levels

ABB's extension of the turbocharger variable turbine geometry (VTG) control system with the CAN/cellular gateway, and the newly available transmission of data to the ABB data server, provides customers with the ability to survey and monitor the actual operation profile and load exposure of each machine over its lifetime. Equipment maintenance and exchange intervals can be optimized leading to lower overall fleet life cycle costs.

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ABB's turbocharger VTG technology is used successfully in diesel-electric traction applications in China, India and Russia, with over 200 locomotives running in China alone. Nowadays, the maintenance and exchange of individual turbocharger components are based on engineering experience and the assumed load profile predicted for a given application category. However, the wear, fatigue and contamination of turbocharger components are a function of the actual operation profile and load exposure of each individual machine. The difference between assumed and actual load profile results in unnecessary part exchange, unexpected machine downtime and higher than necessary fleet life cycle costs.

Enter the CAN/cellular gateway, which ABB has extended to the VTG turbocharger →**1**. The gateway and the prototype transmission of data to the ABB data server was developed in close collaboration with the ABB Ability™ team. This innovation is made possible because turbochargers equipped with a VTG already include a control system and sensors for data measurements required to derive the load profiles. It is then possible to easily implement algorithms for surveillance and monitoring directly within this control unit.

This type of system is most effective only if the recorded data is transmitted periodically and on-site attendance of ABB service engineers is not required. Having this in mind, ABB has developed the data transmission to function in two ways: as pre-processed operation histograms, which require only low transmission periodicity (eg, on a daily or weekly basis) and, expanded to a higher sampling rate, transmission of the actual signal and component status. By recording the actual load profile and exposure over the entire lifetime of the turbocharger it is possible to determine equipment maintenance and exchange intervals individually.

By recording the actual load profile and exposure over the entire lifetime of the turbocharger it is possible to determine equipment maintenance and exchange intervals individually.

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01 System overview of the turbocharger equipped with VTG controller and data transmission.

In this way ABB helps its customers to reduce component exchange intervals and unexpected or unnecessary machine downtime.

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Customers are able to identify installations that deviate from the expected operation profile and ABB can provide individual service recommendations.

In addition, ABB Ability offers highly customized access to the monitored data and surveillance of other locomotive components such as traction converters, motors and transformers.

Customers obtain a complete overview at the fleet level, the locomotive level and the individual component level. The dashboards and key performance indicators can be individually customized and adapted to customer expectations. Customers are able to identify installations that deviate from the expected operation profile and ABB can provide individual service recommendations that help to lower overall fleet life cycle costs and minimize the customer's total costs of ownership. ●

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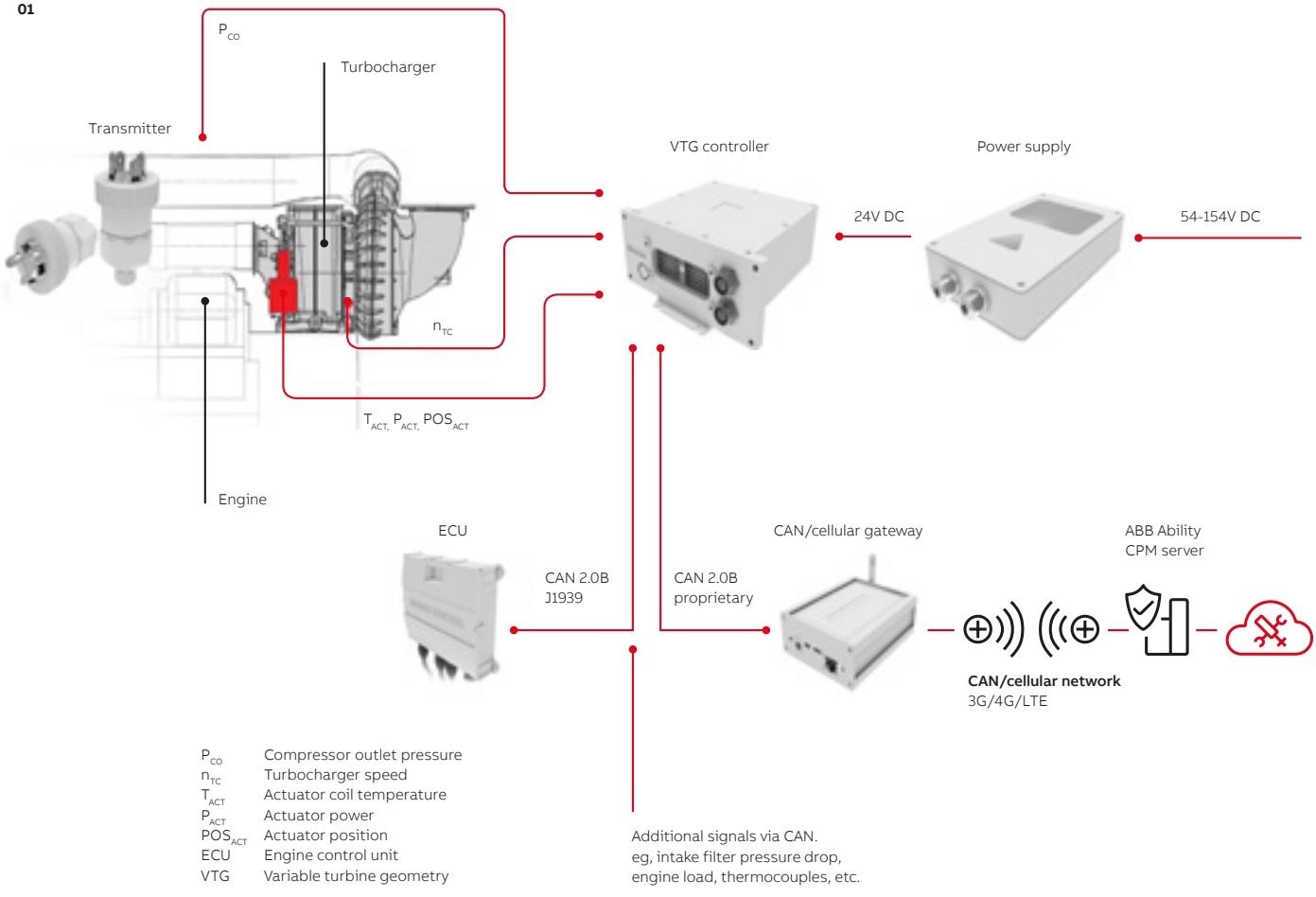

P_{CO}	Compressor outlet pressure
n_{TC}	Turbocharger speed
T_{ACT}	Actuator coil temperature
P_{ACT}	Actuator power
POS_{ACT}	Actuator position
ECU	Engine control unit
VTG	Variable turbine geometry

DIAGNOSTICS AND DATA

What currents tell us about vibrations

Valuable condition monitoring data, relevant for an entire drive-train can be unlocked using electrical signals in motors.

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Advances in sensing, connectivity, cloud and computing technologies are driving the digitization of industry at an ever-increasing rate. Add state-of-the art analytics algorithms to the mix, and customers are able to extract considerable additional value from their devices, systems and plants. Digitization increases the ability to diagnose and predict the future health of components with greater confidence and accuracy – and optimize maintenance strategies accordingly.

Condition monitoring, or more specifically, predictive maintenance represents one of the most regularly cited applications of advanced data analytics in an industrial context. From a conceptual point of view, condition monitoring is simple: measure and observe parameters that are indicative of the health of a piece of machinery and, when a change is identified in one or more of these parameters, infer what this means for the likely present and future health of the machinery.

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01 A field service and diagnostic engineer connects current and voltage probes to a motor in order to perform a MCSA.

To implement such an application, the engineers developing it must have an advanced understanding of the underlying physics of the system to ensure that the right data is being recorded at the right times. Rotating machinery is a traditional domain for condition monitoring. Sensors such as accelerometers, thermal infrared imaging systems and oil debris sensors are typically used to detect increases in vibrations, temperatures and particle counts, each of which can be indicative of a potential fault in the equipment. Whilst the effectiveness of these methods is beyond doubt, in many cases safety, spatial or financial constraints make it difficult or impossible to gain access to and attach such instruments to the equipment. Fortunately, there are also other sources of data that are well-suited for condition-monitoring. Interestingly, this data is often already being collected but not used.

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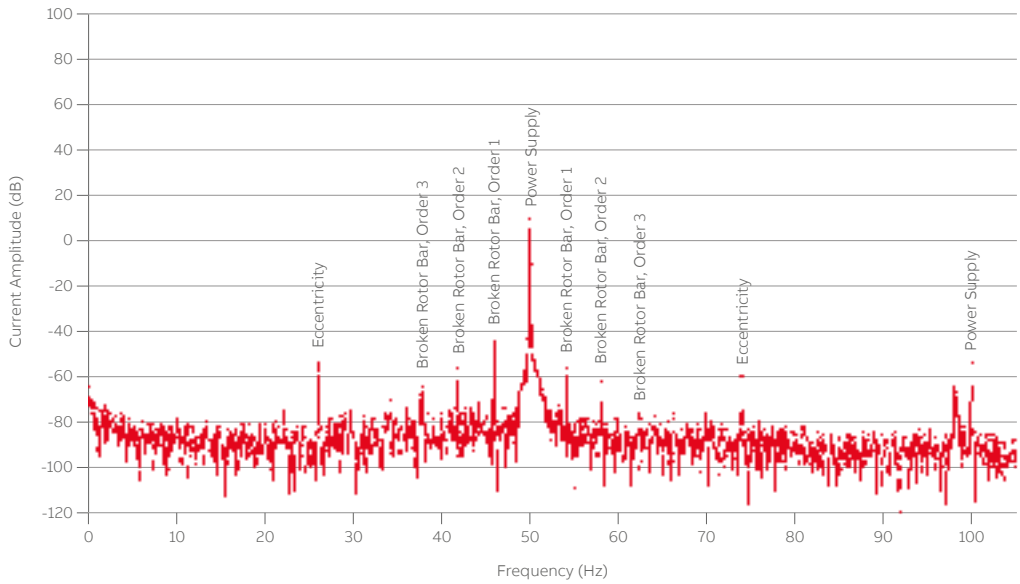
The engineers developing a condition-monitoring application must have an advanced understanding of the underlying physics of the system.



02

Induction machines

Their low cost and robust design, coupled with advances in control capabilities have made induction machines so popular that they are now one of the main consumers of total energy generated globally. Such machines can be found in large critical installations, such as the megawatt installations in oil and gas compression stations, as well as in multipurpose general use, where they drive a wide array of applications. In view of the broad distribution of these machines, advances in health-monitoring capabilities have the potential to deliver huge gains in terms of improved up-time, reliability and the associated savings →**1.**

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Induction machines are now one of the main consumers of total energy generated globally.

A widely recognized approach for identifying faults in motors is MCSA (Motor Current Signature Analysis). Basically, the currents in the motor's connection cables are measured (for example, using current transformers) and then analyzed (for example, using spectral analysis). Induction motors operate on the basis of electromagnetic induction. Interactions between currents and magnetic fields in the stator and rotor generate the torque that drives the rotating equipment. Induction motor faults such as air-gap eccentricity or broken rotor bars change the nature of the rotating magnetic fields, resulting in modulations of the currents. These may be observed in the power supply cables. Analysis can both identify and quantify the severity of faults in the motor. In contrast to the dedicated condition monitoring sensors discussed previously, the power cables of motors are typically easy to access. Furthermore, motor currents and voltages are often already being recorded for other purposes (for example, protection or control). Condition monitoring can thus be implemented on the basis of existing data, without requiring additional sensors →**2.**

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02 Current frequency spectrum measured on an experimental induction motor with various seeded faults.

Frequency components of interest are highlighted, including those that can be used to diagnose specific fault modes.

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03 Oscillations caused by faults in rotating equipment can propagate through to a connected motor.

Beyond the motor

Whilst MCSA is well established for monitoring motor faults, it is less commonly appreciated that faults occurring in components connected to the motor, such as gearboxes, compressors, pumps or fans may also be reflected in these electric signals. The speed and torque of a motor can be estimated on the basis of the voltages and currents measured at the supply terminals. Whereas many control strategies that allow variable-speed drives to accurately regulate the speed and torque of a drive train are commonly referred to as “sensorless”, in reality they are based on these parameters. Knowledge of the speed and torque can also provide data on connected components. An oscillation of the motor’s mechanical load (due, for example, to a degraded bearing) causes the rotation of the induction machine to vary, which in turn influences the magnetic fields in the motor and the currents and voltages measured at the motor terminals →**3.**

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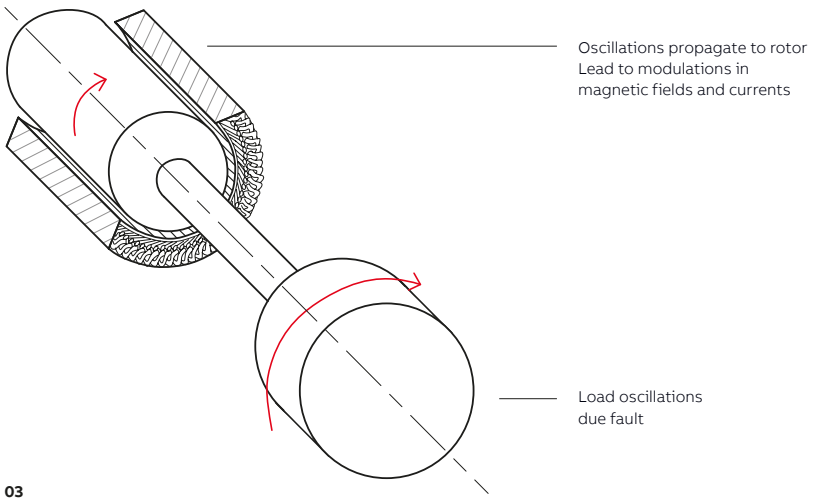
Faults in the induction motor such as air-gap eccentricity or broken rotor bars change the nature of the rotating magnetic fields.

Various technical challenges need to be overcome before MCSA can monitor connected load components. Chief among these is the need to understand the influence of all connected components, as well as a strong understanding of the operation of the motor itself. Cross-disciplinary domain knowledge is required to understand the influence of the electrical subsystems supplying the motor, the mechanical components connected in the drive train and, in many cases, the overall process system which the rotating equipment is contributing to.

In order to illustrate this, a previously developed suite of algorithms was considered, designed for monitoring the health of gearboxes on the basis of electrical signals recorded from a connected induction motor [1]. A mathematical model of a gearbox connected to an induction motor via a flexible coupling was developed. A space phasor model of an induction machine, which often forms the basis of sensorless control strategies, was combined with a low-degree-of-freedom, lumped parameter model of a gearbox. In order to properly understand the signatures that might be observed under healthy operation of the gearbox, various nonlinearities, including backlash and



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tooth stiffness variations, were incorporated into the model. Gear tooth faults were simulated via a no-load static transmission error function. Such a low-degree-of-freedom modelling approach strikes a balance between modelling detail and

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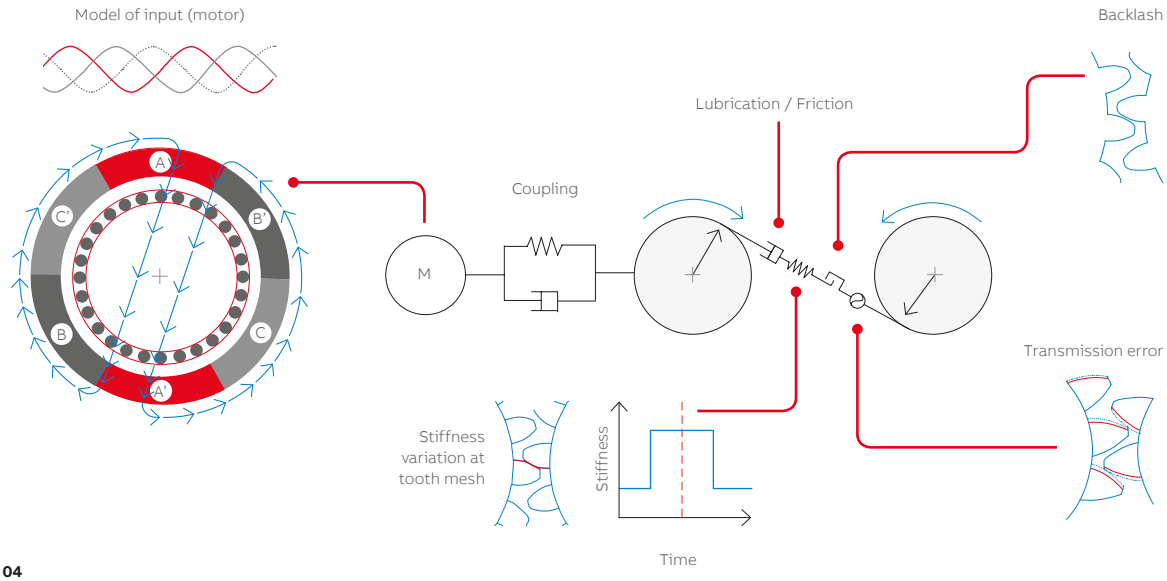
By combining all three phases using space vector approaches such as the Extended Park Transform, the signals can effectively be demodulated.

complexity, allowing the influence of few key parameters on the response of the system to be understood for a wide range of operating conditions and device configurations →**4.**

Insights obtained from this digital model were combined with further domain knowledge to develop signal-processing algorithms that identify fault signatures. Synchronous signal averaging is used regularly in vibration analysis to detect tooth faults in gearboxes. The approach involves recording vibration signals synchronously with the angular position of the gear shaft. By averaging the vibration signal from rotation to rotation, noise components are suppressed and components relating to the gear mechanics reinforced. This approach allows subtle fault signatures to be extracted from noisy signals. ABB investigated whether a similar approach could be applied when looking at measured motor currents instead of vibrations. When examining a single phase in isolation, motor currents are dominated by the power supply frequency. However, by combining all three phases using space vector approaches such as the Extended Park Transform, the signals can effectively be demodulated, leaving only components caused by imperfections and faults in the motor and load. Specially designed experiments validated the



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developed approach, showing that faults in gear teeth could indeed be detected by analyzing the electric currents supplying a connected induction motor. This information may be used to identify

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Equipment does not operate in isolation, but as systems of interacting components.

metrics that quantify the level of the fault. Such information can be trended over time to identify degradation →**5.**

Approaching complexity

Similar processes can be applied to develop methods for monitoring faults in other components, also using motor currents. Planetary (epicyclic) gearboxes are typically found in power-dense, critical applications such as wind turbines, gas turbines, helicopters or mining equipment. Despite having a more complex design than the standard parallel shaft gearbox considered previously, it was found that similar approaches for monitoring tooth profile faults could be applied [2] →**6.** The method has also been successfully applied to diagnosing motor faults in complicated cases such as wood chipping applications, where the measured signals are highly non-stationary. The approach has also proven itself in other load applications such as compressors, pumps and fans.

This article has already highlighted that approaches for monitoring load components using electrical motor signals potentially allow the monitoring of systems that cannot be instrumented with more traditional condition monitoring hardware. There are, however, various other reasons why motor currents should be part of a condition monitoring system:

- The premise that underpins this method is that equipment does not operate in isolation, but as systems of interacting components. Considering components in isolation can lead to false and missed alarms as dependencies on operating conditions and propagations of dynamics between components are neglected. Comprehensive, holistic monitoring approaches to system monitoring are preferable.
- Sensors are often complementary – one type of sensor or feature extraction approach will react better to certain faults than others (and vice-versa). Hence fusing data from multiple sources can improve the reliability and robustness of diagnosis.
- Sensors can fail: The motor current can be used as a fallback strategy when other condition monitoring sensors cease to be available.
- Sometimes motor currents are recorded for purposes other than condition monitoring (e.g. for control purposes in variable speed drives). It has been demonstrated that drive signals can be used for condition monitoring purposes [3-4].

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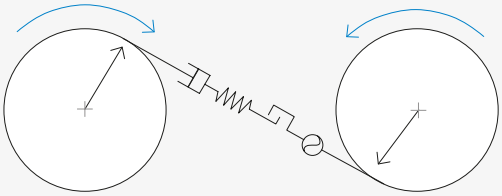
04 A low-degree-of-freedom model of an induction motor and gearbox with tooth faults.

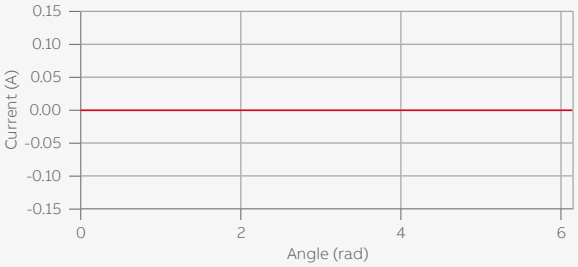
Digital World – Result of Numerical Simulation of Mathematical Model used for Development of Condition Monitoring Analytics

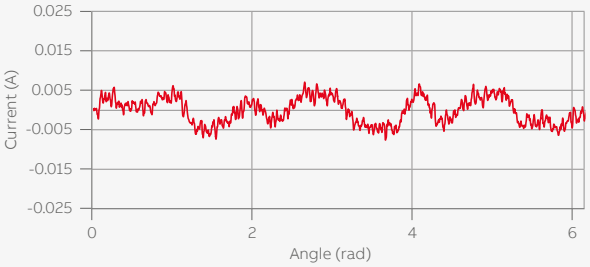
Physical World – Result of Experimental Testing used to Validate Condition Monitoring Analytics Approach

Parallel-Shaft Gearbox

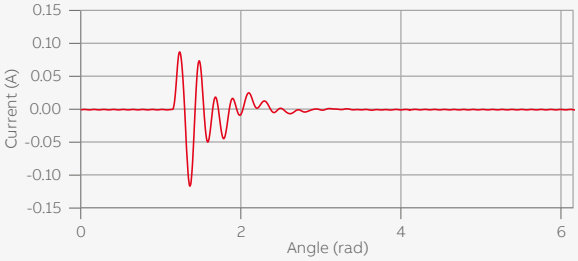


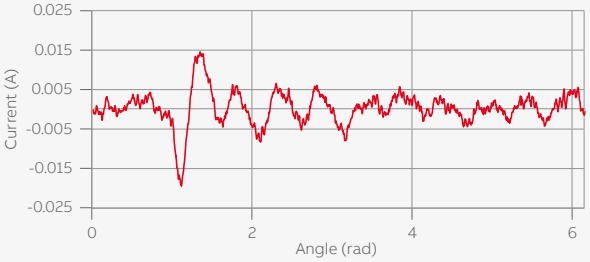
Healthy Gearbox





Gearbox with Tooth Fault





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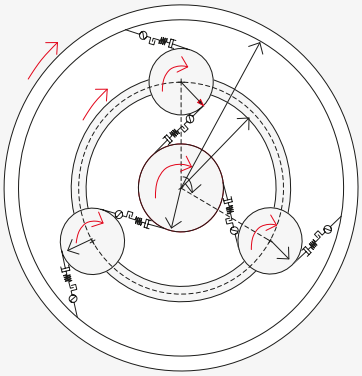
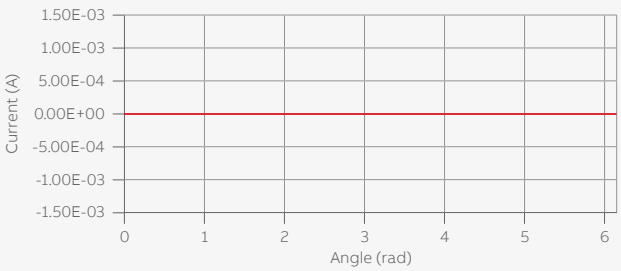
Digital World – Result of Numerical Simulation of Mathematical Model used for Development of Condition Monitoring Analytics

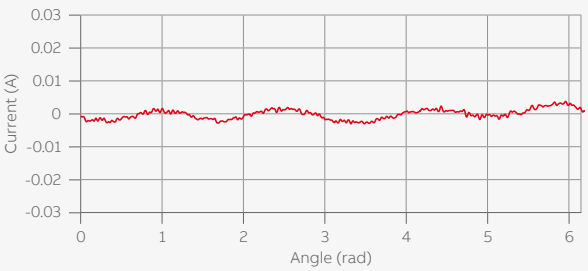
Physical World – Result of Experimental Testing used to Validate Condition Monitoring Analytics Approach

Planetary Gearbox

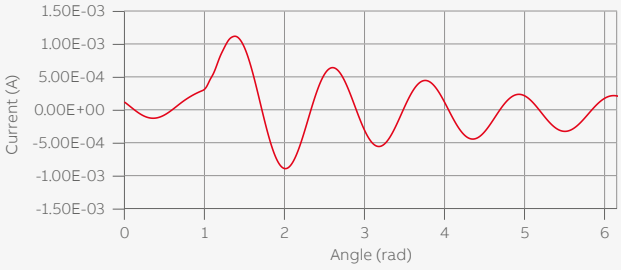


Healthy Gearbox





Gearbox with Tooth Fault



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05 Comparisons between numerical simulation and experimental results validate that gear tooth faults can be observed in induction motor currents.

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06 Gear tooth faults can be observed in induction motor currents even in the more complicated case of a planetary gearbox.

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References

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The digital revolution is enabling the further development of condition monitoring analytics methods for optimizing customer maintenance operations. In order to accurately monitor the health of a component it is necessary to record the right data at the right times at the right data volumes at the right locations. Often value can be extracted from different, non-obvious data

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sources. In this article, for example, it was shown that motor currents can be used either in place of, or in combination with, other sensors in order to monitor rotating equipment. The understanding built during such a development can guide decisions regarding the design of a complete condition analytics system, ranging from the choice of sensors and sampling rates, through to which machine learning algorithm is most applicable and what calculations should be performed at the edge and what should be calculated in the cloud. Development of next-level condition monitoring analytics solutions requires multidisciplinary domain expertise in order to understand customer systems and processes in a holistic manner. With its mastery of the control room obtained over many years of industrial automation experience, ABB is well-placed to continue to develop and deliver further holistic condition monitoring analytics solutions in the future. ●

READERSHIP SURVEY 2017

You have reviewed ABB Review

Because reader perception and satisfaction are important in charting the future course of ABB Review, in ABB Review 3/2017 readers were invited to take part in a survey. The results are being shared below →**1-6.** The ABB Editorial team would like to thank all those who participated in the survey, especially those who took the time to write constructive feedback and compliments in the comments field. Five winners were drawn from the participants, and each are receiving a Bluetooth sound station. Congratulations to Daniel Buser and Bruno Schnellmann from Switzerland, Mustafa Mahmoud from Jordan, Patrick Rossier from Australia and Carsten Sumborg from Denmark.

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01 How do you receive your copy of ABB Review?

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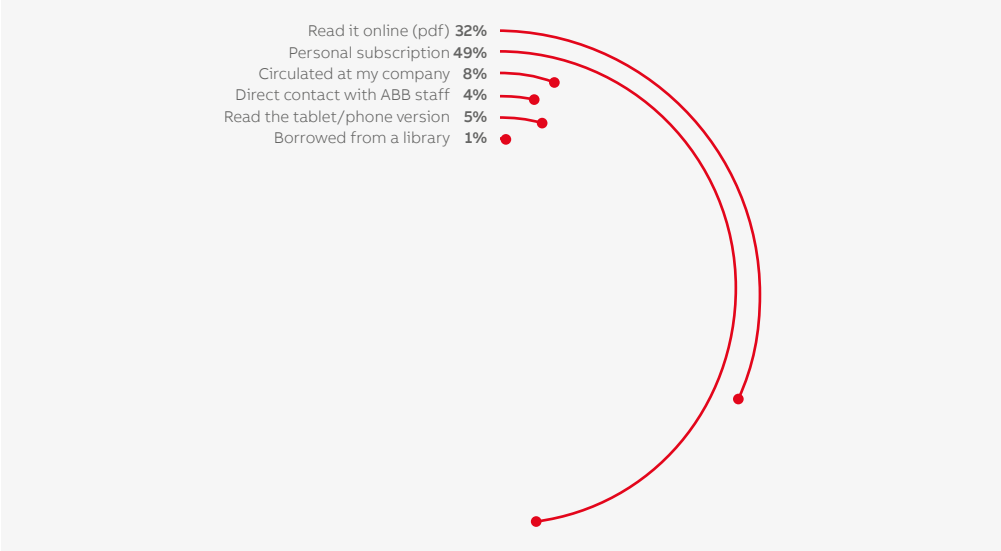
02 How do you use ABB Review? (Multiple responses permitted)



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03 ABB Review is currently available in four languages. If you could choose one additional language for ABB Review, which would it be?

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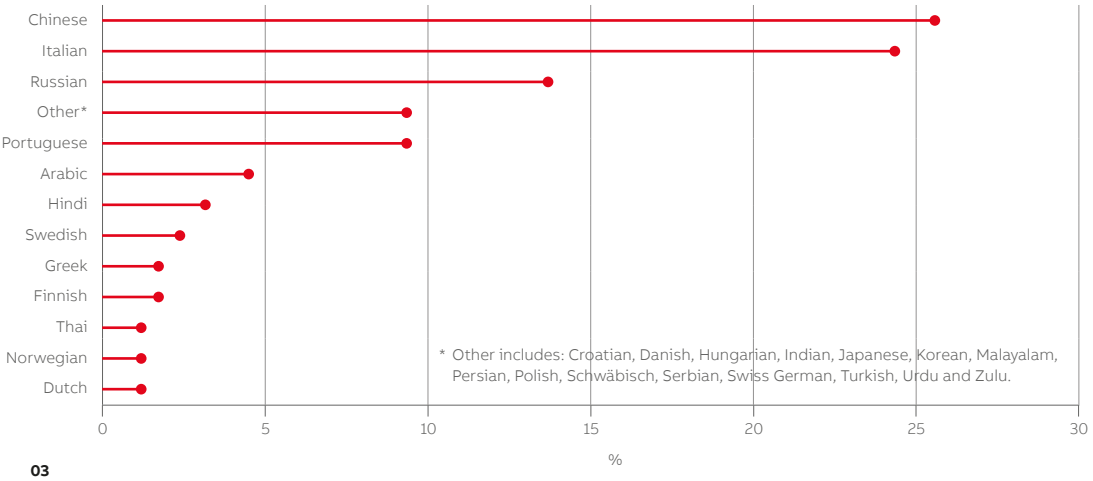

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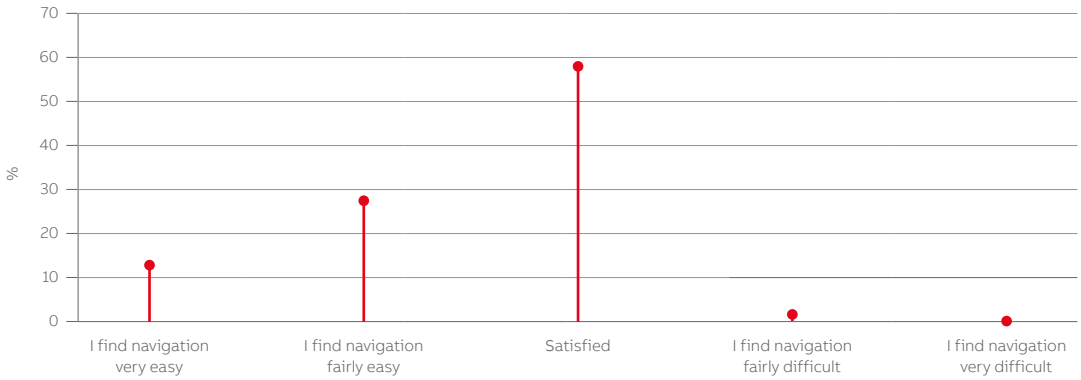

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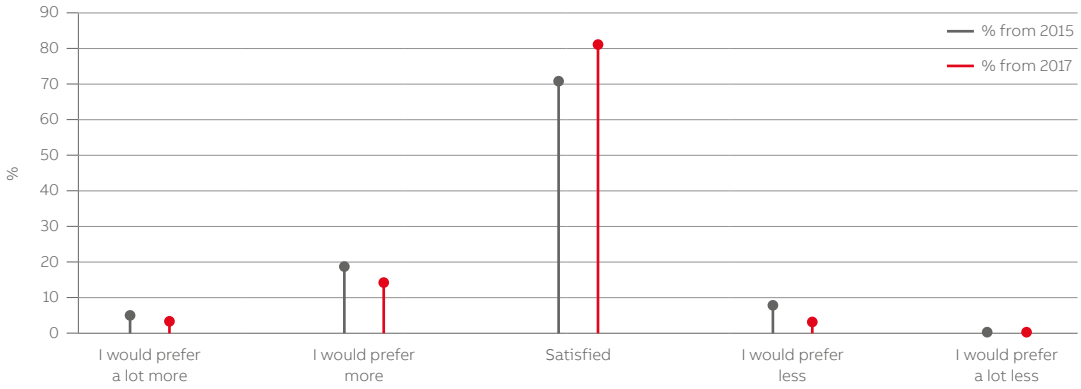

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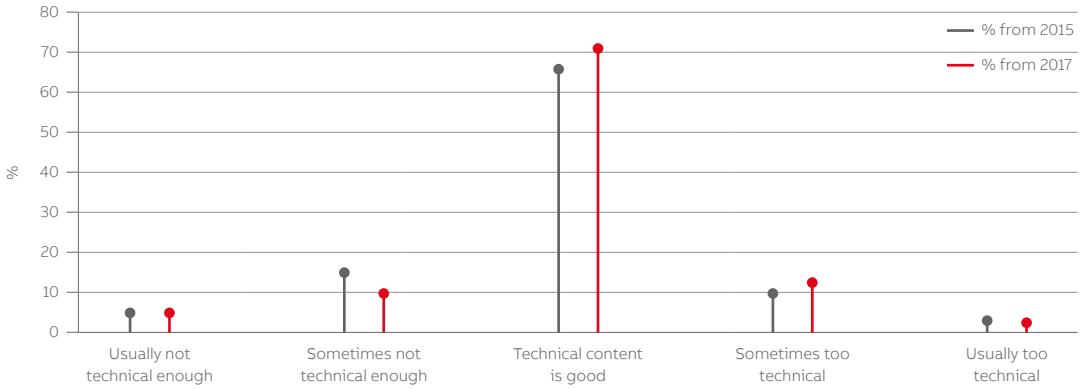

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BUZZWORD DEMYSTIFIER

Factory 2.0

The third installment of ABB Review's Buzzword Demystifier looks at production and the factory of the future – termed Factory 2.0.

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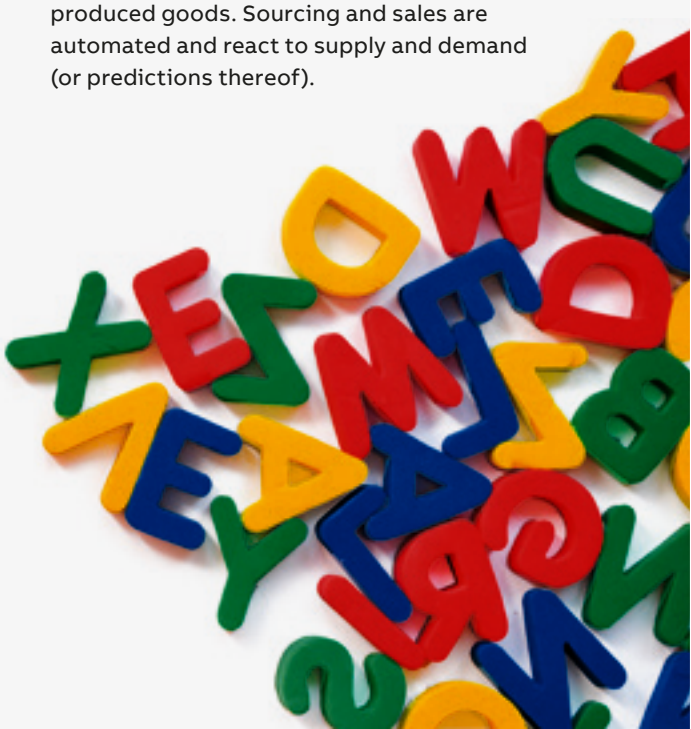
Many consumers are probably not aware of the extent to which retailer-side activities are already automated. When goods are ordered online, myriad warehousing and handling tasks are handled automatically. In a newer development, selected factories are shifting to a setup whereby production is driven by actual orders received online and effected automatically. A flexible Internet-connected factory manufactures many different products and can rapidly introduce new products to meet fast changing demands (driven by technological advancement or changes in the market environment, eg, fashion).

The factory layout and setup must be adaptable both in terms of equipment and of organization. Universal machines and robots will replace highly specialized ones in a step-by-step manner. The investment of suppliers will shift from being tied up in equipment and its configuration and will instead become software-based. The site at which the product is physically manufactured is no longer defined by a unique factory location, but the manufacturing site can vary from order to order according to available capacity and cost optimization of supply and delivery chains.

This factory of the future, or Factory 2.0, is characterized by six points:

- **Virtualization** will make data and parameters in a factory available digitally and seamlessly accessible to everyone. Because a single instantiation describes the entire factory and its processes, production can easily be duplicated elsewhere. The digital description also facilitates simulation, trouble shooting, and repairs.
- **Supply-chain and delivery** will be subject to Internet-based trading of the received and produced goods. Sourcing and sales are automated and react to supply and demand (or predictions thereof).



- **Communication networks and inter-connectedness** are paramount, and total knowledge of activities and equipment status is used for its optimal deployment.
- **Humans** will transition from tedious and repetitive tasks and instead concentrate on problems that require dexterity and intelligence supported by new tools like augmented reality, virtual assistants or else.
- Factories will be independent grid assets with autonomous **energy supplies** and the potential to offer ancillary services to the network operator.
- The needed **flexibility** of the production is enabled through autonomous organization and control of the production process. Control and automation tasks are performed wherever needed in the cloud as well as among the intelligent devices. Devices and systems will autonomously respond to changes effecting the environment of the factory. ●

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Excellence in design

Tomorrow’s products and services are born in today’s designs; as such, ABB uses cutting-edge tools and methods to develop technologies that will not only be relevant in the future, but help define it. The next issue of ABB Review will yield behind-the-scenes insights into the company’s design process, ranging from advanced simulations and testing of hardware and software, to novel approaches to collaboration.