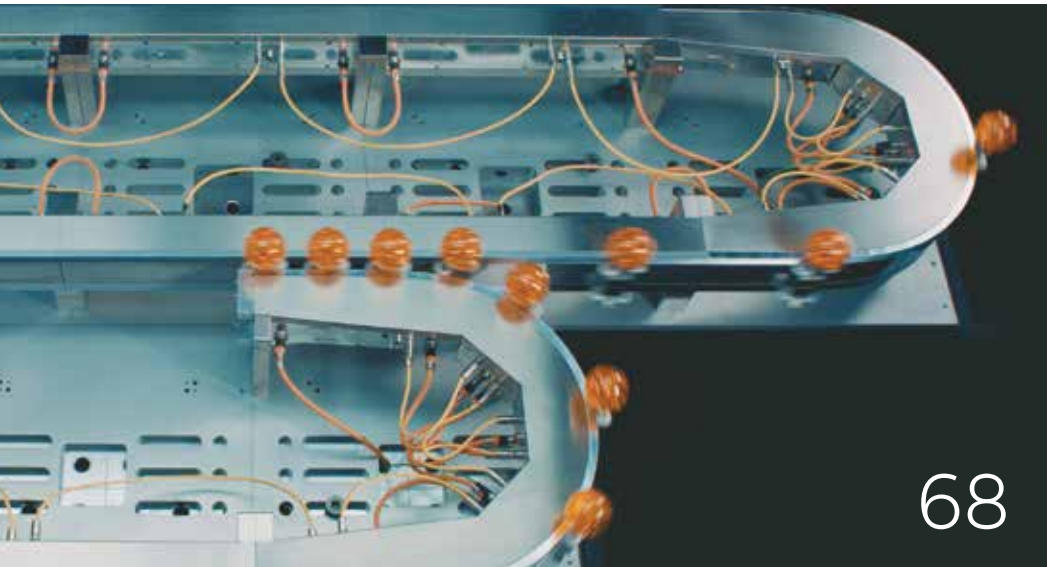
review

02|2018 en

Excellence in design

Transformer vibroacoustic analyses

TruONE™ automatic transfer switch

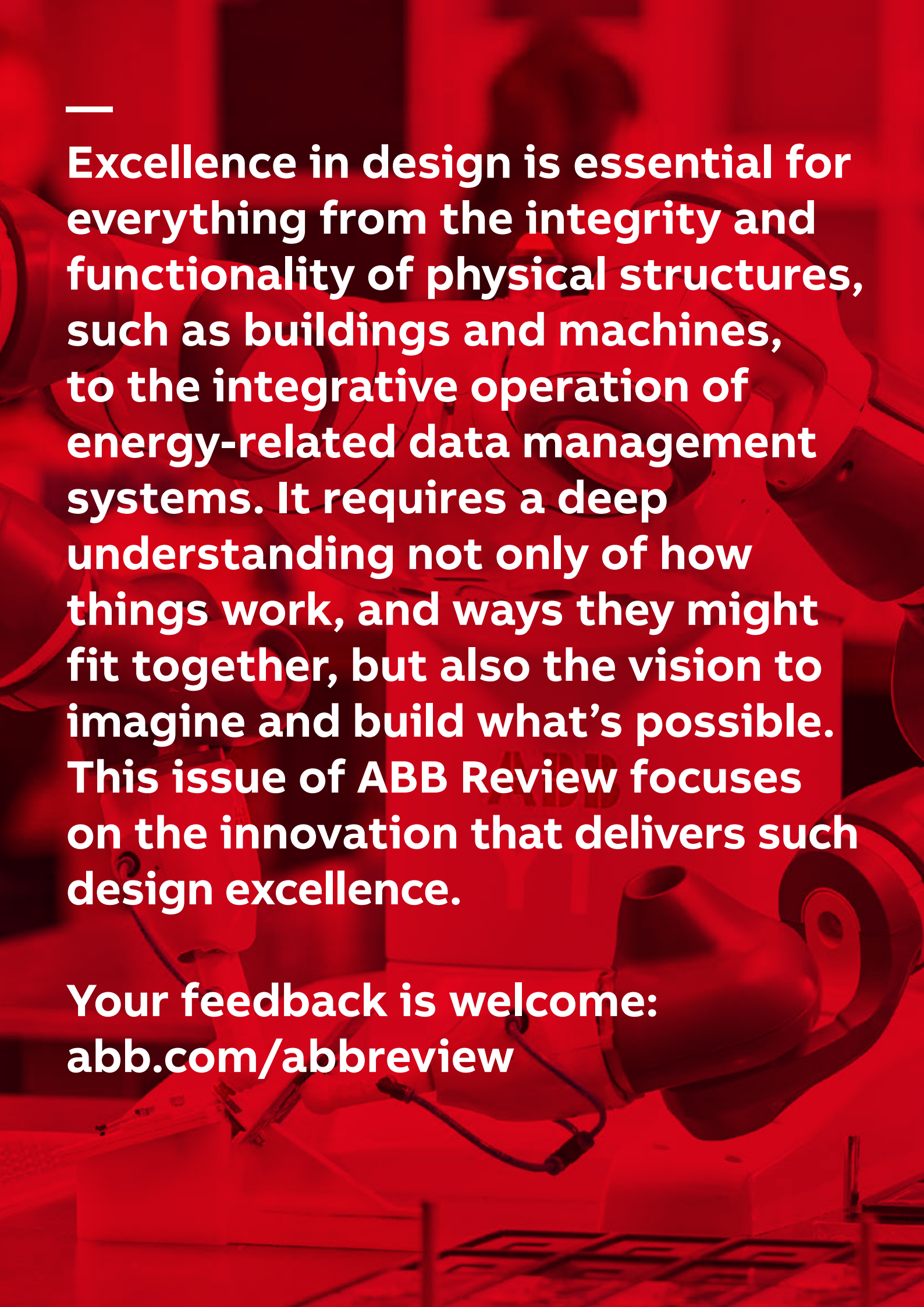


Intelligent product transport on track

Making sense of complexity

Electromagnetic flow meter digital twin

Fast, high-resolution web analysis



Excellence in design is essential for everything from the integrity and functionality of physical structures, such as buildings and machines, to the integrative operation of energy-related data management systems. It requires a deep understanding not only of how things work, and ways they might fit together, but also the vision to imagine and build what's possible. This issue of ABB Review focuses on the innovation that delivers such design excellence.

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EDITORIAL

Excellence in design

Dear Reader,

What is it that characterizes a well-designed product? In an industrial context, it is no longer sufficient that a device performs its own tasks flawlessly. More importantly, the device must be self-aware and fit in seamlessly with the rest of the plant and the broader value chain. By partaking in the data-flows, processes and intelligence made possible by digitization, the device becomes part of an advanced digitized production environment in which the whole is so much more than the sum of its parts.

The availability and sharing of digital information lies at the core of the concept of “digital twin”. Beyond the capturing of individual data streams and trends, physical and contextual information is also captured digitally, permitting the behavior of a device or entire system to be modelled or predicted. Non-observable or future parameters can be simulated. A digital twin supports and removes uncertainty during design and configuration while supporting applications and ensuring availability and reliability through condition monitoring and advanced services.

I trust this issue of ABB Review will raise awareness of some maybe less-known aspects of digitization being designed into products.

Enjoy your reading!

Bazmi Husain
Chief Technology Officer

Excellenc in design

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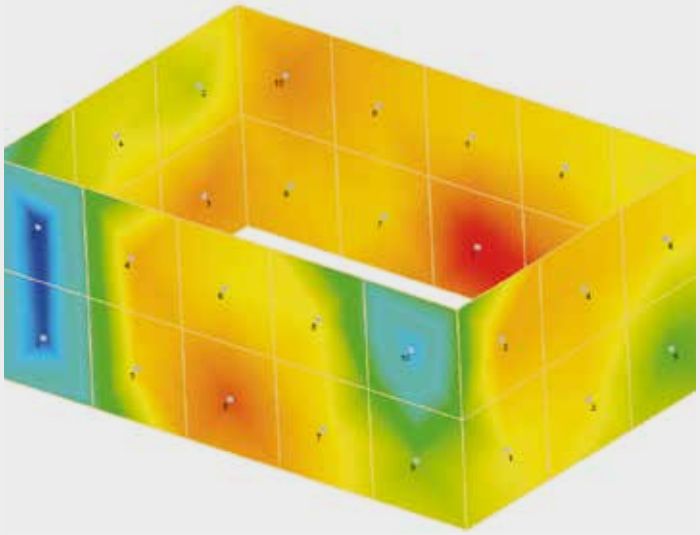
It can be said that unpredictability and noise evidence the absence of visibility into a system; ABB innovates ways to reveal these dependencies and patterns, and then model optimal performance in areas such as process control environments, HVDC components, and transformers.



08

EXCELLENCE IN DESIGN

Making sense of complexity

Industry 4.0 and associated developments in the digital world are ushering in a new era that promises to reshape process control environments by making a vast range of tasks more manageable and understandable.

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Process control environments are being reshaped by Industry 4.0 – the cyberphysical-systems-based fourth industrial revolution, which is itself being driven by technologies such as digitization, the Internet of Things, Big Data, artificial intelligence and virtual reality. These technologies hold the promise of making many increasingly complex tasks such as fault detection and diagnosis, as well as process optimization, more understandable and manageable.

Inexpensive sensors and AI are already making it possible for a single operator to manage an entire plant section.

What's more, they are opening the door to tomorrow's networked control centers. To be successful, however, these developments will require advanced collaborative work environments and a high-performance workforce.

Just as self-driving cars are set to transform the transportation sector, sophisticated digital automation programs are dramatically changing the operation of industrial processes. Driven by inexpensive sensors and powerful artificial intelligence algorithms capable of image recognition, vibration monitoring and much more, such programs are increasingly replacing human sensing. Indeed, in many cases, they are already making it possible for a single operator to manage an entire plant section.

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01 Modern hydrocarbon processing plants have myriad subsystems that must work together flawlessly. Optimized data management is the key.

Nevertheless, the picture is still far from ideal. Although integrated industrial information systems gather operational data to enable collaboration [1] and make real-time data available to appropriate individuals, McKinsey [2] has shown that in the case of offshore platforms, only a small portion of the resulting data is actually used as a basis for operational decisions →2.

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Why isn't the potential of Industry 4.0 being more fully realized? The answer often boils down to complexity.

Data availability: breaking down information silos

Why is the potential of Industry 4.0 not being more fully realized? The answer often boils down to complexity. Modern process plants are highly interrelated systems. A problem in one part of a process tends to propagate across different sub-systems and plant components. Advanced automation systems add dynamic interactions between these components, making it difficult to obtain a clear assessment of potential problems. Added to this inherent systems complexity is the human element, which may involve the collaboration of a multidisciplinary team and the involvement of specialized expertise, often represented by an external supplier.

			Comment	Source
	People and processes	0%	Schedule predominantly based on OEM- recommended maintenance intervals	Interviews with operational staff
	Deployment	< 1%	No interface in place to enable real-time analytics to “reach” offshore	
	Analytics	< 1%	Reporting limited to a few key performance indicators (KPIs) which are monitored in retrospect	BI and KPI walkthrough
	Data management	~ 1%	Data cannot be accessed in real time, enabling only ad hoc analysis	Walkthrough of infrastructure and band-width between off- and onshore
	Infrastructure	60%	Only ~ 1% can be streamed onshore for day-to-day use	
	Data capture	100%	~ 40% of all data is never stored – remainder is stored locally offshore	Assessment of storage capacity (on the highest capacity asset)

~ 30,000 tags measured

02

Unfortunately, collaboration between personnel from different disciplines, locations and organizations →3 is often hindered by the fact that the information needed to solve the problem at hand is hidden within information silos. Many companies also lack the organization and work processes to support multi-disciplinary collaboration, and therefore tend to execute work based on a relay race approach instead of as a collaborative effort. Companies are hardly blind to these challenges.

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The idea is to provide the same level of digital support to the industrial worker as has been available to office workers for years.

In fact, it is clear to most that, because of the trend toward growing levels of digitally-generated data, they need to improve the way they work in order to be competitive.

Progressive companies are responding by improving workforce effectiveness through the introduction of digital technologies. For example, many are introducing bring-your-own-device (BYOD) policies, as well as solutions that enable employees to work effectively wherever they are, whether in the control room, on the shop floor, or working remotely. The idea, in short, is to provide the same level of digital support to the industrial worker as has been available to office workers for years.

Information previously hidden within control systems or proprietary tools is now increasingly made available through improved connectivity and integration across systems and network layers. This trend is, in turn, opening the door to Web-based applications that support consolidation of data from different systems and tools, making these easily accessible from any location. All in all, easy access to data and a common work environment is the first step to enabling effective collaboration to support process operation. Improvements in analytics and visualization techniques also help workers to make sense of increasing amounts of data.

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02 Only a small percentage of the data generated in many industrial processes is being used as the basis of operational decisions.

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03 Collaboration across locations, disciplines and organizations.

Other technology trends are also supporting a new collaborative approach to work. Video conferencing technology has matured, allowing many companies to have remote operation centers that support local control rooms with open video links between locations. High quality video conferencing technology is also available from mobile devices or personal workstations, enabling operators to obtain instant access to remote expertise.

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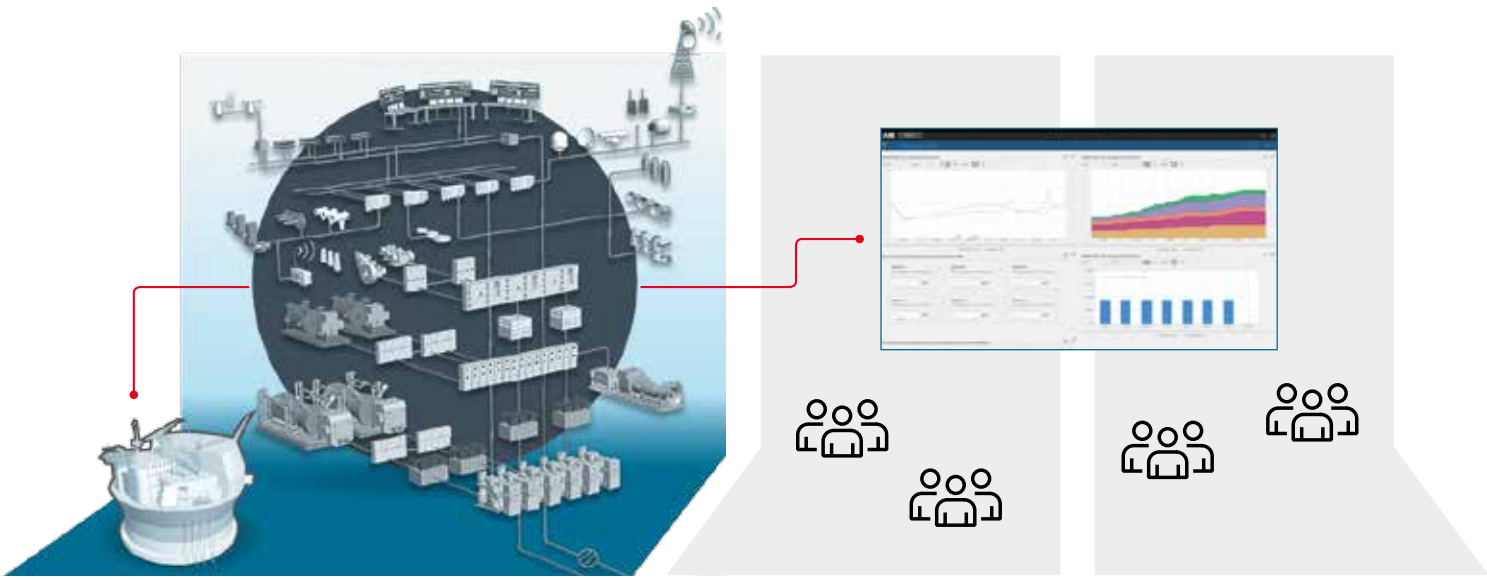
Digital technologies are blurring the boundaries between local and remote operation.

In combination, the introduction of digital technology for easy access to information, independent of location, and the proliferation of video conferencing to support remote collaboration, are blurring the boundaries between local and remote operation.

Insights into process operation

Modern automation systems can cover most aspects of normal operation but also handle many anomalous situations. Advanced control techniques such as model-predictive control (MPC) and state-based control (SBC) [6] allow the automation of very complex tasks, such as the startup of an industrial plant. Indeed, automatic control performs better than typical human operators. As a result, operators are less and less involved in the inner control loops that are directly in contact with processes. Their tasks are increasingly shifting to supervisory control [7], where the operator manages and supervises a large number of control modules. But being less involved in direct process control also means fewer possibilies to develop a feeling for a process by training on the job – a problem that was dramatically illustrated with the loss of flight AF447 [8].



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To be able to take over when automation fails, operators need higher qualifications and a profound understanding of underlying technical processes, automation systems and control modules. Simulator training is necessary to develop a feeling for processes.

Not only can Industry 4.0 have a profound influence on information flows and availability, it is also set to have a huge impact on industrial quality control.

Operators should also be deeply involved in the optimization of process operations, because this keeps them involved and helps to build up the required knowledge that allows them to take over in case of automation failure.

Not only can Industry 4.0 have a profound influence on information flows and availability, it is also set to have a huge impact on industrial quality control [9]. Big Data techniques make it possible to distill historical process data into algorithms that can predict the quality of production [10]. Developing problems can be detected early and countermeasures can be taken before impact becomes significant. Previously, it took an operator many years to accumulate comparable experience.

Remote expertise can also play a decisive role in failure avoidance. For example, in the case of the Deepwater Horizon oil spill [11], the investigation report clearly states that one major factor contributing to the accident was the incorrect interpretation of available measurements. Quite likely, advice from highly qualified remote experts would have avoided this accident.

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04 An extended operator workplace.

Process performance optimization
Key performance indicators (KPIs) for process operations in areas such as control loop performance, alarm management, energy efficiency and overall equipment efficiency are described in detail in [12]. Managing these KPIs is not a classic operator task but is becoming more and more important in terms of ensuring good production performance. Areas such as operations, maintenance and analytics need to be managed holistically to achieve the best results. Many of the associated tasks can either be performed by centralized internal service centers or outsourced to specialized external service providers.

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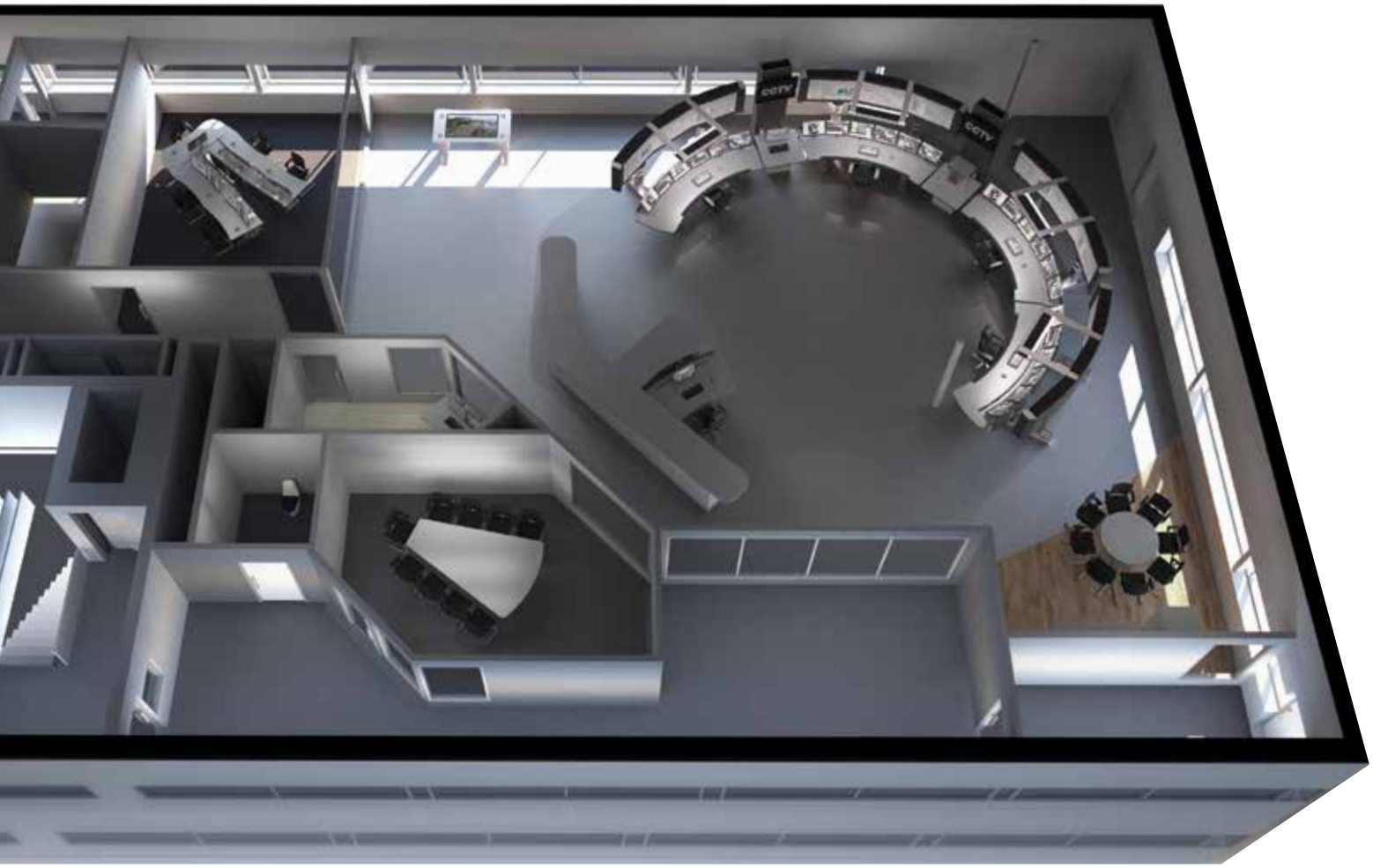
A challenge will be how to design collaborative environments that are integrated with remote service communities.

Typical goals are increased production plant throughput, efficiency, and uptime [13]. These can be achieved through a structured approach to revealing the sources of and responses to process variations and upsets. By reducing process variations, operational flexibility, plant regularity, safety and integrity will be increased, while off-spec production, energy costs, environmental impact, operator stress, and equipment wear will be reduced.

An example is provided by Dow Chemical, which has introduced a global analytics layer that distills vast amounts of data into readily understandable information and metrics [14]. As a result, experts from a centralized analytical technology center can now support plants globally to determine manufacturing obstacles, improve efficiencies and develop best practices.

Tomorrow's control rooms and operators
As mentioned above, most simple parts of traditional operator work have been taken over by automation. Modern operators now have a very different profile from their predecessors. They supervise large numbers of control modules and must be able to quickly diagnose complex situations, collaborate with various support units and coordinate field operators and maintenance personnel. They decide when it is time to bring in external expertise and manage the integration of remote experts. To achieve their full potential, they need a work environment that supports these activities.

In this connection, a challenge will be how to design collaborative environments that will replace traditional control rooms. Often, such centers will not need to be physically close to a process, but will need to be much better integrated with remote service communities in their own company, as well as associated service providers and suppliers.



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The involvement of experienced control room designers from an early stage on will be essential to the design of next-generation collaborative operation centers. Such centers will require a totally new approach that takes the full potential of Industry 4.0 into account. As the traditional way of building control rooms becomes obsolete, new best practices will have to be defined.

In tomorrow's control centers, the roles of operators will evolve from reactive to predictive problem solving and analytics.

The new centers will contain fewer operators, while the roles of operators will evolve from reactive to predictive problem solving and analytics. To achieve this, operators will have to be highly qualified and capable of interacting with many other specialized functions, such as IT/OT support, multifunctional support, technical and remote support, asset risk management, alarm handling, safety, cyber security and maintenance management.

Frequent interactive communication with a very broad range of remote service specialists – something that is still rare today, but that will be the norm tomorrow – demands a new look at factors such as room layout, working zones, monitors, cameras, analytical tools and remote collaboration workspaces.

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05 The newly designed collaborative operations center.

Although working in a 24/7 environment can be exciting, it can also lead to reduced life expectancy. In view of this, →4 presents a platform that can be adapted and even automated to meet each user's needs. For example, the distance between eyes and monitors can be automatically adjusted to reduce eye strain, and lighting can shift throughout the day to optimize circadian rhythms. Furthermore, big data analytics makes it possible to create a data-driven "day by day" improvement program for operators.

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Technological development that is driven by operators' needs can be expected to transform tomorrow's working environment.

→5 illustrates the newly designed collaborative operation center for an energy and environment company. Five traditional control rooms with 12 operators will be replaced by a new collaborative operations center hosting two operators who will call in remote expertise on demand.

Next-generation operators

As control centers metamorphose into collaboration centers, a major challenge will be to attract the next generation of operators – a generation for whom the connection between personal ergonomics and health is fundamental. This increasingly important factor calls for workplace designs that not only minimize acoustic disturbances, while optimizing factors such as illumination and air quality, but take into account aspects of the psychosocial working environment such as gamification, collaboration, individual space, flexibility, learning, sustainability, social presence, emotional engagement, and creativity. All in all, Technological development driven by operators' needs can be expected to transform tomorrow's working environment. ●

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EXCELLENCE IN DESIGN

Numerical simulations improve bushing performance and lower cost

Lately, customers – especially those in China – have asked for significant increases in the current ratings of new high-voltage direct current (HVDC) systems. To accommodate these new requirements, while minimizing development costs, more advanced simulations have to be employed, especially for critical current-bearing components such as bushings.

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Over the past few years, the power-carrying ability of HVDC lines has risen into the 10 to 12 GW range. This rise has been accompanied by a commensurate increase in voltage and current: Whereas the type test current of the first 800 kV power systems was around 4,000 A, that of more recent – 1,100 kV – HVDC systems is as high as 7,500 A. To handle these new requirements and to minimize development costs, more advanced computational fluid dynamics (CFD) simulations must be used.

To handle new requirements and to minimize development costs, more advanced CFD simulations must be used.

Bushings – numerical methods

A critical HVDC component, present in all electrical networks, is the bushing. A bushing is an insulated conductor that carries current, at a high potential, through a grounded barrier (a wall or a transformer) to the transmission line. As a bushing has no operational redundancy, its specification must be very stringent so as to ensure a long lifetime (up to 40 years) and trouble-free operation under very varied and extreme conditions.

ABB has scientists experienced in many types of numerical studies and with strong theoretical backgrounds and practical experience in the design and production of UHV (ultrahigh-voltage) AC and DC bushings. A solid knowledge of bushing thermal, electrical and mechanical simulation, and skill in constructing accurate numerical models that have been validated by many experimental tests, makes it possible to carry out fast and low-cost high-voltage (HV) bushing thermal performance studies.

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01 Test stand for the large HV Bushing – ABB Ludvika, Sweden.

The popularity of numerical methods has increased significantly in the past 10 years, mostly as a result of an increase in computational power and the consequent ability to solve ever-more-complex physical problems in a reasonable time.

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Numerical analysis allows design optimization and performance enhancement before testing against the required technical standards.

The great advantage of numerical analysis is the capacity it delivers to carry out in-depth studies of product behavior under various conditions in a short time and at reasonable cost. Further, numerical analysis allows design optimization and performance enhancement before testing against the required technical standards.

Until recently, most thermal simulations treated all bushing constituent materials – even oil and air – as solids; only rarely were fluid dynamics included. However, with the advent of bushings for very high voltages came the requirement for new, capable thermal models that would also keep development times short. There was, too, a need to integrate several different existing approaches into a common thermal model for bushings.

Thermal effects in bushings

A thermal simulation gives the temperature distribution in a bushing for different currents and different ambient temperatures. Such a study is essential because some components have very strict temperature limits, in order to exclude thermal degradation and consequent electrical breakdown.

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Condenser bushings consist of three primary components: an outer insulation for minimizing creepage currents and preventing external flashover; an inner capacitance-graded insulation “condenser”

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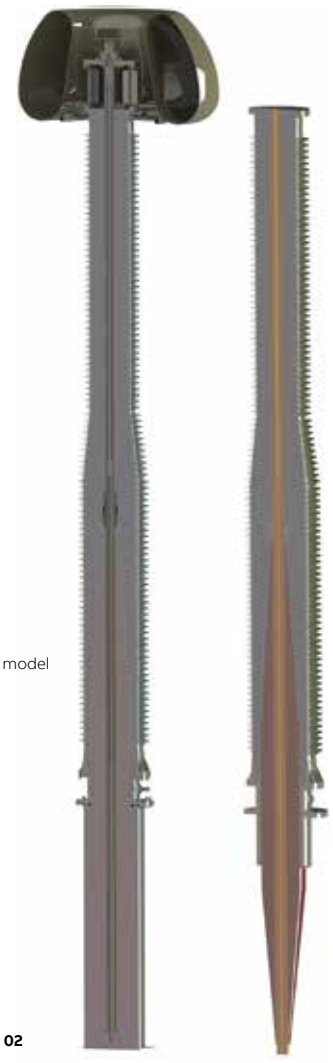
Thermal simulation of HV bushings is a complex exercise and many parameters influence the final result.

for distributing and stabilizing the electrical field (thus “condenser”); and a conductor system for carrying the current. For the condenser core, there is a critical temperature at which dielectric losses start to increase and trigger a thermal runaway – ie, the temperature rise increases the dielectric losses, which increase the temperature, and so on in a positive feedback loop that continues until thermal breakdown.



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To minimize the risk of a bushing failure in the system, regulations laid out in international standard IEC 60137 – as well as in stricter ABB standards – that define maximum allowable temperatures, are followed. Temperature rise tests performed on actual bushings are complicated, resource-heavy and time-consuming, especially for larger bushings →1.

Building an HV bushing thermal model

Thermal simulation of HV bushings is a complex exercise and many parameters influence the final results – for example, heat losses; treatment of conduction, convection and thermal radiation processes; material parameters; and turbulence modeling in the case of SF_6-filled bushings. In general, the thermal simulation process can be broken down into four steps:

- Preparation of the geometry model
- Generation of the computational mesh
- Setup of the numerical model parameters
- Numerical analysis and post-processing of the results

Preparation of the geometry model

Preparation of the bushing geometry model is usually the simplest part of the simulation process, as, in principle, it requires just the import and simplification of the device’s CAD model. Most of the small features such as screws, fillets, etc. are removed from the model as they do not have an observable influence on the simulation results →2.

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02 Example of model simplifications conducted to prepare a CAD model for CFD simulations.

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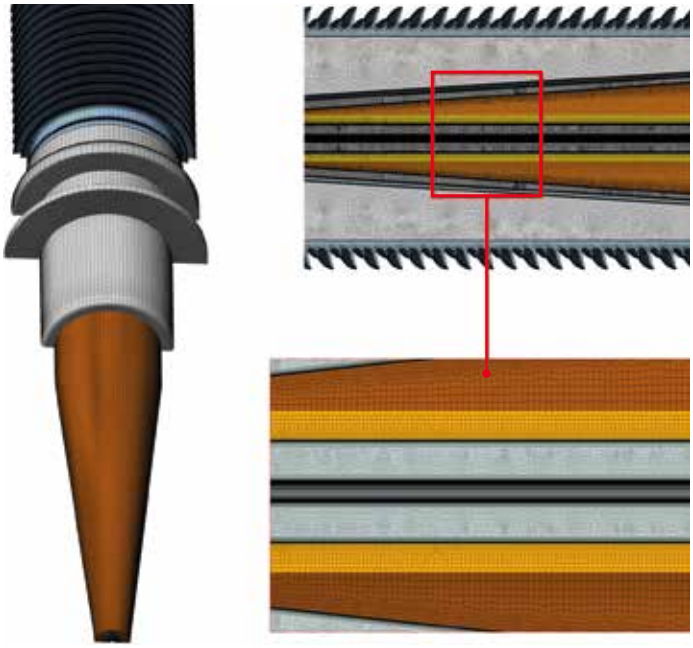
03 Example of computational mesh for a GGF 600 bushing.



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Generation of the computational mesh
When a geometry model is ready for simulation, a numerical mesh representing the computational domains must be created. Mesh quality is an important parameter as it has a significant impact on the speed of the numerical model's convergence and the quality of results. A low-quality mesh, eg, one with too few elements, may cause divergence of a properly prepared model; too many elements will disproportionally increase computation time. Modelling SF_6 flow in, for example, GGF bushings,

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Mesh quality is an important parameter as it has a significant impact on the speed of the numerical model's convergence and the quality of results.

requires the wall regions near the SF_6 flow to be appropriately meshed as the gas flow in a bushing enclosure is driven purely by buoyancy forces (natural convection flow) that arise mainly next to the "hot" conductor and "cold" enclosure surfaces →3.

Setting up numerical model parameters
When the computational mesh is prepared and its quality is acceptable, it can be transferred into CFD software, where the problem can be set up and solved. Setting up the numerical model is the most complex part of the simulation. In addition to some common model configuration functions – enabling energy equations, applying gravity forces, etc. – setting up also entails several other important tasks: heat loss and materials definition; initial, boundary and operating condition specifications; turbulence model and thermal radiation model characterization; and solver settings selection.

Numerical analysis and post-processing of the results
In the numerical study, the values of the requested temperatures, velocities, pressures, etc. are calculated in each cell of the computational mesh. The solution process is iterative, which means that – starting from initial, random conditions – the solution to the investigated problem is updated step by step. Correctness is tracked by so-called residuals, which describe the imbalances in the model's equations of mass, momentum and energy. A numerical problem is considered solved when the values of the residuals are minimized – ie, the temperature, velocity or pressure fields in the model do not change in the subsequent calculation steps. Additionally, user-defined monitoring tools are used for tracking simulation-specific values like velocity, temperature and pressure; in a stable solution, their values should reach a constant value.

Finally, the results obtained must be assessed from both a physics and a numerical point of view. In this step, the final confirmation of the veracity of the applied mesh and equations can be obtained. This assessment is also required to affirm that the simulation fulfills the basic principle of conservation of mass and energy.

All heat transfer processes inside the bushing and on its external boundaries must be properly captured for a reliable numerical representation.

Versatility and accuracy of numerical simulations
As mentioned above, all heat transfer processes inside the bushing and on its external boundaries must be properly captured if a reliable numerical representation of the bushing is to be constructed. Modern commercial FEM (finite element method) and FVM (finite volume method) simulation packages – such as Ansys Fluent or COMSOL Multiphysics – employ sophisticated algorithms and all the models they generated during the work described here have been shown to be accurate →4. Care must be taken with the thermal simulations as they are highly sensitive to boundary conditions. Therefore, the heat transfer rate at the external surfaces of the model must be carefully specified. In many cases, it is hard to predict heat removal from the system. For example, in the case of convection boundaries, the migration of heat will depend on air or oil properties, velocity and temperature as well as the shape of the surface from which heat is dissipated.

Results from temperature rise tests of different types of bushings were used, together with reports on the materials' physical parameters, to build the simulation model. Initially, a target accuracy was set of a maximum ±2 K difference between simulation and temperature rise test results; a performance inside this margin would endorse simulation as a satisfactory bushing design tool.

04a

04b

04c

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04 Examples of the results given by numerical simulations.
04a Temperature distribution.
04b Velocity streamlines.
04c Temperature isosurfaces.

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05. Temperature distribution along conductor. Comparison of 3-D numerical model and heat run test results.

An example of the bushing conductor temperature distribution measured during a temperature rise test and calculated numerically is given in →5. Comparison of the curves shows that the average accuracy of the constructed numerical model is about 2 percent, with a maximum discrepancy of 1.3 K.

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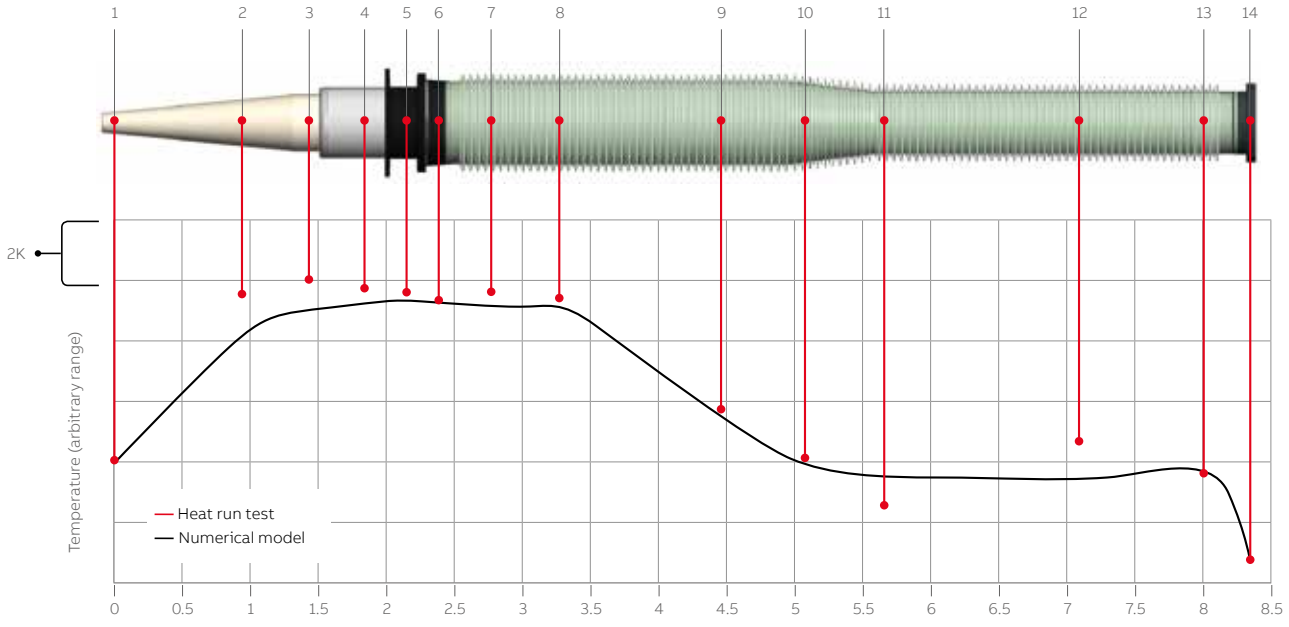
Overall, the new thermal model gave results that confirm the important role of computer simulations as an additional tool in the production of HV bushings.

The figure clearly shows that, for a properly prepared theoretical and numerical model, results can be in very good agreement with tests. This confirmation opens the way to further study or design fine-tuning based soley on theoretical calculations – a much more cost-effective and time-efficient approach than redesign and measurement of a real device.

Overall, the new thermal model gave results that confirm the important role of computer simulations as an additional tool in the production of HV bushings. During the development of the new bushings for the 10 GW and 12 GW HVDC projects, numerical simulations were used to design bushings with unprecedented current ratings. ●



05

PROTECTION AND SAFETY

Vibroacoustic analyses for noise mitigation in transformers

The acoustic noise emitted by a transformer is often as important a parameter as the device's power rating, voltage or losses. Novel vibroacoustic analysis techniques and numerical modeling identify design improvements that reduce transformer noise levels.

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In these times of intense competition in the transformer market, strong product differentiators are essential in attracting the attention of the customer. One area of differentiation is the level of noise that a transformer emits.

Industrial noise is classed as pollution. Transformer noise, due to its harmonic nature, is considered a particularly unpleasant noise pollutant and has, therefore, always been the target of specific design effort in ABB products.

New vibroacoustic tools now allow detailed analysis and identification of noise and vibration sources.

However, the recent appearance of new tools for vibroacoustic analysis have changed the rules of the design game: 3-D scanning laser vibrometry and sound intensity scanning, supported by capable multiphysics numerical modeling, now allow detailed analysis and identification of noise and vibration sources.

Furthermore, these tools and techniques also facilitate the design of systems that reduce transformer noise with an unprecedented precision and efficiency.

Transformer noise and vibration

Hum is an inherent transformer characteristic that originates from physical phenomena in the core and windings. In non-loaded transformers, magnetostriction of the magnetic core is the main source of hum; in transformers under load, it is winding vibrations [1,2]. In both load modes, the noise has a harmonic nature, but the modes differ in the frequency spectrum and dominant frequency that is presented →1.

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Title picture. ABB has developed design techniques that reduce the noise transformers, like the one pictured here, emit.

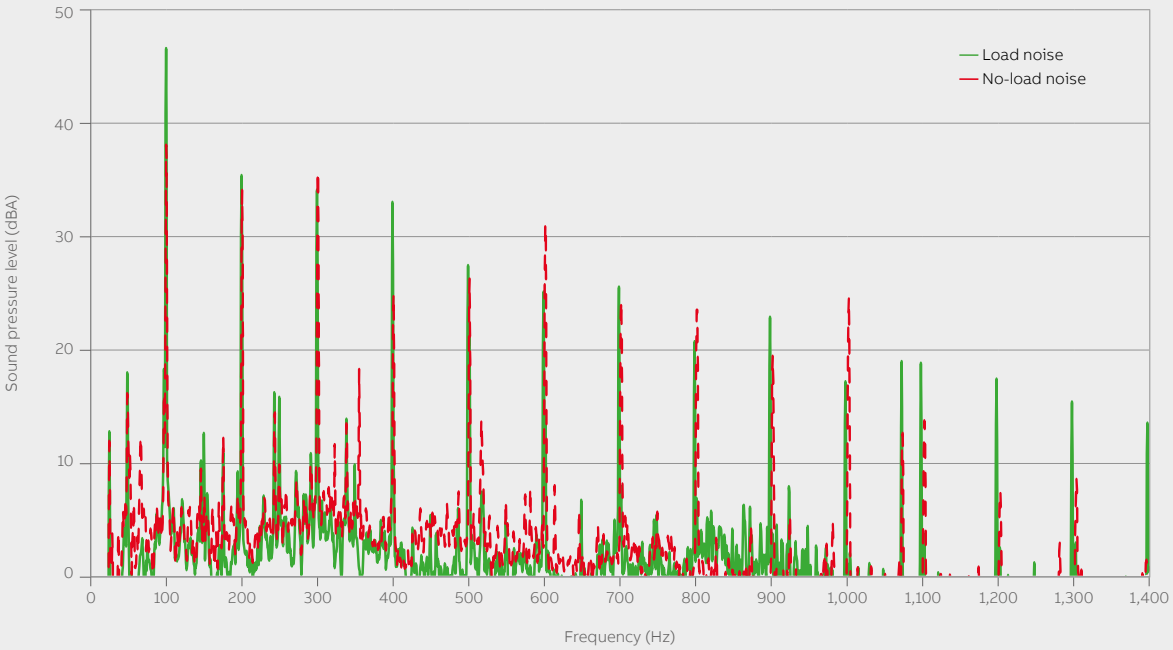
Though a power transformer's active part – which is usually immersed in oil – is the origin of vibrations, the ultimate noise radiator is the transformer tank. Improper mechanical design of the transformer, especially the tank, can induce local structural resonances and, consequently, exacerbate noise radiation. A reliable identification of these noise and vibration sources is required if design countermeasures are to be undertaken.

Laser measurement of vibration

One of the best techniques for measuring structural vibrations and operational deflection shape is scanning laser doppler vibrometry (LDV) as it directly measures vibration velocity. LDV measures the Doppler shift created in the reflected laser beam by the vibrating surface.

Due to the very high frequency of the laser light (~400 THz), the measurement is precise →2. LDV is a non-contacting technique so does not influence the device under test and, more importantly, allows measurements to be made from a safe distance on power products, such as high-voltage transformers, that are energized and operating.

Moreover, in contrast to the traditional accelerometer approach – a slow, lower-resolution method that must take the transformer load situation into account – LDV allows continuous high-resolution 3-D scanning and can deliver thousands of vibration measurement points and detailed deflection data in a very short time →3.



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Measurement of noise using sound intensity
A good way to identify areas of critical noise radiation is to perform a sound intensity scan. Sound intensity is a vector quantity, so it provides information on acoustic direction as well as magnitude (standard noise measurements based on pressure level measure only magnitude). As a result, sound intensity probes are highly directional and thus less prone to interference from background noise. A sound intensity scan is a very efficient sound source localization method when a grid is set up to define a surface and measurements normal to the surface are made from a number of equally spaced points. The results are then used to calculate the sound power over the grid or to create intensity contour maps. By interpolation, iso-intensity lines can be drawn for a single frequency or an overall level →4.

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LDV allows continuous high-resolution 3-D scanning and can deliver thousands of vibration measurement points and detailed deflection data in a very short time.

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01 Load and no-load acoustic noise spectrum comparison for a power transformer.

—
02 Laser Doppler vibration measurements.

Vibration-to-noise correlation
A good understanding of how energy is converted from vibration to noise is needed when analyzing transformer acoustic images and vibration patterns. →5 describes the main steps in the conversion of structural vibration to audible noise. The acoustic power radiated by the structure can be calculated by knowing its surface dimensions, radiation efficiency and vibration velocity.

—

Numerical analysis also provides a tool to evaluate the efficacy of potential noise attenuation solutions.

The decibel-scale conversion is done according to the acoustic power level formula. Because the transformer noise is measured in units of A-weighted sound pressure level, the vibration velocity is also presented in A-weighting [3,4].

Multiphysics numerical modeling
Numerical analysis not only assists in an understanding of the noise generation itself but also provides a tool to evaluate the efficacy of potential noise attenuation solutions: Virtual prototyping, which saves time and money, is enabled, as is testing prior to final implementation and validation.

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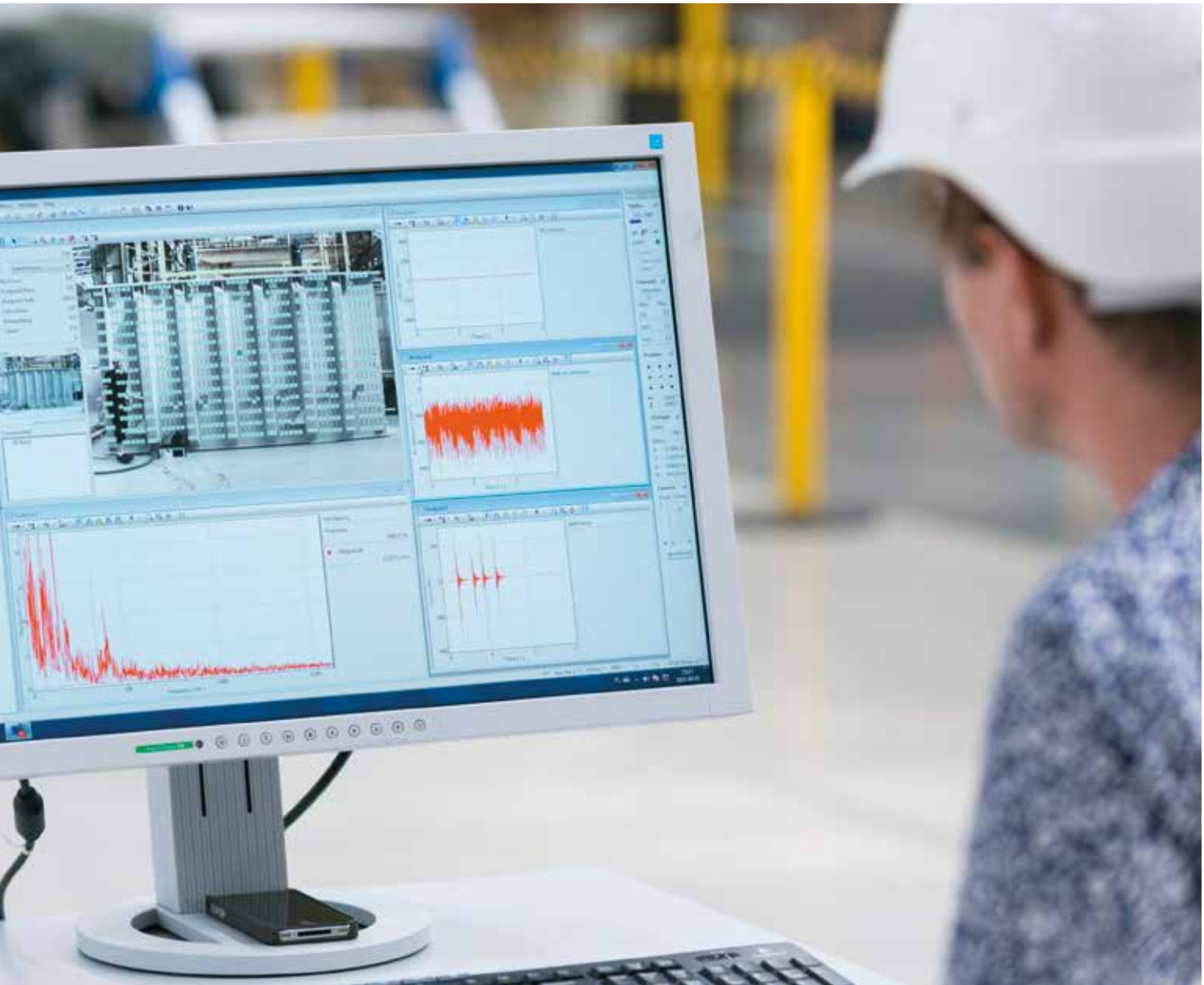

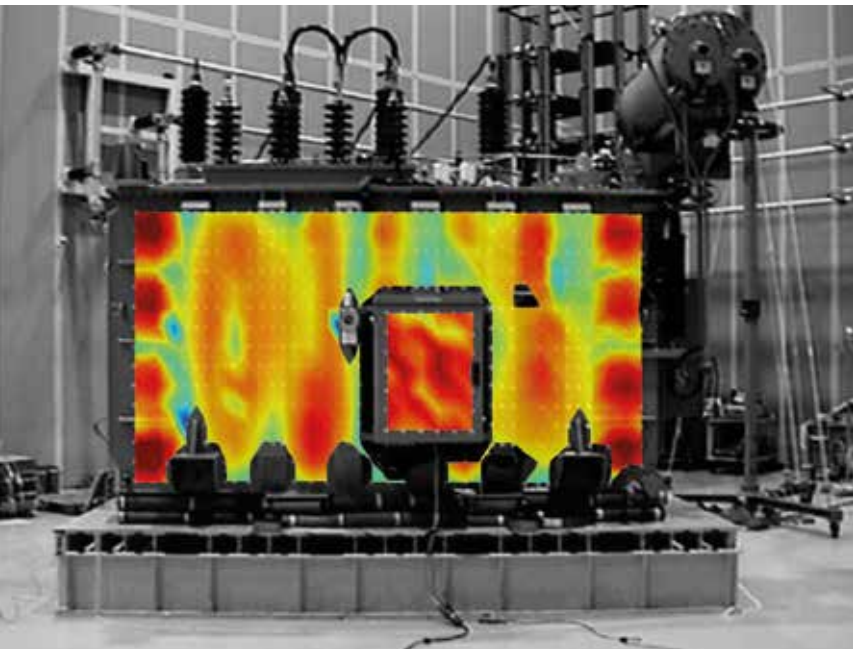

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The energy flow involved in transformer noise constitutes a typical multiphysics phenomenon that can be reflected in numerical predictions involving structural dynamics, electromagnetism and acoustics →6-7. The structural model, including excitation forces, is calculated in a full harmonics analysis – taking into account fluid/structure interaction as this is crucial for obtaining the correct vibration pattern of the tank. However, it is mandatory that any full analysis of a structural system in which the acoustic response is the output, must start with accurate operational modal analysis and a good correlation with the system eigenvalues derived from the real test data provided by the 3-D laser vibrometry.

A well-defined vibration model of the outer faces not only gives a proper acoustic radiation pattern but also delivers information about areas with large vibration amplitude and thus makes an invaluable contribution to the implementation of noise attenuation countermeasures.

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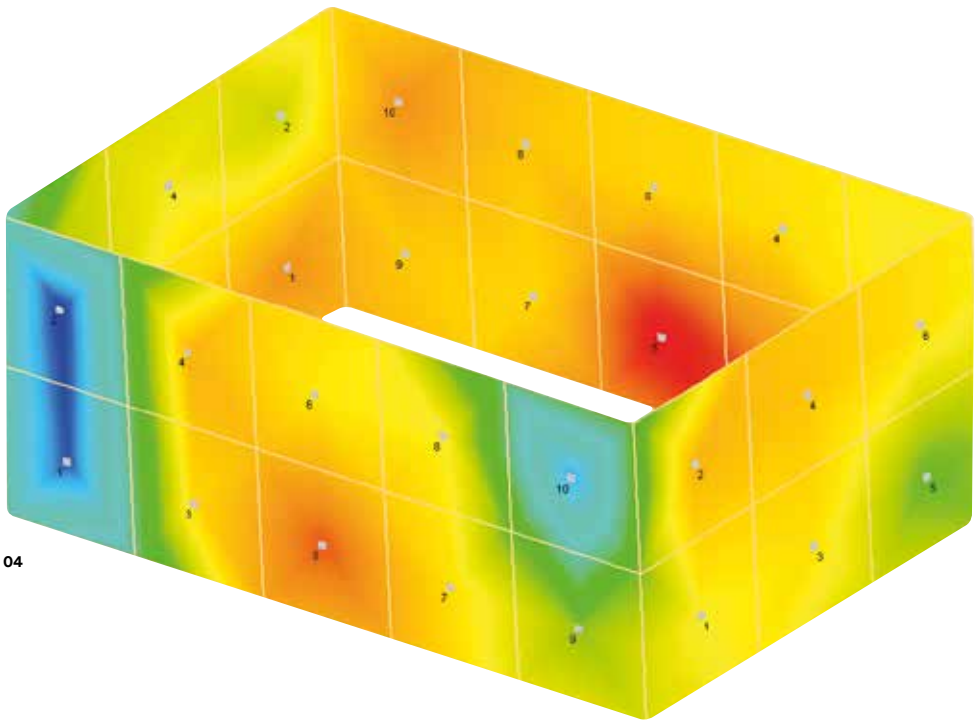
A well-defined vibration model of the outer faces gives a proper acoustic radiation pattern and delivers information about areas of large vibration amplitude.

Noise mitigation technology

An enclosure is the most common solution for noise mitigation, and not only in the transformer business. A typical acoustic enclosure can reduce emitted noise by 20 to 30 dB, which is significant. However, some transformers exhibit noise frequency spectra that are resistant to such baffling.



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03 Operating deflection shape of 40 MVA transformer tank at 100 Hz.

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04 Sound intensity field around power transformer.

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05 Structure vibration to sound pressure level conversion diagram.

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06 Complete numerical model of power transformer including electro-magneto-mechanical and acoustic coupling.

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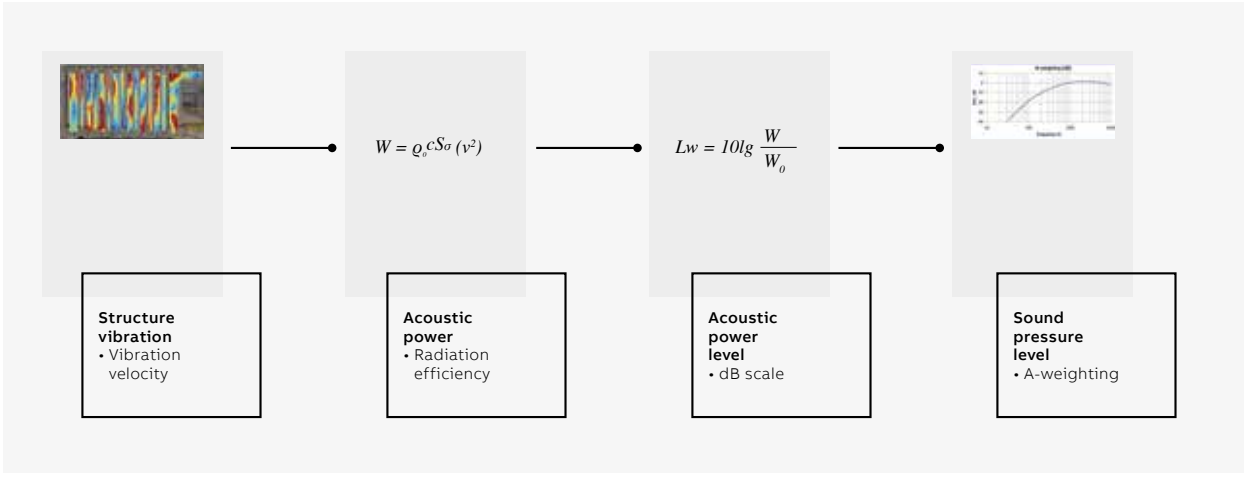
07 Acoustic radiation of the transformer tank in the pressure cavity.



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For this, and other, reasons, ABB is working on noise reduction solutions that are embedded within the transformer, invisible from the outside and designed so the customer can maintain and service the transformer in the normal way.

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Vibroacoustic methods for power transformers can be applied to a wide range of other products.

Broader application

The vibroacoustic methods for power transformers described above can be applied to a wide range of other products: Large motors where bearing diagnostics and vibration transfer through mountings are critical; noise emitted by capacitor banks; turbocharger structural analysis; and many others. The growing end-user desire for reduced environmental impact in terms of emitted noise levels will be accompanied by a growing use of vibroacoustic measurements and multiphysics modeling. ABB's expertise in LDV and acoustic modeling allows it to listen to customers more intently than before. ●

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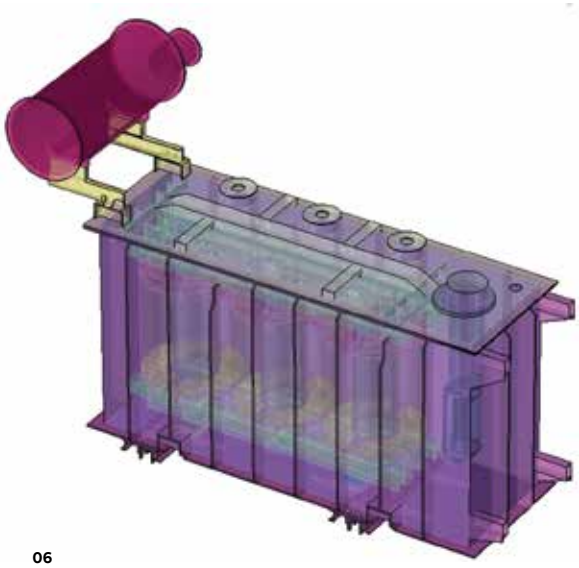

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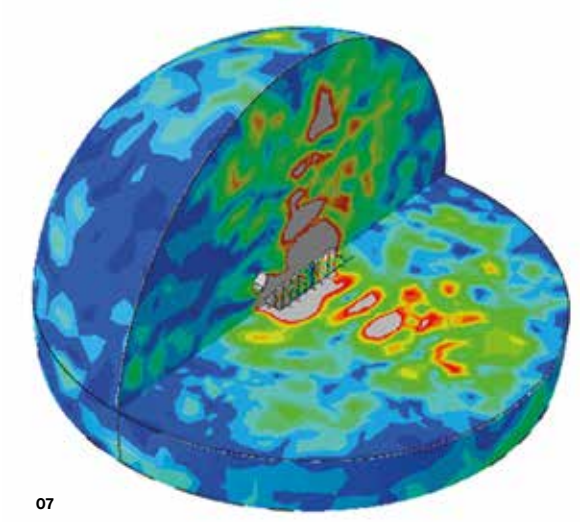

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Digital systems and analytics

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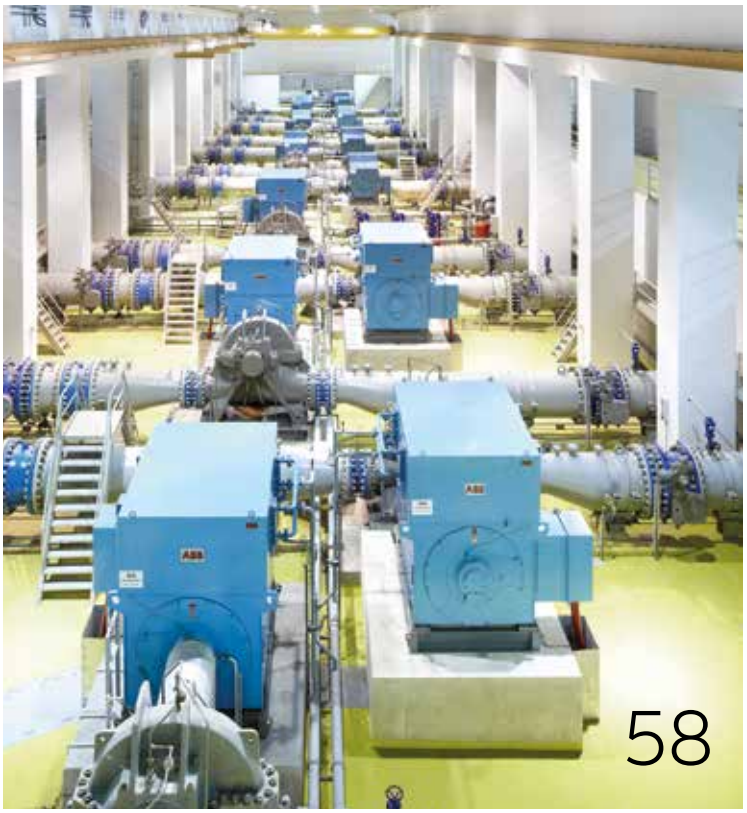

ABB leads the digital transformation of industries with over 70 million connected devices, and 70,000 control systems worldwide. It's also pioneering both online and offline tools to transform vast amounts of data into actionable insights that help design better manufacturing processes and controls.

EXCELLENCE IN DESIGN

The smart water revolution

External innovators can lend great impetus to new product development. By teaming up with just such an external partner – TaKaDu – ABB can now, in addition to its existing water business portfolio, offer water utilities solutions that leverage the full potential of digitization.

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Hugh Courtney, President of the International Partnership of Business Schools, a consortium of leading business institutions that aims to elevate global business education, is credited with saying, “in a globally competitive economic environment, the only source of sustained competitive advantage has to come through innovation.” Traditionally, the innovation that is so vital for new business development came from inside the business. In recent years, however, the speed, depth and complexity of technological development have forced enterprises to rethink their approach to innovation and seek inspiration from outside the company. In many cases, collaboration with external agents has become an indispensable strategy when trying to stay ahead of the competition. ABB has long followed such a path, with notable success.

The World Bank estimates global water loss due to leaks and bursts at 25 to 30 percent, representing a $20 billion cost savings opportunity.

In 2009, external collaboration was taken to a new level with the formation of ABB Technology Ventures (ATV), ABB’s strategic venture capital investment arm [1]. Based in Zurich, Switzerland, Silicon Valley and Chennai, India, ATV partners and invests in breakthrough technology startups that drive strategic value for ABB.

ATV’s partnership with TaKaDu, which dates from 2012, provides a perfect example of how an ATV investment can lead to a better offering and new customers.

Let's talk water

Water presents some of the world's most pressing social, political and economic challenges, and water crises rank among the top ten global societal risks in terms of impact, according to the World Economic Forum's Global Risks Report 2018 [2].

More concretely, the UN predicts that half of the world's population will not have access to clean water, enough water or water at all by 2030 should consumption and pollution issues not be adequately addressed. The factors contributing to more demand for water, such as climate change, population growth, new ways of living - and thus changes in domestic, commercial and industrial water consumption - are amplified by factors on the supply side.

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Typically, utilities either have no data, or if they have it, they do not analyze it, depriving themselves of visibility into their water network.

AMIR PELEG - "THE HI-TECH PLUMBER"

At 51, Amir Peleg, who likes to call himself, "the hi-tech plumber," has a string of successful startups under his belt, among them YaData Ltd. (novel technology for behavioral targeting; acquired by Microsoft), Unipier Ltd. (formerly Cash-U) and EVS, (Elbit Vision Systems) Ltd. He founded TaKaDu Ltd. in 2008.

Amir Peleg holds a B.Sc. degree in Mathematics, Physics, and Computer Science from the Hebrew University of Jerusalem and an MBA from INSEAD (Institut Européen d'Administration des Affaires or European Institute of Business Administration), Fontainebleau, France - a graduate business school. As a youth, Amir Peleg won a special prize for young inventors from the Weizmann Institute, Israel. He is also Chairman of SWAN, the Smart Water Networks Forum.

01

On top of inadequate infrastructure investment, the World Bank estimates global water loss due to leaks and bursts at 25 to 30 percent, representing a $20 billion annual cost savings opportunity. Typically, utilities either have no data, or if they have it, they do not analyze it, depriving themselves of visibility into their water network. Repairs are carried out reactively and rarely in a planned way. Often, the first indication of trouble is when a concerned citizen reports water flowing down the street.

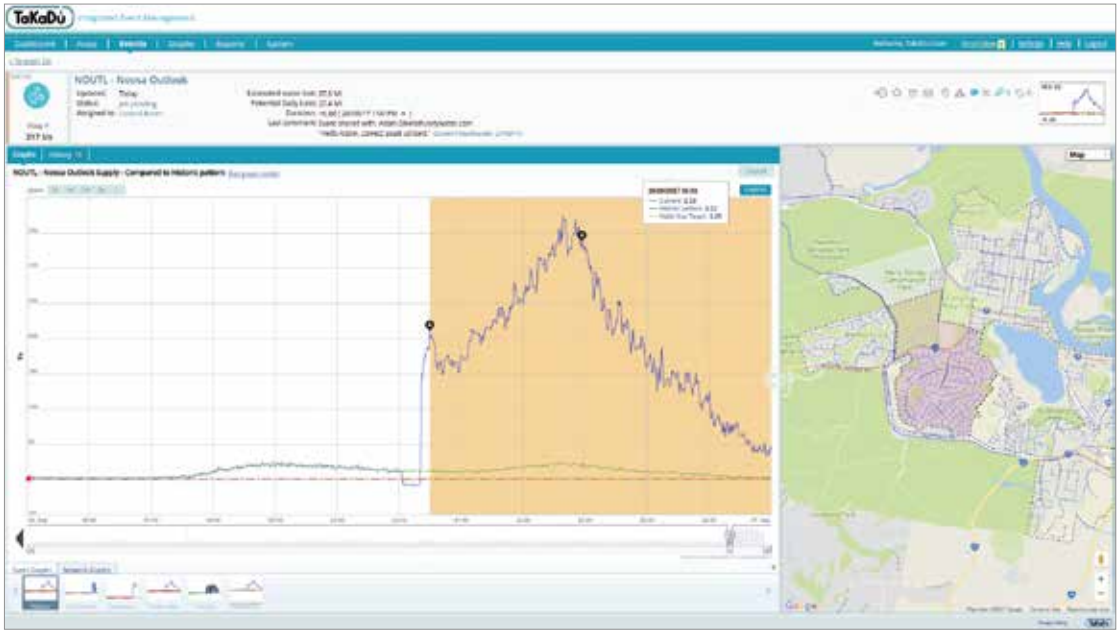
TaKaDu's solution analyzes and processes data that is captured by various smart sensors in the system equipment.

TaKaDu technology to save the day

The good news is that new technologies can help to solve the problem. By using digital technologies, data analytics and algorithms based on artificial intelligence (AI), utilities and cities are better equipped to manage demand for, and supply of, clean water and thus extract more value from their physical water infrastructure. Amongst the pioneers introducing these new technologies into the water industry is an Israeli company with which ABB's ATV has gone into partnership: TaKaDu [1].

According to Amir Peleg, Founder and CEO of TaKaDu, no one takes water for granted in Israel – a country in which water is in very short supply indeed →1. In fact, about 50 percent of Israel's drinking water comes from desalination plants – an expensive option – with agriculture irrigation using recycled wastewater (over 85 percent of Israel's wastewater is reused, the highest percentage in the world).

The trigger for Amir Peleg's venture into the water industry came around the time in summer 2008 when he had to reduce his own water consumption due to regional drought. He then found out that the local utilities were losing 15 to 20 percent of the water they were pumping into the network. On top of this, a chance conversation with an engineer brought home to Amir the realization of the inefficient situation in which many water utilities find themselves: Though they lose, on average, 25 to 30 percent of their water and collect a substantial quantity of raw data pertaining to their leaky water networks, very little use is made of this data to provide insight into the state of the water system or to support decision making. From this epiphany, TaKaDu was born.



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02 TaKaDu data analytics example.

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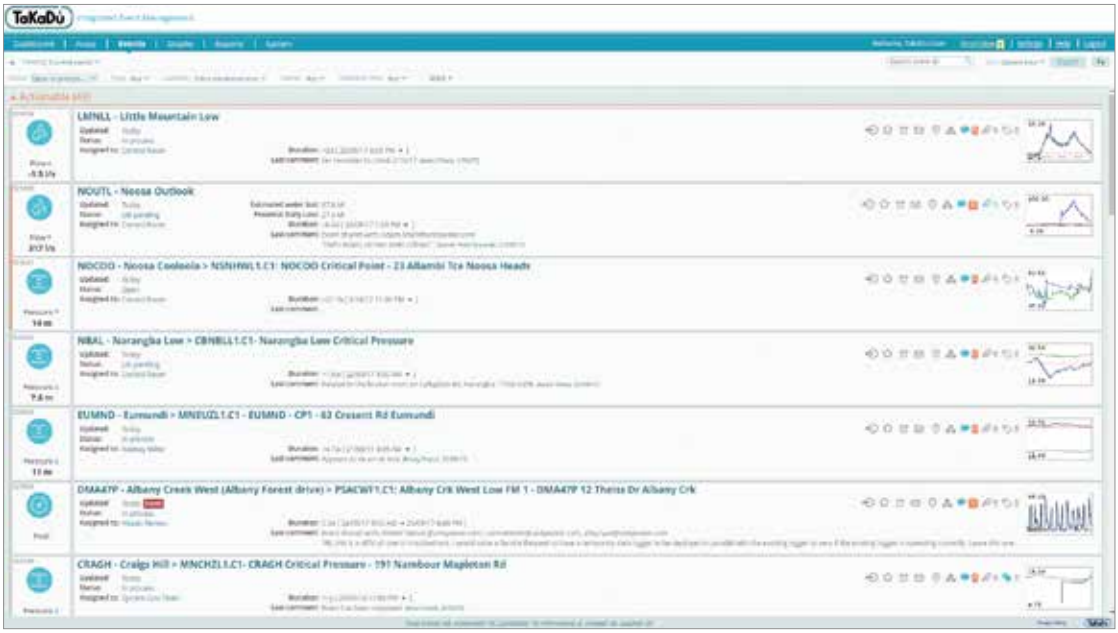
03 TaKaDu event management example.



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Pipeline processing

Amir Peleg and his team started to develop algorithms and use statistical approaches to detect leaks and prevent big bursts in the water networks. TaKaDu's solution analyzes and processes data that

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Multiple data sources are tapped by TaKaDu's patented, cloud-based SaaS to monitor optimal capacity, detect issues in the pipes, meters, valves, and other apparatus, and alert in real time on network faults.

is captured by various smart sensors in the system equipment. These multiple data sources include inputs from network operation and supervisory systems (eg, SCADA), online sensor-based flow meters, pressure data and other external influencers such as weather and calendar events.

The data is then used in TaKaDu's patented, cloud-based SaaS (software-as-a-service) to monitor optimal capacity, detect abnormal behavior of the data classify these as issues ("events") in the pipes, meters, valves, and other apparatus, and alert in real time on network faults. While game-changing for utilities and smart water management, the solution does not require network changes, additional devices or capital expenditure. In summary, TaKaDu's approach can predict, detect, analyze and manage water network events, thus reducing costs and increasing visibility and efficiency →2-5.

How does TaKaDu's technology work? For each water network, or part thereof, the software determines a baseline of normal patterns. For example, it understands the pattern of the water flow by the time of the day, the weekday, the season, etc., and learns, for example, that demand is highest in the mornings and evenings before people go to or after they return from work; and that behavior is different over the weekend or during holidays. The more information that is available about normal water usage behavior, the more precisely the software can detect anomalies such as leaks, a burst or even water theft. At Yarra Valley Water, a utility in Melbourne, TaKaDu's software detected unusual activity at a fire hydrant; when officials turned up at the location they found a strawberry farmer extracting water from the hydrant.

A critical innovative step achieved by TaKaDu was to look at the whole process as managing different types of events and combining all information and knowledge about them in a single interface. To put it in Amir Peleg's words: "In a similar way to how customer relations management (CRM) software drives business relationships with customers in today's enterprise, integrated event management integrates all the data layers a utility has about its network into a single knowledge layer about every incident."

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The more information that is available about normal water usage behavior, the more precisely the software can detect anomalies such as leaks, a burst or even water theft.

The in-depth visibility, real-time detection and quick insights gained into every type of event include the identification of:

- Leaks before they turn into large bursts
- Changes and trends in water pressure or supply interruptions
- Anomalous usage patterns or water theft
- Water quality issues
- Faults in meters, valves, PRVs (pressure reducing valves) and other assets
- Telemetry and data availability issues
- Automatic early warning of operational issues, like open valves and zone breaches.

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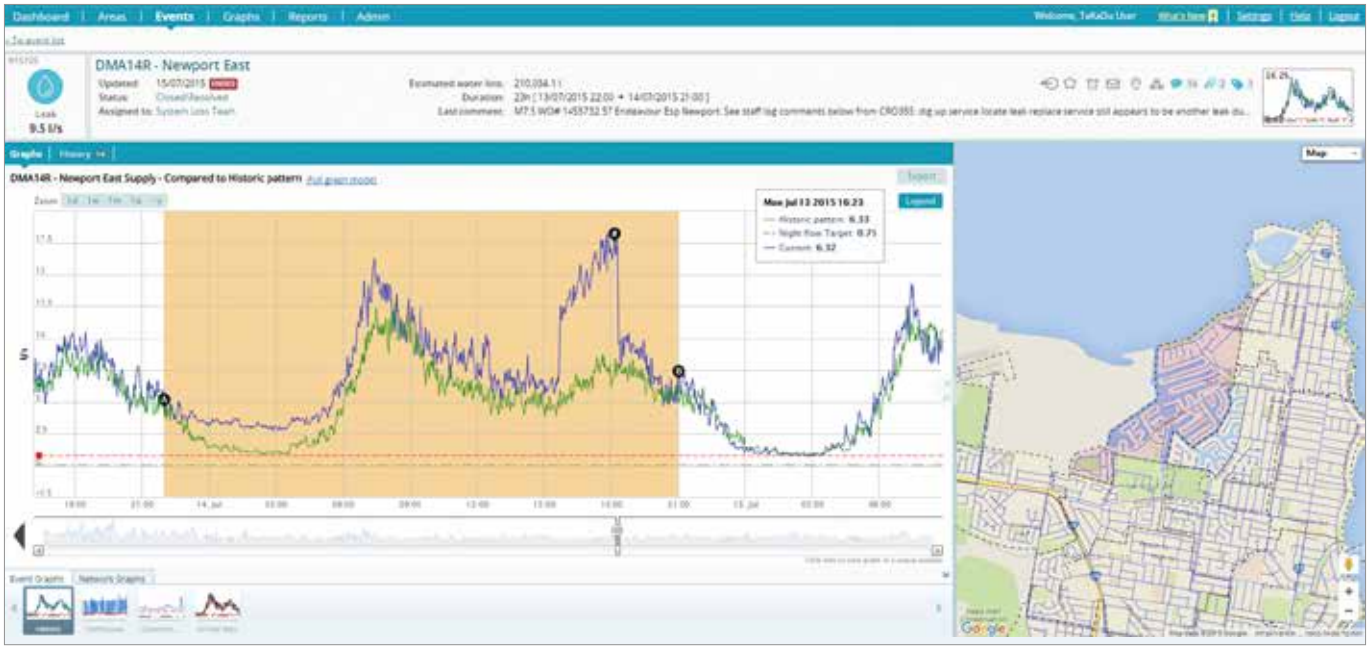

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04 TaKaDu sample management dashboard.

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05 TaKaDu - Typical leak event. Whereas ABB supplies instrumentation, control systems, sensors and measurement products, TaKaDu delivers an AI-based solution that provides early warning of the most likely leakage scenarios and tells the customer the optimal placement of the minimal number of pressure sensors.

According to Amir Peleg, many utilities are in a gray zone – they have some sensors and some analytics, and they ask why they should put in more sensors. But once they see the power of TaKaDu's product, they change their minds. The tailwind they get kicks off a positive feedback investment cycle.

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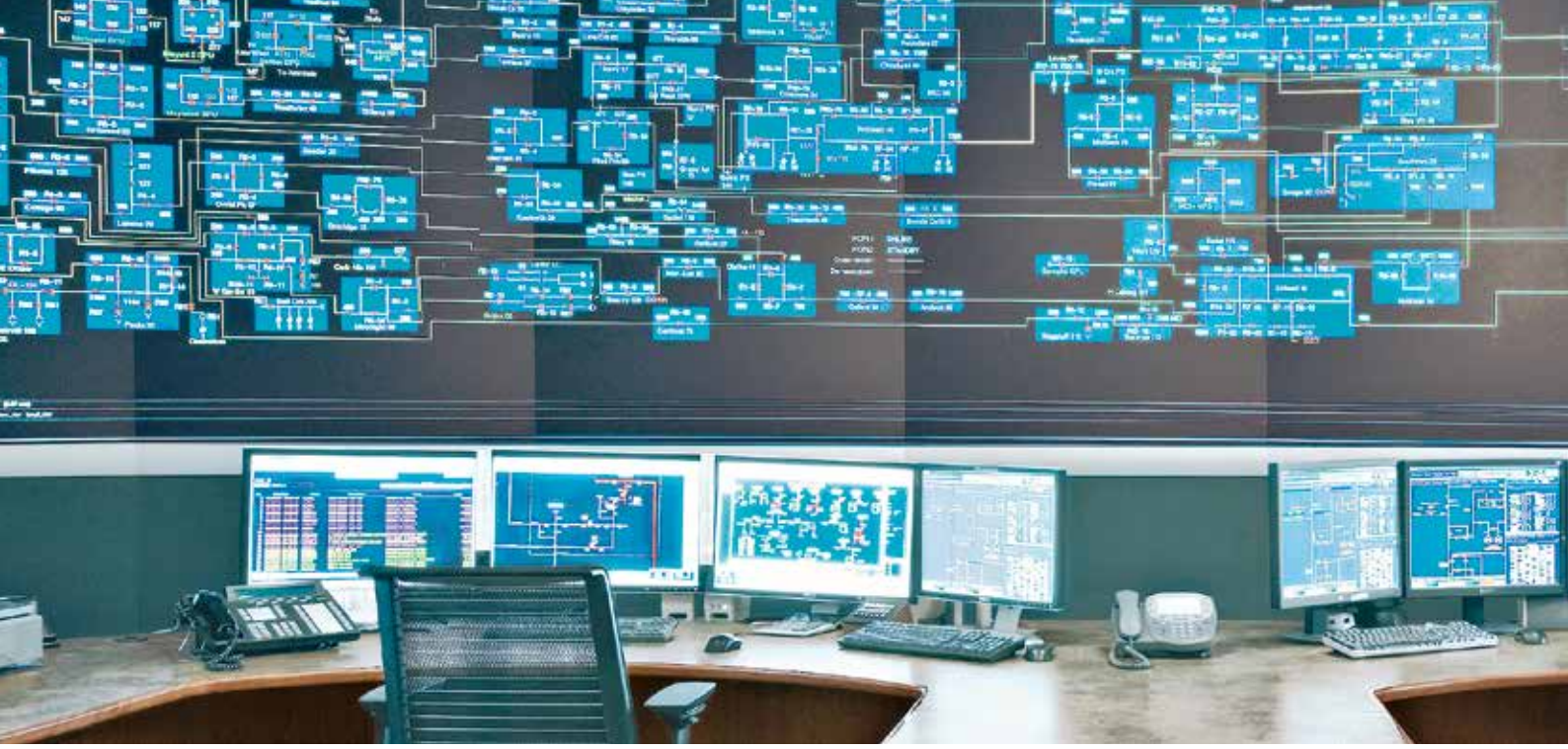
Complementing ABB's automation portfolio for the water sector, TaKaDu gives ABB access to its field-proven monitoring system, which has been widely adopted by water utilities.

Ho Chi Minh City

Complementing ABB's automation portfolio for the water sector, TaKaDu provides its field-proven monitoring system, which has been adopted by water utilities around the world. TaKaDu's innovations allow ABB's customers to produce, transport, distribute, treat and utilize water efficiently, reducing energy consumption, minimizing losses and improving reliability.

"TaKaDu's AI-based solution enables the water industry to catch the wave of digitalization for their sector just in time," says Kurt Kaltenegger, Head of Technology at ATV. "By partnering with TaKaDu we can show the full potential of advanced automation and the use of data to our customers in the water industry." While TaKaDu's solution helps to convert raw data into knowledge, ABB's long experience, established technology and broad customer base offer TaKaDu access and reach.

The powerful ABB/TaKaDu symbiosis is being put to work, for example, in a massive urban project to increase efficiency, reduce water leakage, prevent disruptions and ensure everyone has access to clean water in Ho Chi Minh City – a city that currently loses nearly 50 percent of its potable water to leaking and damaged pipes.



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The Saigon Water Supply Corporation (SAWACO) is deploying ABB's digital control and monitoring technologies together with TaKaDu's Integrated Event Management Solution as part of its restoration of Ho Chi Minh City's water distribution network.

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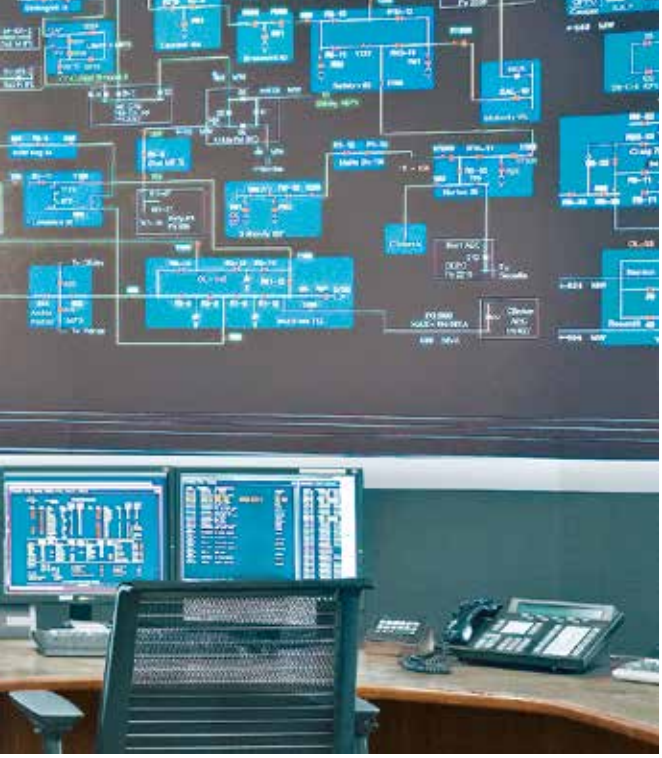
The Saigon Water Supply Corporation (SAWACO) is deploying ABB's digital control and monitoring technologies together with TaKaDu's Integrated Event Management Solution.

The ABB solution – ABB Ability™ Symphony® Plus SCADA – will monitor and control the entire water distribution system and integrate TaKaDu's Event Management solution, which detects, analyzes and manages network events and incidents such as leaks, bursts, faulty assets, telemetry and data issues, and operational failure →6.

ABB's and TaKaDu's complementary solutions will enable SAWACO to monitor the network conditions digitally through multiple data collection points, such as sensors and meters, and offer actionable insights to reduce non-revenue water. SAWACO will then be able to increase the amount of water delivered to the city's industries and eight million residents →7. At a first estimate, SAWACO will hit 50 Mio m^3/year of water savings - equivalent to 20,000 Olympic-size swimming pools - while annual production cost savings could exceed $10 million.

"We're excited to partner with ABB on this project in one of Asia's most dynamic countries," said Amir Peleg, "By converting raw data into knowledge, we can help SAWACO reduce hundreds of thousands of cubic meters of non-revenue water lost per day while significantly improving operational efficiency."



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06 Water network management is just one application of SCADA. Over the years, ABB's SCADA has evolved to fit specific business needs in many different areas.

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07 TaKaDu's technology transforms a water utility's approach to crisis management from one of ad hoc reaction into one that is data-driven and with more efficient decision-making.

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[2] World Economic Forum, "The Global Risks Report 2018." Available: https://www.weforum.org/reports/the-global-risks-report-2018.

[3] www.takadu.com

Charting future waters

From its successful beginning, TaKaDu's technology has gone from strength to strength. The company has transformed water utilities from being reactive entities with ad hoc crisis management into data-driven, efficient decision-makers. TaKaDu's technology is now deployed in 12 countries worldwide, including Australia, Brazil, Chile, Israel, Romania, Spain and the United States, and customers include every type of water utility: small, super-large, rural, urban, private and public.

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TaKaDu's solutions have been internationally recognized as environmentally friendly technology.

TaKaDu's solutions have been internationally recognized as environmentally friendly technology - even winning the Technology Pioneer award from the World Economic Forum. TaKaDu also participated in a panel that discussed water scarcity in front of world leaders at the annual meeting in Davos. However, it was investment in the company that allowed its vision to evolve. On that note, on May 21, 2014, ATV won the Global Corporate Venturing award in the Sub-$50-million Investment of the Year category for its investment in TaKaDu. The awards celebrate innovation, best practice and service in the corporate venturing ecosystem. Among others in the running in the category were Google Ventures, Amex Ventures, Intel Capital, and Nike – further distinguishing ABB as an internationally recognized, innovative and strategic leader and underlining that the ABB/TaKaDu collaboration is a clearly successful and symbiotic relationship. ●

07

DIGITAL AND ANALYTICS

Leveraging advanced process control and analytics in industrial automation

ABB's Advanced Process Control and Analytics Suite comprises tools, online and offline, to deploy advanced controllers and analytic models; this gives process and power industries monitoring, predictive analytics and closed-loop control abilities at the device, edge and cloud and ensures real-time operation efficiency gains.

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What if process and energy industries could optimize operations using emergent technologies like cloud, data analytics, visualization and advanced modeling algorithms as part of the Internet of Things revolution (IoT) to acquire leverage in Advanced Process Control (APC) and Analytics solutions? This evolution of knowledge acquisition, creation and transfer ability is power – power that translates not only to improvements in operational scheduling, but also to the ability to make predictions and estimations even in the absence of reliable measurement data.

ABB leads the digital transformation of industry with over 70 million connected devices and 70,000 control systems world-wide and annual investments of $1.5 billion in research and development, to provide customers in power and process industries with the most unified, cross-industry capability possible. It is this innovative spirit that has led ABB to invest increasingly in APC and analytics modeling abilities over the past 5 years to give customers powerful optimization and prediction tools.

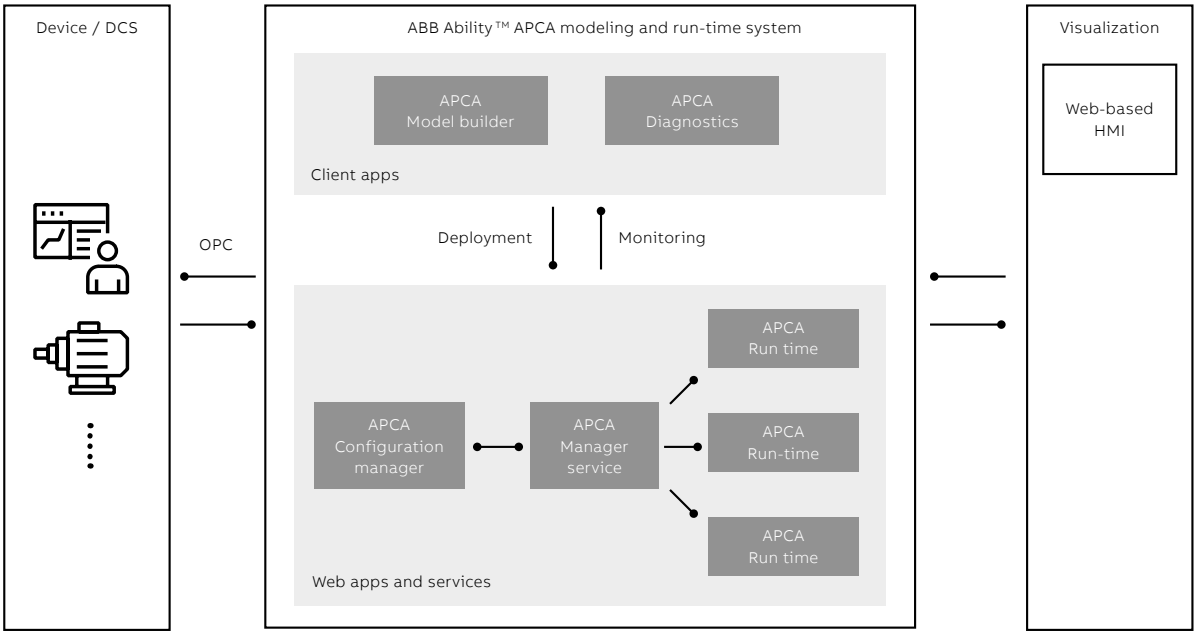
Title picture. Predictive power plant optimization solution based on ABB Ability APCA is employed onboard vessels to enhance fuel efficiency and reduce emissions.

Traditionally, APC relies on model predictive control and moving horizon estimation strategies that use either a linear or non-linear mathematical model of the industrial plant and smart algorithms to estimate unmeasured states and control process variables. APC helps industries attain operational and financial targets by increasing throughput and reducing energy use.

ABB leads the digital transformation of industry with over 70 million connected devices and 70,000 control systems world-wide and annual investments of $1.5 billion in research and development.

Typically, process industries and energy companies integrate APC in distributed control systems (DCSs) such as ABB Ability™ 800xA and ABB Ability™ Symphony Plus, which allows industry users to benefit from distributed resource allocation, redundancy, and communication as well as the intrinsic cybersecurity infrastructure of these modern DCSs.

As APC technology continues to evolve with new components and features, ABB scientists and engineers are exploring the potential of artificial intelligence (AI) with the use of reinforcement learning neural networks as well as edge and cloud technologies for digital analytics and optimization for operational services in the process and power industries.



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Currently, the ABB Ability™ Platform is the digitally enabling technology that allows the implementation of APC solutions.

ABB Ability Advanced Process Control and Analytics Suite

The ABB Ability platform is ABB's integrated industrial internet platform launched in 2017 and currently providing over 180 solutions across industries. It is the technology platform used to build and connect ABB Ability solutions, such as Ability™ Marine Advisory System OCTOPUS software for marine operations management and optimization [1].

A recent innovation in digital solutions is the ABB Ability™ Advanced Process Control and Analytics (APCA) Suite, which offers analytics & optimization (A&O) services.

It comprises several digital-enabling technologies that can reside at the device, edge and cloud levels. This unifying technology operates ABB's own technology and industrial software while leveraging Microsoft's enterprise-grade Azure cloud infrastructure, cybersecurity and services to meet customer needs.

A recent innovation in digital solutions is the ABB Ability™ Advanced Process Control & Analytics (APCA) Suite, which offers analytics & optimization (A&O) services for monitoring, predictive analytics and closed-loop control [2].

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01 ABB Ability APCA architecture showing the deployment and monitoring of advanced controllers and analytics work-flow.

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02 APCA examples of configuration manager displays.

02a APCA Configuration manager main page listing all deployed controllers in an installation.

02b APCA Configuration manager gantt chart view displaying the execution times and schedule of deployed controllers.

The ABB Ability APCA Suite comprises a set of tools that make the deployment of advanced controllers and analytic models a fully streamlined process→1: APCA Model builder (offline), APCA Diagnostics (offline), APCA Configuration manager (online), APCA Run-time engine (online) and APCA Manager web service (online). ABB Ability

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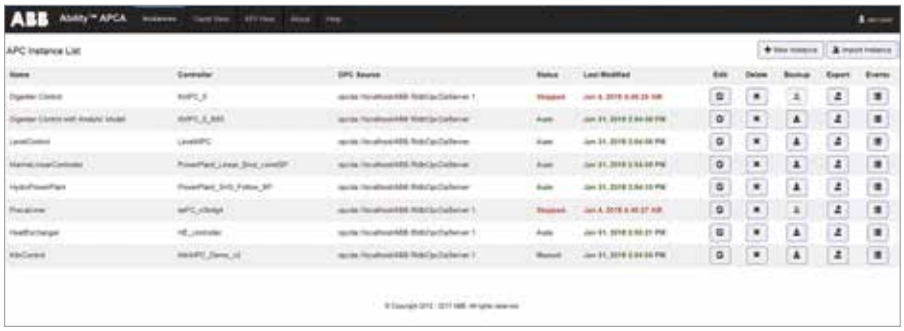
ABB's elegant solution for the pulp and paper industry is OPT800, a solution powered by Ability APCA to improve the efficiency of paper mills.

APCA communicates its deployed advanced controllers and analytic models with the ABB Ability Edge and can operate at the edge in a Distributed Control System (eg, for control), or at the ABB Ability™ Cloud (eg, for optimization).

Developing and analyzing advanced controllers offline

The advantage of developing advanced controllers and analytics offline in APCA Model builder is that the client's applications data can be readily leveraged by carrying out modeling and controller design tasks and analysis before deploying the solutions. Users can import large data sets and perform advanced data processing tasks like resampling, interpolation, and filtering in addition to open and closed-loop simulations. These capabilities deliver true operational advantages.

Security is one of the greatest challenges for industries reliant on data analytics and control and APCA Model builder provides a solution. Ability APCA issues certificates to authorized users to control the authenticity and integrity of the analytic models and advanced controllers developed in APCA Model builder. Thus, only models and controllers with valid certificates originating from authorized users will be digitally signed in APCA Model builder and can then be exported to the APCA Configuration manager. By removing the human decision-making component, security is refined and improved.



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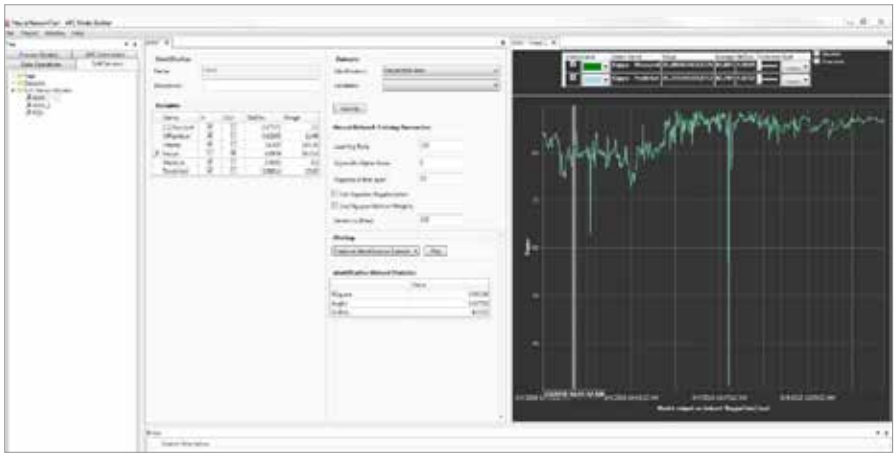

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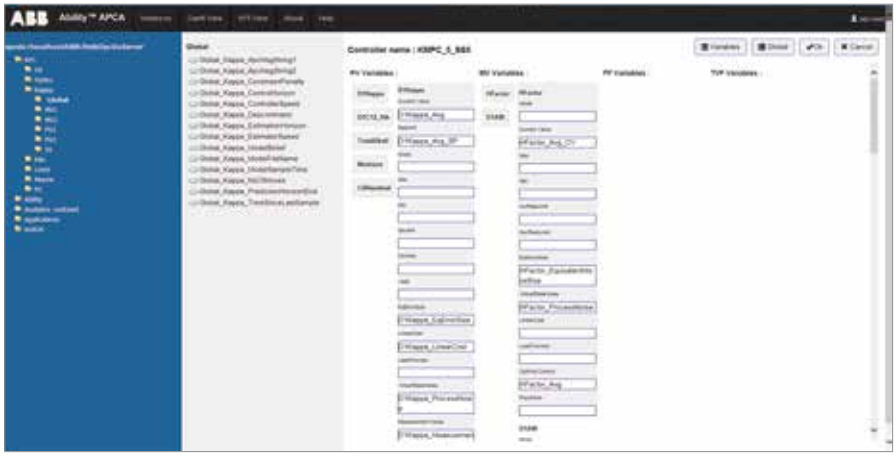

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Furthermore, with APCA Diagnostics, users can analyze the performance of deployed controllers by visualizing the controller actions history from log files. Estimated values of the process variables and the quality of predictions can be compared with the data received from the plant, thus allowing control engineers to easily troubleshoot abnormal situations.

Deploying and monitoring advanced controllers and analytics online

Advanced controllers can be created, edited, imported, exported or deleted by users in a web-application known as an APC Configuration manager →2a, which also verifies the signature once any controller file is imported; this process is similar to the model builder security process. Error messages are generated in cases of invalid files or missing signatures, thereby maintaining security.

A key feature of this online system is the ability to include industrial communication standards (eg, OPC) that allow users to connect to a plant, create or configure tags and map them to imported controller variables. Security is established with authentication and encryption techniques; usually the secure web socket communications (HTTPS), certificate-based security (SSL) and transport layer security (TLS) are used.

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03 Examples of APCA displays.

03a APCA Model builder fitting an ANN model for the Kappa value in a digester.

03b APCA Configuration manager displaying the configuration properties of a loaded controller.

03c APCA Configuration manager displays the map of signal tags to controller variables and parameters.

An APCA Run-time engine instance is created by the APCA Configuration manager when controllers are loaded to the system. The run-time engine contains the optimization algorithms computing in the background. Every run-time engine instance created is monitored by the APCA manager service →2b. If a run-time engine fails, the manager restores the failure within the sampling period, thereby ensuring functionality under adverse conditions. Other run-time instances such as messages or an alarm event will also be either routed and, or displayed in the web application by the APC manager service. Accordingly, the APC manager service and the APC Run-time engine work in concert to safeguard the operation of controllers that have been deployed.

—

The use of ABB Ability SmartVentilation improves air quality and provides mines with energy savings from 30 to 50 percent annually.

Analytics

One problem control engineers often face is the need to infer data from missing measurements or infer backup data for unreliable measurements. In these cases, analytic models can be deduced from either first principles or process data and deployed in the APCA Run-time system.

Analytic models that can be used in the APCA Model builder are: graphical (first principles), linear regressions, nonlinear regression, principal component analysis (PCA), artificial neural networks (ANN) and support vector machines (SVM). Users can test various models and choose the one with either the best fit or performance statistic, thereby leveraging state-of-the-art advanced analytics.

Applications in industrial automation

ABB Ability APCA supports business units within ABB's industrial automation division with optimization and analytic technology to address consequential challenges in its industries.

Improving mill efficiency in the pulp and paper industry

ABB Ability APCA helps process industries such as the pulp and paper industry to optimize operations even when measurements are not adequate or available. ABB's elegant solution for this industry is OPT800 – a solution powered by Ability APCA to improve efficiency. Developed ANN analytic models, based on measurements such as the H factor, alkalinity, moisture, and residual alkalinity are obtained at the digester's blow line and are used to predict the often unavailable Kappa value within digesters [3]. ANN prediction models that are identified, trained and validated in APCA Model builder are then used to design APC controllers →3a-c. The use of analytic models in conjunction with advanced controllers not only strengthens production and yield from 1 to 5 percent but also reduces Kappa value and residual alkali variation between 25 and 50 percent in digesters. Similar reductions in waste and improved variation of key performance indicators are achieved during other stages of the pulp and paper process [4].

Optimizing ventilation systems in underground mines

The newest ABB Ability APCA capability can identify complex multiple-input multiple-output (MIMO) systems using, for example, gain delay models. This technology has been crucial in the creation of the ABB Ability SmartVentilation solution, a modular system that can be integrated into ABB Ability 800xA and is designed to optimize the ventilation systems of underground mines →4.

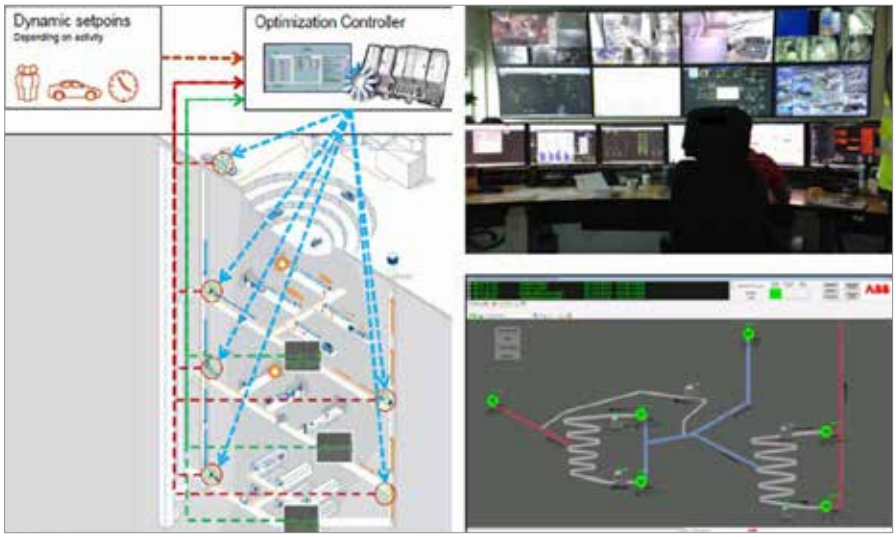
—

By taking advantage of ABB's APCA technology, ship operators can reduce fuel costs and consumption by at least 4 percent, and lower emissions; this reduces the carbon footprint and overall cost of operation.

ABB Ability SmartVentilation maintains optimal airflow levels and provides rapid expulsion of blast gases while ensuring minimum power consumption [5]. While conventional operation of ventilation systems poses safety risks to employees and leads to higher than necessary expenditures for total energy consumption, the use of ABB Ability SmartVentilation improves air quality and provides mines with energy savings up to between 30 and 50 percent annually.

Optimizing fuel consumption in the marine industry

The ABB Ability™ Marine Advisory System OCTOPUS powered by ABB Ability APCA has been successful in the shipping power sector where fuel costs and consumption and power plant operation are primarily responsible for high costs and emissions.



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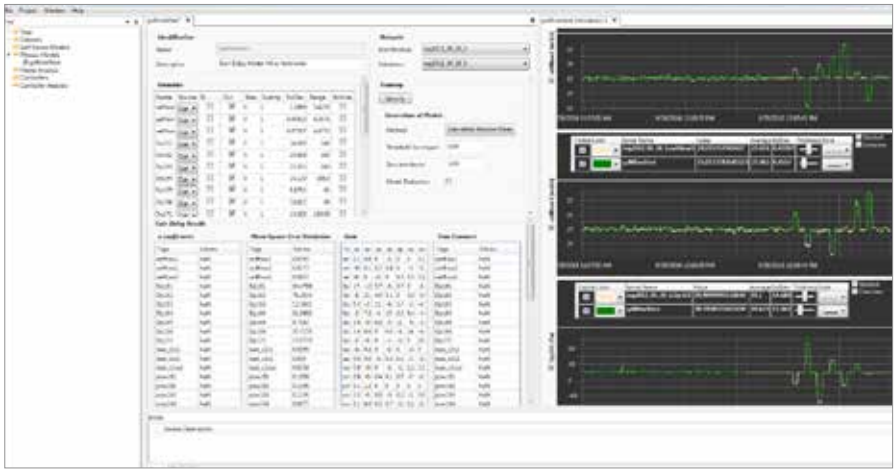

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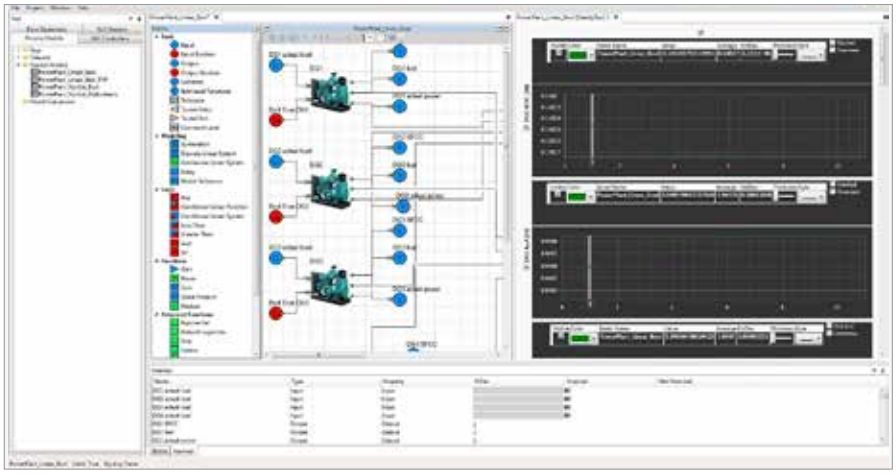

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04a The layout of a mine that employed a gain delay model identified by APCA Model builder to optimize the ventilation system.

04b APCA Model builder fitting a gain delay model for the ventilation system of a mine.

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05 A graphical model of a power plant inside a vessel developed in the APC Model builder showing open-loop simulation plots.

The predictive power plant optimization solution uses the predicted power demand of a ship during its entire voyage as input data, which is then exploited to determine the optimal load for each generator.

This long-term optimization uses a model predictive controller that relies on a process model of the entire plant to predict the plant state in future time steps (prediction horizon) resulting in the optimal distributive load over the entire voyage to be determined →5. An optimal control sequence is then determined for a shorter time span (optimization horizon).

—

The newly designed and updated ABB Ability Advanced Process Control and Analytics Suite revolutionizes data analysis and reduces modeling effort.

The fuel consumption of each generator is modeled as a non-linear function of the loads and online statuses; thereby relying on monitored specific fuel oil consumption curves and user-defined constraints. APC controllers then take into account the identified fuel efficiency model for each diesel generator to adjust the corresponding loads in real time.

By taking advantage of ABB's APCA technology, ship operators can reduce fuel costs and consumption by at least 4 percent [6], and lower emissions; this reduces the carbon footprint and overall cost of operation.

Revolutionizing data analysis

The IoT revolution has provided process industries like the pulp and paper industry and the energy dependent marine transport sector with the ability to deploy and monitor advanced controllers, analytics and optimization solutions at the edge and to and from an industrial cloud. The newly designed and updated ABB Ability Advanced Process Control and Analytics Suite revolutionizes data analysis and reduces modeling effort. The result is improved commissioning and online monitoring of advanced controllers. The new technology has the potential to take software-as-service, as a business model, to an entirely new level making strategic predictions easy and collaborative operations optimal. ●

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DIGITAL AND ANALYTICS

ABB's ORKAN designed to test ABB Ability™ powered machines

ABB's advanced multipurpose test rig for ABB Ability™-powered machines provides capabilities in advanced control methods, condition monitoring design and evaluation of industrial compression systems – contributing to breakthrough technologies that are important for the oil, gas and chemical sector.

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Nowadays, modern manufacturing is undergoing a renaissance – the Internet of Things (IoT) – connected factory is not only linked with devices, systems, computers and humans to attain heightened levels of monitoring, information gathering, analysis, processing and communication in real-time but is also intrinsically connected to information platforms that leverage data and advanced analytics for optimization, decision - making and predictions →1. The proper interaction of all these aspects translates to improvements in efficiency, throughput and overall cost of operations for industry customers. Nevertheless, industrial equipment, which ranges from relatively simple devices to complex machines, must cope with diverse processes such as physical, electrical, mechanical as well as parts responsible for process regulation eg, controllers.

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If centrifugal compressor peak head capability and minimum flow limits are reached, instability ensues and surge will occur – a serious threat to the compressor and the entire installation.

This ever-growing interconnectivity and variety of functions that operate simultaneously mean that today's equipment function reliably and efficiently even under demanding conditions. It is no small wonder that the increase in mutual interactions causes confusion that not only results in additional costs but can lead to equipment or installation failure.

There are many modern production facilities and installations that use drivetrain systems, IT infrastructure and devices that might be susceptible to failure or disturbances originating in the power grid. In many cases, equipment that is critical for plant production processes may be also the root cause of anomalies and adversely influence the power supply itself. The cost of these power quality disturbances for a plant may be dramatic and prohibitive and have a significant adverse impact. Therefore, unplanned severe system shutdowns should always be avoided.

The ability to analyze electric systems is a prerequisite for industries to protect their equipment from grid disturbances and ensure proper functioning within complex systems. Consequently, measures must be taken to mitigate the effects of grid disturbances. Such an approach will establish the possibility of critical ride through capabilities,

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Title picture. Compressors are vital to the OGC sector: upstream, midstream and downstream.

thereby allowing installations to remain operational – a feature that assures safety and continuous profitable operation.

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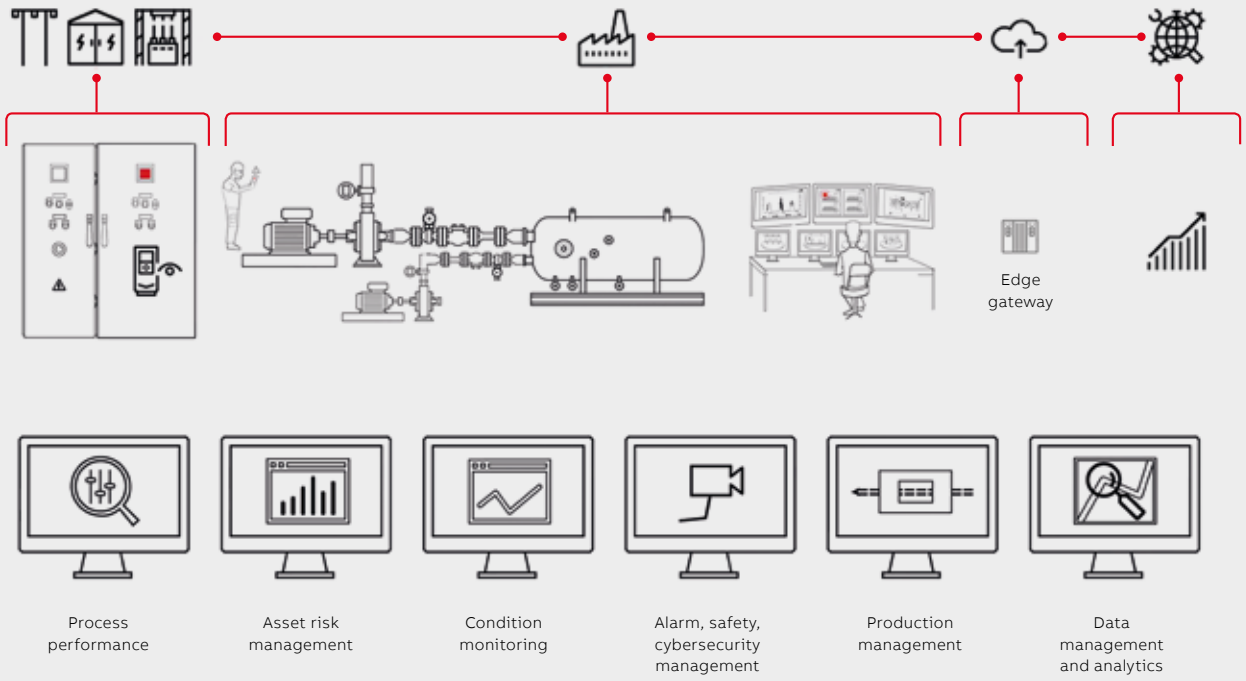
Financial losses incurred as the result of impairment can rapidly accumulate to amounts higher than the purchase price of the compressor.

ABB's pioneering technology solutions enable ABB to play an active role in the burst of innovation currently underway in the fourth industrial revolution.

By combining deep domain expertise with unparalleled experience in connectivity, ABB enables customers to know more, do more, reach more – this dedication to customer service has been a key ABB strategy since its founding more than 130 years ago.

To remain at the forefront of digital and technological innovation, ABB develops intelligent concepts that are verified by means of design review, advanced model simulations and rigorous experiments conducted under strictly controlled conditions, especially with relatively small-scale setups. The ORKAN compressor test stand is one such setup →2.



01

ORKAN – compressor test stand

Oil, gas and chemical industries are reliant on the compression and transport of gas. These processes are responsible for the largest share of the energy consumed by the chemical industry. To improve efficiency, flow compressors are widely employed in many industrial installations. Due to stringent requirements on volumetric flow and pressure ratio, the design and construction of these devices are important. Also, the design performance will largely determine its energy consumption.

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ORKAN is used to test the influence of electric faults, assess stability and further develop ABB solutions that protect machines from flow disturbances.

Engineers have continuously improved construction of flow compressors since their first use more than a century ago. The advanced construction and superior reliability of flow compressors promoted their current popular use in many critical applications eg, gas pipelines. However, this ubiquitous use and reliance on flow compressors necessitate strict compressor reliability requirements.

Equipment failures must be avoided as they can lead to financial losses and safety issues. Financial losses incurred as the result of impairment can rapidly accumulate to amounts higher than the purchase price of the compressor. Therefore, a strong business case exists for the development of a robust and accurate condition monitoring system to keep these compressors fully operational.

To be helpful, any condition monitoring system requires deep knowledge of these complex machines. Centrifugal compressors operate with the highest efficiency within the stable range near the border between the stable and instable operating area; it

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01 ABB collaborative operations deliver actionable insights to optimize performance.

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02 Orkan test rigs are shown-Kraków, Poland.

02a ORKAN test stand 1.

02b ORKAN test stand 2.

is difficult to remian within this operating region. If centrifugal compressor peak head capability and minimum flow limits are reached, instability ensues and surge will occur – a serious threat to the compressor and the entire installation. The longer the compressor operates in this condition, the greater the risk of serious damage. With this in mind, the accurate control of the compressor system is the goal.

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Since 2012, ORKAN has been testing the integration of different ABB technologies with remote cloud and local solutions.

The application of a condition monitoring system yields potential rewards, with advanced algorithms offering both the promise of transformational gains in safety and additional compressor throughput. The ORKAN test rig was developed by ABB for this purpose. It features two machines to reflect multiple types of applications (eg, series and parallel operation) and to replicate operations in real-world plants →2.

The rig is used to test the influence of electrical faults occurring at the process side, assess stability for diagnostics purposes and to further develop ABB solutions that protect machines from flow disturbances. In recent years, the test rig has been successfully employed to develop and test multiple solutions including stand control modes such as grid disturbances modes, supply control modes (electric and mechanical) process control modes (basic process control, suction pressure control, discharge pressure control, and anti-surge control).

The test stand is equipped with ABB devices such as: ACS880 and ACS850 low-voltage drives, two induction motors, AC800 PEC controller, AC500 High Performance, AC500 CMS PLCs, Emax circuit breaker, and a variety of flow, pressure and temperature sensors. The inclusion of an ABB ServicePort application allows all users to view, scan and track all key performance indicators (KPIs) to enable maximum performance of the compressors and the processes involved →3.

Case studies

Since 2012, the test stand has become a pioneering platform to test the integration of different ABB technologies with remote cloud and local solutions - for example, equipment condition monitoring and diagnostic algorithms testing, and evaluation of the interaction between control and diagnostics systems. By combining control and diagnostics, ABB solutions give customers a competitive advantage. ORKAN is also used as a test bench for large-scale data gathering and for evaluating IoT and cloud solutions →4. In addition, the test stand has multiple communication protocols implemented. These key features promote versatility in connectivity engineering design, analysis and testing. The vast amount of data gathered during tests permits exploration of different methods of analysis: condition monitoring through diagnostics and prediction – a necessity for industries such as OGC.

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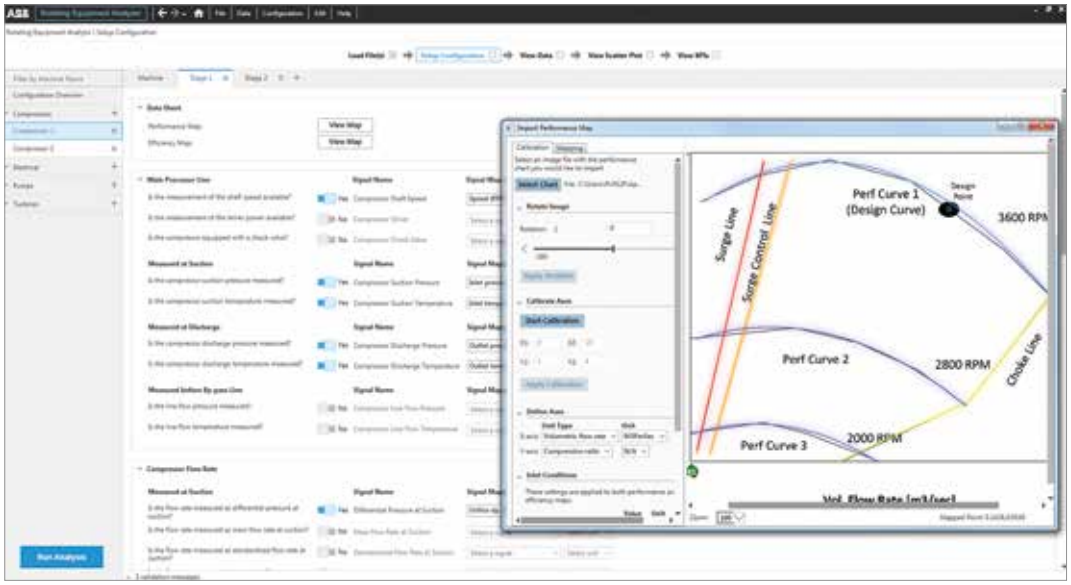

03

The test stand studies include the analysis of crucial deployment strategies to answer the questions: How will the end user exploit the results of the analysis? How can the results be presented in an intuitive way? A primary goal of test stand investigations is to tailor the solutions for different use cases – end users of data such as service engineers, operators, maintenance managers; mechanical, electrical and process departments; and condition monitoring experts, among others. It is also important to obtain simple meaningful and actionable insights. These perceptions translate to: traffic light-type status indication, clear statements on current and future health and the possibility to drill down to the root cause of issues, among others.

The test stand has also been adopted to investigate the ABB Ability Rotating Machines Analytics solution, which integrates wireless sensors and compressor control systems with the ServicePort platform.

Recent activities

The development of accurate control and condition monitoring methods is dependent on much more than the use of sophisticated simulation models. Even complex simulations do not reflect the real world nor do cross-correlations of various parameters describe all processes of importance to compression systems or deliver outcomes that completely replicate nature. Moreover, the successful operation of theoretical solutions in numerical environments does not guarantee that the solutions will function in reality.

The accumulation of possible disturbances, inaccuracy of parameters and the large degree of model idealizations typically employed can make the most advanced theoretical solution completely useless in the real world. For this reason, artificial intelligence (AI) or machine learning (ML) are considered good test cases for operation verification on this test stand. In November 2016, ORKAN was first used to develop and test technologies for ML and predictive diagnostics for rotating machines, which are critical assets in the OGC sector.

Since 2017, the test stand has also been adopted to investigate the ABB Ability Rotating Machines Analytics software suite, which integrates wireless sensors and compressor control systems with the ServicePort platform and its inherent connection with the ABB Ability™ cloud →3.

Shaping the digital future

Taking a leap into the future of industry today, ABB is developing a unified, cross-industry digital capability – extending from device to edge to cloud – with devices, systems, solutions, services and a platform that interacts optimally together. ABB Ability delivers just that capability. Moreover, ABB has embarked on the next step, to create a digital representation of sensors, devices and systems – a digital twin – practically an identical copy of the physical devices.

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03 ServicePort rotating channel display shows surge potential.

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04 Display of DL400 software tool used to gather data to assess process and control system performance.

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Footnote
1) See also "ABB's Electromagnetic flowmeter digital twin drives performance", on page 58 of this issue of ABB Review.

The test rig takes advantage of digital twin capabilities. The digital twin requires a consistent data model that contains the measured variables and the mapping that leads to a digital representation. This function requires that measurements easily reach the digital twin representation, which in turn, necessitates the engineering of a communication infrastructure. To be an adequate approach, this sophisticated infrastructure must be tailored to the digital twin and its unique object. ABB fosters this approach to breakthrough digital industrial technologies at its global corporate research centers[1]. Nevertheless, to take full advantage of the rapid advances in digitization, industry would require not only a digital mirror, but a virtual representation with capabilities different from the actual physical object – a digital avatar. Like the twin, the digital avatar is a digital object that represents the real world but, unlike the digital twin, the avatar can interact within the digital world in ways that differ from how the object would typically respond in the real world. Always at the forefront of innovation, ABB is currently exploring this concept.

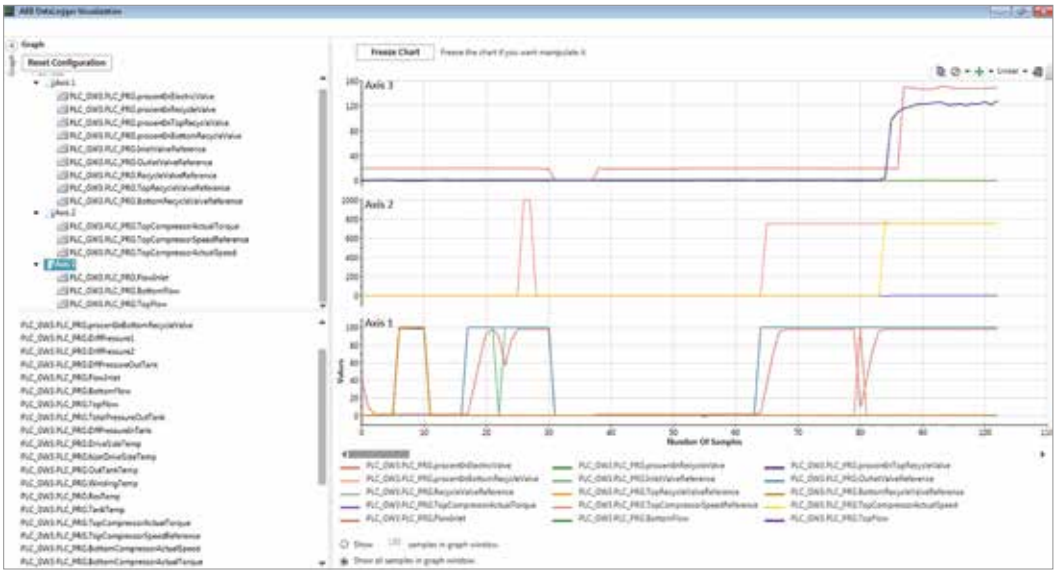
ORKAN is an ideal setup to embrace and incubate the disruptive technologies; to explore and test digitally transparent connected devices and systems as well as digital-enabling services.

Outlook

The birth of technological innovation is dependent on environments that promote invention, design, simulation, experimentation and the ability to deploy novel technologies and solutions. These core bench capabilities are an essential starting point that allows business to capitalize on advances in technology and compete successfully in the digital race toward the future.

The ORKAN multipurpose rig satisfies all of these requirements and more. It is an ideal setup to embrace and incubate the disruptive technologies; and to explore and test digitally transparent connected devices and systems as well as digital-enabling services. ORKAN is a part of ABB Ability – the unified, cross-industry digital capability, from device to edge to cloud. ●

04



DIGITAL AND ANALYTICS

Real-time and full-web, pulp, paper and paperboard analysis

How can the latest imaging technology be used to analyze more and smaller details on high-speed, high-quality web product machines? And how can full-web data be processed to enhance product quality evaluation and improve manufacturing process monitoring and control?

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A web imaging system (WIS) →1 is mainly used for quality analysis, ie, the detection of defects and other undesired abnormalities. Holes, spots and dirt particles are examples of discrete defects, while wrinkles, streaks, and slime spots are examples of so-called weak defects. Both types of defect should be detected to ensure an adequate product quality.

A web imaging system is mainly used for online quality analysis - ie, the detection of defects and other undesired abnormalities - of a product such as pulp or paper.

In many cases, evaluation of the quality of web product emerging from today's high-speed and high-quality machines relies on remote laboratory measurements or online measurement results that are derived from only small portions of the product area. Recently, however, ABB introduced new methods for analyzing large numbers of interesting target regions of a web product in real time – and over the whole product area.

These new methods and derived measurements allow pulp and paper manufacturers to:

- Monitor the overall quality factors of a product online
- React immediately to improve the product manufacturing process
- Evaluate the overall product quality
- Classify the manufactured product areas based on specific customer requirements

These measures deliver significant savings compared to cases where a poor-quality measurement of a portion of the web leads to the discarding or downgrading of large amounts of good-quality product.

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01 ABB web imaging system.

The ABB analysis methods exploit recent advances in imaging and real-time data processing technologies to capture an image of the product, then separate the interesting and uninteresting regions of the image. The latter process is often called region of interest (ROI) segmentation. A subsequent step involves real-time morphometric (ie, size and shape measurement) analysis of ROI sizes, lengths, widths, angles and ratios.

—

The methods exploit recent advances in imaging and real-time data processing technologies to capture an image of the product, then separate out the interesting regions of the image.

These analyses must run in real time, regardless of the number of interesting regions per unit time. Therefore, real-time ROI analysis can be demanding if their number is high [1].

Web imaging principles

In a real-time WIS, pulp, paper or paperboard products are first imaged utilizing appropriate illumination, imaging configuration, optics and camera →2. The raw image data generated is then analyzed by the imaging hardware, which needs first to make several corrections to the incoming raw data – for example, position-dependent brightness corrections and gray-scale transformations – and perform ROI segmentation. The segmentation part of the process can be challenging and usually several different segmentation methods and parameters are used in parallel to provide multiple features for subsequent analysis.

01

One way to efficiently handle the large quantity of data involved in the real-time analysis of images with high resolution and dynamic range is to create dedicated hardware based on a field-programmable gate array (FPGA). An FPGA is a programmable logic chip [2] that includes a large number of very simple logic elements that can be connected to create more complex functionality. Today's FPGAs include millions of logic elements and support high internal clock frequencies, large internal memories and dedicated digital signal processing (DSP) blocks. ABB has designed an FPGA-based imaging camera that processes incoming raw image data and transfers only the results and target images having the desired resolution and dynamic range [2]. This data reduction technique enables real-time data processing for the full web to be achieved. FPGA-based hardware platforms also simplify the later inclusion of new measurement features that extend the WIS life cycle.

ABB has designed an FPGA-based camera that processes raw image data and transfers only the results and target images having the desired resolution and dynamic range.

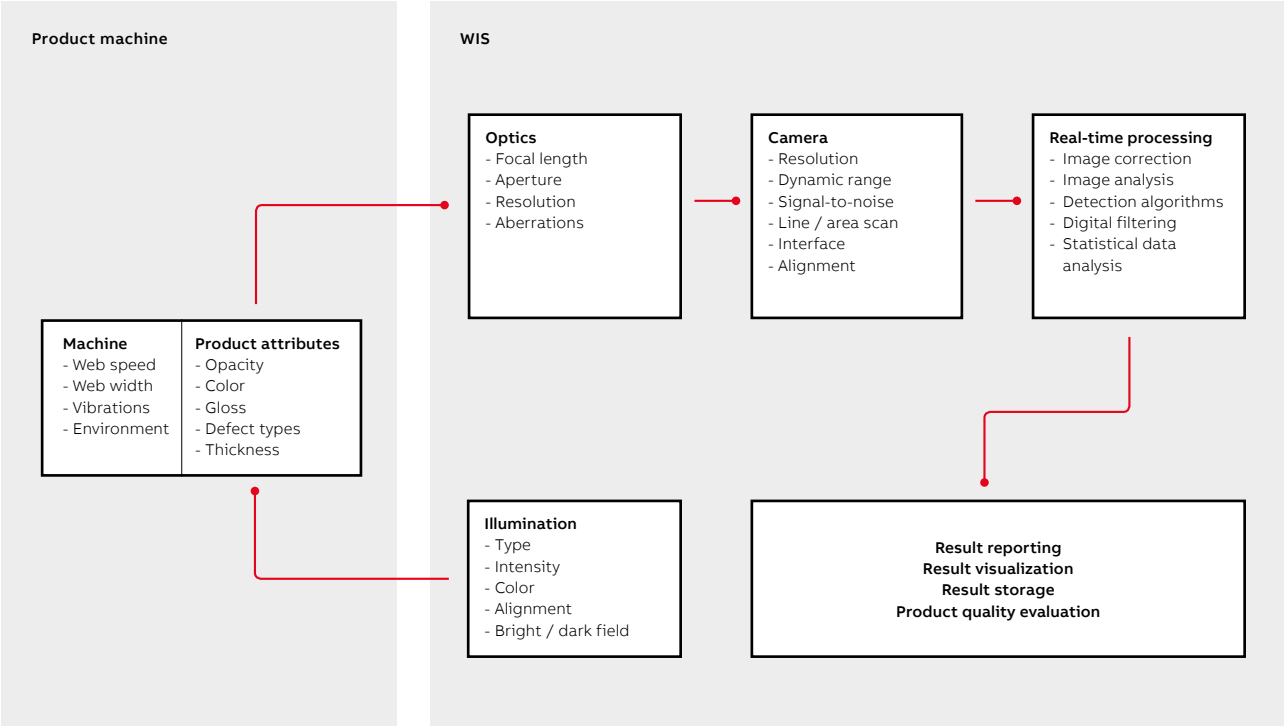
Real-time ROI morphometric methods

ROI segmentation determines the interesting regions of the imaged product. The next step is to analyze, in real time, these regions and generate valuable information about the product quality. This data can then be used to characterize geometric features and classify the interesting regions based on these features.

Important region parameters are, for example, Area, which is the total number of pixels of a region, and Perimeter, which can be used to generate several other geometric properties, such as Roundness →3. When comparing the shapes in →3 it can be seen, for instance, that Roundness differentiates a circle-type region (value 0.92) from a flower-type region (value 0.16) while the Area feature values are almost the same (17,790 and 19,682).

Real-time classification of interesting regions

Three separate tests were performed to assess the new real-time FPGA-based region handling algorithm: a combined intensity and size classification test, a size classification test and a region handling performance test. A test setup that includes custom-built sample-carrier drums provides variable sample speed and adjustable illumination →4.



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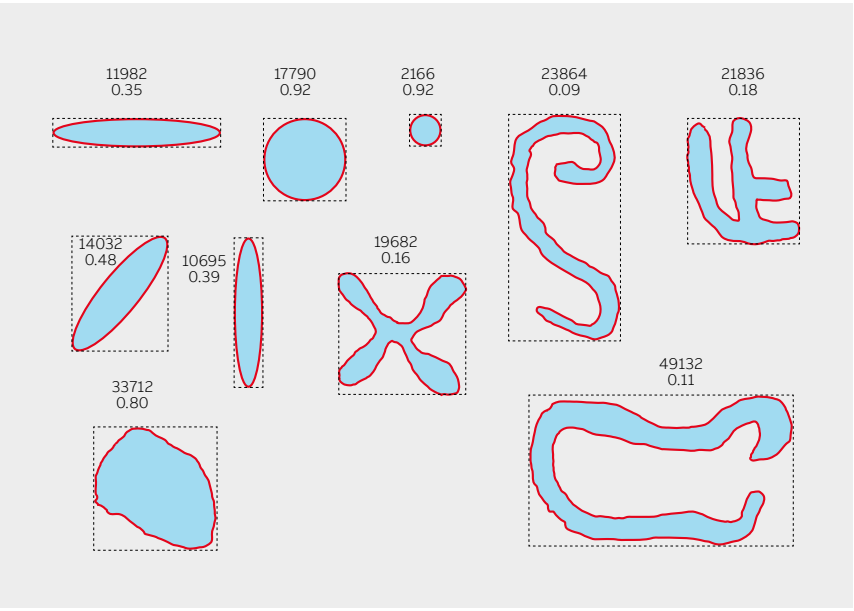

03

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02 Web imaging aspects.

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03 Examples of segmented regions having different shapes. The upper value is the measured morphometric parameter Area; the lower is Roundness, which is derived from the measured morphometric parameters Area and Perimeter.

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04 Rotating drums for the algorithm testing.

Combination of intensity and size classification test
The purpose of the test that combines both intensity and size classification was to assess performance where first a threshold value is set to find the dots and thereafter the size of the dot is determined by using another, potentially more sensitive, threshold. The combination of intensity and size classification performance was tested by scanning (at 115 m/min) a test pattern consisting of 90 gray dots and 90 dots with gray and dark portions, and five different dot sizes (areas 3.1 mm² down to 0.2 mm²) →5.

By using a low-sensitivity detection level, 10,980 dot regions enclosing smaller, darker dots were detected, their sizes measured (based on another, high sensitivity segmentation level), and they were classified based on the measured sizes. In this case, only the gray dots that had a dark region (left side of →5) were detected for the region count due to the lower sensitivity detection level. By using a higher sensitivity detection level, all 21,960 gray/dark spots were detected.

The count, size and intensity classification results corresponded extremely well to the dark dot distribution in the test pattern, ie, the system was capable of detecting dots with the desired intensity, to measure the size of the dots according to a sensitive segmentation level and to classify the detected dots according to their sizes.

Extreme size classification test
The purpose of the extreme size classification test was to determine whether the algorithm is capable of classifying black dots, on densely spotted test paper, into classes according to their sizes, at very high speed.

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Three separate tests were performed to assess the new real-time FPGA-based region handling algorithm.

The test pattern consists of 240 dark dots having five different sizes (0.60 mm² down to 0.06 mm²) →6. The region detection and area measurement performance during the test was about 1.4 million regions/s. The size classification result corresponded very well to the test pattern's actual dark dot distribution →7.

Morphometric region classification test
The morphometric region classification test assessed the performance of the system at high speed with a large number of differently shaped regions packed tightly together: 240 dark shapes having five different sizes between 0.10 mm² and 2.50 mm² and four different shapes →8. The sample was scanned at 420 m/min making the region detection and area measurement performance during the test about 223,000 regions/s.
The size and shape classification results were found to correspond to the test pattern's dark shape distribution.

04

Pulp dirt analysis
Both the amount and visual impact (area and intensity) of visible dirt in pulp, paper, or paperboard can significantly affect the quality of the end product [3-7]. Therefore, one of the most beneficial quality testing procedures is dirt counting and dirt area classification.

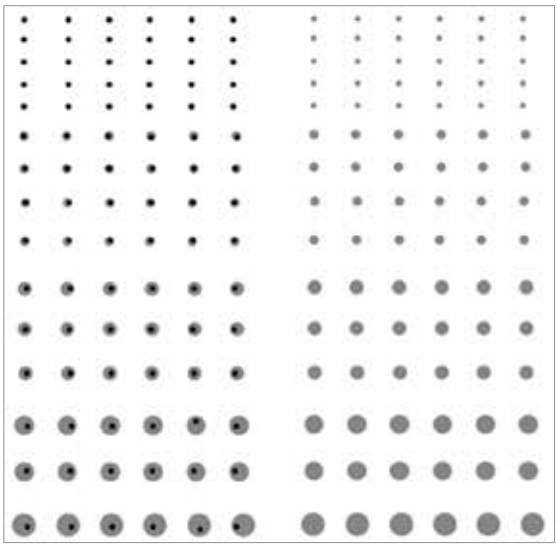
ABB's new real-time methods cover the full web – a situation for which new standards are required.

Several international standards have been published for the dirt analysis procedure, but most of them represent offline laboratory measurements relating to measurements on only a small area of the product.

ABB's new real-time methods cover the full web - a situation for which new standards are required. For the future definition of these standards, it would be beneficial to recognize and define the requirements, and then to discover and standardize the reference values most valuable for the producers. Tests show that ABB's new region handling methods, including dirt area measurement and size classification, provide a reliable, real-time, shape-based dirt classification for the full web and thus a basis for standard definition.

ABB's new real-time dirt analysis product
ABB's DIRT Count is part of ABB's innovative QMS Web Imaging family of integrated imaging products that allows real-time, full-web dirt detection, measurement and analysis of web-based products. It is an automated, online, image-based inspection system that utilizes high-resolution CMOS digital camera technology and real-time methodology. The system inspects the full width of the product web with consistent and repeatable results, detecting and reporting defects and dirt particles as small as 0.01 mm^2. With the application of ABB's advanced imaging technology and increased camera density, defect dimensions can be determined with an accuracy of up to of 0.04 mm.

In pulp drying, while ABB's WIS smart cameras accurately analyze dirt content, they simultaneously continue to provide 100 percent web inspection and hence detect other larger defects and potential production-limiting structural defects within the pulp web. ABB's QMS Web imaging with DIRT Count will allow operators to manage pulp quality of the whole web, thus optimizing production and profitability.



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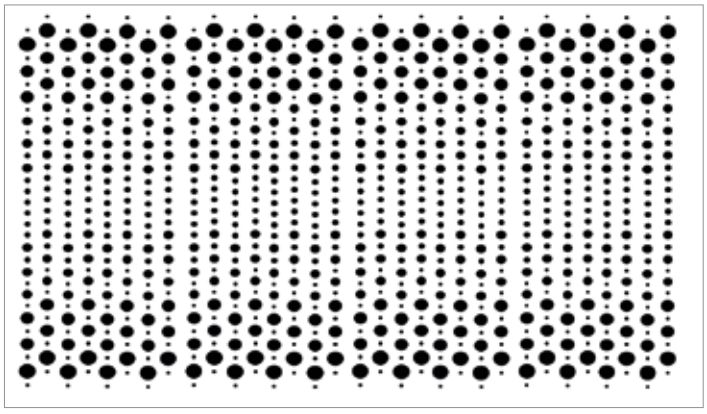

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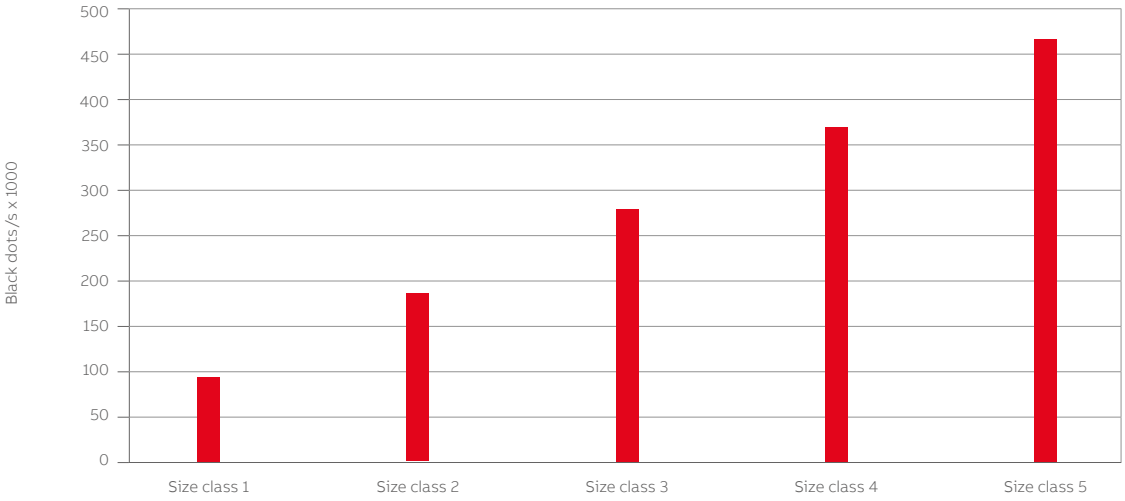

07

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05 A test pattern used for testing the combination of intensity and size classifications.

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06 Test pattern, region size classification.

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07 The region size classification test result. The test results exactly overlie the actual size classification on the test pattern.

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08 The test pattern used for testing handling performance for tightly packed, differently shaped regions.

Full coverage

A smart-camera platform – including FPGA-device-based, real-time parallel image processing support – is one of the most successful hardware solutions for web imaging systems. Computing and data parallelism, as well as flexibility for functionality updates, makes it possible to upgrade an existing WIS with soft sensors and thus extend its life cycle and ensure continued competitive performance.

Modern FPGA-based technologies and image-processing algorithms offer new opportunities to analyze pulp, paper, and paperboard products in real time and to cover the full web even if the ROI density is extremely high. Based on the performance test results of the new methods, with one camera, it has been shown that it is possible to detect over 1.4 million ROI/s, count them, measure their size (area), classify them based on intensity and size, as well as report the results – a feat equivalent to processing over five billion regions of interest per hour per camera.

On top of this, ABB has also introduced new ABB QMS Web Imaging DIRT Count product, which utilizes the ABB WIS hardware and the new ROI handling methodology for dirt particle detection, analysis and classification.

These new ABB web imaging methods and solutions will help improved web-based product quality, cut down waste, increase operational equipment effectiveness and lead to all-round better productivity. ●

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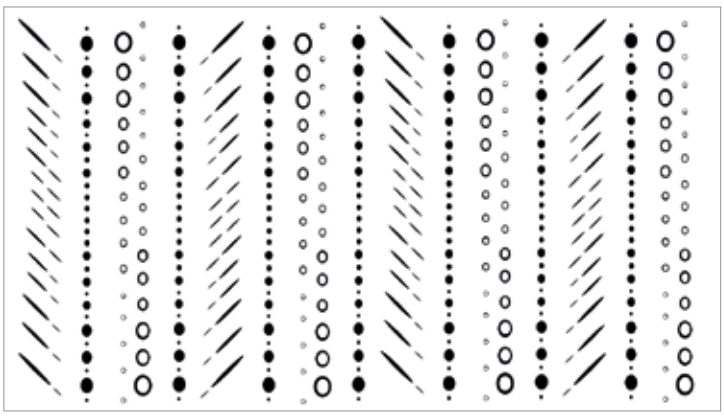

08

DIGITAL AND ANALYTICS

ABB's Electromagnetic flowmeter digital twin drives performance

ABB's flow measurement products reflect state-of-the-art developments in flow sensing technology. ABB's new tool, a digital twin, mimics the actual flowmeter in a virtual environment and predicts electromagnetic (EM) flowmeter performance. The digital twin based on multiphysics modeling enables flowmeter design improvement and performance prediction under field conditions.

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During the last decade new technologies and digitization have begun to dramatically impact conventional process industries involving liquids such as water and wastewater transport and treatment. As these exciting applications have become more plausible and available, ABB's dedicated research teams have worked to ensure customers receive the best and most cost-effective tools to improve their competitive edge. Digital twin technology can do just that by enabling the detection of physical issues early on and predicting outcomes accurately. Looking to the future, ABB has seized the opportunity to apply digital twin technology to improve its flowmeter products to meet process challenges, deliver value faster than ever before and fulfill the ever-increasing customer expectations.

Electromagnetic flowmeters
Production processes require reliable and accurate instrumentation to meet high performance standards. For more than 40 years, ABB has been a reliable partner to the global water industry because of their dedication to product development, system solutions and service. ABB's flowmeters are traditional work horses in the production process industry because they are robust, reliable and above all accurate →1a.

Comprising a major share in ABB's flow measurement portfolio, EM flowmeters are especially appealing to customers, who transport or process conductive liquids due to a unique set of advantages: simplicity of installation, negligible impact on pressure drop, and high accuracy. Furthermore, EM flowmeter performance is not susceptible to variations in temperature, pressure or density nor are they influenced by minor fluctuations in flow profiles. Independent of flow direction, with measurement errors contained within ± 0.2 percent over wide flow ranges, EM flowmeters enable accurate measurement at low flow rates.

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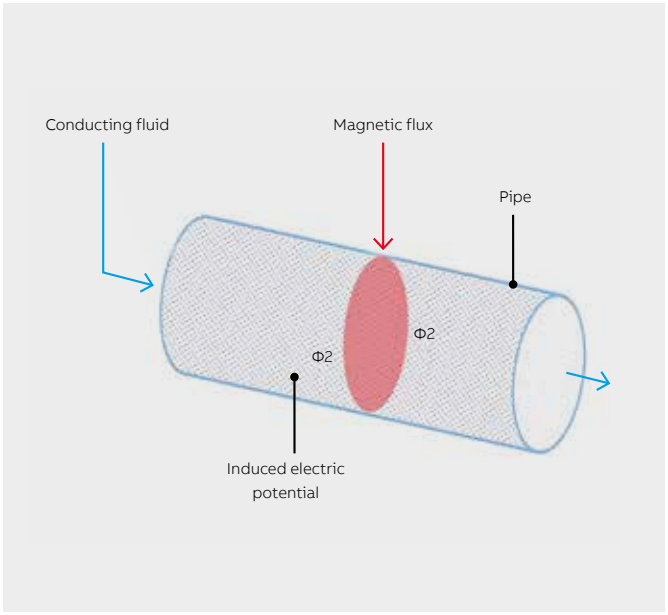
Title picture. Water and wastewater treatment facility.

01a



01b

ABB continually explores tools to improve their electromagnetic flowmeter offering with the aim of meeting high performance standards and cost optimization demands. By combining deep knowledge of flowmeter physics with new verifiable modeling techniques, ABB endeavors to add value to existing flowmeters.

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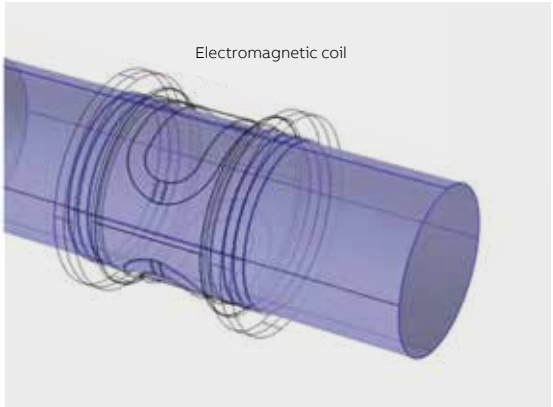
For more than 40 years ABB has been a reliable partner to the global water industry due to its dedication to product development, system solutions and service.

EM flowmeters rely on Faraday's law of electromagnetic induction to determine flow velocity. When a magnetic field is imposed within a pipe through which a conductive liquid like water flows, electric potential or electromotive force (EMF) is induced across the pipe cross section →1b. The EMF is proportional to the flow rate or velocity, and by measuring the induced EMF, flow rate can be estimated. The ratio of induced EMF to fluid velocity is sensitivity, which is related to the calibration factor. While it is important to predict sensitivity, it is just as critical to predict the variations in sensitivity that result from changing conditions. Thermal and structural events that can impact flowmeter operation must be evaluated in the interest of product safety and to assess flowmeter performance under harsh conditions.



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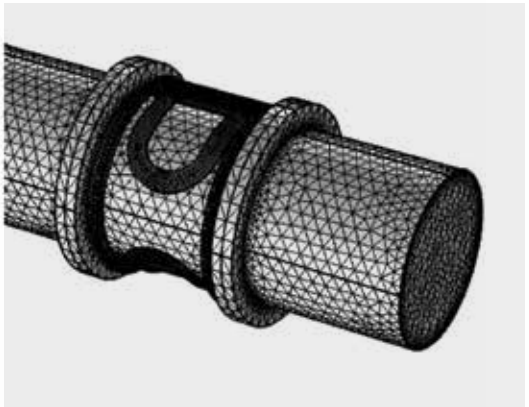

02b

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01a ABB's electromagnetic flowmeter is shown.

01b Interaction of magnetic flux with moving conductive fluid induces electric potential (Φ2) proportional to fluid velocity Φ1 – Φ2.

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02a Geometry of EM flowmeter built using CAD.

02b Discretized geometry for FEA calculations.

02c Several varieties of flowmeters, differing in component design and, or size were modeled.

Digital twin concept

What if one could develop a predictive model based on knowledge of physical processes that would predict flowmeter performance and minimize the need for testing? The result would be unparalleled productivity and heightened performance. ABB has developed a software model of the EM flowmeter based on a multiphysics finite element analysis (FEA) technique to accomplish this. This software model, or digital twin, is a replica that represents the physical asset in the virtual world, thereby mimicking the physical asset's real behavior. Performance complexities can be understood, problems detected, and designs improved based on the resultant acquired process knowledge. This information can subsequently be used to build and operate the product in the field. Digital twins can simulate almost any condition in the virtual world with confidence that the same behavior would occur in the real world.

Multiphysics model

FEA modeling involves discretizing the geometry of an object into smaller finite spaces. The computational model is supplied with information such as material properties as well as operating and boundary conditions. The model solves physics-based equations over the finite domains to derive parameters. This method, which yields three dimensional and, if necessary, time varying information, is employed for performance prediction and design improvement of equipment across industries like oil and gas and aviation. The use of FEA modeling, as opposed to conventional testing

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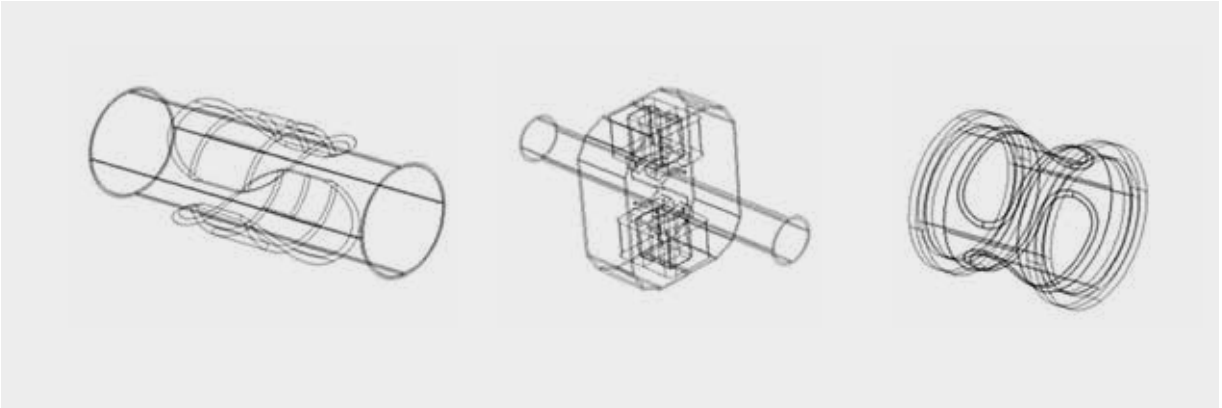
ABB has developed a software model of the EM flowmeter based on a multiphysics finite element analysis (FEA) technique to improve productivity and performance.

methods, ensures that complex processes can be easily understood. Laboratory testing methods are limited by their dependence on the number and placement of sensors employed within the equipment, which is cost-intensive and difficult for process industry applications to accomplish. In contrast, the recent advances and decreasing costs of high performance computing allows diverse and complex physics-based equations to be easily and iteratively solved using FEA.

ABB chose a multiphysics model of the EM flowmeter to improve their already outstanding flowmeter product offering.



02c

Integration of physical phenomena
Initially, the geometry of a flowmeter was constructed using a computer-aided design (CAD) software →2a. The geometry, or the computational

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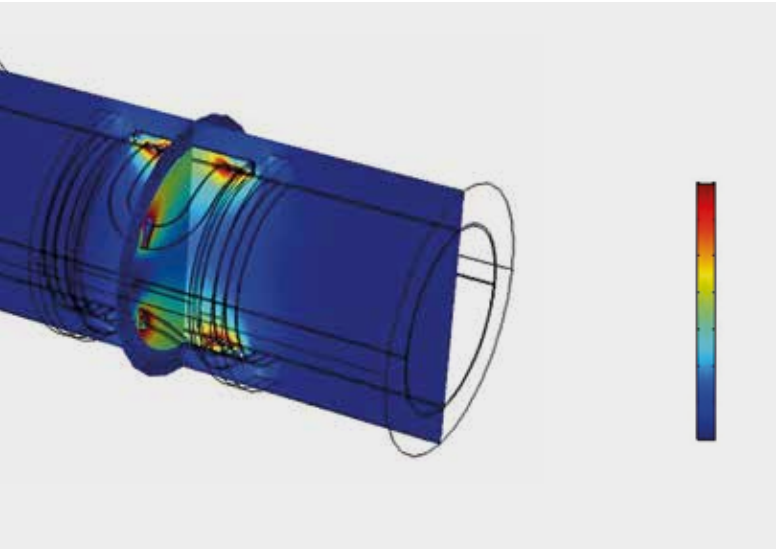
Digital twins can reliably simulate almost any condition in the virtual world with confidence that the same behavior would occur in the real world.

domain, was then discretized into miniscule elements across which equations were solved →2b. Several flowmeter samples of varying design and size were modeled →2c.

The integration of the two primary phenomena, electromagnetism and fluid dynamics, and other diverse physical phenomena within a single model is challenging. Electromagnetism is analyzed by solving Maxwell's equations. These equations initially calculate the magnetic flux density within the computational domain →3a. Fluid dynamics is analyzed by solving equations of mass and momentum conservation for various flow conditions – simulating fluid flow through the pipe →3b. Next, the induced EMF, the result of magnetic flux and fluid velocity interaction, is calculated by integrating the magnetic and flow fields, using the Lorentz equations, derived from Faraday's law of electromagnetic induction →3c. The primary outcome is sensitivity or the ratio of the induced EMF to the fluid velocity. To obtain a comprehensive picture, the model also solves for thermal propagation and structural dynamics parameters. Thermal and hydraulic stresses acting on the pipe wall are calculated →4. Such advanced simulations are essential to predict the effect of challenging harsh conditions on flowmeter health, like the impact of high temperature and, or high pressure liquids passing through the pipe. The ultimate result of these exhaustive calculations is a complete multiphysics model of the flowmeter that can predict performance as well as impending failure under adverse conditions.



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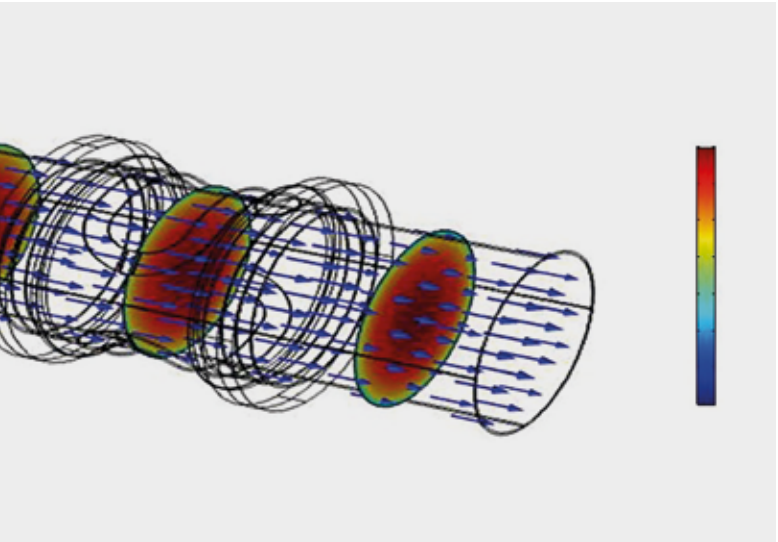

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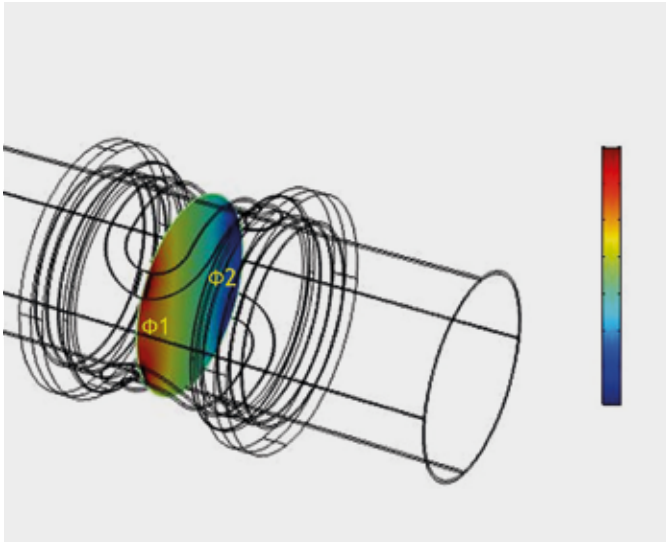

03c

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03 Qualitative physical phenomena were evaluated; red represents maximal values.

03a Magnetic flux distribution.

03b Fluid velocity contours.

03c Electric potential.

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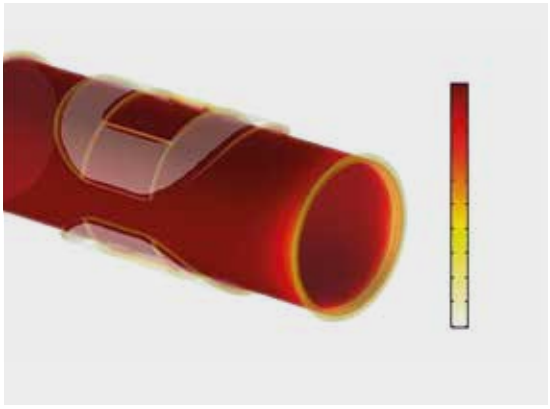
04 Qualitative thermal and hydraulic stress fields are illustrated; red represents a maximal value.

04a Temperature field.

04b Stress field is shown.



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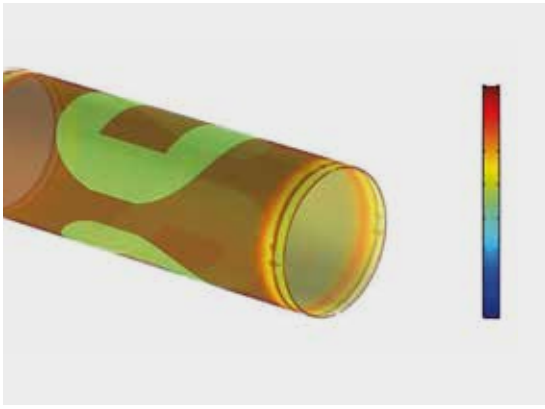

04b

Clearly, modeling has the benefit of minimizing the need for testing efforts, which is cost-intensive and time-consuming. Several ABB flowmeters, of unique design and varying line sizes, were successfully simulated in 2017. A comparison of the sensitivities calculated by the model and obtained during field tests revealed an agreement of 95 percent – establishing the model as a realistic and accurate predictive tool →5. Besides predicting sensitivity, the model could predict linearity of the flowmeter or in other words, constancy of the sensitivity with changing flowrates – measurement accuracy. Not only is the digital twin concept an asset during the testing phase, the model has been extensively leveraged to modify the existing design of the flowmeter to improve quality. By incorporating novel component designs and innovative ideas in the model, improvement in flowmeter performance could be evaluated.

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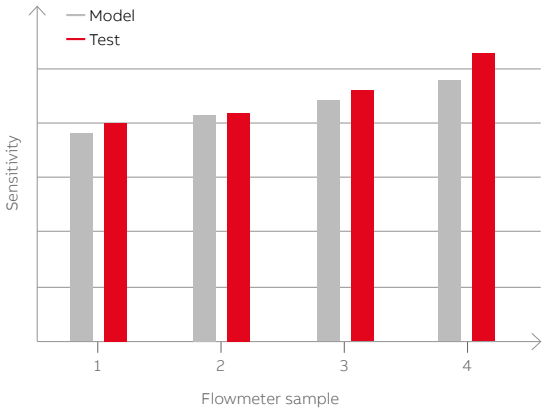
ABB could determine the best location for flowmeter installation in a given piping system, thereby enabling the correction of flowmeter readings.

The modified flowmeter was found to outperform the existing flowmeter product better than the existing flowmeter – setting the stage for future design improvements. The digital twin, applied to flowmeter development efforts, will increase flowmeter sensitivity, improve measurement accuracy and reduce manufacturing costs. Extensive efforts are currently underway to test prototypes of the flowmeter and incorporate the various design modifications and evaluate the feasibility of some of the novel ideas.



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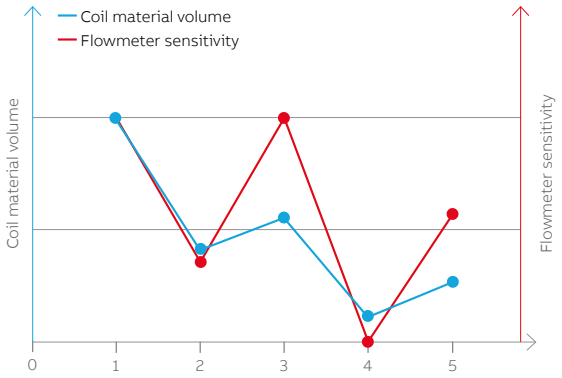

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Doing less creates more

The primary goal of product development is to minimize material usage while maintaining or maximizing performance level. Accordingly, the digital twin model has been used to optimize the design of flowmeter components with the intent of reducing material costs. Being an important component, the electromagnetic coil was modified to obtain the optimal size and, or shape for the ultimate flowmeter performance. Size variation of a given coil was evaluated in a series of iterations →6. In a particular iteration, original sensitivity of the flowmeter could be maintained using significantly less copper coil material. Furthermore, simulations of radically novel coil designs were shown to reduce the amount of material needed to maintain the original performance level. This is of particular value for the development of large flowmeters because coil costs can comprise a substantial portion of the total flowmeter material costs.

Recently, proposed solutions to reduce the overall flowmeter footprint for large flowmeters have been evaluated and verified in the subsequent prototype testing phase.

Replicating field conditions

While development and testing are important phases in product lifecycle, the installation phase has its unique challenges too given that system features like bends and valves can distort flow profiles and impair measurement accuracy. Understanding the systemic effect of piping features on flowmeter performance is therefore crucial. ABB's flowmeter digital twin was expanded to include the customer piping system →7.

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The primary goal of product development is to minimize material usage while maintaining or maximizing performance level; the digital twin model was used to optimize the design of flowmeter components to lower material costs.

The effect of flow modification on measurement accuracy was studied to provide insight into the impact of system features such as upstream bends. As a result, ABB could determine the best location to install flowmeters within a given piping system, thereby enabling the correction of flowmeter readings for an installed flowmeter.

— 05 Several flowmeter varieties were modeled and compared with test data.

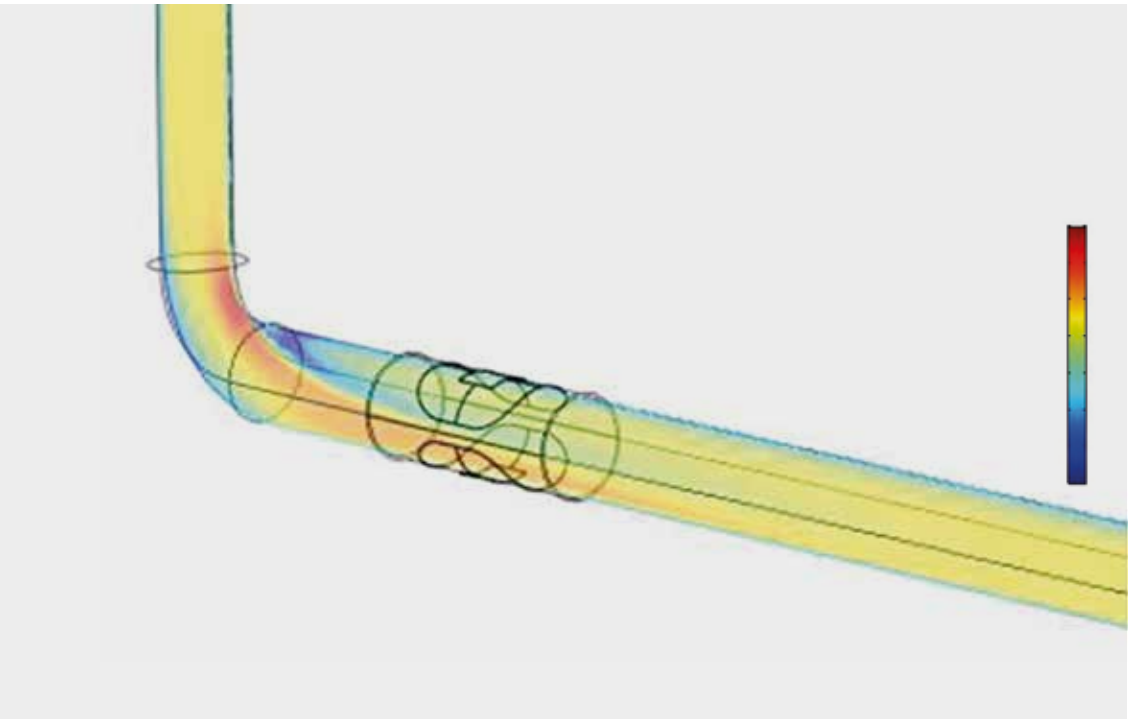
— 06 Iterative modeling performed for optimal coil design.

— 07 Modeling of EM flowmeter installed in customer piping system to predict field performance under distorted flow conditions.

To date, the tool has demonstrated veracity to predict flowmeter performance and enabled engineers to improve the design of flowmeters. The expansion of the model to simulate the manner in which flowmeter operations influence the flow profiles of customer piping systems also opens up new avenues for the improvement of measurement accuracy. The digital twin technology can also be employed to serve as a useful guide for flowmeter installation in the field, which enabled industries like water management facilities to improve their flow control systems in the interest of radically enhancing industrial process performance.

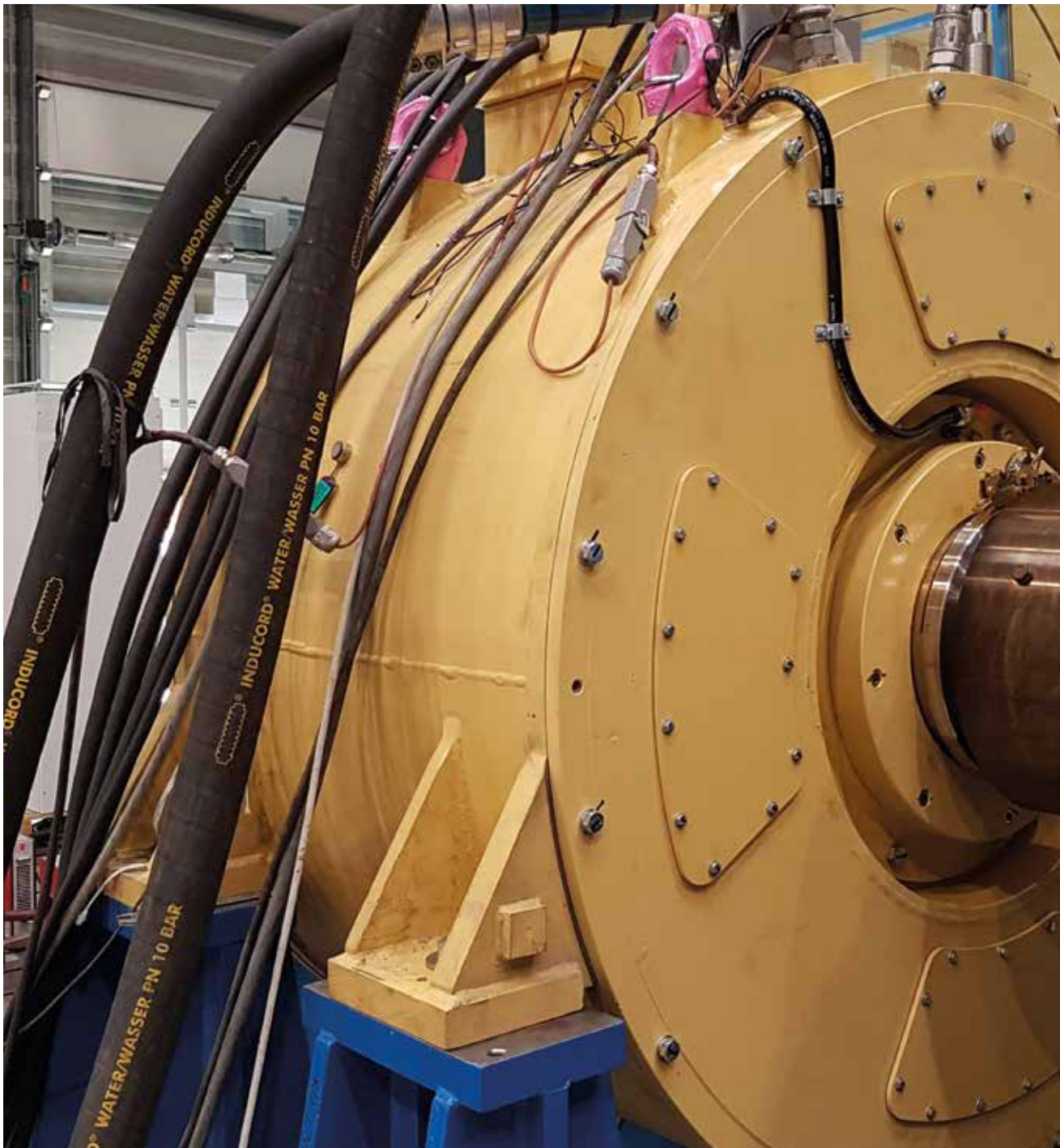
The digital twin technology can be employed to serve as a useful guide for flowmeter installation in the field thereby enabling industries like water management facilities to improve their flow control systems.

Extensive research at ABB concentrates on developing the digital twin model for use in other process industries to provide customers with the most advanced digital means of reaching unparalleled productivity and performance. ABB focuses on maximizing value and producing products with fewer defects, ensuring optimal operation, bringing products quickly to market and improved operation. ●



07

Motion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Designing how devices move, where and when they interact, and what they touch or build is made even more challenging by the variability of different operational parameters, and the insertion of sensing and intelligent technologies into the equation. It's also made more promising.

MOTION

Intelligent transport for production lines

To square the circle of reconciling mass production with batch-of-one production, enterprises need highly flexible manufacturing systems that are also efficient and profitable. B&R's ACOPOStrak intelligent transport system →1 promises to deliver just that. B&R became part of the ABB group in 2017.

Carmen Klingler-Deiseroth
Freelance journalist

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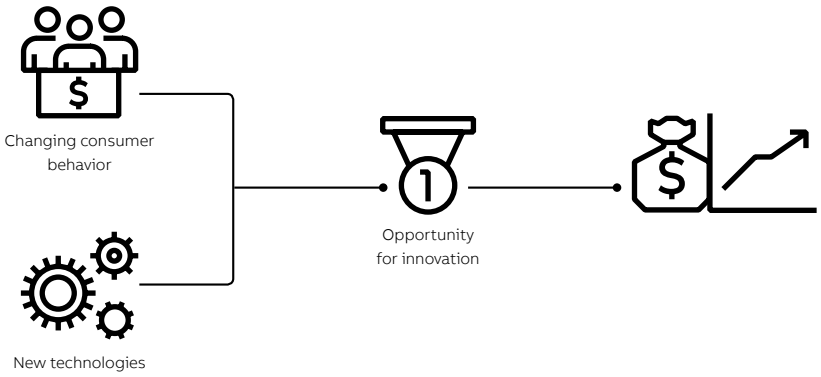
For today's generation of digital natives, the ability to personalize the products they buy is increasingly a given. To keep pace with this rapidly changing situation, the makers of these products need highly flexible manufacturing systems that are, at the same time, efficient and profitable. This introduces a whole new set of demands on plant infrastructure.

Batch-of-one production is nothing new – in fact, it is standard practice in many craft businesses. What is new, however, is the idea of making customized products under mass-production conditions. So far, this has proven difficult to implement in a way that is economically viable. That is because any increase in system flexibility is usually accompanied by a reduction in overall equipment effectiveness (OEE). In short, individualization becomes unprofitable.



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01 The ACOPOStrak intelligent transport system will fundamentally change the way production lines are designed and operate.

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02 The convergence of new technologies and growing demand for personalized consumer goods creates new opportunities for adding value.

The goal of mass customization is, therefore, to keep the three factors of OEE – availability, performance and quality – at a level consistent with what can be achieved in mass production. In addition, manufacturers seek to maximize their return on investment (ROI) and to minimize their time to market for new and improved products. This is the only way to make mass customization viable from an economic perspective →2.

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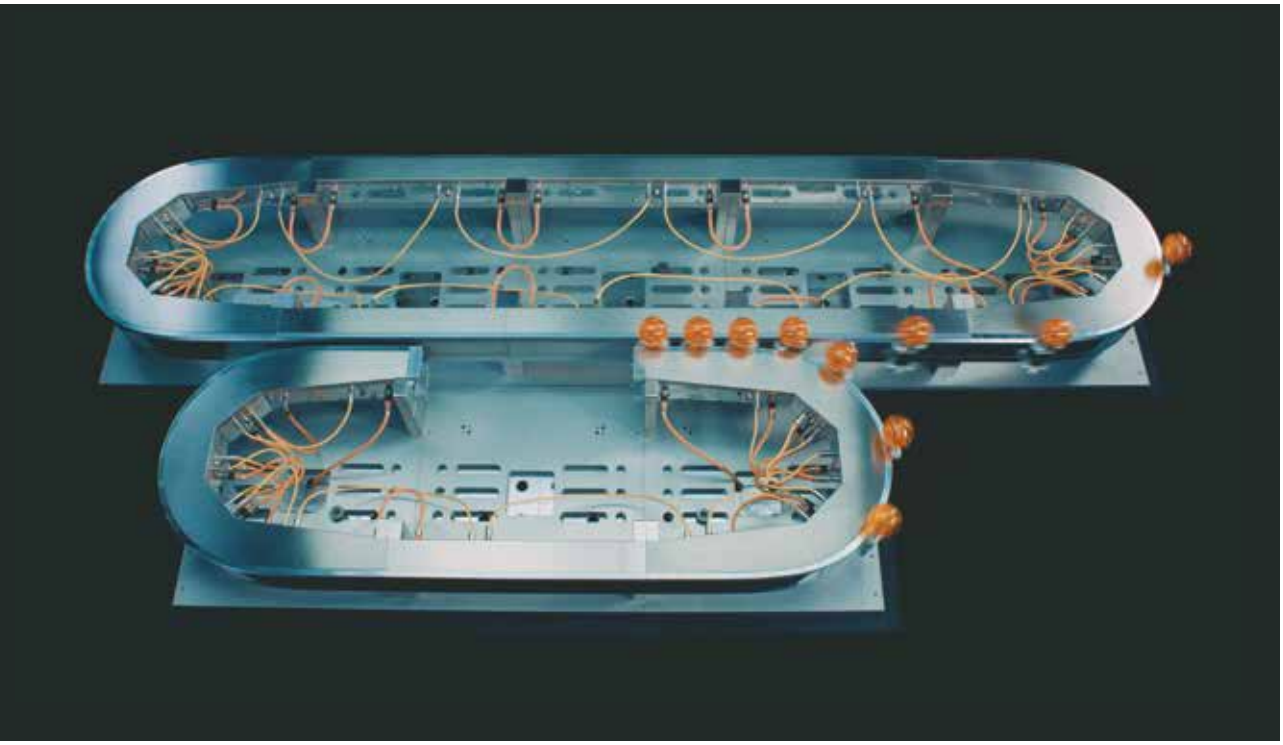
ACOPOStrak is an intelligent transport system whose revolutionary design enables adaptive manufacturing systems and promises a new era in flexible and efficient production.

Up to now, developing flexible manufacturing systems has been a tedious process. In many cases, problems are not seen until the system is up and running. At that point, fundamental changes to the machine design can extend the time to market by months, which is a costly affair.

ACOPOStrak intelligent transport system

If flexible manufacturing is to match the increasing demand for true mass customization and batch-of-one production, then new approaches to mechanical design and motion control hardware must be conceived. Breakthrough innovations in these two areas are at the heart of ACOPOStrak – an intelligent transport system whose revolutionary design enables adaptive manufacturing systems and promises a new era in flexible and efficient production. ACOPOStrak was developed by B&R Industrial Automation GmbH, an Austrian company recently acquired by ABB.

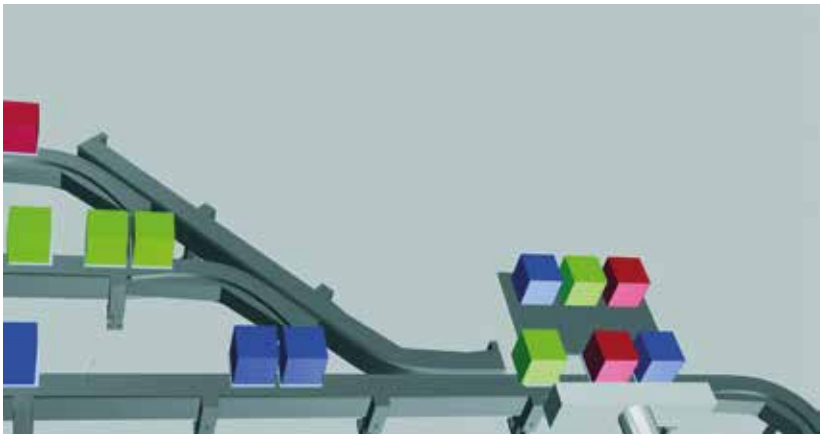


03

Diverter maximizes OEE

So, what is it that makes the intelligent transport system so uniquely suited for automating adaptive processes? The answer lies with the diverter. The diverter is – quite literally – a pivotal component of the system. It is 100 percent electromagnetic, so does not require any additional components, as a diverter-less transport system does, and is, therefore, entirely free from wear. Like a highway junction, the ACOPOStrak diverter lets product flows diverge and converge and allows the shuttles that carry the product components to switch tracks at full speed with no compromise in productivity →3.

The ACOPOStrak diverter allows mass-produced items such as bottled beverages, for example, to 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 →4. To sustain high quality, lines must be able to react to faults and defects in real time – without compromising the production process. Defective products need to be rejected on the spot, while maintaining full production speed. If a defective item is not sorted out immediately following quality inspection and is instead permitted to continue down the line, it may eventually become necessary to scrap an entire job lot of products. The ACOPOStrak diverter allows defective products to be sorted out as soon as they are identified.



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03 ACOPOStrak's purely electromagnetic diverters divide and merge product flows at full production speed.

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04 Mass-produced items such as bottled beverages can be grouped into custom six-packs on-the-fly.

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05 To switch products, the operator simply places the wheels of a new shuttle on the guides of the pit lane, while production continues at full speed.

Parallel processing
ACOPOStrak and its diverters also add a new dimension of flexibility for implementing parallel processing. A 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 – the end customer can increase productivity without a corresponding increase in machine footprint. In other words, ACOPOStrak boosts the output per square meter, which, ultimately, means a higher ROI.

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ACOPOStrak and its diverters also add a new dimension of flexibility for implementing parallel processing.

A machine or line built using ACOPOStrak gives the modularity and flexibility needed to add individual track segments and processing stations in response to changes in demand; the truly adaptive, scalable machines envisioned for the industrial Internet of things (IIoT) has become reality.

ACOPOStrak-based manufacturing systems are also exceptionally fault-tolerant. If there is a problem with one valve in a bottling line, the bottles are simply no longer sent to that valve. The defective valve does not result in waste, which makes a big difference in the OEE quality factor.

Zero-downtime changeover
The hot-swappable shuttles can be replaced tool-free and on-the-fly for unprecedented availability. When 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 new shuttles are mounted in the pit lane and then channeled to the track's production lines via a diverter →5. In the same way, any shuttles that are no longer needed can simply be rerouted to the pit lane. All of this takes place at full production speed.

05

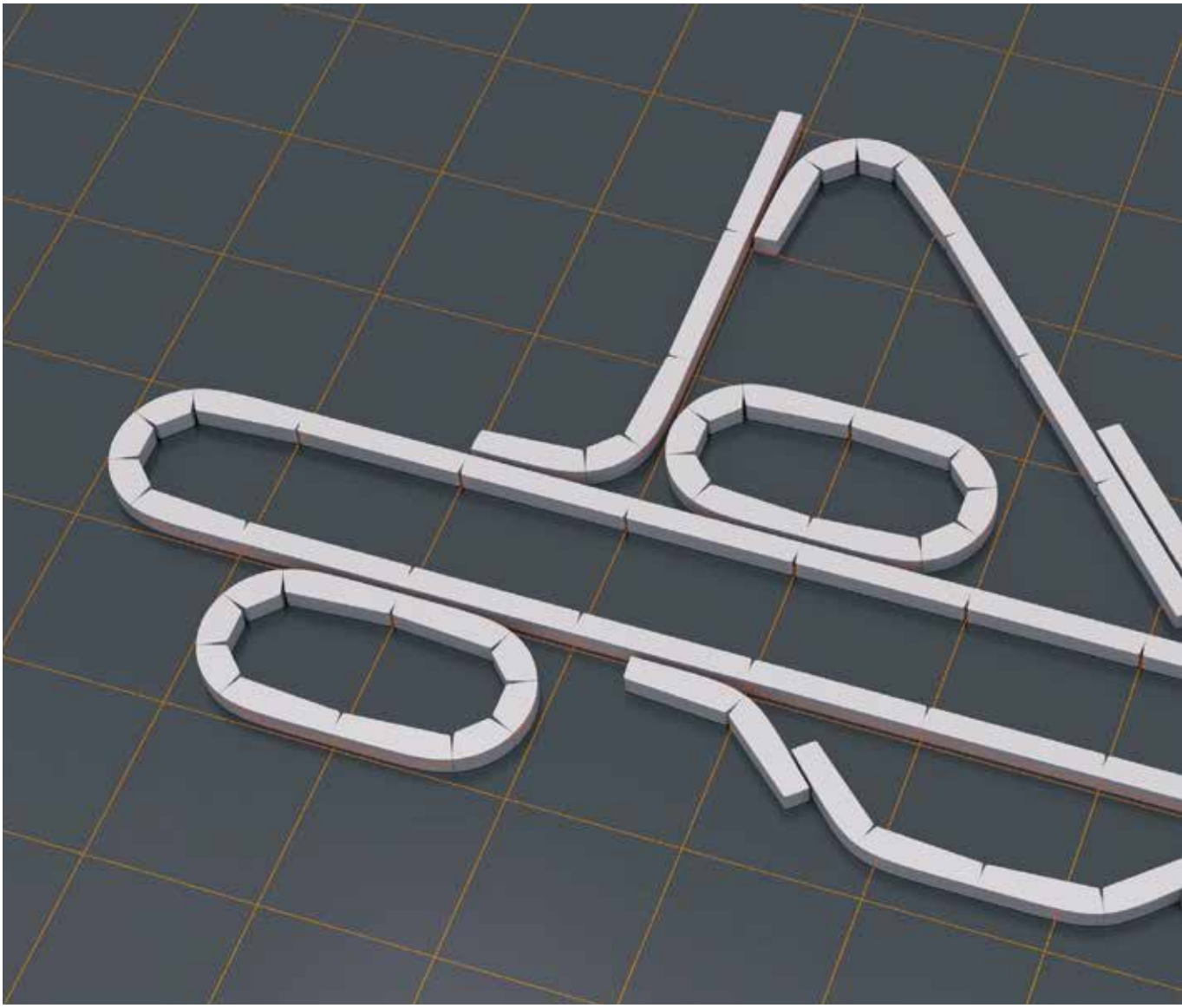
ACOPOStrak's absolute design flexibility allows it to morph into all types of open and closed layouts by arranging the segments in different combinations on a grid →6. The core of the track system is a linear motor assembled from four types of modular segments: a straight segment, a 45° segment and two 22.5° segments – one curved to the right, the other to the left.

Scaling is also simple. In most cases, a conventional manufacturing system does not scale easily: To increase output, it is often necessary to either add a second line or replace the existing line with a larger one. These options require considerable investment and eat up valuable floor space. ACOPOStrak's design flexibility does away with this scalability problem once and for all. If the line also allows one to add and remove stations on site, that opens up yet more possibilities to adjust capacity to changing demand.

Highly dynamic and flexible

The intelligent transport system offers more than just flexibility - it is also unmatched in performance. ACOPOStrak is capable of over 5 g acceleration and reaches top speeds in excess of 4 m/s with a minimum product pitch of only 50 mm →7.

ACOPOStrak's design flexibility does away with the scalability problem once and for all.



06

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06 ACOPOStrak's absolute design flexibility allows all types of layouts by arranging the segments in different combinations on a grid.

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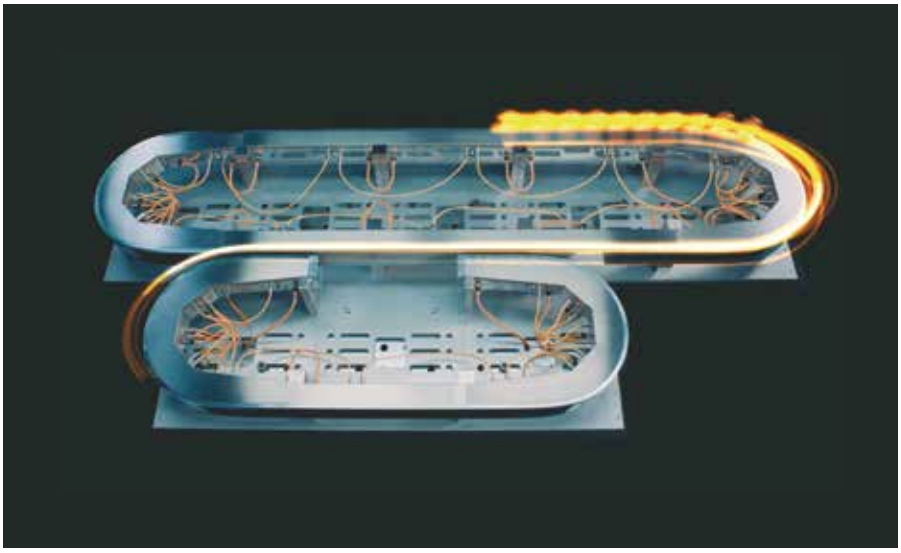
07 ACOPOStrak is capable of accelerating at over 5 g and achieves top speeds of over 4 m/s.



07

Faster time to market
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 or on the actual hardware with no limitations.

—

Developers benefit from process-oriented programming: They simply describe the rules that define the product flow on the track, rather than having to program a multitude of axes and shuttles individually.

Developers can switch back and forth between simulation and real hardware as often as necessary. This shortens development and commissioning times considerably and thus gives a significant advantage in terms of time to market.

Developers also benefit from process-oriented programming. They simply describe the rules that define the product flow on the track, rather than having to program a multitude of axes and shuttles individually. Autonomous traffic control with integrated collision avoidance takes further work off the hands of developers.

With ACOPOStrak, B&R has designed a solution that makes flexible, modular manufacturing systems highly profitable to operate. ACOPOStrak enables high OEE, attractive ROI and short time to market. And with that, the industry is on the fast track to true mass customization. ●

INTERVIEW

A flexible approach to mass customization

Robert Kickinger

To further explore the advantages of ACOPOStrak, ABB Review spoke to Robert Kickinger, Mechatronic Technologies Manager at B&R.

ABB Review (AR): Mr. Kickinger, digitalization is making big waves in industry these days. How does digitalization compare with what you are doing with ACOPOStrak?

Robert Kickinger (RK): The much-discussed topic of digitalization based on communication technology and software takes too narrow a focus in our opinion. A new generation of requirements also calls for radical, innovative thinking in the way products are transported through machines and production systems – and B&R has stepped up to the challenge. By developing the intelligent ACOPOStrak transport system, we have set the stage for revolutionary new machine concepts.

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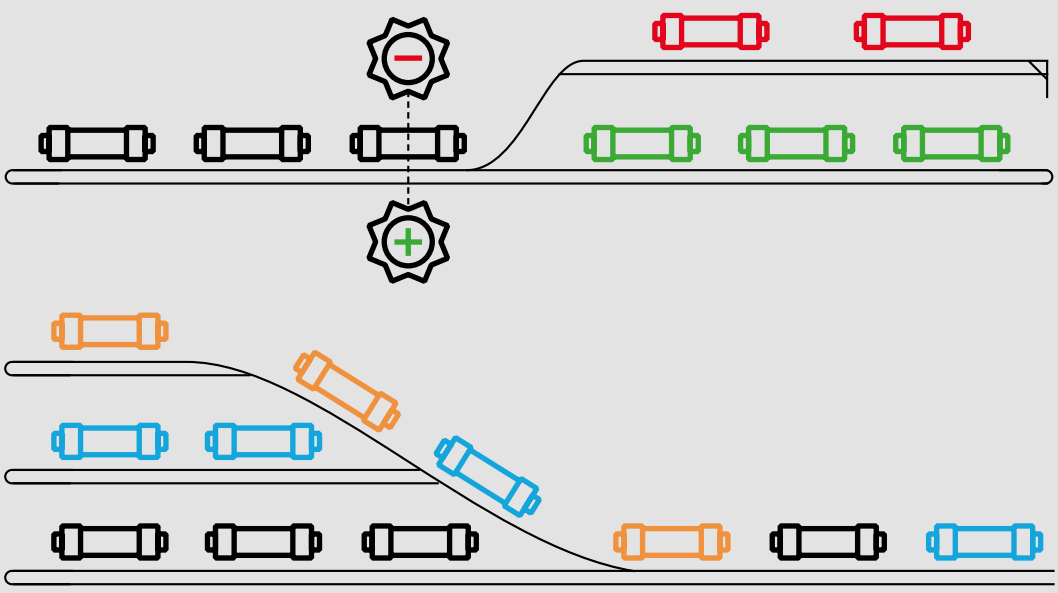

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01 Increasing consumer desire for individualized products is forcing manufacturers to come up with innovative, flexible production techniques.

AR The diverter seems to be a central piece of kit in ACOPOStrak. What are its advantages?

RK The high-speed diverter is the key to ACOPOStrak's flexibility. The shuttles that carry the components can pass through the diverter at product pitches slightly higher than shuttle sizes and still be successfully channeled. The diverter also allows defective product to be taken out of the flow immediately, rather than carrying on to the end of the line. That is a big plus for effectiveness.

AR Does the diverter have other advantages?

RK It's not only products that can be defective, however. If, say, a valve in a bottling line stops working, the automation system should react intelligently by no longer sending bottles to that part of the line, while the process as a whole continues uninterrupted. Traditionally, there have been two options in such a scenario: Either I let the process keep running and scrap all the products affected by the faulty valve, or I stop production altogether. From an economic perspective, neither alternative is particularly attractive.

AR And what happens if you want to change a shuttle - for example, if you need another workpiece carrier for a different product?

RK With ACOPOStrak you would have a pit lane – just like the pits in motor racing or the bench in ice hockey. That way, you can take the shuttles out of the main circulation and work on them at your leisure. There's no need to slow down the main production line.

AR Is the user constrained at all in the production layouts he can construct?

RK Only insofar as he is limited by the four types of modular segments: the straight segment, the 45° segment and the two right- and left-curved 22.5° segments. These give as many layout possibilities as any producer could want. It is also eminently scalable. In other words, ACOPOStrak adapts perfectly to any production site. And at the same time, it opens up completely new machine designs that have never before been possible.

AR How would you summarize the impact of ACOPOStrak?

RK When you combine the performance numbers we're seeing with the benefits of the diverters and the extreme design flexibility you get a total package the like of which the market has never seen before. ROI, OEE and time to market are the main economic factors underpinning all manufacturing operations and, in this context, both the builders and operators of machinery and plants just have to rise to the challenge of increasing production flexibility. Fail to take this seriously and you will find yourself at a big competitive disadvantage. Remember, mass-customized products have been shown to achieve higher margins than their conventional counterparts. Successful implementation, however, stands or falls with key advancements in plant infrastructure.

In summary, I'd say that, with ACOPOStrak, the industry is on the verge of a generational leap in productivity and accelerated ROI for individualized products and small batches.

AR Robert Kickinger, thank you for your time today. ●

Disclaimer: ACOPOStrak is not available for sale into the United States of America until September 2018. Nothing herein constitutes an offer to sell, or a solicitation of an offer to buy. This article is for informational purposes only.

MOTION

Gearless drives for medium-power belt conveyors

ABB's new permanent magnet (PM) motors for medium-power gearless conveyor drives (GCDs) reduce production costs and increase competitiveness. A PM motor, combined with gearless technology, also fulfills eco-design requirements, saves energy, reduces failure rates and lowers maintenance overheads.

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Producers who handle cement, ores, rock, coal and the like are heavily dependent on high-capacity conveyor belt systems that are reliable, efficient and very robust. The hourly cost of a conveyor breakdown can be substantial, so uptime is a parameter of primary importance. ABB has long supplied conveyor systems that meet the stringent demands of producers in a wide range of industries →1.

Gearboxes

ABB classifies conveyor systems by power band →2. Low-power belts are found in almost every material-handling plant; medium-power belts are used extensively for shifting rock and coal; and high-power belts are for more dense commodities, like copper or iron ore that are transported over long distances or steep ascents.

In the high-power regime, conventional conveyor drives face challenges, mostly associated with the gearbox. Building a gearbox that can handle powers above 3.5 MW is a non-trivial task and even when built they are maintenance-intensive when in operation. Further, their lifetime is relatively short. Other challenges are posed by the vast array of drive constructions - ranging from mobile units, where motors are housed within the drive station's steel enclosure, to stationary structures where the motor is foot-mounted on concrete foundations.

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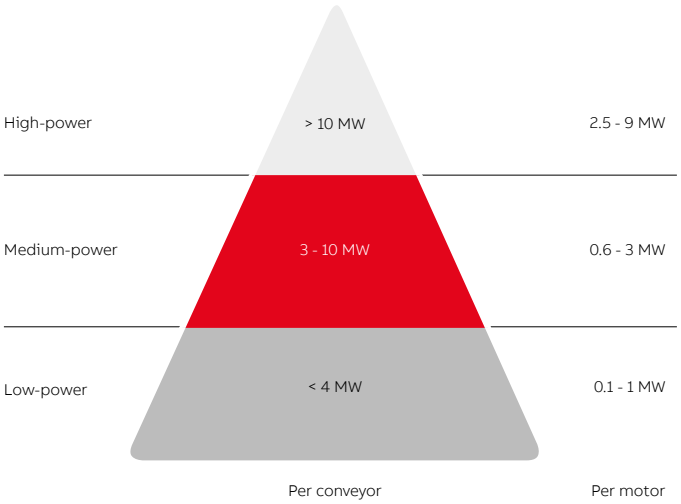
— 01 Typical conveyor drive with gearbox.

— 02 Conveyor classification according to installed power.

Such problems can be avoided by using a gearless drive. A GCD uses a large, low-speed synchronous electric motor mounted on a pulley shaft that is designed to handle the high torque produced by such motors. The motor is controlled by a variable-speed drive (VSD) to produce a shaft rotational speed of typically 50 to 70 rpm. There are usually several drive modules in a drive station and there can be multiple drive stations on the conveyor. The power of existing GCDs goes from around 2.5 to 7 MW, with a total connected power in the range of 5 to 20 MW.

A GCD is of simple construction and, because it has relatively few parts, it is long-lasting and maintenance-light.

A GCD is of simple construction and, because it has relatively few parts, it is long-lasting and maintenance-light. Indeed, drives delivered to the Prosper Haniel coal conveyor in Germany in 1985 are still running today. GCDs are also attractive from an energy-saving point of view: The gain of 2 to 3 percent they bring to the efficiency of high-power systems represents significant cumulative savings in electrical costs over the lifetime of the installation.



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However, a major disadvantage of current GCD technology is that its capital cost is high, which makes it competitive with conventional designs only in the higher power bracket and where a long operating life is foreseen. As well as cost considerations, if GCDs are to be commercially feasible in the medium-power segment, lower weight, more efficient cooling and a more compact size are required. In other words, a new approach is needed if customers with lower-power applications are to benefit from GCDs.

ABB has used its long experience to develop a series of low-voltage PM motors specifically for ABB GCDs.

New GCDs using low- or medium-voltage permanent magnet motors

Permanent magnet motors have been around for decades – in ship propulsion, pumps, fans, blowers, wind power generators, automotive, etc. Now ABB has used its long experience in this field to develop a series of low-voltage PM motors specifically for ABB GCDs.

With a power range of 1 to 3 MW, these new ABB GCDs are ideal for a large number of applications – both newbuild and retrofit – and their costs are comparable with equivalent conventional geared systems.

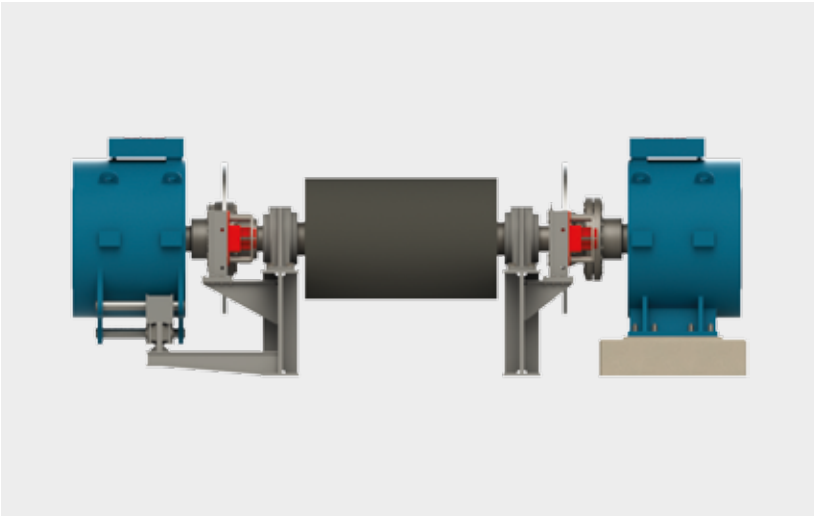
This pioneering GCD concept is lightweight, compact and can be air- or liquid-cooled →3. The motors can be foot-mounted or shaft-mounted, whereby the latter is quicker to install, easier to align and requires less concrete foundation work →4. The heavy-duty design is robust enough to deal with the shocks and vibrations associated with handling cement, rock, coal and other common mined materials. An IP66 rating means the PM GCD is completely protected from dust and water contamination. An added benefit is that the GCD has lower operational noise levels.

A PM GCD has significant operational advantages over geared equivalents:

- Fewer components, so it has a higher reliability (about 50 percent lower failure rate) and less maintenance is required
- Higher efficiency with lower energy consumption and lower noise emission
- Higher equipment utilization
- Operational cost savings (OPEX)
- Energy loss reduced by over 30 percent
- No monitoring and testing of gearboxes
- No oil (reduced fire risk)
- Extended life cycle (expected motor lifetime of 25 years is 10 years longer than with the gearbox-equipped equivalent)

	Geared with frequency converter (kW)	Gearless with frequency converter (kW)
Pump/cooler	0.6	0.6
Transformer	1.24	1.17
Frequency converter	2.44	2.31
Motor	5.88	4.9
Motor excitation	0	0
Gearbox	7	0
Total losses	**17.16**	**8.98**
Total efficiency	**89.1%**	**93.90%**

Device	Efficiency
Squirrel cage induction motor	96.00%
Gearbox	95.00%
Transformer	99.20%
Converter	98.40%
Permanent magnet motor	96.43% (can be designed for higher efficiency (~98% for PM)



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03 200 kW direct-drive PM (SyncPM) and synchronous motor comparison at 70 percent loading (140 kW).

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04 Foot-mounted (right) and shaft-mounted (left). The motor mounted to and suspended by the pulley shaft has favorable characteristics, such as quick installation or swap-out. However, the foot-mounted version is the easiest to design and dimension, especially as the motor weight has no influence on the dimensioning of the pulley shaft. The choice depends on customer preference.

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05 Cumulative cost savings of GCD versus geared drives for a cement industry conveyor system. Conveyor length: 40km; 22 drives of 1,500 kW, 136 rpm; buffer capacity of three days.

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06 The GCD package at the pilot project in the Jänschwalde mine.

06

Gearless drives are especially beneficial in installations where:

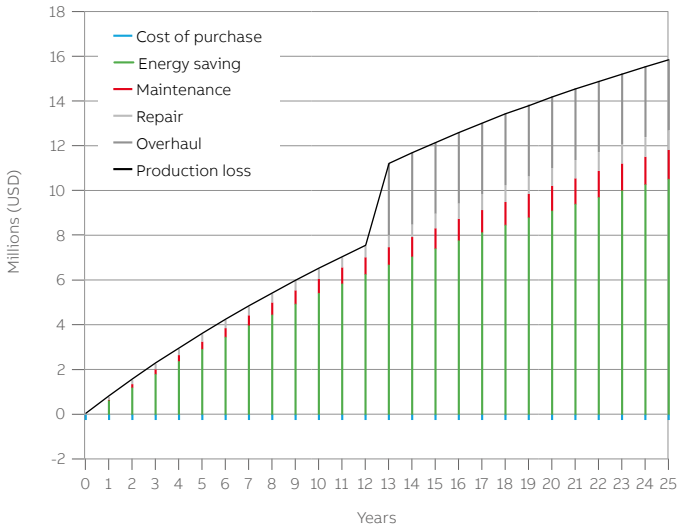
- The planned life cycle is longer than 10 years
- Gearboxes are a source of trouble
- High availability is required, or no redundant production lines exist
- Material buffers are small or non-existent
- Maintenance work is hard to perform (high altitude, high or low temperatures)
- Maintenance personnel is difficult or expensive to source
- Ambient conditions are harsh

PM GCD cost/benefit analysis - a practical example

The following example demonstrates how the new GCD can reduce operational costs for mining industry conveyor systems. It is based on the following conveyor system design:

- Conveyor line: four flights
- Drives: 12 in total
- Power: 1,000 kW
- Tonnage: 8,800 t/hr
- Energy cost: $0.10/kWh
- Gearbox efficiency: 96 percent
- Annual operation time: 6,900 hours
- Stockpile capacity: three days

The results are presented in →5. which shows the cumulative cost savings (including investment) of a conveyor system equipped with the PM GCD compared to the same system with geared drives.



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The major cost factors are energy (electricity), system maintenance, repair and loss of production. The four pillars show the saved cost for each time frame. It is obvious that savings in electricity and overhaul are most significant. After 15 years, a mine would have saved about $12 million by using the GCD.

Pilot project: retrofit of a 200 kW conveyor drive
In July 2017, after one year of planning, ABB started a pilot project with the title “gearless conveyor drive with PM motor,” with Lausitz Energie Bergbau AG (LEAG) in the Jänschwalde open-pit lignite mine close to Cottbus in Germany.

The new medium-power gearless PM drive runs in parallel to the existing geared drive on the 2.5 m wide discharge belt of a bucket chain excavator, located at the end of the discharge boom. The belt has a capacity of 15,400 tons/hour and moves sand - with inclusions of large rocks (ice-age foundlings) that give rise to mechanical shock and vibration. The ambient temperatures faced by the equipment are extreme: -25 to +40 °C.

The GCD package consists of a PM motor, frequency converter and a transformer →6-8. Both drives, geared and gearless, are connected to the same pulley shaft, which allows exact benchmarking.

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The GCD package consists of a PM motor, frequency converter and a transformer.

The two drives are sized according to LEAG specifications and allow 100 percent production with each drive independently. The time taken for dismantling, installing and commissioning was only two weeks.

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07 Pilot gearless drive.

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08 Before installation at the pilot site, the drive was put through its paces in the dedicated test rig at ABB.

The pilot project has established the feasibility of installing gearless conveyor drives on mobile mining machines and shows the suitability of PM torque motors to drive conveyors. The GCD so far has performed very well under the challenging conditions.

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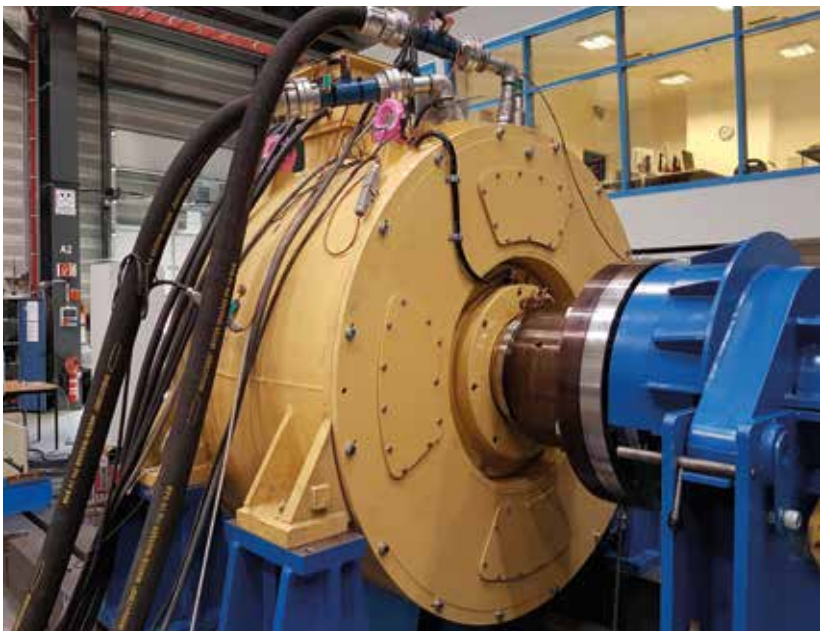
PM GCDs deliver an efficient, long-lasting and reliable solution that helps operators to increase production and annual revenue, and decrease costs.

The potential for energy savings, reduction of failure rate and maintenance, etc. have also been demonstrated. Also, the pilot project proves that it is possible to install gearless drives as an alternative to conventional geared drives and at the same time fulfill eco-design requirements according to ISO 50001 (energy efficiency) so that the environmental certifications held by mining companies is maintained.

Driving future developments

PM GCDs deliver an efficient, long-lasting and reliable solution that helps mining and other manufacturers to increase production and annual revenue, and decrease costs. PM GCDs drastically reduce the effort for maintenance, repair and asset management. While the upfront investment is typically higher when compared to a conventional drive (for a 1.5 MW GCD, the investment for the electric drive is about 10 to 20 percent higher; the combined cost of mechanical and electrical equipment will be around 5 percent higher), the savings in maintenance, energy cost and downtime lead quickly to a return on investment of typically less than one year. When analyzing the total cost model for a GCD acquisition, it should be borne in mind that the conveyor system usually occupies a critical path in the mining or production facility - should the conveyor malfunction, the work rates of excavators, crushers and other processing equipment will be adversely affected too.

The introduction of a GCD for medium-power conveyor drives based on a PM synchronous motor offers exciting possibilities for cement and mining applications. This new concept allows implementation of a gearless motor into an existing or new medium-power conveyor – an exercise that has been practically difficult and commercially infeasible using conventional gearless motors up to this point. ●



08

Energy

90

There’s a revolution underway in the energy sector, not only in new sources and distribution methods for electricity, but in advanced digital and materials technologies used in the components of every system. ABB built Europe’s first steam turbine in 1901. It’s building tomorrow’s technology today.

84

ENERGY

Improved generator circuit breaker enhances power plant protection

A generator circuit breaker (GCB) plays a vital role in power plants: It protects key equipment and increases plant availability. ABB's successor to the HEC 7/8 – the HEC 10 GCB – offers additional benefits, eg, improved switching capability, lower SF_6 volume and leakage rate, extended lifetime and a smaller footprint →1.

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A GCB plays an important part in switching the circuit between the generator and the transformer in a power plant. The GCB protects key equipment while simplifying operational procedures to improve power plant availability. ABB's GCBs have been protecting all types of power plants since 1954 and more than 8,000 are installed in over 100 countries. ABB offers the widest and most modern portfolio of GCBs in SF_6 and vacuum technology with a range of short-circuit currents from 50 kA to 300 kA and nominal currents from 3 kA to 50 kA. To meet the most stringent standards and customers' needs, ABB continues to invest in GCB research and development.

To meet the most stringent standards and customers' needs, ABB continues to invest in GCB research and development.

In the late 1990s, for the high-end segment, ABB introduced the GCB type HEC 7/8, which caters for short-circuit currents up to 210 kA. In 2012, HEC 9 – the world's largest GCB for power plants up to 2,000 MW – was launched.

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01 ABB's new GCB, the HEC 10, successor to the HEC 7/8.

Recently, ABB introduced another high-performing GCB for the HEC platform: Encompassing decades of successful field experience, the HEC 10 is the successor to the HEC 7/8. The HEC 10 offers additional benefits such as improved switching capability, lower SF_6 volume and leakage rate, and extended lifetime - all in a smaller footprint.

Designed to protect the most critical generator applications, the HEC 10 is available in two types:
- HEC 10-170: with rated short-circuit current of 170 kA and rated voltage of 31.5 kV
- HEC 10-210: with rated short-circuit current of 210 kA and rated voltage of 33 kV

Each type is available in two versions:
- L: fully naturally cooled for rated normal currents up to 20 kA
- XL: with an innovative hybrid cooling system for rated normal currents up to 29 kA.

Third generation of HEC technology
The HEC 10 interrupting chamber design is an enhancement of the proven technology found in the rest of the HEC product family. All GCBs within

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The HEC 10 interrupting chamber design is an enhancement of the "self-blast" technology found in the rest of the HEC product family.

this family are "self-blast breakers." In such breakers, the electric arc is blown away from the heating chamber by a gas stream during the current zero-crossing, with the blowing pressure being generated by the arc energy itself.

01

CLASS G1

A class G1 GCB having a rated generator-source short-circuit breaking current equal to I_{scg} (the root-mean-square value of the symmetrical component of the prospective short-circuit current for faults fed by the generator) shall be proved by two tests: one with a current equal to I_{scg} with a degree of asymmetry of 110 percent and one with a current equal to 0.74 x I_{scg} and a degree of asymmetry of 130 percent.

CLASS G2

A class G2 GCB having a rated generator-source short-circuit breaking current equal to I_{scg} shall be proved by one test with a current equal to I_{scg} with 130 percent degree of asymmetry.

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Over the past few decades, ABB has been actively studying and investigating gas circuit breakers. Most recently, major efforts have been directed toward the investigation of thermal and dielectric switching. In close collaboration between scientists and development engineers, the latest findings were implemented in the design of the HEC 10 arc quenching zone. For instance, new design rules for the flow cross-sections around the tulip contacts were used. Moreover, experience gathered during the HEC 9 development, where extensive experiments took place, allowed further optimization of the dielectric switching capability.

The efforts resulted in a significantly improved switching capability for the HEC 10 compared to its predecessor.

These efforts resulted in a significantly improved switching capability for the HEC 10 compared to its predecessor. An improved switching capability allows shorter arcing times – which are necessary for the pressure buildup – and enables enhanced current switching ratings that also cover switching under 180° out-of-phase conditions (a demanding task). The HEC 10's interrupting capability significantly exceeds the minimum requirements of the IEC/IEEE 62271-37-013 standard for GCBs. The whole type test series has been passed without a single failure, proving the unique quality and robustness of the interrupting chamber.

New industry standards

In October 2015, the International Electrotechnical Commission (IEC) and the Institute of Electrical and Electronics Engineers (IEEE) revised the industry standard for GCBs. IEEE C37.013-1997(R2008) was replaced by the new dual logo standard, IEC/IEEE 62271-37-013. HEC 10 is fully type-tested in accordance with – and, indeed exceeds – the mandatory requirements of this new standard.

Meeting the most stringent generator-source short-circuit current requirements

One of the major differences between IEC/IEEE 62271-37-013 and the old IEEE C37.013 is the requirement on the degree of asymmetry of the generator-source short-circuit currents, which are characterized by having delayed natural zero-crossings for a certain period. This requirement was raised from 110 percent to 130 percent to better represent the requirements of real applications [1]. In particular, the new dual logo standard defines two classes, G1 and G2; the latter being of higher performance →2.

The HEC 10 has been type-tested to interrupt generator-source short-circuit currents of up to 160 kA with a degree of asymmetry of up to 130 percent, as per the G2 class, hence meeting the most stringent requirements of the largest generators worldwide.

Tested parameters for out-of-phase	Breaking current (kA)	Peak value (kV)	Rate-of-rise (kV/µs)	Time delay (µs)
90°	85	2.6 x Ur	5.2	1
180°	159	3.2 x Ur	8.1	0.7

03

— 02 Class G1 versus G2 according to IEC/IEEE 62271-37-013.

— 03 Tested values of HEC 10 for out-of-phase at angles of 90° and 180°.

— 04 HEC 10 cooling system.

Exceeding the latest standard's minimum mandatory requirements

Out-of-phase synchronizing may occasionally happen – mainly due to wiring errors during commissioning or maintenance – while connecting voltage transformers and synchronizing equipment. Even though IEC/IEEE 62271-37-013 covers requirements for an out-of-phase angle of only 90°, it is recognized that synchronization with out-of-phase angles of up to 180° can occur. The incidence of a 180° out-of-phase condition can impose very severe stresses on the GCB [1,2] that are not necessarily covered by an out-of-phase 90° test.

In order to guarantee maximum safety in the power plant, the HEC 10 exceeds the minimum requirements laid down in IEC/IEEE 62271-37-013: The HEC 10 has also been tested to cover the requirements for out-of-phase conditions up to 180°. →3 shows a comparison between the tested values for the HEC 10 at out-of-phase angles of 90° and 180°. The high magnitude of the breaking current

In order to guarantee maximum safety in the power plant, the HEC 10 exceeds the minimum requirements laid down in IEC/IEEE 62271-37-013.

and the very steep transient recovery voltage (rate-of-rise equal to 8.1 kV/µs) are evidence of the severity of an out-of-phase 180° test. The successful testing of the HEC 10, also for this duty, proves the high performance of its interrupting chamber design.

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Exceeding the latest standard's minimum mandatory requirements: mechanical endurance
The mechanical reliability of GCBs is tested using mechanical endurance tests. The corresponding standards require 1,000 or 3,000 no-load CO (close-open) operations for the GCB as well as 1,000, 2,000 and, sometimes, 10,000 CO operations for the disconnector and the earthing switches.

The HEC 10 was developed with the goal of simplification and optimization. For instance, the number of parts was significantly reduced compared to the HEC 7/8.

Extended mechanical endurance type tests that exceed the standard requirements have been passed for the HEC 10: 10,000 CO operations for the GCB and the disconnector and 5,000 CO operations for the earthing switches. These tests demonstrated the high reliability and quality of the new system.

Fully separated disconnector and interrupting chamber
The interrupting chamber design of the HEC 10 follows the ABB standard of having both main and arcing contacts in SF_6 with a disconnector provided in series on the transformer side of the breaker. This design provides safe and visible isolation between the step-up transformer and the generator without compromising the safety of the power plant.

Optimized for a compact design
The HEC 10 was developed with the goal of simplification and optimization. For instance, the number of parts was significantly reduced compared to the HEC 7/8, thus enabling a compact design.

Further, the contact systems of the disconnector and the earthing switches were improved by introducing a newly developed calibration-independent bearing system that allows an increased fault tolerance. On the kinematic side, a turning shaft linkage instead of a push-pull one was implemented, thus increasing the intrinsic system safety. In addition, the disconnector's short-stroke design (by ABB) contributes to the HEC 10 compact footprint without compromising the insulation level. Finally, the introduction of field control elements, common in high-voltage engineering, reduces the space required for installation.

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05 The ABB GCB digital monitoring system, GMS600.

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References

[1] M. Palazzo and M. Delfanti, "New Requirements for the application of generator circuit breakers," IPST Vancouver, Canada, July 18-20, 2013.

[2] M. Palazzo, et al., "Revision of TRV requirements for the application of generator circuit breakers," Electric Power Systems Research, volume 138, pages 66–71, September 2016.

An innovative cooling system

An efficient cooling scheme guarantees the safe and reliable operation of the GCB. Based on accurate simulation studies, the cooling scheme of the HEC 10-XL was chosen to be a hybrid system consisting of passive heat pipes and heat sinks equipped with simple and redundant low-maintenance fans that allow the GCB to operate with normal currents of up to 29 kA →4. This innovative cooling system enables temperature and fan operation to be fully monitored online using a GMS600 monitoring system, thus allowing condition-based maintenance.

By avoiding the use of SF_6 cooling radiators, the HEC 10 provides the highest reliability. And with an SF_6 leakage rate of less than 0.1 percent per year, the HEC 10 comes in well below the maximum allowed by the standards. When needed, the fans can be easily exchanged online without shutdown of the generator, thus ensuring maximum power plant availability.

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An efficient cooling scheme guarantees the safe and reliable operation of the GCB.

Additional safety features

The integration of the main drive train into the longitudinal supports of the pole frame is part of the comprehensive HEC 10 layout optimization strategy. The resulting combination of the structural components with the protective functions provides a simple and robust design. Special care in the pole frame design assures protection from unintended access to moving parts between the operating mechanism and the switching components, and thus provides the highest levels of safety for operation and maintenance engineers.

Digital monitoring via GMS600

The HEC 10 is fully integrated with the ABB GCB digital monitoring system, GMS600 →5. The GMS600 can perform many functions – for example, data logging, disturbance recording, drive supervision, and temperature and SF_6 density monitoring. The long-term operation of the hybrid cooling system is also monitored by constantly comparing the fans' speeds against expected values.

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Customers who opt for remote monitoring support from ABB will regularly receive reports about the state of their equipment.

Key cooling system data is logged by the GMS600 and thereby made available for regular analysis in order to give the customer additional information on the safe operation of the GCB. Customers who opt for remote monitoring support from ABB will regularly receive reports about the status of their equipment. Data logged through the GMS600 can be connected via the cloud to appropriate ABB Ability™ tools. 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 enables more knowledge of the system, more capabilities and improved performance delivered by the connectivity of ABB Ability enabled equipment, including GCBs. ●

ENERGY

The power-of-one true ATS

ABB's TruONE™ is the world's first true automatic transfer switch (ATS) to package all necessary sensors, controllers, switches and operator interfaces into a single, easy-to-install device that maximizes ATS reliability, simplifies installation and cuts installation time by 80 percent →1.

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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. Traditionally, the installation of an ATS has been a nontrivial task involving various individual electrical components that all have to be wired up and assembled in an enclosure or panel.

Traditionally, the installation of an ATS has been a nontrivial task.

Such an arrangement certainly fulfills its function in the event of a power outage: Start up the back-up generator automatically, switch the load to it, then return to the main power source when things get back to normal. However, the multiplicity of connections and components involved in a traditional ATS introduces complexity, compromises reliability and limits functional flexibility.

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01 TruONE automatic transfer switch.

ABB's all-new TruONE ATS 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 not only simplifies the installation and significantly reduces the installation time needed but also maximizes the ATS reliability.

Available in an open-style or enclosed ATS product, the core of the solution is the sources-to-load connecting parallel poles and the side-mounted mechanism that not only drives the pole-internal power contacts to the desired position but also contains the controls needed to provide a full ATS functionality. The compact package of poles and mechanism provides everything needed to enable automatic selection between two different sources – something that previously required multiple wire harnesses, distributed electronics, voltage transformers, external controllers and a panel or enclosure to hold everything together.

In many applications, TruONE is also bringing operator safety during manual operation - even under load - to a completely new level by a novel operating handle that sits slightly elevated between the mechanism and the power poles. This arrangement enables manual operation through a panel door cut-out without the need to open the door that protects personnel from panel-internal electrical arcs.

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ABB's all-new TruONE ATS 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.

TruONE also sets a new industry safety standard in that dangerous line voltages no longer need to be connected to a panel door - the detachable human-machine interface (HMI) is completely isolated from the mains, which results in significantly increased operator safety.

Equipping the TruONE ATS with just a few more snap-on accessories – such as current transformers, communication modules and terminal shrouds – that mount within the TruONE footprint provides everything that current top-of-the-line ATSs solutions offer, but in one compact unit that does not need an enclosure or panel to hold the various components together. This will bring a multitude of benefits throughout the ATS value chain.

One of the key inventions in the TruONE ATS design is the way it self-powers all the required functionalities via the mains connections (200 to 480 V AC) without the need for any external voltage transformers. Without this innovative design it would not be possible to realize all the functionalities mentioned earlier within a single unit or offer such a wide range of operational possibilities in just one single stock-keeping unit (SKU) regardless of the voltage level.

02a

02b

Easy installation

One of the greatest benefits of such a single-unit ATS is its ease of installation. An open-style TruONE ATS is as simple to install into an enclosure or panel as the lightest existing enclosed ATS solutions are to mount on a wall. Just by lifting a TruONE ATS into an enclosure and fixing four mounting screws to the back-panel, a full-blown ATS is created. It really is that simple: just four screws allow the provision of all the sensors, HMI, electronics, communication and other functionality required for a complete ATS.

The HMI can be accessed without opening the cabinet door by making a cut-out on the door. Alternatively, the HMI can be flush-mounted to the enclosure or panel door: One would just need to make a 25 mm round hole in the door, detach the HMI from the switch frame, mount it on the front of the door, secure it with a nut included in the delivery and reconnect with a regular RJ45 cable →2-3.

Overall, installing a TruONE is in many ways simpler and 80 percent faster in comparison to traditional ATS solutions. Comparative studies indicate that TruONE use significantly cuts the auxiliary cabling needed while also reducing commissioning time. Ergonomically, the installation is much more user-friendly.

With this world-first true ATS concept, the TruONE range is set to revolutionize how enclosed ATS solutions are created. For the first time, it is possible and economical for panel builders and OEMs to create high-end ATS solutions starting from an open-style solution that is easy to store, straightforward to handle and, most importantly, very easy to install. This approach allows a whole new level of flexibility in production and makes it possible to design an ATS within a system project by project. TruONE also offers a way to shorten ATS lead times as one can standardize on a few open-style SKUs that can take the needed form during in-house production.

Snap-on accessories

TruONE's accessorizing concept, referred to earlier, further improves the simplicity and power of the product. All accessories - which are mounted, without tools, as snap-on solutions - are sited within the footprint of the switch frame. Never before has it been so easy to make an ATS installation cabling touch-safe (IP-2X) as it is now with the TruONE snap-on shrouds. Also, where mechanical auxiliary contacts are needed in addition to the digital I/Os that are included as standard, they can also be simply snapped on without tools at any stage of the ATS solution creation. The same applies to the addition of different communication protocols (up to seven), additional I/Os or a 24 V DC HMI auxiliary voltage supply. Most of the TruONE additional ATS functionalities can be provided through late-

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One of the greatest benefits of such a single-unit ATS is its ease of installation.

stage accessorizing. This, in turn, further simplifies the procurement and storage of the base ATS building blocks needed to realize any possible final configuration, even one for the most demanding end-user.

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02 It is simple to unplug the HMI and fix it to the front door. This procedure allows HMI operation without opening the cabinet and is illustrative of the TruONE's ease of use.

02a The HMI is unplugged.

02b The HMI is attached to the door exterior by two screws, with the HMI connector showing through and secured with a nut. An RJ45 cable connects the HMI to the TruONE unit.

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03 The HMI externally mounted (here with IP54 protective cover).

Simple use

A highly integrated ATS solution might be thought to be inflexible and difficult to use, but the opposite is true in the case of the TruONE.

As already mentioned, the HMI provides local control of the ATS functionality. In existing solutions, there is typically a separate controller that incorporates all the electronics required for ATS control and the associated interface. These controllers are usually bulky and require their own dedicated installation mechanics, which means that they need to be used in the place they are located. This often sets limits on the ATS installation design, specifically the door layout of an enclosed solution.

In contrast, the TruONE HMI, though mountable on the switch itself, can be detached (without using tools) to offer remote control via an RJ45 cable (up to 10 m). This flexibility relaxes limitations on ATS usage. For example, one could now move the ATS HMI to a separate column where other control equipment needed for the installation is grouped. Or, the HMI could be temporarily detached from the switch body during the ATS commissioning to have easier access to it and then returned at system startup. Further, because all the functionality needed for ATS operations is located within the switch itself then, should the need arise, the ATS also operates while the HMI is detached.

03

Reliability

An ATS is an important link within critical power applications. Therefore, it has to be extremely reliable. The one-single-unit ATS approach raises industry reliability standards by significantly reducing connection points within an ATS assembly: Instead of tens of auxiliary and control wires running around an ATS enclosure, an open-style TruONE unit, for example, has none and requires only power connections. Obviously the same applies then to the final, enclosed solution. In other words, tens of potential failure points are eliminated, as are checks for loose connections – often a major source of trouble during commissioning.

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The one-single-unit ATS approach raises industry reliability standards by significantly reducing connection points within an ATS assembly.

Serviceability

While easily serviceable as a product, the TruONE ATS design also opens up whole new vistas regarding the retrofit of old ATS installations. Due to the compact size and self-contained design, even as an open-style solution, this all-new ATS range can replace almost any old installation simply and quickly: The old switch body just has to be substituted by a TruONE unit and the power cables rewired. At the same time, the auxiliary wiring of the old ATS solution can be completely removed as the new enclosure inhabitant, the TruONE, requires a maximum of one control wire connection – ie, the Ethernet cable from the switch to the HMI in the case where door-mounting is a must. When the effort and risk involved in the complex retrofitting of an old, traditional ATS with a similar type is compared to the simplicity of a TruONE retrofit, the decision to go with the TruONE concept becomes one that is very easy for the discerning ATS user to make. ●

BUZZWORD DEMYSTIFIER

Digital twin – virtually identical?

The fourth installment of ABB Review's Buzzword Demystifier explores the meaning of the term, term, "digital twin."

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A typical modern industrial device already creates a formidable digital data-trail. This includes CAD drawings and simulations during the design phase, information on location, connected equipment and configuration from the integration phase, as well as subsequently collected utilization, diagnostic and maintenance data. In addition to such definable, measurable or observable data, algorithms can calculate or simulate non-observable parameters, both actual and predicted.

These data and algorithms typically already exist in various locations or formats. If they could be accessed from one virtual directory – the digital twin – this would provide a comprehensive digital image of the physical equipment. More than being just a static description, this information can be used to simulate the behavior of the physical object. 3-D visualization tools also allow virtual inspection and observation of the equipment and enhance understanding and insight.

Applications of a digital twin include:

Design: Simulation and visualization during the design phase can be used to verify and inspect the overall 3-D design and make sure all parts fit together. Simulations include mechanical, thermal and electrical as well as interrelationships between these aspects.

System integration: 3-D visualizations on a system level can verify constraints such as spatial footprint and physical connections. By connecting to the digital twins of other components, interactions can be simulated, including data transfer and control functionality as well as mechanical and electrical behavior and what-if scenarios. Integration effort on site and the associated downtime for the customer is reduced.

Diagnostics: Observation of the digital twin, for example in a 3-D visualization, can support troubleshooting. Virtual-reality glasses can provide field technicians with an overlay over the real equipment to visualize parameters. Simulations can add non-observable data, such as temperatures of non-accessible parts or material stress.

Prediction: Past and present operational and sensor data in combination with predictive algorithms provide insights into the condition of equipment and the likelihood of different failure modes. This helps plan rational maintenance and reduce unplanned downtime.

Advanced services: If all the advanced service parameters (IoT connectivity, analytics algorithms, etc) are preconfigured in the digital twin, they can be enabled when the equipment is installed and the customer subscribes to these services. In the optimal case, no further engineering is required.

The key to these diverse aspects of a digital twin is the capability to refer to data stored in different places from one common digital twin directory. The digital twin is capable of providing the data required for the different use cases by accessing data from elsewhere in the product lifecycle.

In summary, a digital twin is a complete and operational virtual representation of an asset, subsystem or system, combining digital aspects of how the equipment is built (PLM data, design models, manufacturing data) with real-time aspects of how it is operated and maintained.

The digital twin allows the consistent collection and distribution of information across the physical asset's complete lifecycle to maximize business outcomes, optimize operations and investment (for both customer and ABB) through data processing (eg, simulation, advanced analytics).

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Next 03/2018

Material matters

Materials are undergoing a revolution, both in the ways traditional materials can be used, and in new materials that redefine those traditions. These changes are driven by smarter methods and algorithms, making knowledge a structural building block. The next issue of ABB Review will explore the far-ranging applications and implications for this evolving area via examples from ABB's products, and those developed in partnership with its customers.