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special report

Women in STEM

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Women in STEM

In 2004, ABB Review published 56 articles, with three contributions from women engineers. A generation later, women contribute to an average of eight articles annually. This Special Report celebrates the remarkable progress women in STEM have made over 20 years, while acknowledging persistent imbalances. ABB Review and the highlighted authors hope that this Special Report provides inspiration for those considering or pursuing a career in STEM; growing inclusion and fostering insights.

EDITORIAL

Women in STEM

Dear Reader,

What a delight and opportunity: to guest edit this very special edition of ABB Review.

An opportunity to share my experience as a woman in STEM: are you considering a STEM career? Don't fear it – you are capable. Self-confidence is crucial. If you like it and want to do it, you can do it. I hope this Special Report inspires and boosts your confidence.

Clearly customers are diverse, and to fully support them we must understand their world. Increasing diversity in STEM education and careers is a crucial component of understanding needs and fosters innovation.

A delight because the number of Women in STEM is growing steadily. May this Special Report encourage that growth and inspire future generations.

Wishing you inspiration,

Amina Hamidi

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01

PRODUCTS HAVE A DIGITAL TWIN AND YOU CAN FIND IT TOO!

Double your knowledge

Industrial plants can contain thousands of devices, each with associated documentation. Using Industry 4.0 technologies, an ABB demonstrator shows how to manage the administrative overhead of making sure documentation is comprehensive and up-to-date – throughout a product's entire life cycle.

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01 Industry 4.0 provides tools to help manage administration of the documentation for the thousands of devices found in a typical industrial plant.

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02 Example of an AutoID weblink encoded as a QR code for a temperature transmitter.

Information – such as documentation, manuals, technical data, drawings, notes and certificates – follows a product throughout its entire life cycle, all the way from the design process, installation, operation and maintenance, to eventual decommissioning and recycling. Locating relevant and up-to-date documentation for a product is often a struggle for users as much of it is created, filed

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Digital twins can help the exchange of information between customer tools, ABB's data repositories and other systems.

and updated manually. And even a mid-size plant can have many thousand pieces of documentation →01. Automating the administration of these masses of data faces barriers – for example, uniquely identifying the device, providing machine-readable documents, clear semantics (meaning) of information, standardized metadata and appropriate update mechanisms.

Fortunately, advances in Industry 4.0 specifications for interoperable industrial digital twins help to overcome these barriers. Digital twins create a digital, interoperable, end-to-end solution for information on devices, starting with product design and certification, through production, logistics, transport and distribution, to the customer's facilities, operation and maintenance organizations.

This article will show how digital twins can help solve the challenge of exchanging information between customer tools, ABB's data repositories and other systems.

AutoID – identifying devices and device types

In 2018, ABB was invited to support a European process industry initiative to create a global-scale, smart identification system for devices – from high-volume sensors to large custom-made machines. Robust and secure identification of devices is essential to provide asset-related information.

02 https://id.abb/9AAC129110?SN=3K650000554982

ABB worked with more than 50 partners, suppliers and customers to standardize an identification system ("AutoID"), which resulted in DIN SPEC 91406. ABB is supporting the working group to enshrine the DIN SPEC in an IEC standard, accelerating implementation around the globe.

The approach is as simple as it is efficient in that a unique identification key in the form of a machine-readable label is enough to:

- Distinguish and reference any devices marked with such a coded label.
- Create, process, store and exchange any kind of information related to a physical object.

A basic principle was defined to eliminate the need for a central coordination body to guarantee code uniqueness: The code should contain one element identifying the vendor and a second element under the vendor's control and unique in its domain. Internet addresses (weblinks) were used to solve this coding challenge.

As a physical container, a 2-D code (QR code or data matrix) was chosen, allowing the AutoID to be read by optical scanners and smartphones. AutoID also works with radio frequency identification (RFID) or near-field communication (NFC) to cover applications where optical scanning is not feasible.

ABB uses the weblink feature of AutoID QR codes to take the user directly to the product Web page →02.

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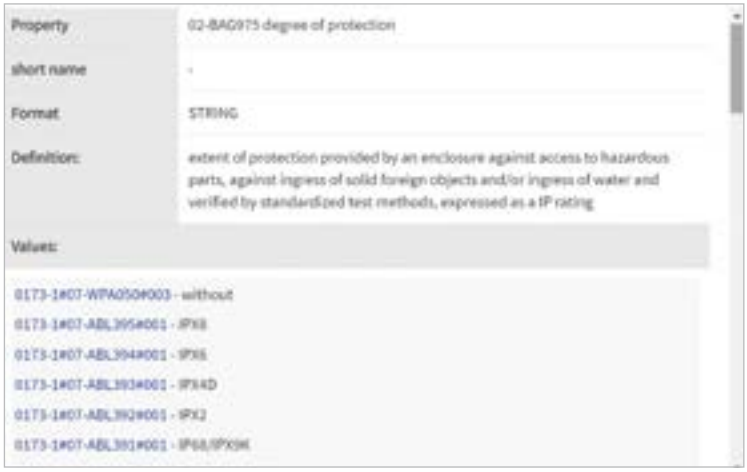

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03 An example of the ingress protection code (IP code) property defined in ECLASS along with an excerpt of allowed values (source: [1]).

—
04 Overview of the product information exchange demonstrator.

Sources of ABB digital, machine-readable product information

Product type-specific information for ABB's large and diverse portfolio is found in several machine-readable ABB sources:

- The ABB Library, developed and maintained by ABB, which contains marketing and technical documents, software, movies and other documents related to ABB products and services.
- The Product Information Management (PIM) system – an ABB master data repository for language translations, ABB's customer-facing ABB Offering Tree, product and parts data.
- The PIM application – this application provides, eg, Web services, XML exports for product data and classification tree exports to downstream applications.
- Product Information Services (PIS) – a master data application that provides consistent navigation, search, selection and presentation of ABB offerings. PIS is deployed as a service to multiple internal and external-facing downstream applications.

These sources are exploited by the ABB product information exchange demonstrator, as will be described further on in this article.

Standardized information formats

Alone, the availability of digital information is not sufficient for a cross-organizational exchange. Luckily, there are standardized concepts available to close this gap.

Technical properties of devices need to be provided to the customer in a form that leaves no ambiguities about their meaning. This challenge is solved by predefined semantic dictionaries like ECLASS [1] or the IEC Common Data Dictionary

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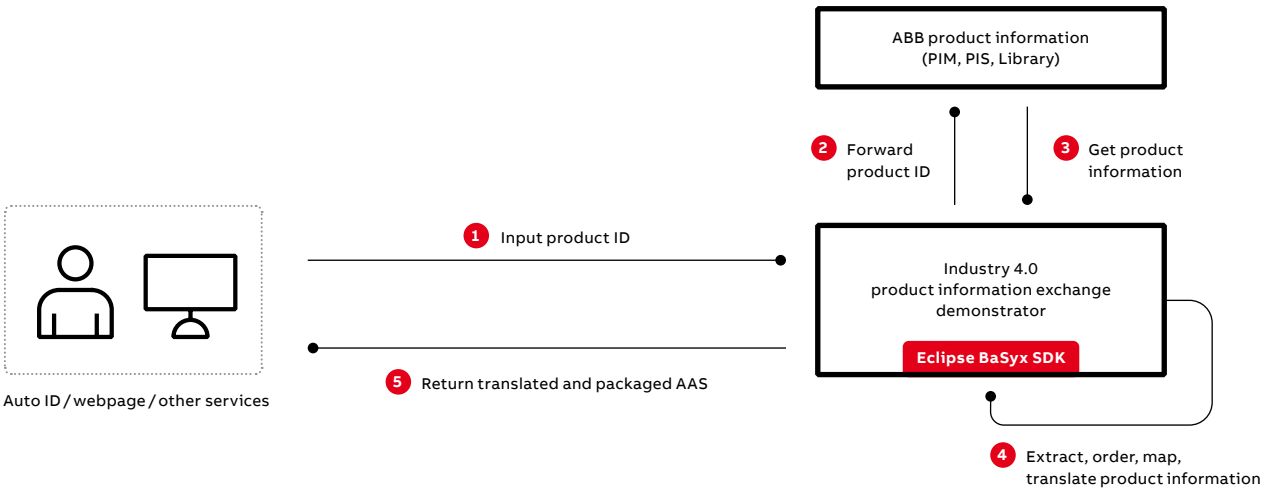
Technical properties of devices need to be provided to the customer in an unambiguous form.

[2]. These dictionaries define equipment classifications, such as "temperature sensor," and properties, such as weight or height, and their values →03. The definition itself is based on the IEC 61360 standard and contains a human-readable



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description, a data format and a unique concept identifier, a so-called semantic identifier.

Regarding documentation, the German standard VDI 2770 defines an information model to package electronic documents and extend them with meta-information. This information provides not only structured multilanguage documentation for any device, but also a way to search, categorize and review this information efficiently.

The industrial digital twin
One of the core ideas of Industry 4.0 is to enable an interoperable, vendor-independent and open information exchange along the life cycle and across organizational boundaries.

This idea is technically addressed by the so-called Asset Administration Shell (AAS) concept, the interoperable implementation of a digital twin in the industrial domain. The development of the industrial digital twin, including AAS, is governed by “Plattform Industrie 4.0”, a German consortium of industrial and IT companies, trade associations, academia and political institutions and the Industrial Digital Twin Association. Ongoing work includes standardization of submodels to enable reuse and cybersecurity aspects to provide access control. Furthermore, an IEC working group (TC65 WG24) is well on the way to turn the AAS ideas into an international standard.

In the context of Industry 4.0, an asset may be any physical or virtual entity that is of value for an organization. In the context of this article, assets are devices and their types. The digital twin is always linked to an asset, adding a digital representation of asset information for specific use cases – eg, for product information exchange. The collection of information for one specific use case of the related asset is called a submodel.

The industrial digital twin consists of a technology-independent information model and mappings to technical implementations suitable for the life-cycle phase under consideration. For example, the digital twin may be exchanged as a file package during application specification. Later, the information can be exchanged using a Web interface in later life-cycle phases, such as monitoring during operation and maintenance.

— Ongoing work includes standardization of submodels to enable reuse.

Digital twin infrastructure – finding the digital twin of the product
Manufacturers will manage the AASs for their products. To locate an AAS, registries allow the identification of, or search for an AAS based on a given asset ID, just as in a telephone directory. If no ID is available, the content of an AAS can be searched or queried by specifying some of its properties.

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05 Product information exchange between customer tools is greatly aided by using digital twins.

05

Putting the building blocks together in a product information exchange demonstrator
The ABB product information exchange demonstrator makes use of all the tools that have been described in the previous sections →04–05.

As a first step, the demonstrator takes a product ID from AutoID as an input. The demonstrator uses this ID to query the ABB information systems described above for product information, documentation and images. The extracted information is assigned to different digital twin submodels and, if necessary, mapped onto the internal digital twin format. Semantic references in the form of ECLASS identifiers are also taken into account. Finally, the digital twin is translated and packaged as an AAS and returned as a file to the user.

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The demonstrator shows how the Industry 4.0 tools work together and address the barriers mentioned.

→06 shows a screenshot of the AASX Package Explorer Tool [3], which is based on specifications published by Plattform Industrie 4.0. The explorer can display the content of an AAS file: In the screenshot, the left part shows the product image. The middle part shows the submodels and their content in the form of a tree. The right part shows details for the selected element – in this case, the documents contained in the documentation submodel.

The demonstrator shows how the Industry 4.0 tools work together and address the barriers mentioned at the beginning of this article:

- The product type of a device is uniquely identified via AutoID.
- Product information is accessible in a digital and machine-readable format from the ABB information systems.
- Information is converted into a standardized format (ECLASS, the IEC Common Data Dictionary and VDI 2770).
- Information is packaged in the form of an industrial digital twin and implemented as an AAS.
- The industrial digital twin can be identified and its content downloaded using the AutoID.

ABB's contribution to industrial digital twin standardization and applications
Starting with early papers on cyber-physical systems and the AAS [4], ABB has contributed significantly to the evolution of the digital twin concept [5]. Since 2017, ABB has led the Plattform Industrie 4.0 working group "Reference Architecture and Standardization," which finalized the first AAS specifications in 2019 and has issued regularly updated versions since then.

From 2016 until 2021, ABB has participated in the BaSys 4.0 and BaSys 4.2 [6] projects, which defined and implemented the first AASs within an industrial and research consortium.

—
06 View of a product's digital twin, including identification, technical data and documentation.

06

07 Emerging hybrid systems pose the next challenge for information exchange between customer tools, ABB's data repositories and other systems. Complete information integration is, however, the ultimate aim.

07

ABB is continuously working toward a vision of industrial digital twins from both standardization and implementation aspects.

At the Hannover Fair in 2019, ABB presented the first end-to-end demonstrator that provides information on a power train (motor plus frequency-converter drive), aggregating information from technical product databases, engineering and configuration tools and online monitoring into a cloud-based AAS. At SPS IPC Drives 2019, ABB presented an interoperable implementation of the "digital nameplate" in a joint consortium of multiple industrial vendors and research organizations.

ABB is continuously working toward a vision of industrial digital twins from both standardization and implementation aspects. Current work includes steps to bridge Industry 4.0 concepts to the process automation domain – for example, by defining a submodel for a process module interface, the so-called module type package [7]. This work is particularly important for emerging hybrid systems – ie, production systems mixing discrete and process equipment, processes and domain standards →07. •

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BRINGING CYBER SECURITY INTO THE OT DOMAIN WITH SIEM

Extending the safety net

Converging industrial operational technology (OT) and IT networks – and ever more sophisticated systems, devices and protocols – offer countless benefits. Such enhancements, however, also make such systems vulnerable to cyber attacks. ABB is researching methods that further improve the security of customer installations.

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Industrial systems are becoming increasingly connected. This connectivity offers many benefits, such as improved productivity and flexibility, but also increases the attack surface available to malicious actors, giving them more opportunities to exploit flaws and vulnerabilities. At the same time, convergence of OT and IT networks is driving an increase in the complexity of industrial setups, devices and protocols. If these sophisticated, interconnected systems are not secured, they become prime targets for cyber attackers →01. Indeed, in 2021, manufacturing became the most attacked sector amid a growing number of intrusions into OT-connected industries in general [1].

One prominent method used to counter cyber threats in complex industrial setups is SIEM.

The impact of cyber incursions may include unwelcome disclosure of confidential information, extended production downtime, financial impairment or loss of property or even life. Affected organizations incur additional costs for remediation as well as reputational damage. Moreover, many organizations must meet certain cyber security requirements for regulatory or standards compliance and may be obligated to report any breaches and suffer associated penalties.

To respond to these risks and ensure compliance, proactive cyber security solutions that can monitor and detect threats to complex industrial setups are required. One prominent method used to counter cyber threats is security information and event management (SIEM).

Introduction to SIEM

The term SIEM was introduced by Mark Nicolett and Amrit Williams of Gartner in 2005 [2]. SIEM combines two concepts: Security information management (SIM), which involves the collation of security information at a central location for further analysis, and security event management (SEM), which is the real-time evaluation of event data.

The central idea of SIEM is the monitoring and evaluation of event data from various sources such as applications, network components, servers, or any other event-logging entities to

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01 Convergence of industrial OT and IT setups and increased connectivity demand the very best cyber security.

discover patterns of potential security-related irregularities. The results of the monitoring and evaluation process can either be reported on alert-enabled dashboards or directly funneled into a security orchestration automation and response (SOAR) system to trigger automated responses to a threat.

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SIEM tools collect event data at a central location and apply security rules to it.

SIEM tools collect event data at a central location and apply security rules to it. The evaluation of the event data happens in real-time, which means that the rules are permanently applied to find individual events as well as aggregations and correlations of events within given time frames. SIEM tools can be established as on-premise solutions or as cloud services.

SIEM rules are configurable – for instance, concerning parameters that are specific to the automation system they are applied to, such as user accounts, individual IP addresses or allow-listed external domains to which the system may connect. Safety-critical tags are also important parameters that contextualize the rules and these are also specific to each instance of the control system. Changes in critical tags can be monitored by SIEM tools.

Each commercial SIEM product has its own rule specification, which impedes rule-interoperability across vendors. An open-source initiative, SIGMA, tries to overcome this barrier by introducing a generic rule specification and offering conversion tools to translate the general rules for different target SIEM products.

Challenges for SIEM adoption

The benefits of digitalization are driving businesses to rethink OT and IT strategies, enabling previously disconnected systems to connect to enterprise networks and cloud services. Here, SIEM is essential to ensure that security is maintained by detecting malicious activity. Adoption of SIEM in OT environments is, however, currently uncommon – one of the challenges to its implementation being that lessons learned from the classic IT world often do not apply in the OT area. Moreover, each OT network is individual and assumes unique operating states that should not

02

— 02 The four pillars of ABB's approach to cyber security.

— 03 ABB's risk reduction roadmap.

be interpreted as attacks. This dilemma results in a trade-off between the generality of SIEM rule sets, which implies maintainability, and customization, which ensures practicality.

A further complicating factor is that the OT umbrella also covers (resource-constrained) embedded devices that do not have monitoring capabilities.

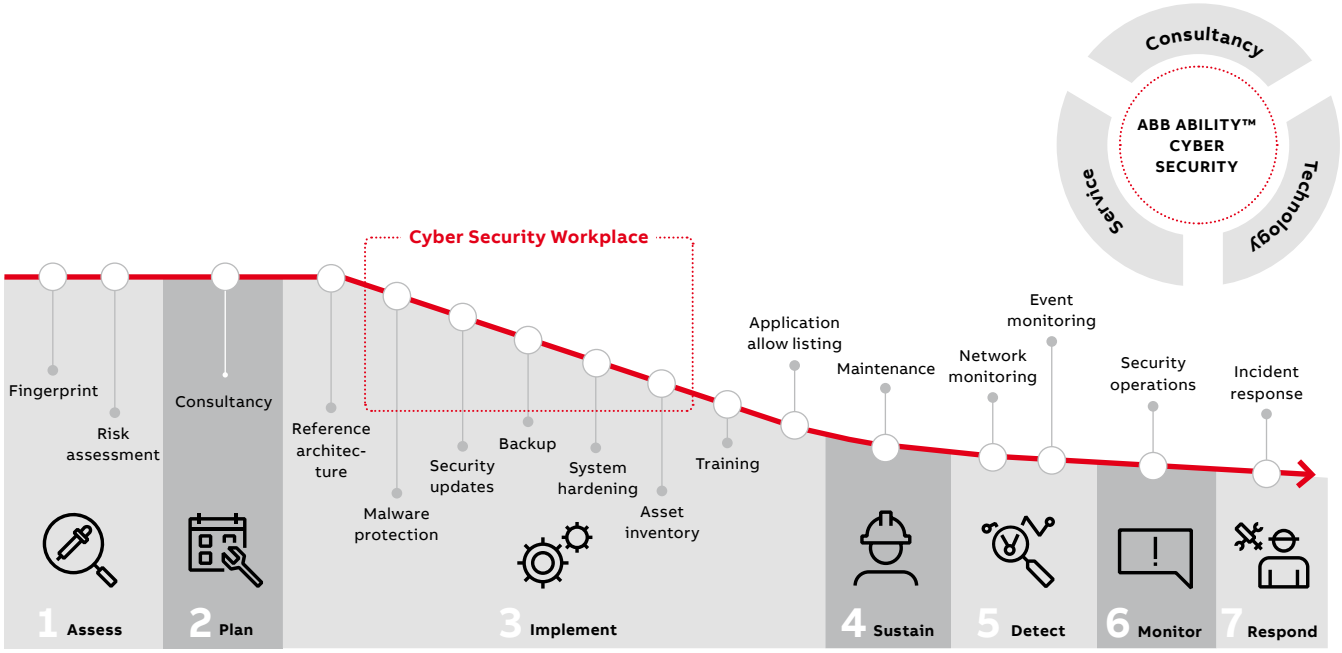
Another obstacle impeding the application of SIEM technology to the OT domain is the potentially high rate of false alarms that results from the fact that OT systems have frequent changes in production setups and show recurring regular operator interventions. Maintenance and safety-oriented operator interventions might also share similarities with attacks. This complicates general monitoring rules that separate good and malicious activities. Judging these situations is time-consuming and requires plant familiarity and security knowledge.

Further drivers for employing SIEM

The demand for better cyber security in industrial contexts has increased in the past few years and continues to do so. As well as the negative impacts of a cyber breach mentioned above, demand is also fueled by another significant consideration: emerging standards and laws. These include:

— The demand for better cyber security in industrial contexts has increased in the past few years and continues to do so.

- The German Federal Security Information Act (BSIG). In its current form, the BSIG established the obligation, from May 2023, to use attack-detection methods that continuously and automatically record and evaluate suitable parameter characteristics from ongoing operations.
- The IEC 62443 set of security standards, which requires a business entity to have the ability to identify failed and successful cyber security attacks or breaches and the capacity to identify and respond to incidents. A further



03

requirement is the capability to centrally manage a system-wide audit trail and make it available to an analysis instrument such as a SIEM tool.
- The ISO 27001:2013 and ISO 27019:2017 standards, which stipulate the necessity of event logging and assessments of events as well as the extent of the capability to respond to cyber incidents.

ABB's approach to cyber security
Care and collaboration are part of ABB's core values, which means ABB helps customers build and maintain safe and secure operations and supports them in meeting best practices and adhering to regulations. ABB also partners with established SIEM tool vendors to supply and build upon market-accepted solutions and ecosystems.

Cyber security at ABB is composed of four connected pillars: cyber security solutions, services associated with these services, cyber security consulting and intelligence – ie, ABB's unique expertise as market leader in automation technology – that underpins this edifice →02. Bringing cyber security to the customer is based on six steps:

> ABB helps customers build and maintain safe and secure operations and supports them in meeting best practices.

- Assessment of the cyber security situation.
- Planning the activities, tools and services needed.
- Implementation of tools and services, including activities such as system hardening, implementation of a security architecture and security training.
- Maintenance – for example, software patches or updates. Here, the ABB Ability™ Cyber Security Workplace™ can ensure patches against known exploits are installed as quickly as they become available. The operator is informed about update progress and told which systems are missing updates [3].
- Ongoing threat monitoring, detection and response.

→03 shows ABB's risk reduction roadmap. In this process, ABB builds especially on its knowledge of control systems and their deterministic nature. By using the information in the control system, ABB can tailor cyber security to the specific needs of particular industrial facilities.

Ongoing research
Current cyber security offerings are comprehensive and follow established good practices. Nevertheless, there are still open questions and problems to be solved in this field. Two such aspects are actively studied at ABB.

Firstly, there is context and event annotation. As described above, the state of the OT environment can be very "colorful" due to factors such as on-demand adjustments to schedules, interventions by operators to return to the steady state, or maintenance activities. Judging cases without this context can be difficult and time-consuming. Adding annotations to events to contextualize them can simplify handling and facilitate automation that accommodates SIEM rule adjustment.

Secondly, devices, down to the smallest sensors, in converging OT/IT networks are becoming more complex and more capable. In the future, it will be important to monitor these devices for security-relevant information and integrate them into a SIEM tool, just like any other asset. This evolution brings several challenges as these devices are usually heavily resource-constrained and embedded and, as is commonly the case with existing devices, not designed to support monitoring functionality. ABB is investigating ways to integrate this type of device into SIEM structures. One potential approach is to deploy monitoring agents directly on the device itself and securely transmit the information they gather to a SIEM tool based on standard protocols, where possible, to ensure interoperability with existing security infrastructure. For legacy devices and heterogeneous environments, ABB is investigating ways to monitor and extract security-relevant information external to the devices, avoiding the need to modify them or the software or protocols they use.

These improvements can help obtain much more security-relevant information from industrial installations and annotate it, based on operational context – ultimately supporting ABB customers in making the right cyber security decisions when faced with threats. •

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STATE-AWARE LANE ASSISTANCE ENABLES BETTER CONTINUOUS PROCESSES

Beware of the state

Because various operating states exist in continuous production processes with distinguishing characteristics, data-driven solutions must take into account states and substates of the system to derive useful insights. ABB provides the ultimate state-aware solution to better support operators.

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Despite the emergence of machine learning (ML) techniques in a variety of industries that can handle dynamic and complex processes based on the proliferation of available data, the chemical process industry is not always able to use this data optimally in their continuous production processes. Even though the increased abundance of available historical time series data from

ABB set out to provide a means to accurately identify and calculate the process state and substates.

various plant operating states, eg, startup, shutdown, half-load or full-load, might be available as the Internet of Things (IoT) devices proliferate, determining state is no easy matter. There are many reasons for this. For example, manual operations can cause a change in the operating state; the signature of various states usually coexist within a large amount of data, making identification of these states difficult. Moreover, a number of substates could exist within one operating state, thereby further complicating state determination.

Industrial systems follow rules unique to a given operating state.

Simple examples of such states include “startup”, “running” and “shutdown.”

If machine learning disregards the state, it may miss context.

ABB has embedded state awareness into machine-learning training data.

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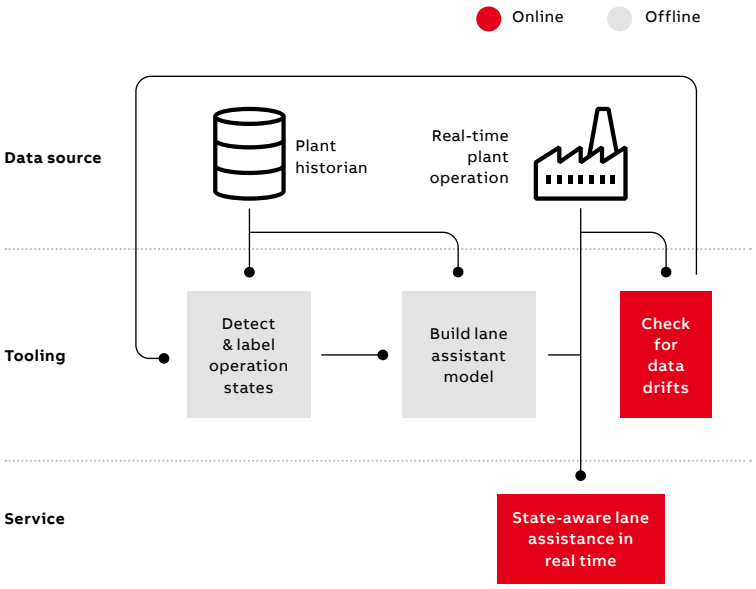
01 Because continuous processes are a mainstay of the chemical industry, operating state determination is critical for automation .



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— 02 The schematic provides an overview of the workflow for the state-aware operator support.

ABB set out to resolve such challenges by providing a means to accurately identify and calculate the process state and substates to enable operators to more accurately evaluate and correct production processes.

Why determine the state?

Imagine that the feed flow rates of multiple types of fuel gas influence the operating status of a gas-fired power plant. When analyzing data from such processes, it is critical to incorporate information about process state because the exact same behavior exhibited by the data in one state

— Information about operating states should be included as a prerequisite for data analysis and ML model building.

can be normal, yet indicate a fault in another state. It follows that the optimal way to operate the process in question can deviate dramatically depending on the operating states. In addition to contributing to safe operations, the occurrence and the characteristics of each operating state could be relevant for experts in their evaluation of the performance of the process to enable more efficient and sustainable operation →01.

Providing the correct and optimal support to a specific determined scenario is critical. Therefore, ML models, which are configured to support operators in such processes, should be state-aware. In turn, this means that the information about operating states should be included as a prerequisite for data analysis and ML model building. Such determination is demanding for a myriad of reasons: The process operating states might not be explicitly documented, or if documented the format could be difficult to process for data analysis and ML model configuration. Moreover, the root cause of the change of operating states could make identification challenging because of the sheer number of manual operations present during the production process in question.

Solution architecture

In a rigorous effort to address these challenges, ABB developed an innovative architecture using ML-based techniques →02. In offline training of the model, this data-driven solution utilizes signatures of the varying operating states to identify the states derived from the unlabeled, historical time series data and to label them accordingly. For example, the generated power is correlated with the power plant load; a high value for generated power would indicate that the process is in the full-load state while less generated power might indicate that the process is running at a half-load state.

ABB's solution can successfully identify states with simple signatures and such that are more complex. With the operating states identified, the solution then analyzes the operation and configures state-aware ML models that generate the operating lanes for all, or, the most important operating states individually.

When deployed for online operator support, this solution labels the currently active operating state in the process using the available online data and applies the corresponding ML model to generate operating lanes for operator support in real-time. Simultaneously, it monitors the drift in the online data, eg, when none of the previously identified states can be applied to the newly generated data, and triggers the retraining workflow such that the new operating states can be identified and the ML models can be updated to account for the new states.

ABB's innovative solution is part of ABB Ability™ PlantInsight Operator Assist, which provides a compact overview of complex plants and appropriate support for operating personnel in these

plants. The solution is developed for and has been verified in several customer use cases with real-life datasets from various processes, such as chemical production, oil refineries and power plants.

Data-driven state identification

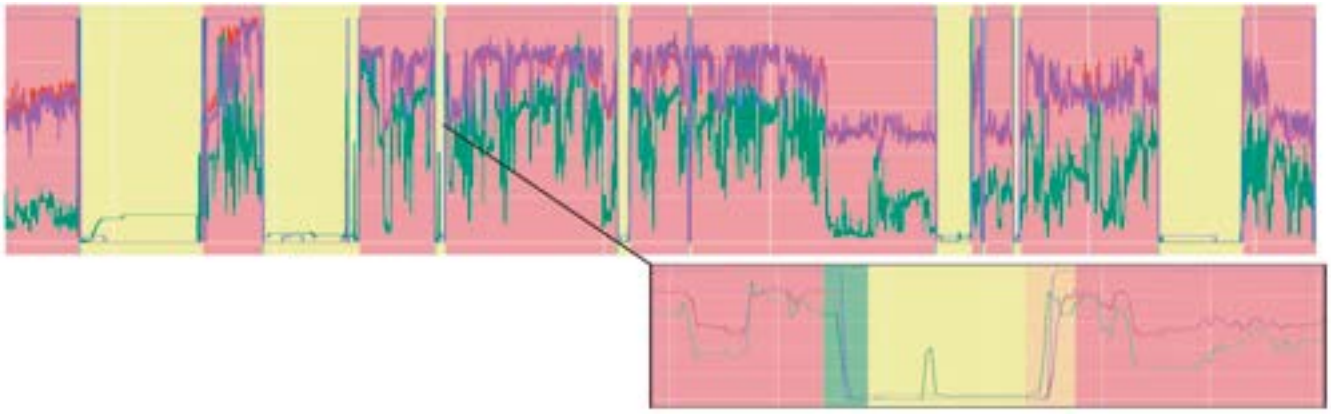
In the first step of the workflow, the historical time series data are segmented and clustered using unsupervised time series clustering algorithms such as the well-known time-series KMeans and Toeplitz Inverse Covariance-Based Clustering (TICC) [1]. The clusters of the segment should represent various operating states. An example of the identified states is given in →03, namely "running", "not running", "startup" and "shutdown", from the unlabeled time series data. The "running" and "not running" states can be easily distinguished from one another by evaluating the time trends, ie, all process variables had non-zero values when the process was in the "running" state as exhibited by the pink-colored area in →03 while all variables have almost zero values when the process was "not running" as displayed by the yellow area in →03. In the case of a short period when a shut-down occurred, followed by a startup, ABB's solution successfully identified the short but significant transition periods of "startup" (orange area) and "shutdown" (green area) →03.

This innovative ML-based architecture solution is part of the ABB Ability™ PlantInsight Operator Assist platform.

Because the major states, ie, "running" and "not running" are identified during the process, even though the process was constantly running, the possible existence of substates within the major states are indicated in this case. By applying the time series clustering algorithm to the time windows identified to be one or more specific major states, ABB's solution enables the identification of possible substates. In one instance, the substates correspond to the flow rates of two different types of fuels (indicated by red and blue lines on the graph), and the ratio between these rates, which are being supplied during the process under investigation. In this example, the yellow-colored period indicates when the "red" fuel was dominant and the "blue" fuel was insignificant; whereas the green-colored period is identified as the time in which the "blue" fuel was more dominant than the "red" fuel.

— 03 An example of identified operating states from the historical data. Pink region: "running" state; yellow region: "not running" state; orange region: "startup" state; green region: "shutdown" state.

— 04 Substates identified during the process: the blue curve and red curve are a measure of the flow rates of two different types of fuels. The gaps between the colored periods belong to the "not running" state identified previously; they were removed from this analysis.



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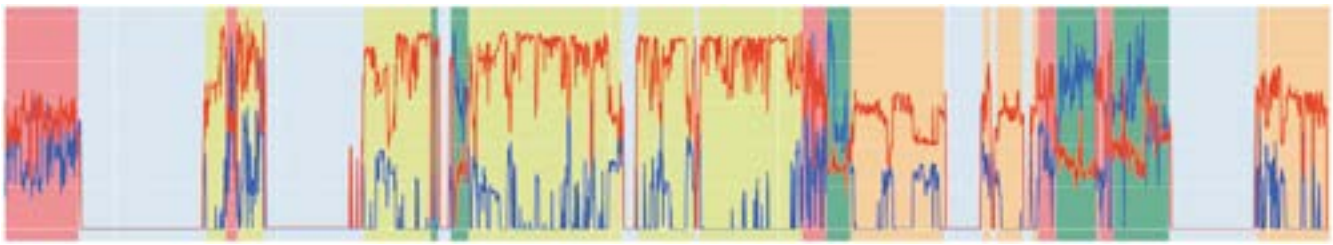

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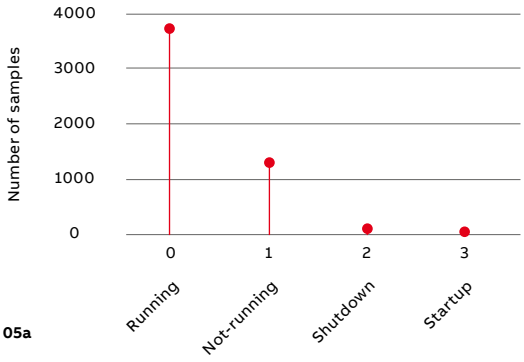

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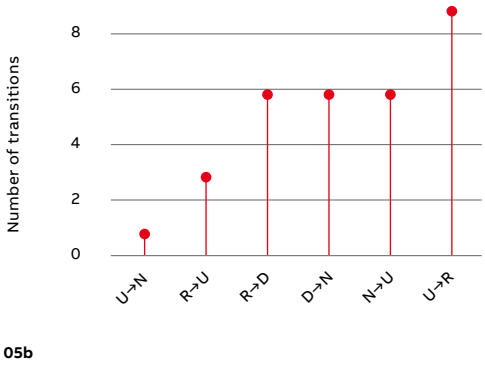

05b

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05 Statistical results of the operating states.

05a Duration of each operating state is shown.

05b Transition frequencies between the states are shown (R: "running"; N: "not-running"; U: "startup"; D: "shutdown").

Thus, ABB's ML-based fully automated solution identifies the operating states and substates existing in the process under investigation rapidly, accurately, and easily. The task of identification of the states by a human expert would, in contrast, be tedious, time-consuming and therefore less efficient.

Analysis of the states

Once operating states are identified, ABB's solution goes one step further by analyzing the operating states to generate additional useful insights regarding the historical performance of production. For example, the statistics of the identified states and corresponding periods represented in the historical data can be calculated. Two examples of the statistics employed do just that →05, namely to analyze the duration of each operating state and the frequency of the transitions between the states. The conclusion could be that the running time is around 65 percent and the not-running time is 20 percent, approximately, over the given period. Additionally, a typical operation sequence can be identified from the frequency analysis that such a sequence makes: "running" → "shutdown" → "not-running" → "startup" → "running" (R→D, D→N, N→U, U→R) →05. It is noteworthy that the transition from "startup" to "not running" occurred once; this might indicate an unsuccessful attempt to startup. Such information would be relevant in regard to a retrospective analysis of the production performance.

—

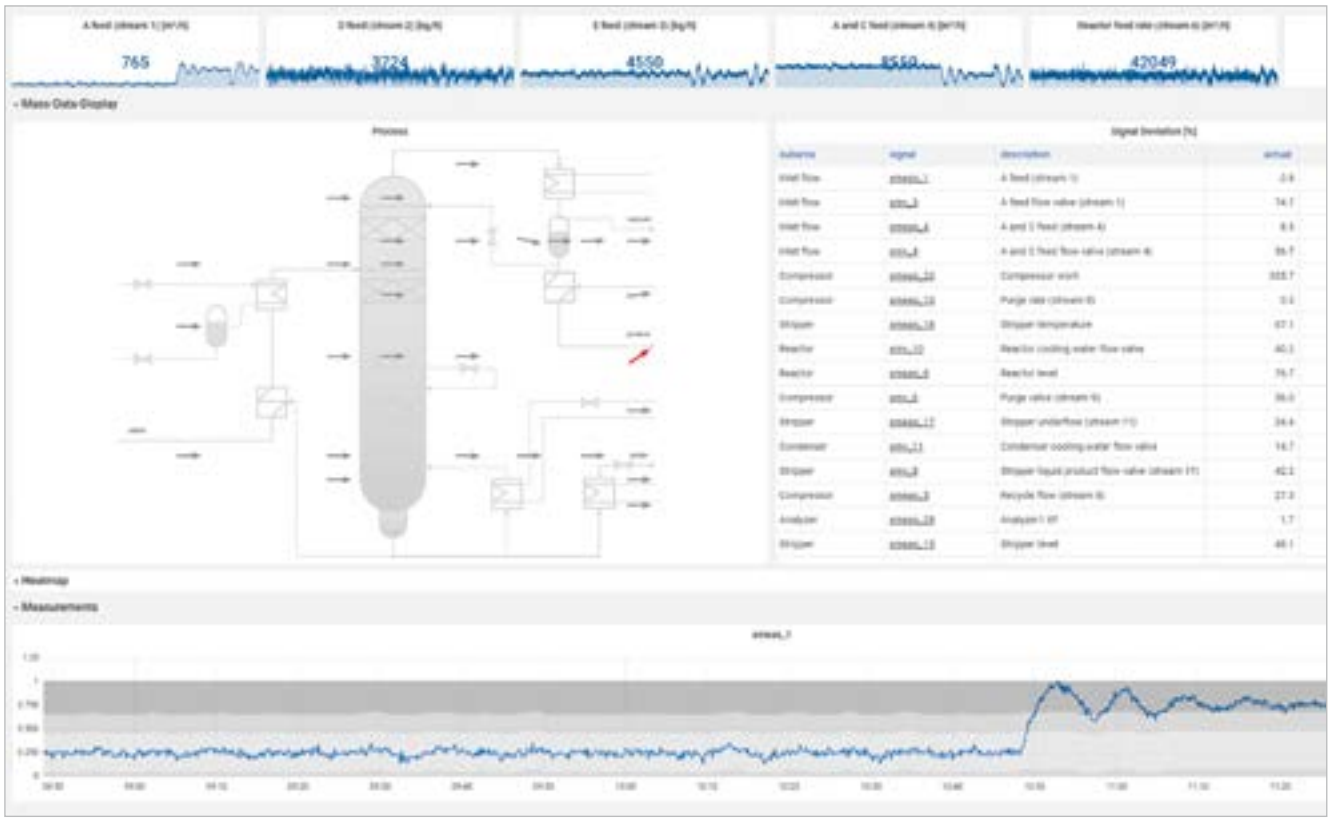
ABB's solution analyzes the operation and configures state-aware ML models that generate operating lanes.

Moreover, the labels generated by the unsupervised time series clustering algorithm can be further leveraged and explained by XAI (explainable AI) methods [2], which will soon become mandatory in the EU, to extract rules for process operation. For example, for the "running" state presented in →03, the rule would be: when the blue curve is above a certain threshold value, which fits well with the empirical knowledge of the process experts, such that: when the process is running normally, a key process variable should be nonzero. Such rules not only enhance the confidence of domain experts in data-driven solutions, a challenge in sophisticated data-driven solutions, but will also yield insights when labeling of the operating states occurs in real-time.

State-aware lane assistance

To present information to the operator in an intuitive and efficient way, ABB Ability™ Plant-Insight Operator Assist adopts the concept of operating "lanes" as if the operator was driving their process and, as such, they should remain in the lane to guarantee safe, sustainable and efficient production→06. The lane is presented as a dynamic, adaptive band around the time trend of selected process variables.

ABB's solution further empowers the configuration of the operating lanes via multivariate, state-aware ML models. One way to accomplish this task is to train one ML model, eg, an auto-encoder, for each important operating state using data collected from this state only. Such ML models can capture the behavior of the process in a given state better than a general model that is trained using data from a variety of states [3]. The ML models are then used to calculate the operating lanes; such lanes take into account both the current process state and the relationship between several process variables. Compared to the bandwidth of conventional static alarm limits of process variables, such



06

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06 The schematic provides an overview of the workflow for the state-aware operator support from the ABB Ability™ PlantInsight Operator Assist.

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[2] The Royal Society "Explainable AI: the basics policy briefing", 2019, [Online] Available: https://ec.europa.eu/futurium/en/system/files/ged/ai-and-interpretability-policy-briefing_creative_commons.pdf [Accessed July 17, 2023.]

[3] R. Tan, et al., "An on-line framework for monitoring nonlinear processes with multiple operating modes" in *Journal of Process Control*, Vol. 89, 2020, pp. 119–130.

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Originally published in ABB Review 04/2023, pp. 296–300.

lanes are much more adaptive and can be much narrower; this can enable early detection of even minor deviations of the process from the ideal production.

It is essential for both the operators and the operator support systems to be aware of the historical and present operating state, eg, the loading conditions, the input materials, and the expected grade of end product that may exist in their processes. Only in this way can they properly evaluate performance and make the right decisions accordingly. ABB's ML-based solution

—
With state-aware support, operators can better understand and evaluate the production operation and performance.

addresses these needs by providing a fully automated, unsupervised workflow to enable the identification of the operating states and substates from time series data. Not stopping there, ABB's innovative digital solution provides additional useful insights by deriving and presenting the historical states. The state information is incorporated in training state-aware ML models that generate operating lanes to detect deviations from optimal production.

With the state-aware support this solution offers, operators will be able to better understand and evaluate the production operation and performance in their specific processes, both historically and in the present, thereby maintaining a safe, sustainable, and efficient production. •

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VIRTUAL PROTECTION AND CONTROL FOR MEDIUM-VOLTAGE SUBSTATIONS

The virtues of virtualization

01 Virtualization helps solve many of the challenges faced in maintaining and updating hardware in substations, such as this one in Finland, where virtualization field tests took place.

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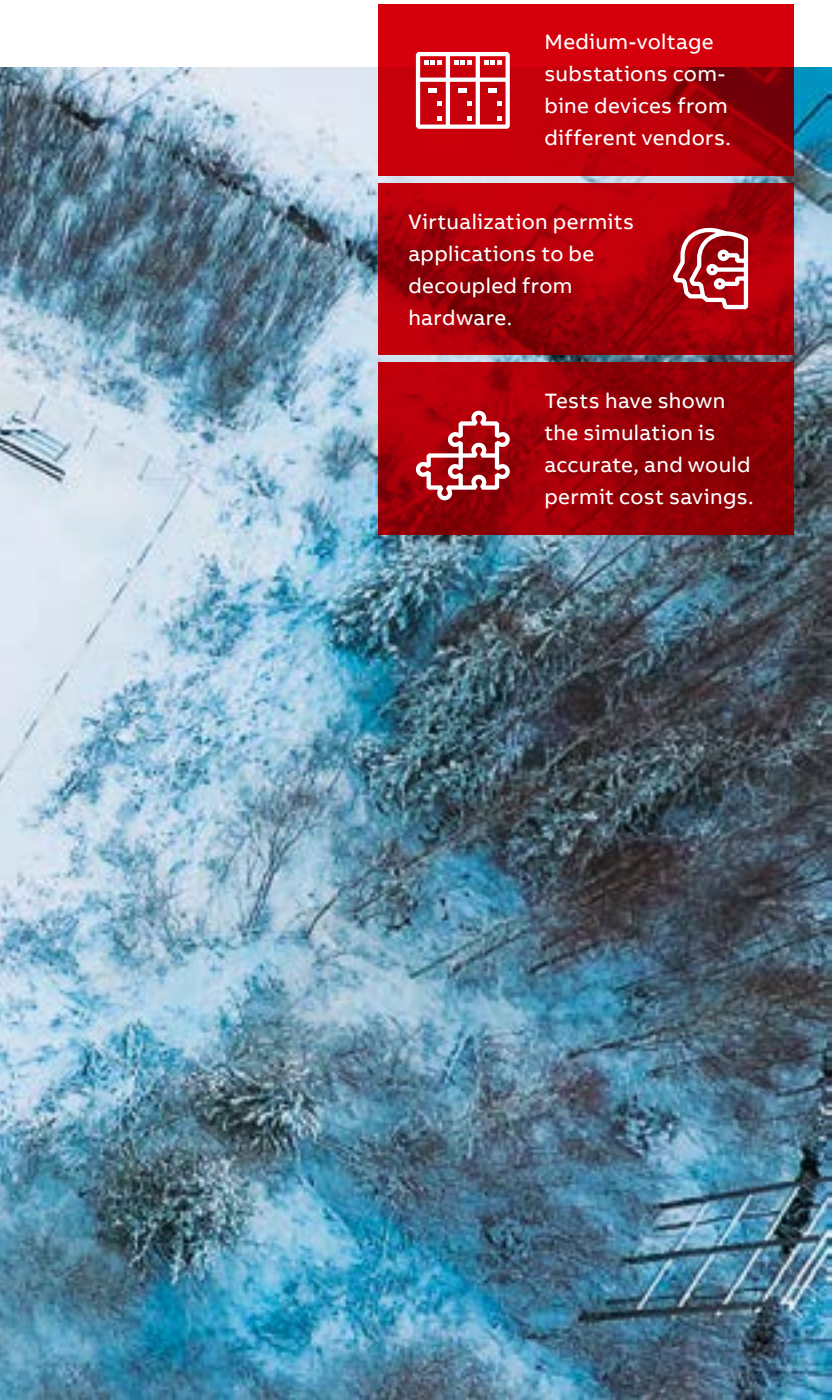
01

To adapt to the rapidly changing power grid environment, medium-voltage (MV) substation operators must reduce costs, simplify equipment maintenance and updates, and accommodate increasing numbers of distributed power sources. Virtualization helps solve these challenges.



Although they generally go unnoticed by most, MV substations are found everywhere there is any appreciable concentration of people or industry →01. Responsible for stepping down the voltage delivered by high-voltage (HV) transmission systems, substations are vital for the supply of electricity to industrial and residential customers.

Modern substations typically feature devices from multiple vendors. These devices run applications, on their proprietary hardware, that are essential to the functioning of the substation. However, maintaining and updating a myriad of proprietary devices is an expensive and challenging business. And substation operators face other challenges, too – for example, the rising numbers of distributed energy resources (DERs) on the distribution grid. This increase in DERs brings with it the need for further investment in intelligence and resilience across the grid. Moreover, the distribution system operators (DSOs) are under constant pressure to reduce capital expenditure (CAPEX) and operating expenses (OPEX) generally.

One effective way to address these challenges is to introduce a flexible and rapid deployment of applications in substations. The DSOs can then not only deploy applications from different vendors onto the same hardware but also add functionalities or upgrade existing functionalities on demand. The key to accomplishing flexible and rapid application deployment is virtualization.

Virtualization decouples software from hardware

The concept of decoupling software from the underlying hardware – ie, virtualization – has been very successful in the IT landscape over the past few decades. Indeed, virtualization technology is the workhorse that enables modern

The key to accomplishing flexible and rapid application deployment is virtualization.

cloud infrastructure as it reduces hardware costs and simplifies maintenance. With virtualization, applications run in a “virtual” environment, abstracted from the actual underlying platform and isolated from the other applications running

02

— 02 Virtualization helps free software from its dependence on the underlying platform.

on that platform. Virtualization enables software to be deployed, executed, exchanged and migrated almost independently of the underlying platform →02. Virtualization also helps to achieve high availability and resiliency at a reasonable cost. These benefits of virtualization technology

— When applied to substation automation, virtualization technology faces challenges not seen in cloud computing.

can be exploited to assist DSOs in addressing the challenges and limitations they face in substation automation while also making it easier to deploy and scale new applications.

Customizing virtualization for substation automation

Virtualization in computing environments can take place at different levels:

- In hardware, in virtual machines (VMs) that provide the functionality of a physical computer without the developer having to deal with actual physical hardware.
- In the operating system (OS), in so-called containers. In contrast to a VM, which virtualizes an entire hardware machine, a container virtualizes the software levels above the level of the OS and can isolate processes and control the access of processes to CPUs, memory, etc.
- At the function level, as in serverless computing, where there are still servers involved, but these are abstracted away from the application, so the developers do not have to worry about provisioning or managing server infrastructure as this is handled by the cloud provider.

When applied to substation automation, virtualization technology faces challenges not seen in cloud computing. While the cloud has ample and scalable computing, storage and networking resources, the resources available in substation devices are more modest. Furthermore, the applications running on the devices are of mixed criticality (safety-critical and non-safety-critical) and some applications may require specific hardware configurations – for example, support for the Precision Time Protocol in a network card. Moreover, many substation applications have special timing and high availability requirements that must be met during operation.

These needs sharply differentiate virtualization when it is applied to distribution or substation automation. Consequently, careful resource assignment and provisioning are required when consolidating several VMs or containers onto

devices. Otherwise, resource contentions can result in non-deterministic delays that could compromise the real-time guarantees for the applications running in the VMs or containers.

ABB investigated the applicability of virtualization technology in MV substations, specifically the use of real-time protection and control applications in Linux containers that provide virtualization at the OS level. Multiple instances of centralized substation protection and control on the same host were run

Resource provisioning and management are critical for an implementation of virtualization in substation automation.

and effective real-time performance of the control and protection applications using tailored resource provisioning and virtual networking solutions was demonstrated. The discussion below shows just how critical effective resource provisioning and management are for a successful implementation of virtualization in substation automation.

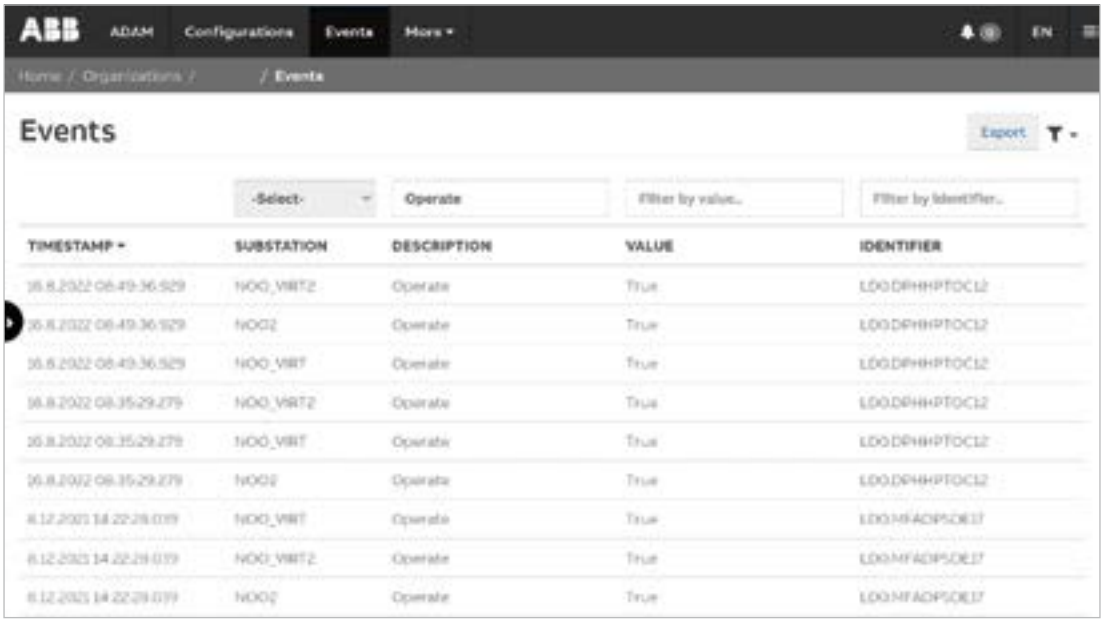
Implementation and resource management
ABB researched the applicability of running demanding real-time workloads in Linux, using not only OS-level virtualization with containers but also VMs. The basis of the test systems is a Linux kernel with a PREEMPT-RT patch for real-time operation. In essence, PREEMPT-RT is a Linux kernel patch that adds real-time capabilities. Although PREEMPT-RT may not be suitable for very fast real-time loads with latency requirements in the order of a few microseconds, in reality only the more realistically achievable millisecond latencies are needed for substation automation applications.

To achieve the real-time performance required in substation automation, the protection application must:

- Receive the incoming voltage and current measurements promptly.
- Have guaranteed access to the computing hardware when needed.
- Complete calculations within a limited period and be able to send out a response action in time.

These conditions create different challenges for a virtualized setup with multiple applications sharing the same host system.

Latent latency challenges
The first obstacle is retrieving process data from the merging units (MUs) in a timely manner. MUs act as interfaces that receive process data such as measurements from instrument transformers and switchgear alarms and indications. The focus here was placed on digital substations where process and control data are exchanged over an Ethernet network, as specified in the IEC 61850 standard. In such situations, multiple applications need to share the physical network access with virtualized networking technologies, such



03 Screenshot of one of the rare substation events showing how the multifrequency admittance-based earth fault protection operated at the same time (to the millisecond) across all three substation instances.

03

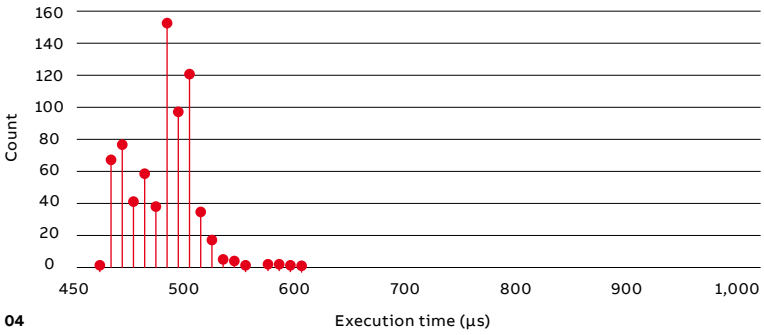
— 04 Execution times show good compliance with requirements.

— 05 Compliance with the internal cycle time: Execution times of the internal functions met the required deadline (red line) throughout a whole year of operation.

as a virtual switch or macvlan (a network driver that presents software containers to the physical network as if they were physical devices). Therefore, various ways of attaching a virtual environment to the host physical network were studied. This investigation was performed using the virtual product known as ABB Ability™ Smart Substation Control and Protection for electrical systems SSC600 SW.

— Scheduling performance is not significantly impacted by running the software inside containers on modern hardware.

Since mainstream network virtualization approaches do not optimize for latency, substantial pitfalls for real-time operation (due to how network drivers defer work for later) were discovered. The final setup was optimized to avoid these pitfalls. Modern networking hardware can also help to improve the situation through explicit virtualization features.



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Accessing the CPU as needed

With data arriving on time, the next step toward achieving real-time performance is to gain access to the CPU when needed. Scheduling process execution is a core task of any OS, and Linux with PREEMPT-RT offers multiple real-time policies and enables the protection software to preempt other applications.

It was found that scheduling performance – ie, getting the CPU exactly when requested – is not significantly impacted by running the software inside containers on modern server hardware and is not the main bottleneck on a properly configured system, at least for latencies above a few dozen microseconds. However, the protection process or a whole VM might still be blocked by another application with a similar priority or by one of the many OS housekeeping tasks. Different CPU core allocation policies were studied and potentially dangerous contentions were resolved by exclusive allocation of CPU cores to applications, including maximum isolation of the OS to dedicated CPU cores. Exclusive allocations further ensure proper sizing of host hardware to guarantee the availability of sufficient computational resources for all applications.

The policy chosen is also a good match to the high computational demand of protection algorithms and the mostly horizontal nature of

05

scaling in modern hardware with its consistently increasing numbers of CPU cores.

Not forgetting memory considerations
Even with calculations started at the right time and dedicated CPU cores available, interference can still delay computations unacceptably. For data-intensive applications, such as protection and control, execution timings depend strongly on the transfer times of data between memory and CPU. A modern system employs multiple levels of fast intermediate memory (cache) to reduce retrieval times for frequently used data. Unfortunately, the cache size is limited and holds further potential for interference between applications with high data loads. Therefore, policies of cache partitioning and exclusive reservation of memory bandwidth were implemented.

With careful consideration of resource reservations, it becomes possible to fully isolate virtual real-time applications from each other and ensure steady operation with timely responses for all of them on the same platform.

Pilot installation and performance
The project work moved from early proof-of-concept studies to lab tests of virtual protection and control to validation of real-world deployments in the field.

In the laboratory, the team validated protection reaction times of the whole system running in different configurations and virtual environments, and with varying loads, against actual signal injection in hardware-in-the-loop tests and real-time network simulations. In all tests, the virtual setup succeeded and lived up to the timing and functional requirements of the equivalent dedicated embedded protection and control device.

The test in Finland validates that the approach works for virtual protection and control in real substations.

Following the positive lab results, ABB moved to validation in the field in collaboration with one of Finland's leading DSOs. One IEC 61850 certified server was deployed in a research cabinet at a substation in Western Finland province →01. Using careful resource partitioning, this server can run two fully configured virtual SSC600 instances in parallel.

06

Since the deployment in September 2021, the instances complied with all functional and timing requirements of the physical SSC600. Some (of the very few) events observed at the substation were captured and, by comparing event logs, it could be seen that the behavior of the virtual instances perfectly aligns with the behavior of the physical counterpart →03. →04 highlights a critical performance index: compliance with the internal cycle time. →05 shows how the execution times of the internal functions met the required deadline (red threshold). The carefully designed virtual network layer allowed the arrival of all the incoming sampled measurement value traffic in time with no late samples or other losses during normal operation. The only observed packet losses happened during external data disconnection events, unrelated to the virtual setup.

The field test in Finland successfully validates that the approach chosen is fit for purpose for virtual protection and control in substation automation in the real world. Virtualization provides substation operators with a way to reduce costs and make equipment maintenance easier as well as successfully take on board the rapidly rising numbers of renewable power sources appearing on the grid →06. •

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06 Virtualization will help substation operators to reduce costs and successfully tackle the rapidly changing power grid topology.

Originally published in ABB Review 02/2023, pp. 118–123.

GOFA™ CRB 15000

A helping hand

ABB's newest collaborative robot, the easy-to-use and award-winning GoFa™ CRB 15000, features intelligent sensors in each joint to support close human and robot collaboration. This highly approachable cobot enables class-leading reach and speed for payloads up to 5 kg.

—
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A new era of robotics is gaining momentum – that of collaborative robots (cobots) – robots that work safely alongside humans without the need for protective barriers and without jeopardizing speed and safety. Having introduced the world's first collaborative robot, YuMi™, in 2015, ABB is recognized as a global leader in robots with more than 500,000 robot solutions shipped to date.

In February 2021, the newest members of ABB's family of collaborative robots, GoFa™ and SWIFTI™ were introduced in a virtual launch event with around 10,000 live viewers [1]. GoFa handles 10 times heavier loads than YuMi, has higher maximal speed than other cobots on the market; and the integrated sensors in each of its joints ensure collaborative safety. Gofa also comes equipped with Wizard easy programming, which enables first time users to teach the robot programs within minutes. By supporting new tasks and applications, ABB's GoFa is a game changer. In 2023 ABB launched two more variants of the GoFa CRB 15000, expanding payloads to 10 and 12 kg, and the reach up to 1.62 m as well. These new variants extends GoFa's capabilities to be able to take on more applications, for example welding and palletizing, etc

Robotics to meet industry's needs

For many years, industrial robots like those used in the automotive industry, have handled heavy and large payloads, yet required safety fences to keep anyone from coming too close to the robot's fast-moving arm – a potential hazard. These robots have helped businesses lower operation and labor costs, while improving production output, product quality, and employee safety as they take on the hazardous and repetitive work of humans.

With data services, machine-learning, artificial intelligence, decreased product life cycles and differentiated products driving technology and business nowadays, ABB believes that cobots could speed up automation processes and help businesses adapt quickly to changing circumstances and respond to changing customer demand. But, this requires newly designed and engineered robots to work faster, reach further, operate more flexibly and safely alongside humans. ABB's newest collaborative robot, GoFa, is designed and engineered with this in mind – as a helping hand for enhanced flexibility and efficiency.

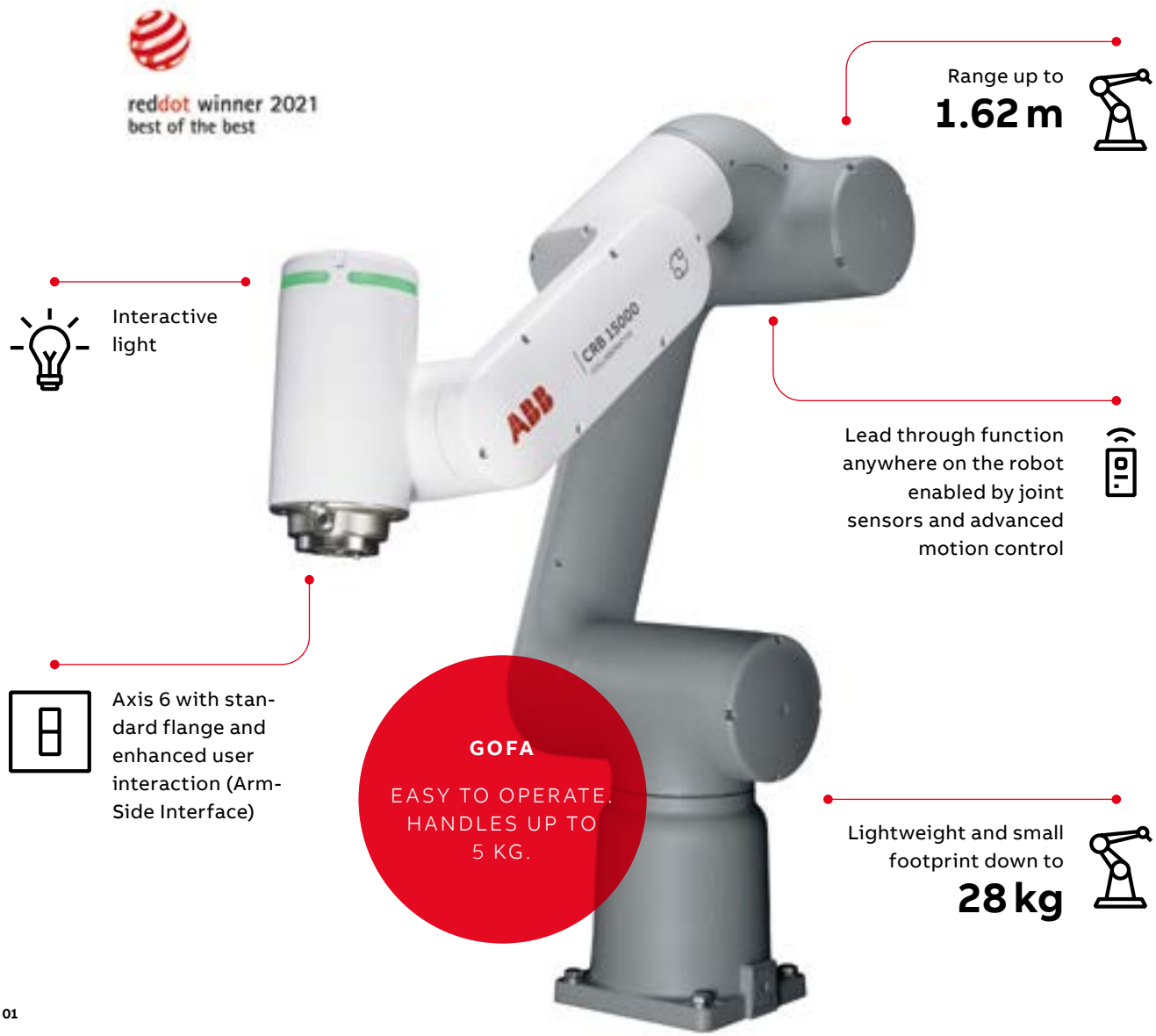
—
The new six-axis GoFa™ CRB 15000 Collaborative Robot supports the growing demand for varied robot solutions.

New collaborative solution
Built on the success of YuMi, the new six-axis GoFa™ CRB 15000 Collaborative robot supports the growing demand for varied cobot solutions. Designed to safely work with humans and other robots, GoFa helps businesses automate processes involving heavier loads and longer reaches than previously possible.

Designed to minimize its footprint and weight while maximizing speed and reach, GoFa provides heightened flexibility. Designed with a maximum speed of up to 2.2 m/s and to handle payloads up to 5 kg (10 times more than one-arm YuMi), GoFa weighs only 28 kg, and has a footprint of just 165 mm² and can be mounted in any direction →01 – 02 [2,3,4]. This sleek, compact and portable cobot can be easily moved between locations as needed. And with a reach of 950 mm, GoFa outperforms other cobots that can handle up to 5 kg by approximately 12 percent →01 – 02. With a 70 percent longer reach than ABB's YuMi single-arm robot, GoFa enables loads to be picked up and moved over greater distances, thereby helping to reduce the number of cobots that may be needed in a single space. All of these features make GoFa ideal for diverse applications, from machine tending and material handling through to picking and packaging [4]. GoFa meets industry needs – stepping in whenever and where ever needed to assist humans and robots directly and continuously.

A cobot is a robot designed to work alongside and collaborate with humans.

ABB has introduced the GoFa™ CRB 15000, featuring graeter payload and performance.



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01 GoFa's main beneficial features at a glance.

Better performance and productivity
In addition to assisting workers with repetitive, dangerous and ergonomically challenging tasks, GoFa can support short-term process changes and be deployed quickly to perform new tasks in production lines as required, eg, when there is fluctuating demand or production batches are small. Faster than other cobots in its class →02a, GoFa can perform more operations in a set period than competing cobots. GoFa is therefore, ideal for assembly or picking and packaging tasks where items need to be quickly and accurately transferred between locations. GoFa can even be mounted easily on Automated Guided Vehicles (AGV). The author of this article finds that this ability provides users of all sizes, from SMEs to large companies, with the flexibility to quickly adapt to changing circumstances and respond instantly to changing customer demand without having to incur delays arising from having to find extra staff at short notice.

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GoFa is ideal for assembly or picking and packaging tasks in an environment with other people nearby.

GoFa is powered by OmniCore™ with its best-in-class motion control and path accuracy →02a. OmniCore features a 50 percent reduction in footprint compared with previous robot controllers and can be easily integrated with the latest

Specification of GoFa	
Robot version	CRB 15000
Reach	950 mm
Payload	5 kg
Armload	No armloads
Number of axes	6
Protection	IP54
Mounting	Any angle, including table mounting, wall mounting, and ceiling mounting
Controller	OmniCore C30
Customer power supply	24V/1.5A supply
Customer signals	4 signals (for IO, Fieldbus, or Ethernet)
Tool flange	Standard ISO 9409-1-50
Functional safety	SafeMove Collaborative included All safety functions certified to Category 3, PL d

02a

Performance (according to ISO 9283)	
Max TCP velocity	2.2 m/s*
Max TCP acceleration (normal control motion @nominal load)	36.9 m/s²
Max TCP acceleration (e-stop @nominal load)	61.6 m/s
Acceleration time 0–1 m/s	0.097 s
Pose repeatability	0.05 mm
1 kg picking cycle 25 × 300 × 25 mm	0.66 s

02b

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02 Important specification and performance information for GoFa CRB 15000.

02a A summary of specifications for GoFa CRB 15000.

02b List of performance according to ISO 9283.

* Safe collaborative speed will be lower, refer to the SafeMove configurator app for recommendation. Customers should always do a safety risk assessment of their cobot application.

digital production technologies, including a wide variety of communication protocols, fieldbuses and advanced vision systems. →02b.

A safer working partner

With GoFa's advanced and comprehensive safety functions (certified to Category 3, PL d) risk to human workers is prevented and the need for costly and space-restricting barriers and cages is no longer required [3,4]. Safety is accomplished by factoring in the robot's speed, the combined mass of the robot and its payload; and the ability of the robot to stop immediately upon contact. Designed with integrated intelligent torque sensors in each of its six joints, GoFa offers superior power and force-limiting performance →01 –02. Together, these features prevent the risk of injury by bringing GoFa to an immediate stop if the robot detects any contact with a human worker.

Moreover, the aluminum and plastic joints that feature a rounded geometry, have no pinch or trap points that could ensnare a human worker. The additional comprehensive set of safety functions provided by ABB's SafeMove™, with an easy configurator app, ensure safe installation.

Because safety is crucial for all, even first-time users, ABB included a visual safety configurator on its tablet-like FlexPendant to ensure that even novice users can configure the robot safely with SafeMove. Thus, users can avoid issues such as clamping that can affect safe robot operation. Further, with an interaction status light that varies in color, depending on GoFa's operating status, users quickly know whether the cobot is in standby, programming, operating or in stop mode →01 [2,3].

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Designed with the user at the forefront, technological and physical features make GoFa safe, approachable and easy to use.

Form follows function

Despite GoFa's superb built-in safety features, ABB knows the importance of ensuring workers feel safe and comfortable working alongside cobots. Observations of YuMi, made over five years by the author of this paper, confirm that workers feel safe working alongside the robot thanks to its unique and non-intimidating design. As with YuMi, GoFa was designed with the user at the forefront, using a combination of technological and physical features to make the new cobots approachable and easy to use.

GoFa employs slim, straight arms that give the cobot a user-friendly, yet strong appearance, while the advanced use of color, material and finish gives GoFa a modern, sleek look. Its simple arm-side interface (ASI) design with two buttons and light ring resembles the easy-to-use interfaces of consumer products. Gofa is therefore more accessible even for first-time robot users who are more accustomed to consumer technology than to industrial machinery.

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03 GoFa's working range is depicted.

03a The working range of the robot arm is shown from the side view.

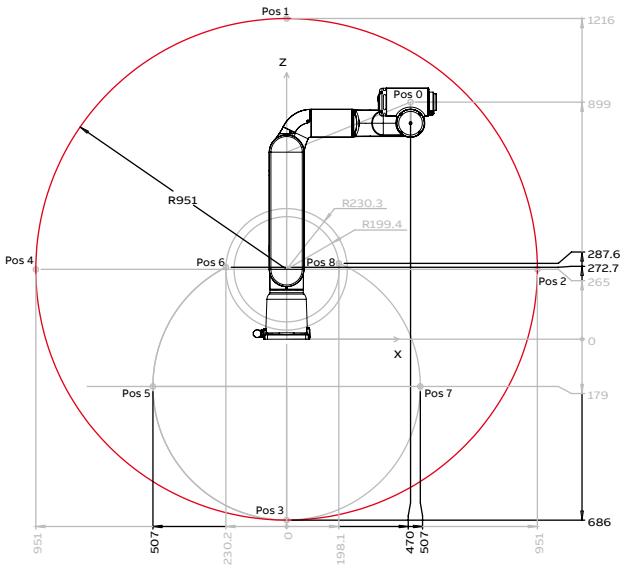
03b Gofa's working range makes it useful in diverse settings such as the example shown here.

Award-winning design
Safe, approachable and appealing, GoFa stands out. In 2021, ABB's GoFa cobot was awarded the prestigious Red Dot Best of the Best Design Award in recognition of its unique design concept, to make the new robot appealing and accessible to users [5].

With the jury assessing thousands of entries every year, Red Dot's "Best of the Best" award is for groundbreaking design and is the highest award in the competition, reserved for the most aesthetically appealing, functional, smart or innovative design.

Sami Atiya, President of ABB's Robotics & Discrete Automation Business Area said "Making robots more approachable, easier to use and more intuitive is key to our vision to make robots as familiar in the workplace as a laptop is today." He added, "GoFa is a gamechanger, reinforcing the importance of good industrial design to make it easier for more people to work with robots. Creating an approachable design will ensure robots are adopted across a range of workplaces outside traditional factory environments."

Easy to set up and use
Beyond world class design, ABB provides innovative, advanced and connected solutions for all of their collaborative robots and GoFa is no exception. With all functions implemented on the intuitive, graphical, tablet-like FlexPendant, eg,



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03b

— In 2021, GoFa was awarded the Red Dot, Best of the Best design award in recognition of its unique design concept.

SafeMove configurator, GoFa is a snap to set up, configure and operate →04. Installation includes a start-up package that provides ABB Ability™ condition monitoring and diagnostics as well as a support hotline to access ABB's expert technical assistance.

The Wizard easy programming feature, possessed by all ABB's families of new cobots (GoFa™, SWIFTI™, single arm YuMi™) and an increasing number of industrial robots, allows novices to quickly and easily create robot programs even without the ability to code. Users can teach their robot new tasks in minutes by simply dragging and dropping graphical boxes in the app. ABB has added online tutorials and how-to videos on topics from setup and programming, through to operation and troubleshooting.

Experienced ABB robot users have not been neglected either. Wizard Skill Creator allows expert users to create their own customized blocks, known as Skills, which can be produced to control grippers or create actions for specific applications such as laboratory automation.

Existing customers appreciate that their expert ABB robot users can continue to access engineering tools, eg, RAPID programming, RobotStudio®, as they have previously without the need to

—
04 Wizard Easy programming allows novice users to easily drag and drop existing boxes and with Wizard Skill Creator users can create their own customized blocks.

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05 RobotStudio® is ABB's simulation and offline programming software for programming, configuration and virtual commissioning before installation.

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Originally published in ABB Review 01/2022, pp. 48–53.

Approachable, fast and intelligent, GoFa stops immediately upon contact, thereby protecting workers of all kinds.

learn new systems for ABB's cobots. Overall, GoFa offers beginners and experts alike all the engineering and programming tools they need to create programs and teach their robots easily [1].

Customer value

Not surprisingly, since its launch in 2021, GoFa has received an overwhelmingly positive response from ABB's customers. Customers especially like the Wizard easy programming feature. Further, both novice and experienced customers appreciate the user-friendly experience, akin to that of tablets, resulting from having functions implemented as apps on the FlexPendant.

Overall, GoFa™ CRB 15000 Collaborative Robot is ushering in a new era of collaborative robots – approachable, fast and intelligent; this cobot reaches further than ever, yet stops in milliseconds upon contact, exactly what workers need from a helping hand. •

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THE ROAD TO AUTOMATED ENGINEERING

Topology machine

Automation engineers still must create much control logic and process graphics by hand. The DEXPI (Data Exchange in the Process Industry) initiative aims to automate such tasks by standardizing plant topology models. ABB research demonstrated how these models could save costs and increase quality.

01

Creating control logic and process graphics for control and monitoring systems such as ABB Extended Automation System 800xA, ABB Ability™ Symphony Plus, or ABB Freelance still requires a significant amount of manual work. While engineering libraries provide low-level reuse and bulk engineering tools automate the handling of I/O lists, automation engineers must still translate many customer specifications by hand. Consequently, the DEXPI industry initiative – supported by BASF, Equinor and Bayer – is currently working on standardized plant topology models to automate additional engineering tasks [1]. An ABB research project demonstrated how these models could save costs and increase quality. The findings are based on the analysis of four plant specifications from recently executed System 800xA projects.

Plant engineering today

Today's process engineers specify piping and instrumentation diagrams (P&IDs) as blueprints for the automation of a production process →01. These drawings describe the required equipment – such as tanks, pumps, motors, and valves – and instrumentation, eg, sensors for temperature, flow, level and pressure. Although there are naming conventions and industry standards for the shapes of the components in P&IDs, different computer-aided design (CAD) tools offer process engineers a lot of freedom. They can create custom shapes, add free-text annotations and unintentionally draw unconnected pipes – all of which complicates algorithmic analysis and prevents automated processing of the encoded information.

Consequently, P&IDs are often exchanged as PDF files (or even printouts) from which control logic and process graphics are manually derived by automation engineers. Based on their experience, the engineers can compensate for some semantical ambiguities (eg, shapes that do not fully conform with standards). However, they also often encounter inconsistency or incompleteness in the diagrams in relation to other specification documents, which leads to time-consuming communication feedback loops with the process engineers.

A few CAD tools already feature support for so-called Smart P&IDs, but these are not yet widely used in the industry. Smart P&IDs include a database that contains structured tables of the encoded information (eg, instrumentation lists) and metadata for the drawn items (eg, pipe diameter, alarm limits, etc.). Algorithms can process such structured information much more easily than drawings consisting of generic boxes, lines and circles. Currently, Smart P&IDs are usually stored in formats specific to a particular CAD tool, which complicates the construction of software tool chains.

Topology engineering

Since 2011, the DEXPI initiative has worked on a common P&ID specification standard, expressed as object-oriented concepts in an XML file format. This standard can be considered to be a standardized version of Smart P&IDs. The specification captures both drawing information (eg, graphical coordinates and drawing instructions) and abstract models of equipment, instruments and their dependencies. The latter are also called "topology models" since they express the plant topology as a kind of network, analogous to the topologies of electronic circuits or computer networks [2]. The initiative is driven by large automation customers, such as BASF, Bayer,

A few CAD tools already support so-called Smart P&IDs, but these are not yet widely used.

Covestro, Equinor, Evonik and Merck. All major CAD tool vendors are also involved, for example, Autodesk, Aveva, Hexagon and Siemens →02. The specification has matured in recent years (Version 1.2 was released in 2020) and CAD tool vendors frequently participate in DEXPI working group hackathons (intense software development sessions) to test the DEXPI XML importers and exporters that will find their way into the next product release.

01 Automation of control logic and process graphic creation can save time and cost and increase quality.

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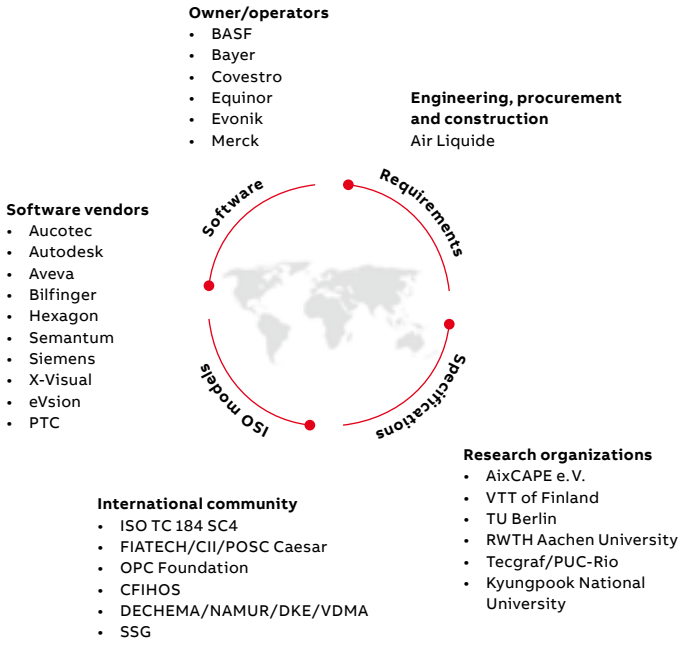

02

— 02 DEXPI initiative – a common P&ID XML file format for CAD tools.

Topology models are at the center of "topology engineering," developed over the past few years in scientific communities, which aims at utilizing topological information to carry out engineering tasks. Standardized models in DEXPI XML file format allow tasks that are currently performed manually to be automated:

- Control logic generation. To some extent, interlocking logic and state-based control can be derived from plant topology models [3].
- Process graphics generation. The graphical layout derived from a P&ID and encoded in a topology model can serve as a template for the creation of human-machine interfaces for plant operators.
- Simulation generation. Topology models can be mapped to object types in simulation frameworks (eg, Modelica), thereby creating low-fidelity plant simulators to use in factory acceptance tests and to train operators.
- Root-cause analysis. The operator can query plant topology models to investigate the root causes of anomalies [2].
- Alarm management. Cascades of alarm messages in an industrial plant may overload human operators; plant topology models can be used to limit such "alarm floods."

CAYENNE Topology Editor

A recent ABB research project has implemented a prototype software tool called "CAYENNE Topology Editor" to demonstrate the possible automation of engineering tasks using plant topology models. The tool supports the creation of plant topology models from DEXPI XML files, from Microsoft Visio P&IDs and from proprietary SmartPlant P&ID exports →03. In brownfield projects, topology models can also be derived from existing 800xA process graphics, which contain coarse-grained topological information. Users can inspect and edit imported topology models visually.

The CAYENNE tool provides a control-logic generator that can synthesize interlocking logic from the topology models. A rule engine supports the generator and applies predefined, domain-specific rules to topology models in order to generate the control logic. For example, if a level indicator on a tank issues a "low" alarm, a pump on an outlet of this tank is stopped. The rule engine traverses the topology model and searches for the pattern encoded in the rule. Once a match is found, it retrieves the relevant tag names and generates the required control logic, conditionally linking the alarm condition signal for the cause to the control signal relating to the effect. The tool supports the generation of System 800xA Control Builder M control diagrams and function block diagrams. In addition, IEC 61131-11 Structured Text can be generated, as well as cause-and-effect matrices.

The CAYENNE tool provides a control-logic generator that can synthesize interlocking logic from the topology models.

CAYENNE process graphics generator

Also provided by the CAYENNE tool is a process graphics generator, which maps the layout imported from a P&ID to the shapes contained in an ABB System 800xA engineering library. This enables the partial generation of System 800xA process graphics, which can then be completed manually by an automation engineer. The tool supports generating equipment, instruments and pipes. The positions and sizes of the shapes are preserved, which involves translating between the graphical coordinate system of the topology model and the process graphic. This mapping can be customized for different System 800xA engineering libraries so that their specific shapes can be displayed in the process graphics. This procedure has been demonstrated for the System 800xA "standard" library and the

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03 Topology engineering: from P&ID via topology model to control logic and process graphics.

"reuse" library that is normally used for oil and gas plants.

Integration with AUCOTEC's Engineering Base
The CAYENNE Topology Editor has been integrated with AUCOTEC's Engineering Base tool – used by ABB in greenfield projects – as a prototype. AUCOTEC is currently implementing a DEXPI XML importer for Engineering Base, which will enable ABB's Plant Data Processing (PDP) Tool to be combined with a topology model. The CAYENNE Topology Editor can generate process graphics from Engineering Base as well as create interlocking logic that "glues" together the function blocks generated by the tool.

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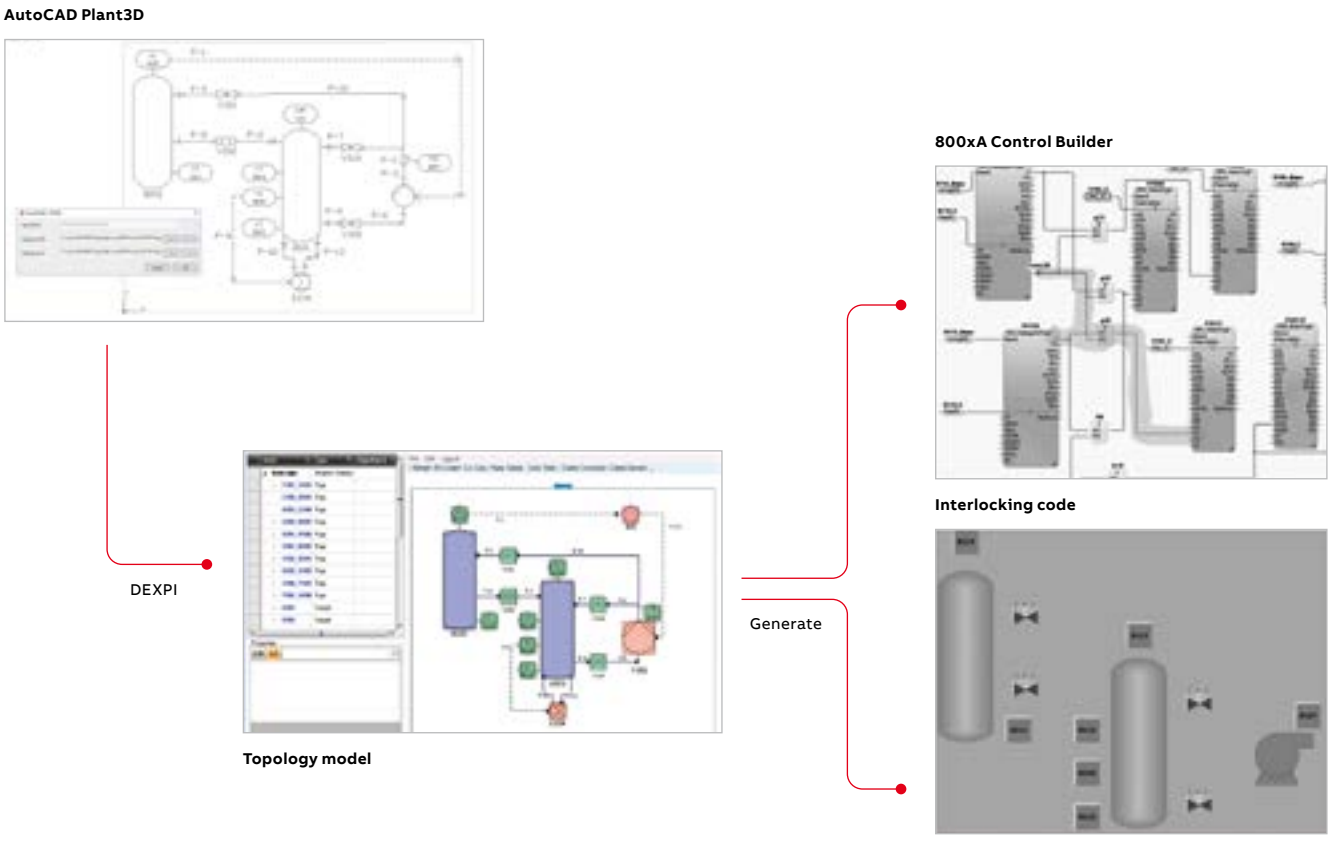
ABB conducted four retrospective studies on specifications from automation projects already in operation.

Case studies
To evaluate topology engineering and to investigate if the CAYENNE Topology Editor could have sped up engineering, ABB conducted four retrospective studies on specifications from automation projects in plants already erected and automated [4]:

- A mid-sized fertilizer production plant in South America with around 1,000 I/Os →04. The evaluated plant segment contained 18 vessels, eight pumps and a reactor.
- A fuel production plant (4,000 I/Os) in South America.
- An oil separation process (400 I/Os) in the Middle East that featured separation vessels, instrumentation and a sophisticated piping structure.
- An upstream oil production process (7,000 I/Os) in South America →05. This process included a large number of parallel, similar pipelines and instrumentation, so only a selection was analyzed.

For each case, a research team analyzed the EPC plant specifications and selected a representative plant segment, which consisted of 10 to 20



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04 The specifications for this fertilizer production plant were used to test automated engineering using topology models.

P&IDs per case. Afterward, topology models for the CAYENNE Topology Editor were created. As the P&IDs were only available as PDF files, this work required the redrawing of the P&IDs in formats supported by the CAYENNE tooling. For example, the research team created Microsoft Visio P&IDs based on the PDF files, which took roughly one day per case. Once EPCs export their P&ID files in the DEXPI XML file format, this step can be omitted. Importing the created files into the CAYENNE Topology editor yielded the required topology model.

Afterward, the research team analyzed around 50 to 100 interlocks per case, specified in cause-and-effect matrices. For each cause/effect pair, the connecting process topology path within the P&ID was looked up. By comparing this part to the path of other cause/effect pairs, generic interlock concepts were identified and encoded as rules. For example, a commonly observed pattern was that if a pressure sensor raised a "high" alarm, a preceding valve needed to be closed. For many interlocks the generic rule needed to be defined only once and could later be applied multiple times. If these rules had been available before the project, the cause-and-effect matrices could have been generated to a large extent using the CAYENNE Topology Editor.

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Based on the case studies, the estimated cost savings for process graphics generation are even higher – around 50 percent.

In total, 91 percent of the interlocks in the case studies could be generated by rules. The case studies yielded 92 interlocking rules in total, 73 percent of which were classified as "generic," meaning that they would likely apply in other plants. The remaining 27 percent of the rules contained plant-specific patterns that may hold only for very similar plants; the effort expended on these is only justified if they occur numerous times within the plant.

A few (7 percent) of the rules were applicable across all four case studies. The reason for this low percentage is the plants' heterogeneity: Where, for example, fertilizer production mainly concerns level measurements, the upstream oil production almost exclusively concerns pressure measurements in pipelines. Selecting cases with greater similarity (eg, five fertilizer plants) would likely increase the cross-case reuse of interlocking rules significantly.

Estimated cost saved by interlock generation and the elimination of manual coding and testing is around 15 percent of the overall effort for control logic engineering. Human error sources

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05 Upstream oil and gas production: Many interlocks could be generated based on topology models for an installation such as the one shown here.

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are also removed. Based on the case studies, the estimated cost savings for process graphics generation are even higher, at around 50 percent.

A significant step toward automating engineering

Topology models are key elements for automation of engineering tasks for ABB's System 800xA, ABB Symphony Plus Operations and ABB Freelance. All major vendors of CAD tools are working on support for the recently developed DEXPI XML standard for PIDs. Topology models extracted from these diagrams enable partial control logic and process graphics generation and have been used to generate plant simulators for operator training in the past. To reap the benefits of topology models, more case studies need to be conducted to improve tooling and concepts. The required software tooling will be optimized for usability and integrated into other engineering tools. This step will take the automation industry a long way down the road to fully automated engineering. •

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Topology models are key elements for automation of engineering tasks.

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AUGMENTED OPERATOR FOR EFFICIENCY AND CONSISTENCY

Smooth Operation

Created to identify, unravel and demonstrate how to resolve potential problems with confidence, the Augmented Operator supports operators to achieve performance excellence by drawing on vast available data and artificial intelligence capabilities.

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Control room operator actions have a significant and direct impact on uptime, product quality and production output as well as safety; basically on all aspects of industrial plant performance →01. To ensure consistent and efficient operation, operators can now draw on the vast amount of available relevant industrial data.

By combining data with deep learning models, profound and transformative opportunities are possible. Recognizing these possibilities, ABB has taken the initiative to develop analytical tools to get the most out of this data.

The Augmented Operator project was initiated in 2020, thanks to a long term association between the oil and gas company, OKEA, and ABB, with the aim of supporting plant operators to achieve operational excellence. ABB developed comprehensive and easy-to-use decision-support tools using deep learning and transformer models, process mining, graph search and causal analysis methods. These tools access and analyze existing data sources such as historical process, alarm and event data, audit trails, engineering documents, standards, and safety procedure. In this way, ABB's Augmented Operator will help operators to grapple with and resolve abnormal plant situations. Successfully field-tested on data accessed from Norway's OKEA oil platform, Draugen, ABB's Augmented Operator meets the strenuous requirements of real-world industrial settings.

The Augmented Operator workflow
Using artificial intelligence (AI) capabilities, ABB's Augmented Operator workflow was designed to answer five crucial questions every plant operator faces →02:

- Is anything wrong?
- Why does it go wrong?
- What can be done?
- Will it work?
- Has it happened before?

Is anything wrong?
To determine if anything is amiss, the Augmented Operator uses deep learning models, with Long Short-term Memory (LSTM)/Recurrent Neural Networks (RNN) and Convolutional Neural Network (CNN) and Autoencoders, trained on process data to support operators in monitoring. These models are capable of detecting deviation

—
The Augmented Operator project, initiated by OKEA and ABB, aims to support operators to achieve performance excellence.

– signatures of potential undesired behavior in the process – early enough to allow operators enough time to intervene and prevent a system shutdown. In addition to timing, the ease of access of such information is essential. Hence, the deep learning models are created in a way that enable customer self-service; the input signals of the models are derived from operator screens and process topology. The Augmented Operator can also highlight the tags that are

Control-room operators must take critical decisions impacting complex systems.

Augmented Operator is an ABB tool that uses AI to guide operator decisons.

The tool was successfully implemented on an oil platform.

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01 The Draugen oil platform, operated by OKEA in the Norwegian Sea.

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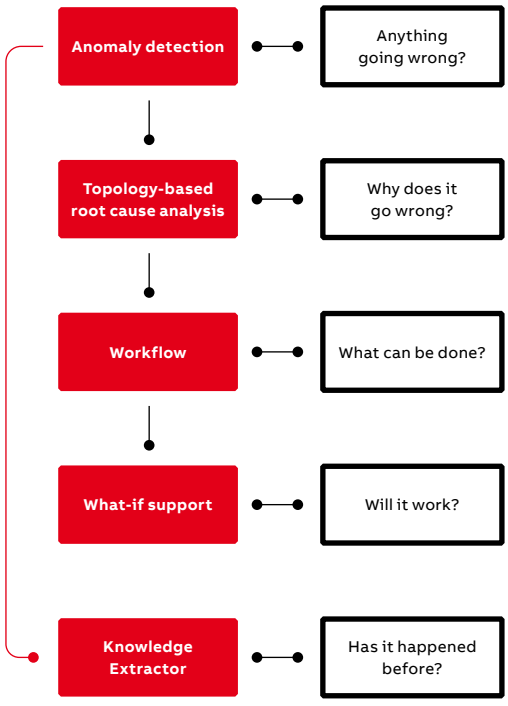
02 The Augmented Operator workflow, illustrated here, supports operators in dealing with abnormal situations.

responsible for the current anomaly so that users can take specific actions accordingly.

The detection of anomalies in process data is the entry point of the Augmented Operator workflow →02. When early signatures appear, they will be detected as an anomaly by the models. Relevant information about the anomaly will also be provided to the operator, eg, what the operator can do to prevent the anomaly from developing into more severe problems or to mitigate the impact on the process. The information will also be communicated to other functions of the Augmented Operator.

In order to circumvent interoperability issues, the Anomaly Detection functionality was designed to be compatible with ABB's digital tools →03 and has been onboarded onto ABB's Genix™ Model Fabric. Here, it can receive time series data, calculate the contribution of the anomaly indicator and the process variables, thereby providing



02

information about the process performance in real-time →03.

Why does it go wrong?

Another advantageous feature is the root-cause analysis support function →03. Here, this function, receives the abnormal tags from the anomaly detection model and detects the process signals and actuators that are potentially related. It analyzes the existing engineering artifacts, including various diagrams and the process topology model among others, and the operation information. In addition, live- and historical event and alarm data and variables are used to derive the context for a set of triggered alarms. The produced result is a novel presentation of alarms, plus detected anomalies, with contextual enrichment, including the dependency relationships based on the topology model of the process, or the plant, and the chronological ordering of all related alarms →04. Such features help to reduce the operators' manual challenge of actually finding the necessary information and mentally capturing the information during his/her analysis [1-3].

ABB's solution relies on Transfer-entropy to statistically confirm the presumed causal relationships derived from the plant topology model. The system highlights those actuators identified as the process variables, within the process model, that have the most contributory influence on the undesired event. By highlighting these actuators, the operator can more easily decide how to amend an undesired situation.

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03 A diagram that illustrates the anomaly detection and contribution-based root cause analysis.

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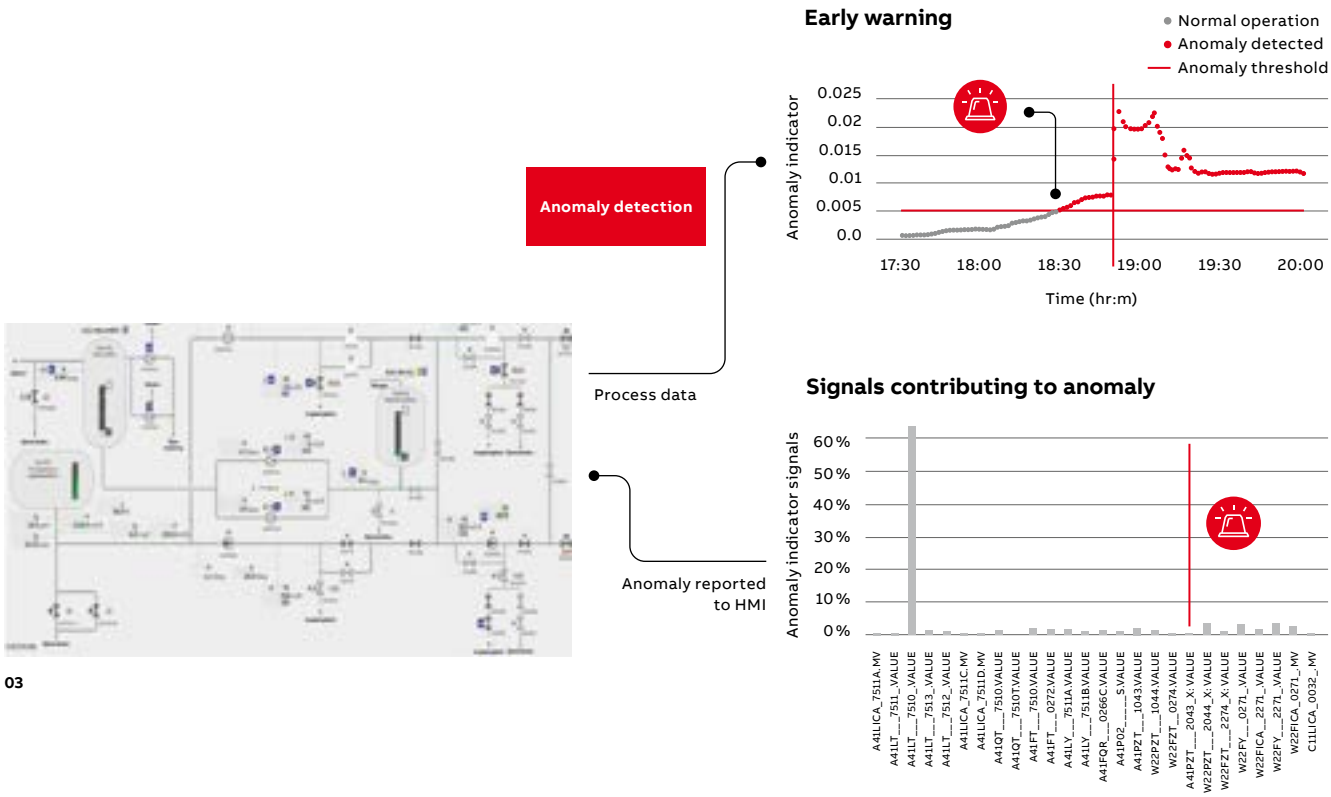
04 Topology-based Smart Alarm List screenshot is shown.



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05 A control room setup at the Draugen oil platform; ABB envisions that such control room operations could benefit from the Augmented Operator.

By ascertaining the causal relationships, the operator can troubleshoot and resolve problems with ease.

What can be done?
Not only must operators unlock potential problems that arise, they must discern what they can do to rectify or modulate difficulties →05. Because the Augmented Operator learns from previous historical operator actions and can generalize this knowledge into workflow documents, operators can now decide how best to deal with any problematic situation.

While expert operators probably know which actions are required under most circumstances, except perhaps for unusual and difficult situations, novices might even find routine situations taxing. The Augmented Operator supports all operators, experts and novices alike, with blueprints for process amelioration from the workflow documents.

The plant historian records an audit trail of the operator's interactions within the plant. This log of interventions is used to learn how operators have previously interacted with the plant. The log includes hints as to the opening- and closing of valves; overrides of systems and set point changes. By analyzing the temporal flow of the historical actions, reaction times and waiting times between actions can also be extracted. Using this information, workflow mining techniques allow blueprint processes for different plant situations to be extracted →06. Common situations that can be analyzed via this process are alarm response activities, and startup- or shutdown of components – fostering operator decision-making →06.

Will it work?
Just providing operators with possible steps that enable blueprints for various plant situations is not enough to ensure smooth operations under anomalous situations; the operators must be convinced that their actions will work. The Augmented Operator provides this certainty.

Once a possible course of action is identified from historical operator actions, operators can test this procedure for any undesired side effects using a "what-if" tool. This highly desirable feature allows operators to test actions such as set point changes or actuator positions, before implementing them in the real-world system.

It must be noted that there are benefits and challenges associated with such a tool. Although, process simulators appear to be the perfectly matched tool for such functionality, complexity can be an issue for some industries. For processes of moderate complexity, as typified by the chemical, oil and gas industries, such simulators achieve only a speed-up factor of 5- to 10-fold compared to the actual real process. If a process takes around one hour to settle after an action is implemented, then the operators must wait between 6 and 12 minutes to initiate a response. Such a response time duration is simply too long to allow the operator to test several alternative action courses in an interactive and iterative fashion – a potential disadvantage that could, in certain cases, increase risk.

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By combining data with deep learning models, ABB recognizes that profound and transformative opportunities are possible.

To obviate the short comings of first-principle-based process simulators, machine learning-based surrogate models have been developed for the Augmented Operator workflow. The key here is to capture the process

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06 Stages of the the Workflow Mining Process including the steps and related components that enable blueprint processes for various plant situations.

transitions correctly, including aspects like overshot/undershot with regard to alarm limits or the time-lapses that occur until steady-state is reached following the implementation of an operator action.

Testing the "what if" model approach

The Augmented Operator system approach has now been applied to the Norwegian OKEA Draugen Oil Platform →02 using its 800xA Simulator system and the availability of rich historical data gathered from the collaborative operation center. The previously described what-if model was tested using specifications given by the Draugen operators. The objective was to capture operator changes made to the rotation speed (RPM) of one of the main pumps in Draugen's water reinjection systems; and to predict, ten minutes ahead, the impact of these RPM changes on the related trip signals encountered in the downward flow to the well. For this purpose, a Deep Neural Network (DNN) with a LSTM architecture was

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Relying on AI capabilitites, the Augmented Operator's workflow was designed to answer five crucial questions.

trained to predict the platforms' response to changes in RPM →07. Such Deep LSTM Neural Network architectures have proven suitable for multi-dimensional time series forecasting using, eg, Tensor Flow, because they can keep a context of memory to attack temporal and spatial problems. The successful run of the model in a real-world environment – an oil platform – lends credence to the efficacy of this tool in moderately complex process industrial environments.

Has it happened before?

The Knowledge Extractor of the Augmented Operator provides an alternative way to gain further valuable insights into possible plant incidents and to perform scenario studies by analyzing similar past situations →07.

Consider an incident in which an operator observes that water and oil level set points in a scrubber are too close, thereby leading to strong interactions. The operator might wish to know if this happened previously. Currently, (s)he will investigate shift logs and previous trips to compare similar events; this is a manual and cumbersome process. The Knowledge Extractor component enables operators to snip a part of the trend that is of interest and to search for similar set point changes in the process data that occurred previously →08.

The Knowledge Extractor also allows fast access to written documents eg, incident reports, routinely received from service engineers, analysts, and other engineering firms, by posing natural language questions such as "What should be done if the oil and water level set point are too close in the scrubber?".

Building and testing the Knowledge Extractor

The Knowledge Extractor uses time-series-based pattern mining techniques to perform similarity searches to find particular scenarios of interest from the process history data →08. Moreover, deep learning models were used to understand natural language, especially the intent behind words. For this purpose, pre-trained deep Natural Language Processing (NLP) models that are based on the latest Google publications [4,5] were fine-tuned to generate a novel contextual question-answering system. The research team at ABB developed multiple prototypes in order to answer the questions posed to the system.

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07 An illustration of the experimental process in which the DNN with a LSTM architecture was trained and validated.

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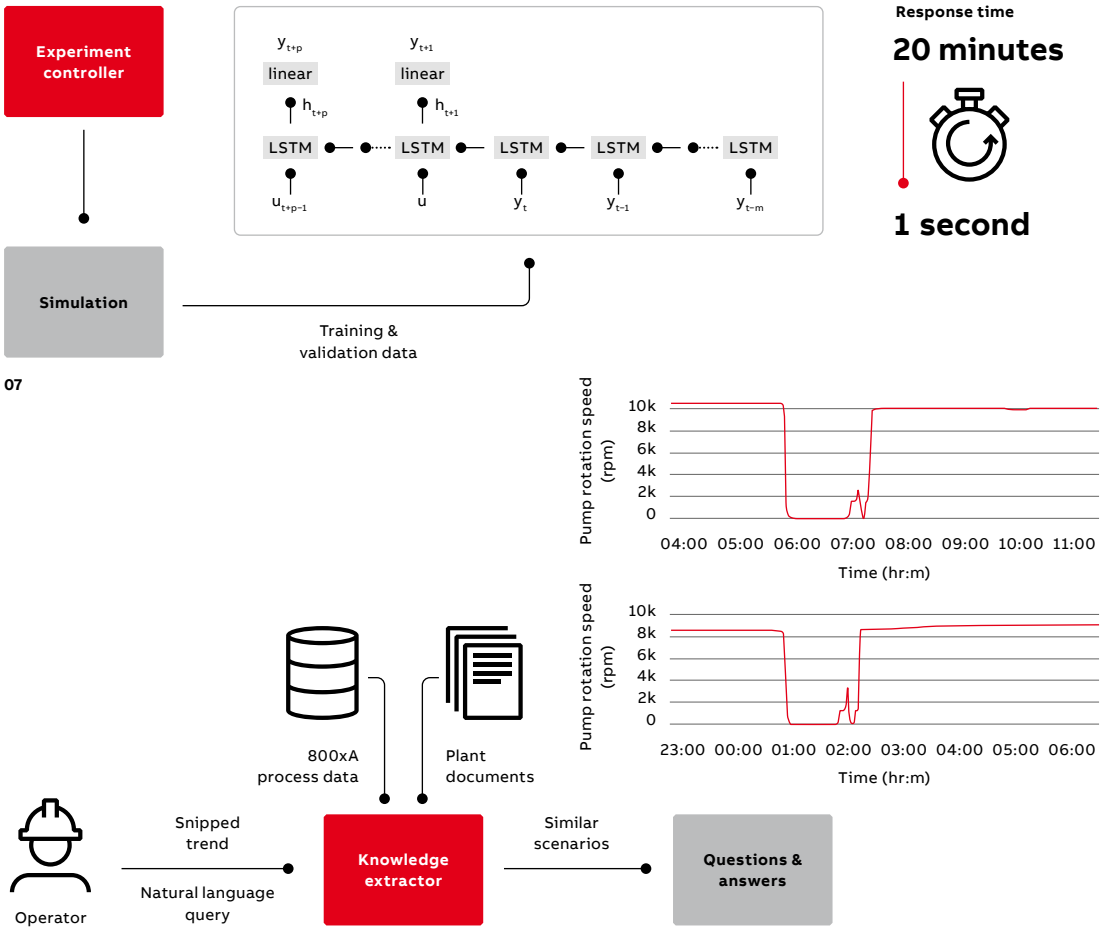
08 A diagram that illustrates how the Knowledge Extractor functions using natural language queries to search for contextually similar scenarios via NLPs.



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This prototype was tested on the trip data from the real-world Draugen oil platform where it was applied to specific scenarios. For example, whenever gas pressure increases over a specific threshold, the pump trips, and the level of the feed-water rises in the degassing tank. Relevant trip data was generated whenever an operator restarted a pump multiple times after a trip occurrence. By using the Knowledge Extractor tool, similar trip scenarios could be identified from the historical process data →08. Moreover, the ability to pose natural language questions and access tuning service reports from previous years enabled operators to determine that low suction pressure caused the multiple pump trips.

By designing Augmented Operator to address five crucial questions, ABB has created a tool that will not only be able to access vast amounts of data, identify and analyze anomalies, past and present, but also provide solutions for operators that will work. Aptly demonstrated and validated on a rich data set supplied by OKEA, ABB's innovative solution has proven its viability in real-world industrial environments. •

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Tested and validated on the Draugen platform, Augmented Operator has demonstrated its viability in the real-world.

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STRETCHING THE LIMITS OF MEASUREMENT

Know your strength

In a cold rolling mill, measuring and controlling the thickness of aluminum metal strip is as important as it gets. ABB's Millmate thickness gauging (MTG) system does this accurately, dependably and safely. With the novel High-pass Mode option, customers will soon be able to read high frequency thickness variations of thin aluminum strip (0.6 mm – 0.1 mm) for use in feed forward control.

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01 The gapless gauge head with nothing above the pass line to obstruct the passage of the strip can be installed below the mill table for protection during threading, tail out and strip breaks.

Control of aluminum thickness in a rolling plant assures quality and reduces waste.

ABB's Millmate uses pulsed magnetic fields to provide accurate measurements.

The system performs in harsh environments to high specifications.

Lightweight, strong, highly reflective and recyclable, aluminum is ideal for many consumer and industrial product applications. Its use can lower energy costs and reduce CO_2 emissions that are so crucial in today's market [1]. It is no wonder that aluminum sheet metal is in high demand, eg, as packaging material and for can production; for transportation vehicles especially for body-in-white for cars, eg, Ford's F-150 model, etc. [1]. For instance, the North American lightweight material market is estimated to grow dramatically between 2020 and 2025 with aluminum expected to capture the highest market share in terms of value [1]. However, achieving a specific aluminum end-product demands producers to control the chemical composition, work hardening and thermal history of aluminum, or alloy, and its thickness.

To this end, aluminum cold rolling mills require thickness gauging systems that are dependable, safe, robust, compact, and accurate; they must also operate in a harsh and spatially restricted environment. The capability of minimizing thickness deviations during the rolling process is critical. Although this may seem easy to achieve, it is actually dauntingly difficult.

Committed to developing the best possible gauges for measurement and analysis, ABB has engineered the unique gapless MTG Box Gauge system →01 with Pulsed Eddy Current technology (PEC) →02 to determine both resistivity (between 27 nΩm and 65 nΩm) and true strip thicknesses (0.5 mm – 8 mm) for aluminum and clad aluminum [2]. Despite this amazing achievement, ABB

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In cold rolling mills, tighter thickness tolerances can mean higher efficiency and access to additional markets.

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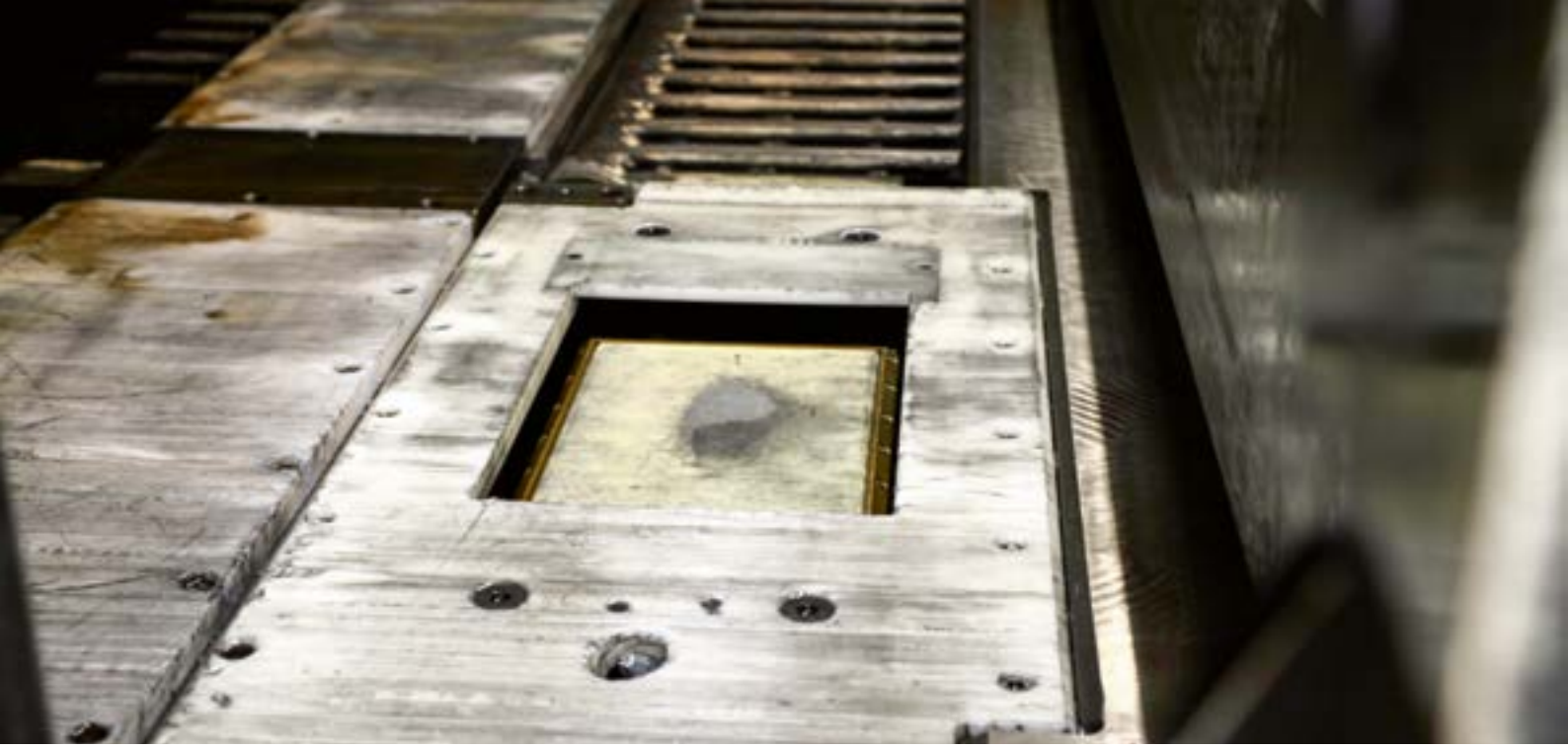
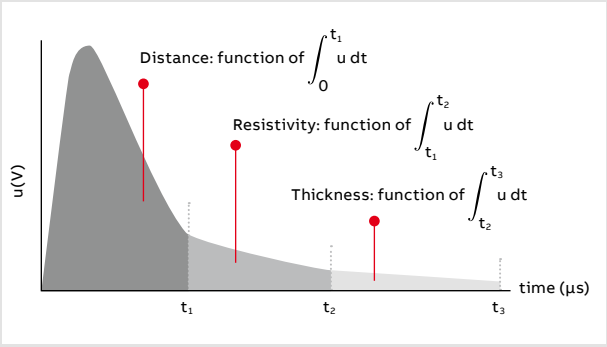
continues to push the limits of thickness measurement. With the new High-pass Mode option that calculates thickness variations for thin aluminum strip (between 0.6 mm and 0.1 mm) customers will be able to measure fast thickness variations for use in feed forward control under specific conditions.

The rolling process and keeping thickness in-line
During rolling, metal is subjected to intense pressure and tension in a harsh environment (in the presence of dust, steam, emulsions or other fluids);



02

THE PEC OPERATING PRINCIPLE – THE BASIS FOR MTG'S SUCCESS



ABB's PEC technology is based on a revolutionary principle and is critical to the success of the MTG system. This patented PEC technology allows thickness, resistivity and distance between the sensor and the material being measured to be determined at different times [2]. A pulsed weak magnetic field is generated by electric coils placed in the box gauge head just below a cover plate. After the abrupt interruption of the constant excitation current fed to the coil, the magnetic field produced by the eddy currents in the metal sheet is measured by the voltage it induces in the coil. By tracing the entire penetration sequence via the voltage induced across the coil, this unparalleled process allows three unique signal values at three different times to be derived: the distance, the electrical resistance and the thickness. Thus, the MTG gauge sensor determines true thickness independent of alloy content accurately, with a low signal drift, dependably and safely.

03

shape and thickness are altered through rolling and stretching to reach the final size and thickness. As the metal is rolled, the speed increases to compensate for the change in thickness. Creating the right balance between the reduction due to the force of the mill and the reduction due to extruding the material through the gap is crucial; if the process is off-balance even slightly, the metal strip could break or cobble with disastrous results. Thus, thickness gauge systems must control thickness within tight tolerances while the material moves through at varying speeds; thereby ensuring maximal productivity and minimizing costs associated with non-conforming strip. In cold rolling mills, where aluminum sheet is produced to exacting thicknesses, and production continuing around the clock, tighter thickness tolerances can mean higher efficiency and access to additional markets. For instance, the high-volume production process used for deep drawing cans in the aluminum can market has extremely tight tolerances; producers require a strip thickness deviation of only a few µm for a strip thickness of 200 µm for the entire strip (lengthwise and widthwise).

ABB has developed the MTG, with PEC technology to measure true thickness with outstanding accuracy and dependability in this harsh and challenging mill environment →01.

MTG – gapless gauging for aluminum strip
With many competitive advantages over conventional radiation-based gauges for aluminum thickness measurements, the MTG family of gauges is gaining acceptance worldwide [2]:

- **Robust and compact design**
  The aluminum-bronze gauge housing has superior chemical and mechanical properties

— 02 Because it measures independent of environment, the MTG gauge can be located close to the roll gap, even interstand. Covered by heavy-duty fiberglass reinforced epoxy plate, the electric coil in the MTG gauge head is protected from impacts and shocks originating from the metal strip.

— 03 The PEC response, generated by a small magnetic field, is only influenced by thickness and resistivity; this allows the MTG gauge to measure true thickness independent of environment.

— 04 The schematic illustrates the procedure by which the High-pass Mode measures thickness variations for thin aluminum strip.

that protect the gauge from the harsh mill conditions →01.

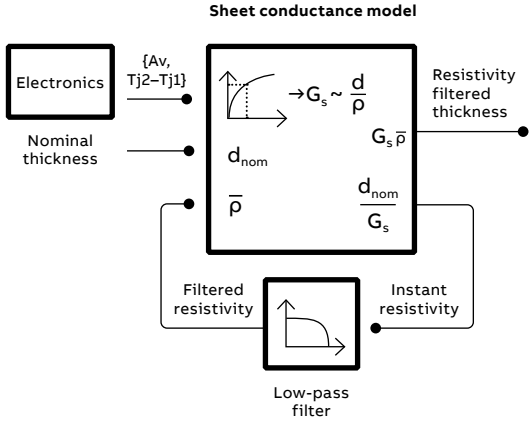
- **Gapless**
  The gauge is gapless, with nothing above the pass line that can obstruct the strip passage →02. Consisting of one sensing element box, the MTG Box Gauge head can be installed below the mill table for protection during threading, tail out and strip breaks.
- **Alloy independence**
  Amazingly, the PEC sensing technology measures true thickness independent of material composition →03 with no need for alloy compensation.
- **Independent of mill environment**
  The gauge is insensitive to anything, eg, coolant, steam or dirt, except for the metal strip in the measuring zone and is therefore ideal for interstand applications.
- **Tight thickness tolerances**
  Alloy chemical variations will not influence the alloy independent MTG gauge. The harsh environment (eg, lubricants) will not impact the measurements either. With an accuracy, in the mill, of +1.5 µm ±0.05 percent, metal strip producers can form the desired thickness at the tolerances demanded.
- **Safe for humans and the environment**
  Because the MTG gauge does not rely on radiation-based technology, health and environmental concerns are eliminated. No restricted areas are required, nor is it necessary to dispose of radioactive waste.
- **Infrequent and rapid calibration**
  The gauge arrives calibrated along with 12 calibration plates. Once in use, calibration is performed every six months and can be conducted in only 20 min. The calibration plates ensure that the gauge measures absolute thickness and thickness deviations according to traceable standards.
- **Negligible costs for maintenance**
  Without fragile or aging components, radiation sources or detectors, high voltage transformers or precision mechanics, the MTG gauge is nearly maintenance-free.
- **Increased mill production time**
  Gauge measurements are material-independent so there is less downtime due to reduced need for calibration and maintenance.
- **Short and competitive return on investment (ROI)**
  By reducing mill downtime, non-conforming material, maintenance, need for spare parts, frequent calibration and security requirements for radiation-based technology, the MTG is a cost-effective alternative to radiation-based devices, with a short ROI.

Stretching the limits

In operation for over 15 years, the MTG with PEC technology allows strip producers to meet tight tolerances and replace their X-ray and contact gauges to improve their competitiveness for standard aluminum strip production. But, what if the measured signals of the MTG gauge could be used to measure thickness of very thin standard metal strip (thicknesses as low as 0.1 mm)? Currently, radiation-based gauges, X-ray and Beta-gauges can measure in this range with high

— The MTG Box Gauge system with the revolutionary PEC technology determines resistivity and true strip thicknesses for aluminum.

speed/low noise. The mechanical contact gauges and the MTG C-frame gauge, with a rather small gauge gap, can also measure accurately in this range but only at the strip edge; no center measurements are possible. Most significantly, the safety and environmental costs associated with radiation-based gauges and the impracticality of mechanical gauges make these methods disadvantageous for aluminum strip producers.



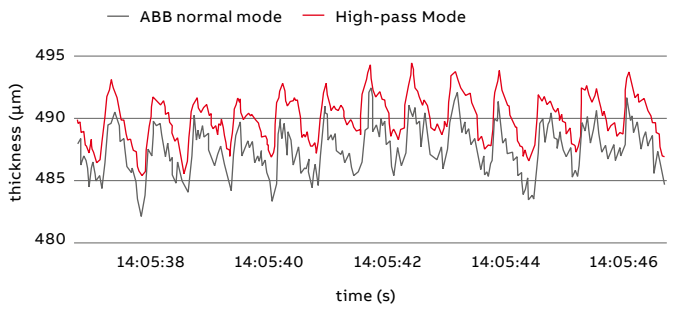
G_s Sheet conductance
d Thickness
d_{nom} Nominal thickness
ρ Resistivity
$\bar{\rho}$ Mean resistivity

04

High-pass Mode

Always exploring ways to meet producer's needs, in 2019, ABB's researchers began investigating a MTG gauge function for thin strip aluminum measurement. Although absolute thickness cannot be directly measured for thin strip, ABB created an option that will, under specific conditions, determine thickness variations at high frequency (faster than 0.024 Hz), for thicknesses between 0.1 mm and 0.6 mm, and with a high signal-to-noise ratio: the High-pass Mode option [4]→04. Nonetheless, certain conditions must be met for the high pass filtered value of thickness to be calculated:

- Because persistent thickness changes that last more than 10 seconds will be zeroed, this function is only possible for use in feed forward control (interstand or entry side).
- The relative variation in resistivity of the material must be less than the relative variation of the thickness because in High-pass Mode conductance, which is the reciprocal of resistivity, reflects thickness →04.



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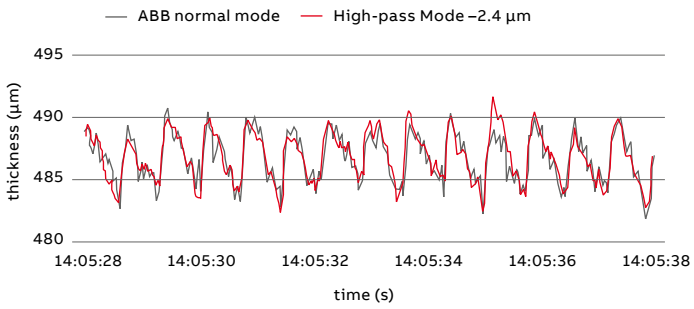

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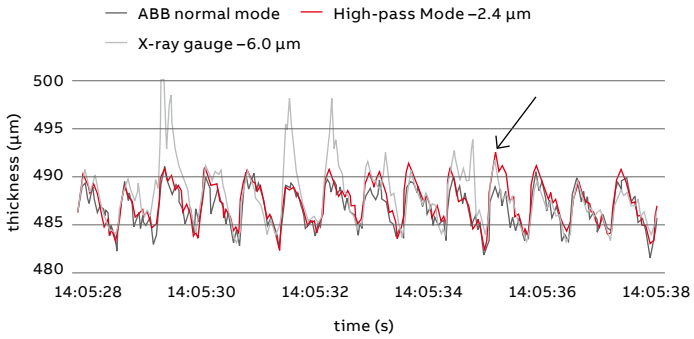


05c

- For the signal to indicate thickness variations accurately the nominal thickness must be close to the actual average thickness.
- Because only rapid thickness variations are measured, any slow variations will not be detected.

The path to thin strip measurements

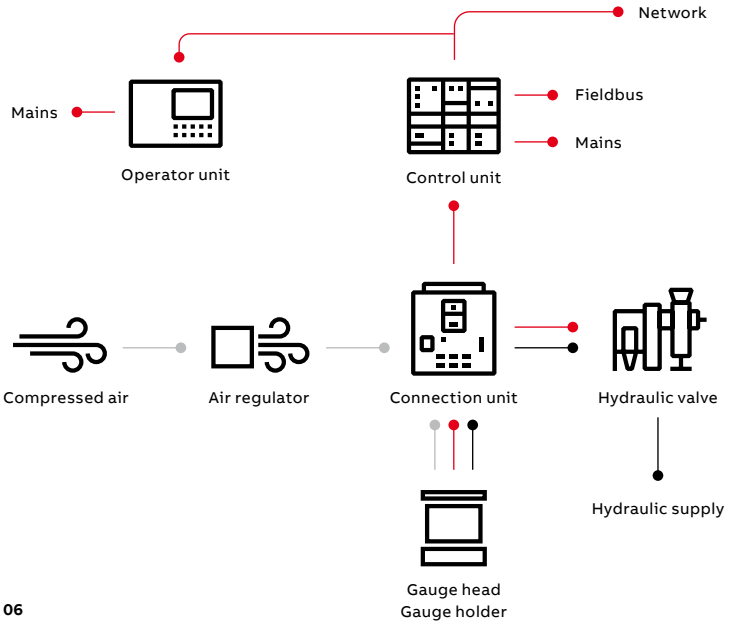
ABB's innovative High-pass Mode will provide customers with a practical measurement option for gapless gauge measurement of deviations in thickness of thin aluminum strip. The signals are insensitive to the environment eg, lubricant, dirt or other non-conductive materials. The sound theoretical basis and rigorous testing demonstrate that slight variations in alloy content have, in practice, a negligible effect on the measured thickness.

A comparison of ABB's Box gauge thickness variations measured in normal operating mode with those of the High-pass Mode for a thickness of 490 µm was made →05. Although the MTG gauge measures true thickness independent of alloy composition, this becomes increasingly difficult as the strip becomes thinner due to the physics of electromagnetism. In this test case, the MTG gauge measures close to the lower limit of the method, which is slightly less than 0.5 mm, and therefore produces a measurement with greater fluctuations than comparable measurements generated by the High-pass Mode for a strip with a thickness of 490 µm →05a.

However, the High-pass Mode does not measure absolute thickness, its signal variations are centered around the nominal thickness of the strip being measured. Nonetheless, a close correlation exists between the thickness variations of the High-pass Mode and the normal MTG Box gauge output when the mean resistivity is filtered using a 10 s running average. Resistivity variations that are faster than 10 s will, however, contribute

ABB's High-pass option can determine high frequency thickness variations for thicknesses between 0.1 mm and 0.6 mm.

to a thickness deviation error in High-pass Mode. Here, a drop in resistivity lasting only 0.5 s was noted →05b. Such a decrease, 0.4 nΩm (0.7 percent), causes an erroneous increase in the thickness measured, 3.5 µm (0.7 percent), in High-pass Mode as theoretically expected →05b.



06

Comparison of the MTG gauge strip thickness measurements with measurements obtained from an X-ray gauge indicate that slight local changes in the alloy composition of the strip will also affect the X-ray gauge measurements →05c.

Such encouraging results not only corroborate the theoretical expectations, they demonstrate that ABB's High-pass Mode filtered thickness variations are comparable to those obtained from the MTG gauge and X-ray methods as long as the specific conditions are met.

The MTG system – working together for dependability and accuracy

The MTG system (gauge head, control and operator unit, air regulator, hydraulics and the connection unit) have been designed for ease-of-use, optimal function, dependability, connectivity and integration ability →06 and can be connected to Automatic Gauge Control (AGC) systems in mills for feed forward, feedback and mass-flow control. With multiple integration interfaces, eg, Profibus-DP fieldbus communication, network communication via VIP, OPC DA, and Modbus TCP, an operation unit (to adjust set-ups, thickness value and status information), Human Machine Interface (to view thickness deviations as real-time data and trends), diagnostics part for error information, etc. and a service part (for calibration, manual control function, and service–based use case) the systems is flexible and operator friendly and efficient.

Mounted on a vertically moving frame, the gauge adjusts automatically to the right measuring distance via a hydraulic positioning system; rapid positioning allows measurements to be made almost instantaneously, when tension comes on. In this way the thickness-controlled strip length can be maximized. Changes in the distance caused by small changes in speed or tension are corrected for automatically.

The integration of system components and outstanding capabilities of each device and unit allows metal producers to attain specified thickness within tolerances 24/7, safely, with negligible costs for maintenance. The MTG system with the gapless gauge and PEC technology enables accurate true aluminum thickness measurements. The material independence, environmental and safety benefits, and quick commissioning time results in increased productivity and higher yields for standard metal strip producers in a sustainable process [2,4].

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With the High-pass Mode option, producers will be able to control thin strip thickness deviations in feed forward control.

Thanks to ABB's new High-pass Mode option, producers will soon be able to control thickness deviations of thin aluminum strip in feed forward control, thereby enabling aluminum producers to meet the ever-increasing tolerance requirements and access new markets. •

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05 Results show the efficacy of the High-pass Mode in comparison with the MTG Box gauge and the X-ray gauge.

05a The input thickness measurement of a cold rolled strip (for 10 s) with a nominal thickness of 490 µm (actual thickness is a few microns less than the nominal thickness) with output signals is shown.

05b The resistivity decrease (0.4 nΩm) leads to an erroneous increase in the thickness measured in High-pass Mode by 3.5 µm (0.7 percent). The High-pass Mode signal has been compensated for the difference in absolute magnitude in order to make the comparison easier.

05c The small resistivity change measured in High-pass Mode also affects an X-ray gauge used to measure strip thickness. The thickness measured by the ABB gauge in normal mode is alloy independent, but not in the High-pass Mode.

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06 The MTG system is a smart measurement system designed for optimal commissioning, operation and service.

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A FORMULA FOR ACCELERATING AUTONOMOUS ANOMALY DETECTION

Teach and detect

Machine learning is becoming increasingly important in identifying anomalies and thus improving the level of quality control autonomy in process industries [1], [2]. But training such systems to identify meaningful deviations from normal data is often challenging because of a paucity of real-world examples.

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With a view to overcoming this drawback, Corys and ABB have combined two simulation technologies to create an environment that generates data that is remarkably similar to that produced by specific processes in real industrial plants. This new level of simulation accuracy opens the door to tailor-made, targeted and accelerated anomaly detection capabilities.

Industrial facilities need to run as smoothly as possible. To do so, indications of potential problems, such as anomalous vibrations, temperatures, pressures, and sounds need to be detected, identified, analyzed, and managed in their earliest stages. Anomaly detection, a key form of machine learning, can play a major role here by effectively supporting plant operators as they monitor the health of industrial systems.

Machine learning models, however, are typically trained using historical plant data. But as industrial systems are very robust, there are often not enough examples of real failure cases in the data to train reliable models. Moreover, even if some failure cases did occur, they are often hard to find in the data because they were not labeled as such by the operator, or because they were not noticed when they occurred. Furthermore, this state of affairs can lead to the mistaken identification of anomalous situations as being normal.

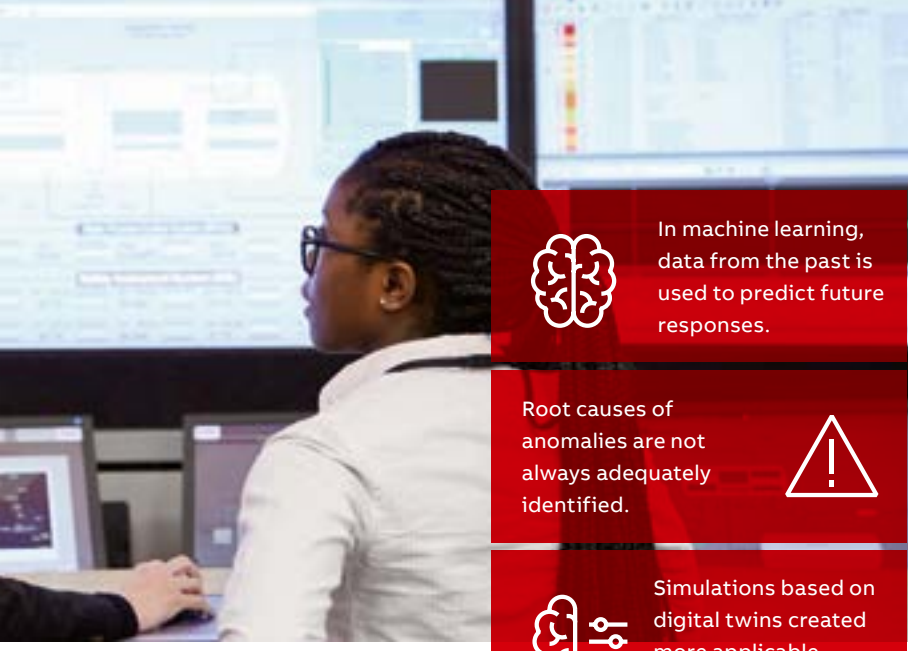
Creating an infrastructure for machine learning research

With a view to overcoming these drawbacks, data scientists are using high-fidelity process simulators, such as the Indiss Plus Simulator from Corys [1], to train machine learning models on specific normal and abnormal plant situations, such as, for example, valve failures, in order to correctly label such events.

For instance, Corys and ABB have created an infrastructure for machine learning designed to explore the potential – as well as the data requirements – of different algorithms in a realistic setup. →01 shows the experiment's infrastructure for machine learning research created by Corys and ABB. At the heart of the

A combination of simulation systems generates data that is remarkably similar to data produced in industrial plants.

infrastructure are the simulation tools of the two companies: Corys' process simulation Indiss Plus and ABB's control system simulator 800xA Simulator [3]. Individually, both tools have been proven to be highly accurate in several operator training projects. Now, in a combined configuration, the tools can generate a simulation of the behavior of a process and its associated automation system, such as, for instance, a real plant's control logic, including alarms and safety logic.



In machine learning, data from the past is used to predict future responses.

Root causes of anomalies are not always adequately identified.

Simulations based on digital twins created more applicable training data.

A key advantage of Indiss Plus in this setup is that it also opens the door to simulating various plant equipment failures, eg, a valve leakage as shown in →02. The resulting failure data can overcome the issue of not having a sufficient number of failure cases to support machine learning.

To create simulation data sets suitable for the training and validation of a machine learning model, the execution of simulation experiments must be automated. In the present case, an experiment controller was developed as shown in →01. The experiment controller takes in an experiment plan describing when to perform various operator actions like setpoint changes and when to trigger failures within the Indiss Plus process simulation. The experiment controller performs batches of experiments, starting and stopping the process simulation from different initial process states and automatically performing operator actions. It also starts the data collection that receives data from an 800xA Simulator, making it possible to use ABB's 800xA as a simulated control system in a simulator, with identical operator layout, view and control logic as in the plant. The data and a protocol of the actions performed by the experiment controller are stored in a time-series database and made available to a data scientist for the training of machine learning models.

Case study: Developing a machine learning model for anomaly detection

In the study described in this article, simulated datasets were used to train a model for anomaly detection that would be able to detect simulated device failures.

A feasible approach in machine learning for detecting anomalies in signal timeseries is to utilize so-called autoencoders [4]. An autoencoder is composed of two artificial neural networks,

Simulated datasets were used to train an anomaly detection model that could detect simulated device failures.

the first one learning to compress the data (encoder) and the second one learning how to reconstruct the compressed data (decoder). For the purpose of anomaly detection, the degree of

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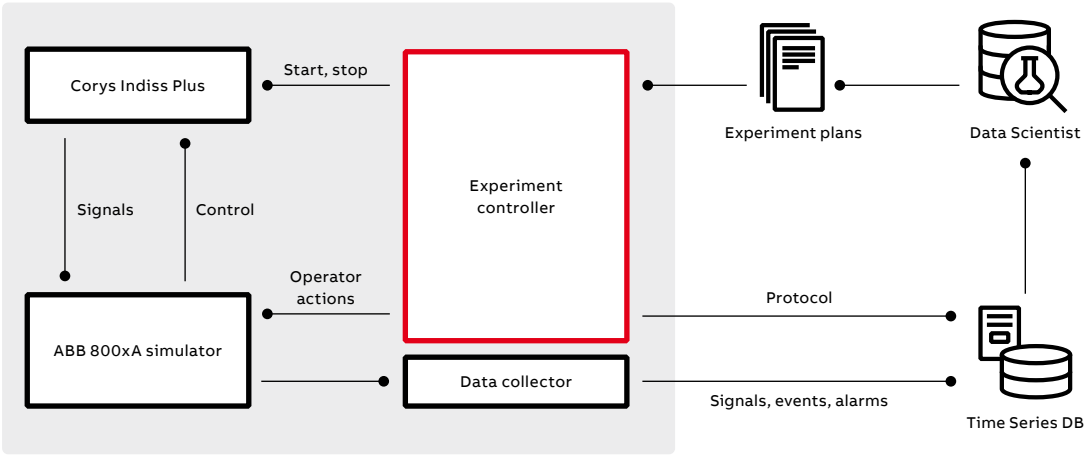
01 Data generation and collection infrastructure.



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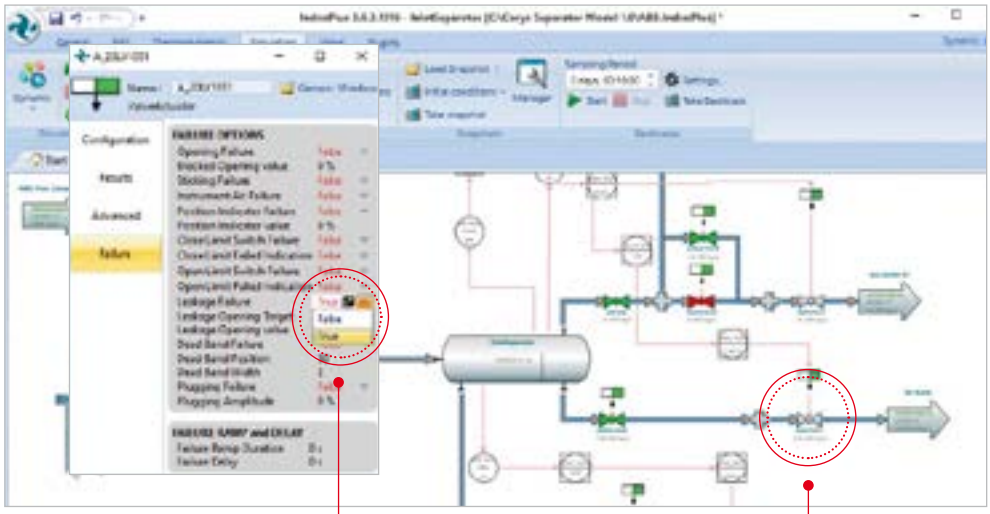

02

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02 Simulation of a realistic plant equipment failure using Indiss Plus (here: a leakage of the selected valve).

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03 Separator vessel in a three-phase separator process.

error indicated by the reconstructed data is used to measure how abnormal the data is.

For the purposes of the current study, Indiss Plus from Corys was used (a high-fidelity process simulator). Here, Corys had implemented a high-fidelity simulation model of a three-phase separator process that is typically used in oil production. The core component of this process is a separator vessel that segregates fluids from a well into three outputs: oil, gas, and wastewater. In order for the separator to function properly, it is important to maintain the oil, water, and gas levels in balance. This is performed automatically by the control system by adjusting several valves →03. If a setpoint in one of the levels is changed, the system will adjust the other valves automatically to keep the whole separator in balance.

The above-described simulator was used to train an autoencoder to detect a physical valve failure such as a valve blockage or leakage. Such failures are often difficult to detect by operators, particularly if they are not represented directly in an HMI, which can occur eg, if sensors for detecting these failures are missing. The idea was to train an autoencoder that learns the signal trends from the three-phase separator process during normal operation, ie, when there are no failures. The trained autoencoder was then applied to try to reconstruct the trends for different simulated device failures.

In the current evaluation the autoencoder was able to detect device failures as anomalies because the signal trends that represent these failures had not previously been seen by the autoencoder during model training. This led to a relatively high reconstruction error. When the error was higher than a predefined threshold, the autoencoder classified this situation as anomalous and reported the anomaly to the user. As shown in →04, this anomaly threshold was exceeded exactly at the time of the device failure; but when the failure was removed in Indiss Plus, the reconstruction error from the autoencoder went back to normal. When an anomaly is detected, a subsequent step is to locate its potential root cause. In →04 the root cause was found to be in the oil valve.

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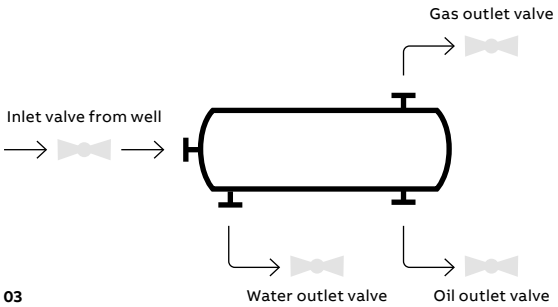
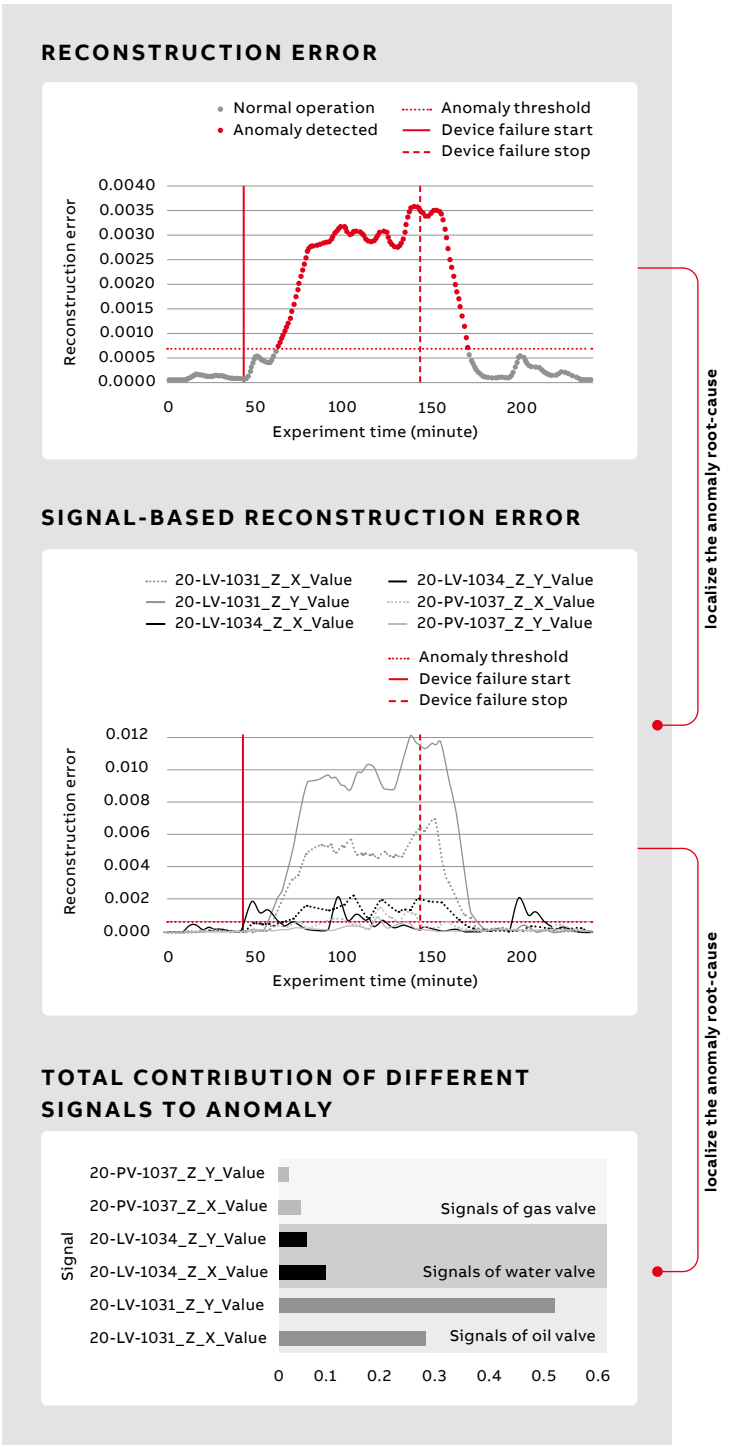
A simulator was used to train an autoencoder to detect a physical valve failure such as a blockage or leakage.



03

Toward hybrid digital twins

The research described in this article outlines how ABB and Corys have worked together to create an infrastructure for reproducible machine learning research. The Corys Indiss Plus and ABB 800xA Simulator tools create an environment



04

that produces data that is remarkably similar to that produced by real industrial plants. The key difference is that machine learning scientists have full control of the data generation and can test and evaluate their approach in a sound and comprehensive way. The combination of high-fidelity simulation based on first-principle models and machine learning enables the creation of plant digital twins composed from different types of models that can be leveraged

—

Hybrid digital twins hold the promise of becoming a key enabler of future autonomous industrial plants.

depending on the different types of functionalities the digital twins should deliver to the various plant stakeholders, ranging from operators to plant managers. Such hybrid digital twins hold the promise of becoming a key enabler of future autonomous industrial plants.

The logical next step in this research will be to test the machine learning infrastructure described in this article in a simulation of an actual customer plant. This will make it possible to investigate the potential benefits of machine learning models that have been pre-trained using simulation models of actual applications. •

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04 Detection of a device failure (here: valve leakage) with the help of an autoencoder model that was trained with simulated process data.

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SUSTAINABILITY IN THE LIFE OF AN ELECTRIC MOTOR

A circular future

By developing a circularity framework, ABB is taking steps to embed a mindset of sustainability in all it does, from designing out waste to efficient use and reuse. The design and use of highly efficient motors and handling motors responsibly at the end-of-life shows just how ABB's strategic ambitions translate into impactful actions.

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Global energy usage, including industrial energy consumption [1], is projected to increase by almost 50 percent by 2050. Today, electric motors are among the biggest consumers of electricity world-wide, accounting for between 43 and 46 percent of global electricity consumption (7,108 TWh) [2]. Hence, the energy efficiency of electric motors impacts energy usage considerably .

Used in a wide range of applications, eg, fans, blowers, and machine tools, electric motors are ubiquitous in modern life.. A leading driver for increased electricity consumption, industrial motors are predicted to contribute to over 30 percent of the total growth in consumption until 2040 [3].The significant role that electric motors could play in driving sustainability and influencing climate change going forward is apparent →01.

Without a doubt, sustainability is critical to industrial business strategies, including ABB's. Sustainability is key to ABB's company purpose and the value they create for all stakeholders. This strategy rests on three pillars: reducing carbon emissions, preserving resources, and promoting social progress. By developing and implementing a circular approach business strategy, ABB is not only true-to-purpose but is generating tangible data-driven results that customers can use to make a difference.

Circular approach and life cycle thinking
Since the early days of industrialization, the traditional model of running a business has been based on a linear approach to resource consumption that follows a take-make-dispose pattern [4] →02, in which raw materials are extracted from mines and used to manufacture a product, sold to customers, who then dispose of it when it no longer serves their purpose →02a. However, a linear approach does not necessarily help eliminate waste optimally, nor can it protect industries exposed to business risks associated with resource-connected supply chain disruptions [4]. Such challenges call for a different economic model, one based on a circular approach to value creation – a circular economy →02b. Following a

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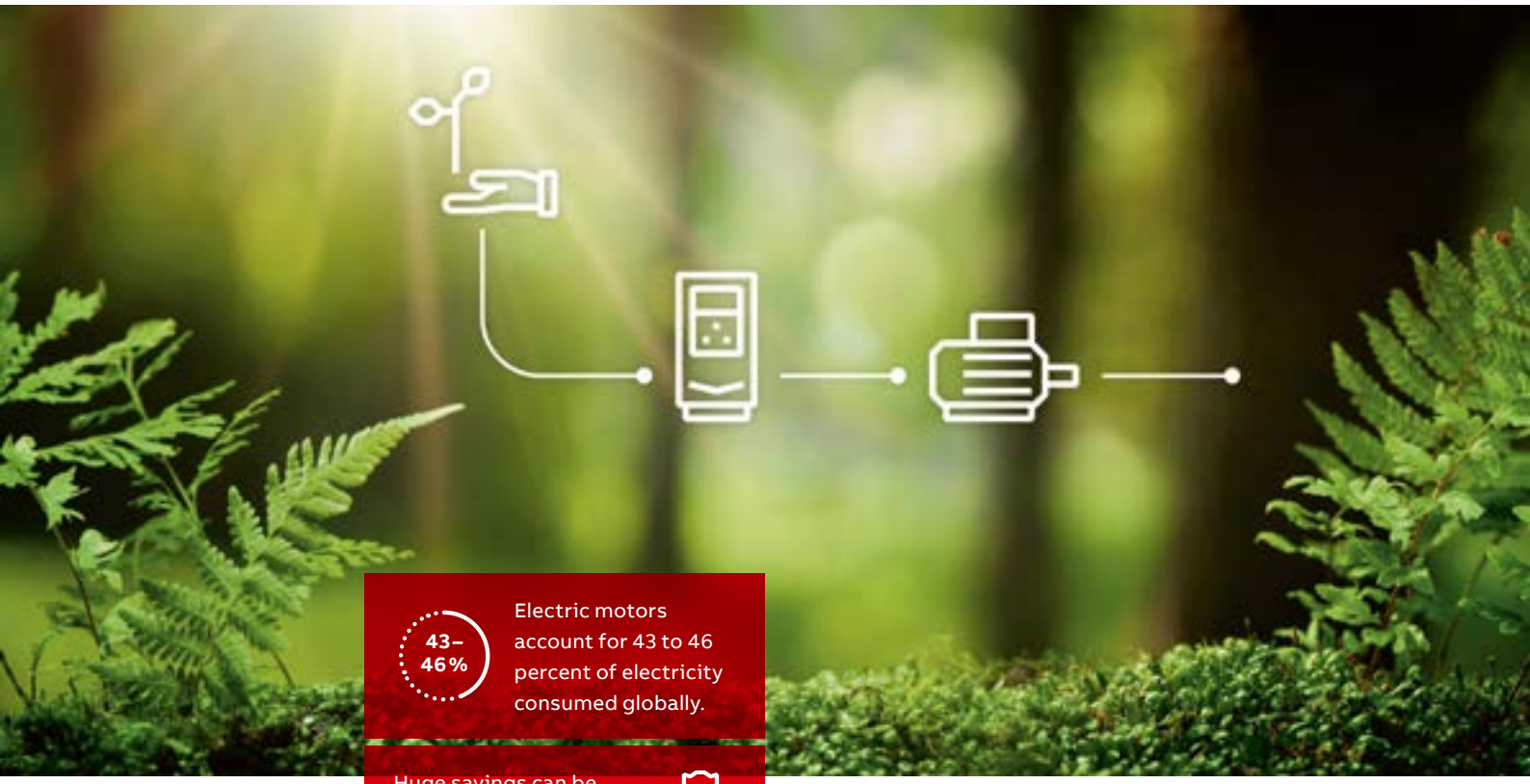
Sustainability is key to ABB's company purpose and the value they create for all stakeholders.

take-make-take pattern, this industrial system is restorative or regenerative by intention and design. The core aim is to "design-out" waste, not simply "eliminate" waste [4]. A circular approach (also known as "closing the loop") encompasses three basic strategies:

1) Design out waste and pollution (focus on product design)
2) Keep products and materials in use (focus on business models)
3) Regenerate natural systems (focus on regenerating resources)

Grounded on the concept of "life cycle thinking", defined as a "way of thinking that includes the economic, environmental, and social consequences of a product or process over its entire life" [5], the circular approach considers a



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01 By increasing the energy efficiency of electric motors, ABB is helping to contain energy consumption and reduce greenhouse gas emissions.This is in step with the latest Ecodesign Regulation (EU) 2019/1781, which came into effect in October 2019; and applies to low-voltage induction electric motors and drives as indicated by the icons.

product, process or service in the system holistically – from raw materials, through to manufacturing, consumption (or use) to end-of-life, with the possibility of influencing sustainability at every stage – an absolute must for product sustainability.

Life-cycle assessment of an induction motor – making data-driven decisions

A life cycle assessment (LCA), based on life cycle thinking, is a structured and scientific process used to understand and assess the impact of a product, process, or service over its life cycle as the materials flow within the economy through different stages. Relying on the principles and framework described in ISO 14040:2006, material flows are measured against several different impact categories linked to the environment and ecosystem, typically global warming potential (eg, Co_2 emissions), ozone-depleting potential, water scarcity, etc.

For an LCA evaluation, ABB chose a low-voltage (LV) induction-type motor. The environmental impact caused by material and energy flows across different phases in the motor's life-cycle was determined using SimaPro. In a LV motor's 20-year life cycle, the usage phase contributes to more than 99 percent of direct/indirect carbon

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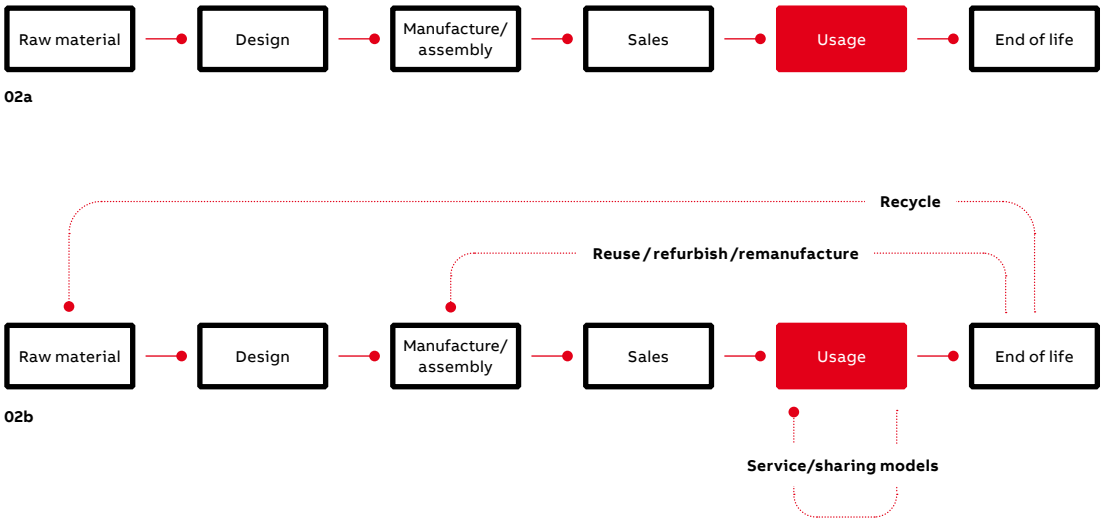
The circular economy is restorative or regenerative by intention and design.

emissions. The significance of a motor's energy efficiency to sustainability is evident →03. Nevertheless, the materials in a motor are no less important from a sustainability viewpoint. Metals, which constitute more than 98 percent of a motor's structure, are recyclable and therefore reusable – a sustainability advantage→04.

LV motors are already manufactured efficiently nowadays: The design phase uses materials optimally and production is automated in energy efficient factories. Based on ABB's results, the most practical way to enhance the sustainability footprint of a motor is to design/use motors with high efficiency and to handle the materials appropriately and responsibly at end-of-life.



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02 Typical stages of a product's life cycle are shown based on the traditional approach and the circular economic approach. While eliminating waste and conserving resources are both key objectives, the primary resources of concern are materials and energy in the scenario evaluated.

02a Linear approach is shown.

02b Circular approach is shown.

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03 Distribution of CO_2 footprint in a LV motor's 20 year life cycle. The results allow ABB to make data-driven decisions.

Energy efficiency: a key sustainability driver
Energy efficiency has become a business-critical topic [6], often used in conjunction with sustainability. A recent global survey on energy efficiency reported that 97 percent of industry leaders are already investing, or plan to invest, in improving energy efficiency [6], primarily citing cost savings followed by corporate sustainability commitments as grounds.

Because motors are among the largest consumers of electricity, their design and use contains tremendous potential to save energy. Electrical motors are robust with a long technical life: It is common to find working motors that are 50 or

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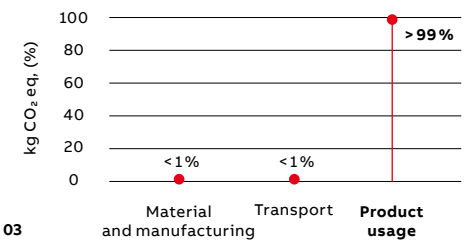
Designing and using highly efficient motors is one way to impact the sustainability footprint of a motor.

60 years old. Thus, the installed base in industry and infrastructure does not, in general, meet the efficiency standards of today. Replacing such old inefficient systems as well as motors that are over-dimensioned and consume more power



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than necessary with more efficient alternatives would be one of the most cost-effective and impactful ways to reduce energy consumption and related emissions [7]. For example, installing an IE5 SynRM motor to replace an IE3 motor could reduce annual CO_2 emissions by 22,000 kg for an application rated at 315 kW [8]. And, from a resource perspective, the rotor of a SynRM motor does not utilize magnets or rare-earth materials, making this product even more sustainable.

Despite the significant savings customers can achieve by upgrading a motor, still greater energy savings result if a high-efficiency motor is used in combination with a variable-speed drive (VSD). For applications, eg, in pumps, fans, and compressors, adding a VSD can typically reduce energy usage by 25 percent [9]. If the more than 300 million industrial electric motor-driven systems currently in operation would be replaced by optimized, high-efficiency equipment, global electricity consumption could be reduced by up to 10 percent [10] – a phenomenal reduction.

Environmental value of end-of-life management
According to a World Bank report [11], a low carbon future will be mineral intensive due to an increased need to source more materials to enable clean energy technologies. Because the supply and availability of key minerals will probably be impacted, recycling could play an increased role in meeting this demand, thereby supplying the low-carbon transition. Recycling of motors and their components could contribute to material availability, reducing the need for virgin materials and massively reducing the environmental impact.

ABB estimated this potential using SimaPro to perform a detailed analysis of the environmental impact of recycling the metals in the motors at the end-of-life →05. Practical scenarios were

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04 Materials such as metals used in motors and their components are designed, produced and used with a sustainable material flow in mind; this includes recycling and reutilization.

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05 Environmental impact results of recycling metals corresponding to 10 tons of electric motors.The results are compared with water, energy use in a typical villa over time.

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modeled utilizing realistic data associated with the recycling processes and transport. Recycling 10 tons of motors has the potential to save around 30 tons of CO_2 emissions, 300 MWh of energy and 91,000 m^3 of water – a highly positive outcome →05. In comparison, approximately 300 MWh of energy is used to heat an average-sized villa for 16 years; 91,000 m^3 of water can fill 36 Olympic-sized swimming pools→05.

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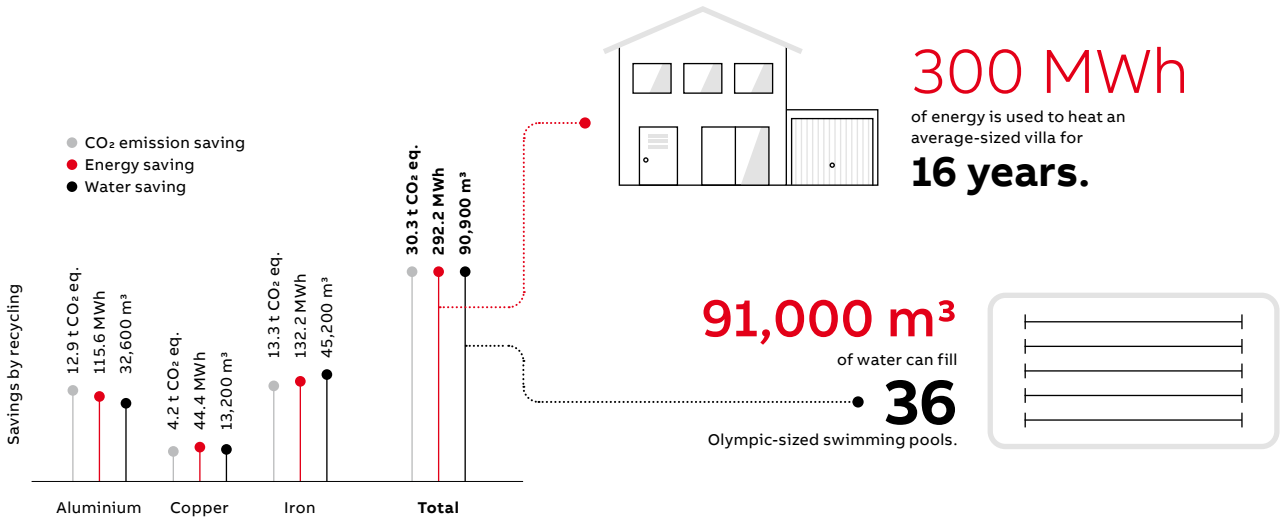
Recycling of motors could contribute to the demand for key minerals needed for the low-carbon transition.

Nonetheless, metals have another advantage – they can be continually and endlessly recycled and reutilized →04. Imagine the environmental benefits if a product's metals would always be recycled at the end-of-life. Recognizing this potential, ABB is keenly interested in the end-of-life management of electric motors and other products – circular material flows are the future.

Closing the motor loop through collaboration and digitalization

Because sustainability is inherently collaborative, encompassing planet, people and profit, an organization's sustainable growth is tied to the optimization of these three factors. However, organizations cannot directly influence and control these parameters in isolation, there are other stakeholders in the value chain whose interests, interconnected and equally important, must be simultaneously optimized. Collaborations,



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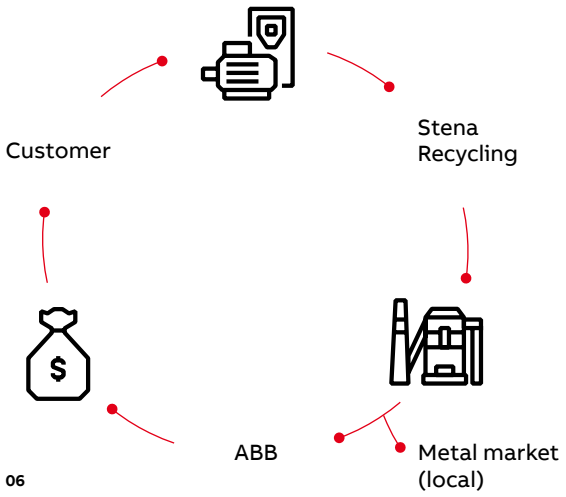

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06 Motor take-back and recycling business model is depicted, which emphasizes the collaboration between ABB, Stena and the customer.

alliances or partnerships form the foundations from which a greater impact and a successful sustainable transformation is achieved. By working together with all key stakeholders, a shared sustainability value can be created; one that is long-lasting, scalable, and transformative.

Encouraged by the positive environmental impact results of metal recycling, during 2021 ABB pioneered a collaboration with the Swedish company Stena Recycling →06 to offer customers the opportunity to recycle their old, end-of-life and inefficient electric motors (smaller LV- and larger HV variants) [12,13], sustainably. The concept has now been successfully deployed in various countries, such as the Netherlands and Switzerland, and ABB is anticipating adding 10 more countries in 2024. Beyond lowering emissions, this motor take-back and recycling business model prevents the risk of old, inefficient electric motors from landing in the second-hand market and impacting the environment adversely.

Optimized for the lowest environmental impact, the entire take-back and recycling process is sustainable by design; it considers the total weight of the to-be-recycled motors, distances to be covered, type of transport to be utilized and frequency of transport.

Bringing about sustainable transformation through collaboration can be further strengthened and accelerated through the digital transformation. With the Industrial Internet of Things (IIoT) revolution fully underway, data-driven decision-making can be used to minimize waste and enable a productive and sustainable future. Digitally enabled products, solutions and services can be used to capture real-time data to disclose the status of equipment and systems, thereby triggering appropriate decisions to optimize and improve energy efficiency. For example, ABB placed smart sensors for energy analysis on motors at SCA facilities in Munksund, Sweden, one of ABB's customers [13]. The smart sensors delivered information about the condition and active power on the motor shaft that was used. Data assessment makes it possible to determine the active and reactive power used,

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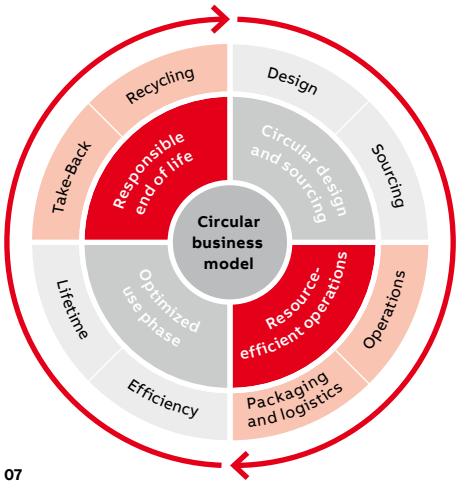
ABB and Stena Recycling offered customers the opportunity to recycle end-of-life and inefficient electric motors.

annual active and reactive power consumption, and whether the motor is correctly dimensioned for the application as well as savings potential (kWh, € and kg CO_2) if the motor is replaced. So far, SCA Munksund has recycled 28 tons of motors with ABB's recycling circular model. Based on the assessment, eleven tons of motors were identified, replaced and transported to the Stena Recycling plant [13].

ABB's motor take-back and recycling business model is flexible. The scheme can be tailored to include relevant digital solutions, energy-efficient motor offerings, primarily to improve the sustainability value of the whole process. In fact, a combination of processes involving recycling inefficient motors and replacing these with new and more energy efficient motors – an "upcycling" initiative – lowers carbon emissions in both process steps – a winning solution for customers. There is also the opportunity for still greater sustainability benefits: ABB can, in specific cases,



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07 ABB's circular framework business model is shown, which highlights the importance of efficient operations and responsible end-of-life management.

offer customers economic incitements based on the value of the recycled metals, such as a certificate of destruction and an environmental report together with Stena Recycling, when they purchase new products from ABB [14].

Making change happen with circularity

Decision-making for product sustainability must start with data and an understanding of the environmental impact associated with the entire-life cycle of the product, which in this case, is an electric motor. Depending on the carbon footprint at different phases of the life cycle, appropriate opportunities exist for sustainable improvements as assessed through LCA modeling and brainstorming →07. While the presented case is specific to a scenario in which the motor has an expected application life of 20 years; another scenario with a motor characterized by a shorter life, and hence different sustainability assessment results, would require other approaches to be adopted to minimize environmental impact.

By focusing on energy efficiency during the use-phase and a recycling business model at the end-of-life →06, ABB achieved the most positive environmental contribution possible. Looking ahead, more opportunities to further strengthen the motor's sustainability will certainly arise, eg, utilizing better materials or other business models that allow the circular approach within a phase or multiple phases →07.

With increasing awareness and future technological developments, the vast opportunities to improve a product's sustainability can be daunting, and, yet the concept of "circular thinking" will remain at the core of product sustainability. Adopting the right circular approach will be

ABB's circular framework provides the opportunity to ponder the most appropriate circular approach to sustainability.

the key to the best sustainable solution. ABB's circular framework provides the opportunity to ponder the most appropriate circular approach for an existing or future product. Ultimately, the responsibility lies with ABB to define how to create a circular future for their products and ABB is doing just that. •

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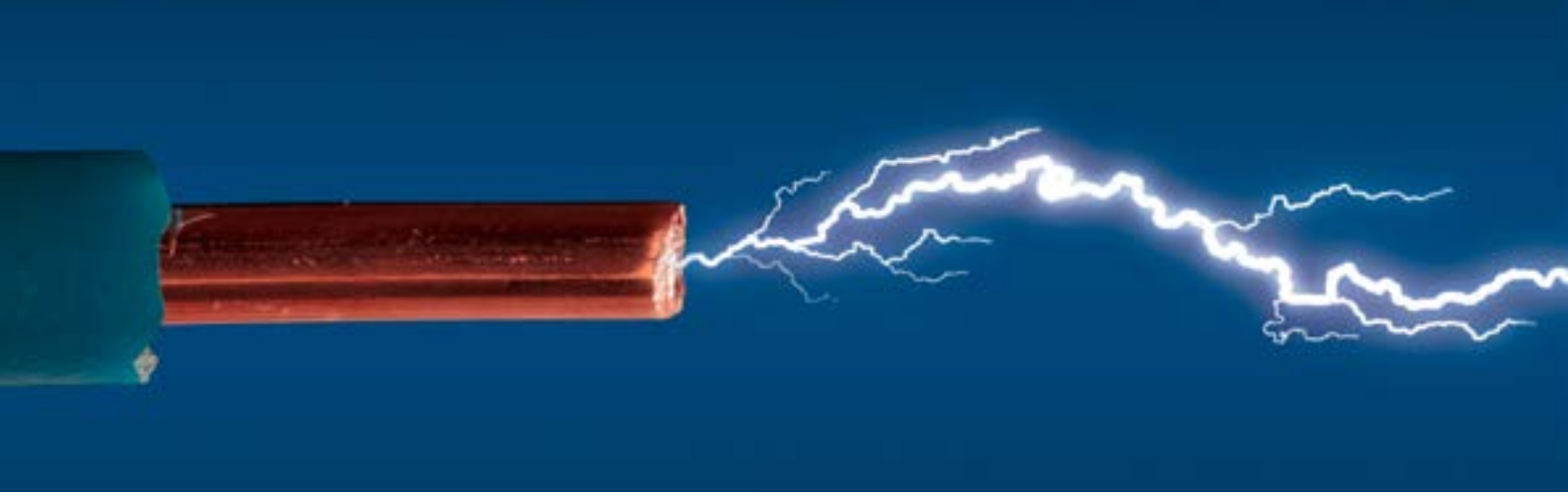

ROGOWSKI COIL CURRENT SENSORS FOR ARC FLASH DETECTION

Flash of inspiration

ABB's TVOC-2 Arc Guard System™ is an optical arc flash mitigation device with one of the fastest reaction times on the market. Adding the CSU-2 current sensing unit to the TVOC-2 eliminates nuisance trips arising from non-arcing-related flashes →01.

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With temperatures of over 10,000 °C, current densities of up to 100 A/cm² and violent pressure waves, an electric arc flash in an electrical enclosure is an extremely dangerous and undesirable event.

Most arcing accidents in electrical equipment are down to human error (eg, when an operator is working on the equipment), faulty connections, or inquisitive animals. Most often, the accident occurs during switchgear maintenance or installation when the cabinet door is open. With the door open, the frontline defense of arc-proofed switchgear design – strong doors – is absent.

Accidents are rare but serious when they occur. Injuries can be severe or even fatal and damage to equipment extensive. Replacing and repairing the damaged equipment can lead to lengthy downtimes.

It is clear, then, that arc flashes are events to be avoided at all costs. If they cannot be avoided, their effects must be minimized. An arc guard system is, therefore, a necessary part of a modern switchgear design.

Much work has been conducted to mitigate the effects of arc flashes and ABB has had effective countermeasure products on the market for some decades. ABB's TVOC-2 Arc Guard System™ – the new version of a well-established arc guard system that has been protecting people and electrical equipment from dangerous electrical arcs for over 35 years – is a device that uses optical sensors to detect an electric arc →02. The TVOC-2 interfaces perfectly with ABB Emax 2 circuit breakers, for instance, to provide a fast-response active protection system that limits the damaging effects of internal arcing.

Arc flashes in switchgear cabinets pose a significant risk to humans and equipment.

ABB's TVOC-2 Arc Guard System™ sets new standards in arc detection.

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01 The ABB CSU-2 current sensing unit.

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02 ABB's TVOC-2 Arc Guard System™.

TVOC-2 Arc Guard System
The TVOC-2 Arc Guard System employs optical detectors that sense the light flux associated with the electric arc phenomenon. Upon sensing extraordinary light levels, the TVOC-2 sends a tripping signal to the circuit breaker. Current interruption stops the local power grid from feeding further electrical energy into the arc. The reaction time of the detection is less than 1 ms. →03 shows example locations for the optical detectors. Strategic detector positioning will eliminate interference between zones of detection. Sensors are calibrated to have equal light sensitivity and their fish-eye lens design lets them observe a large solid angle, so orientation is not critical.

Electromagnetic interference (EMI) immunity is conferred by the use of fiber-optic cables, which are not only impervious to the EMI that will certainly accompany an arc fault but also faster at transmitting signals; every microsecond counts during an arcing event.

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ABB's TVOC-2 Arc Guard System™ uses optical sensors to detect an electric arc.

To avoid false tripping due to camera flashes, nearby welding activity, sunlight, etc., the arc mitigation device can be combined with a current sensing unit and set to activate only when an overcurrent is also registered. This is where the Rogowski sensor comes in.

ABB Rogowski coil current sensors
Over the past few decades, ABB has developed Rogowski coil current sensors for use in electrical equipment such as switchgear. Now, that same technology provides a basis for the new ABB CSU-2 current sensing unit for the TVOC-2. The CSU-2 detects the fast current rise that accompanies faults associated with arc flashes. To eliminate nuisance tripping, the TVOC-2 will only trip the circuit breaker if it "sees" a flash and, at the same time, the CSU-2 current sensing unit detects an overcurrent.

The Rogowski coil is placed around the conductors. The current flowing through the conductors creates a magnetic field in the sensor's winding and thus induces a voltage in the winding. This voltage is proportional to the first derivative of the primary current and is presented as an output on the secondary terminals. The sensor response is linear over the whole measuring range, up to short-circuit currents, which means the sensor covers a much wider range than the current transformer conventionally used.

The Rogowski coil current sensor has several advantages over more traditional approaches.

Benefits of ABB Rogowski coil current sensors
Sensors based on alternative principles, such as the Rogowski sensor, are replacing conventional instruments in switchgear and other electrical installations as part of a strategy to significantly reduce equipment size, increase safety, offer greater rating standardization and provide a wider functionality range.

A variable clamping system for new installations and a split-core solution with an open loop for retrofits make Rogowski coil installation quick, easy, safe and reliable. The current sensor is

02

connected to the CSU-2 by an RJ45 connector. A green indicator light on top of the CSU-2 flags that this connection is secure. The CSU-2 current sensing unit continuously supervises the Rogowski coils' functionality to ensure fast and reliable detection of overcurrent.

One current sensor can be used for nominal currents from 100 A to 4 kA and still measure peak currents of more than 150 kA without saturating. This wide measurement range allows the same current sensor to be used in applications with quite different loads – for example, incoming and outgoing feeders. This aspect of the sensor has further advantages: panel builders can now operate with a smaller inventory and interchangeability of parts is enhanced. Furthermore, the same sensors can be used if a substation were to be upgraded for higher primary currents.

— One current sensor can cover from 100 A to 4 kA and still measure peak currents of over 150 kA without saturating.

Rogowski coil sensors offer not only significant space savings compared to standard current transformers but also easier handling and storage, due to their light weight. Also, the absence of a ferromagnetic core means the power losses experienced by conventional solutions are eliminated and, therefore, the sensors exhibit extremely low energy consumption. Lower energy consumption improves both the economic and environmental credentials of the solution. Air cores are not susceptible to saturation, a major problem in current transformers with ferromagnetic cores →04–05.

The CSU-2 uses dedicated and factory-calibrated Rogowski coil current sensors in order to ensure fast and safe tripping at low as well as high current levels.

Guarding the future of electrical installations

Arc protection systems are becoming an essential element of electrical cabinet design. Because such systems reduce damage and downtime costs, some insurance companies encourage their use by reducing the cost of cover for sites

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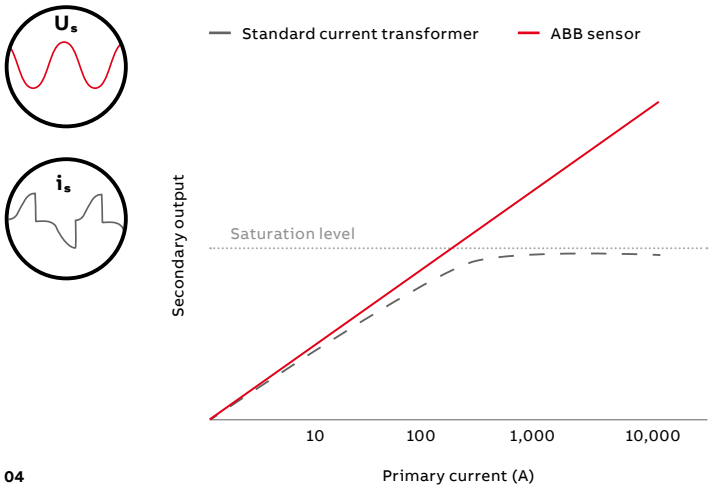
— 03 Optical detectors are placed strategically for best coverage.



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04 The sensors' linearity means there is no saturation and no distortion of secondary signal.

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05 Rogowski coil sensor elements. The sensing coil surrounds the conductor.

05a Medium-voltage version with an openable coil.

05b Medium-voltage version with a fixed coil.

05c Low-voltage version with a small-diameter coil.

05d Low-voltage version with a large-diameter coil.

where they are installed. Protection against arcing events is also becoming enshrined in legislation. For example, the Low Voltage Directive of the European Union stipulates that measures to prevent damage by excessive heat, caused by arc flashes, for example, are to be taken.

The combination of the TVOC-2 Arc Guard System™ and the CSU-2 current sensing unit ensures an electrical installation adequately addresses all aspects relating to arc flashes. The duo ensures continuous operation, safety and protection. The Rogowski current sensor is easy to install or retrofit and will provide a current measurement with a longer life time and reduced maintenance requirements.

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The combination is one of the most effective and reliable arc mitigation products available.

With a design based on ABB's decades of experience in the arc mitigation field, the TVOC-2 and CSU-2 ensure the safety of personnel even when the cabinet door is open and provides all-around, comprehensive arc protection. The combination is one of the most effective and reliable arc mitigation products available. •

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SF_6, often used in switchgear, is a potent greenhouse gas.

Alternative gases are seeing increased use, but pose physical challenges.

ABB is overcoming these challenges by rethinking the action of the switchgear.

Photo: © Michael Vogel

PUFFER-TYPE LOAD BREAK SWITCH FOR SF_6-FREE APPLICATIONS

Climate switch

Vacuum-technology load break switches (LBSs) are used in switchgear filled with environmentally friendly alternatives to the SF_6 insulating gas. These switches have some drawbacks. Refined puffer interrupter technology promises a reliable, cost-effective and easy-to-use LBS alternative.

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Environmental concerns related to the global warming potential of SF_6 are promoting a new generation of gas-insulated switchgear (GIS) based on environmentally friendly insulating gases. In this switchgear, vacuum switching technology is used for the LBS and much research effort has concentrated on the dielectric and thermal challenges [1, 2] this technology poses. Vacuum switches are also costly and require an additional disconnector switch, which includes a complex drive mechanism.

Refined puffer interrupter technology promises a reliable, cost-effective and easy-to-use LBS alternative →01.

Puffer interrupter technology for eco-efficient insulation gas

The puffer interrupter consists of a compression chamber and an interruption chamber →02. The principle of operation is to “blow out” the arc by

01

— 01 New puffer interrupters offer advantages over the vacuum circuit breakers (VCBs) used in switchgear like this SafePlus Air CCV (ie, 2 x VCB + 1 x isolator switch) GIS.

using the overpressure generated by compression of the gas by the piston. The compressed gas is released into the arcing zone, where it cools the arc ignited between the contacts. The arc is extinguished at the first current zero (CZ) crossing if the contact distance and cooling achieved is sufficient to withstand the transient recovery voltage (TRV). The TRV arises from magnetic energy trapped in the inductances on the load side of the circuit breaker, where it gives rise to a current that circulates between the capacitances and inductances there. This current can generate a transient overvoltage. The difference between the voltage potential upstream of the breaker and these transient overvoltages gives the TRV.

SF_6 is very suitable as an insulating gas in switches due to its intrinsic capability to both cool the arc and quickly restore the insulation level after the switching event. Replacing SF_6 with eco-efficient alternatives in a puffer interrupter reduces interruption performance both in the thermal and dielectric phases (see following two sections) due to inferior arc-quenching properties and lower dielectric strength of alternative gases.

ABB has designed a puffer interrupter that overcomes these challenges posed by eco-efficient gases. Significantly better interruption performance in SF_6 alternatives is achieved by creating a so-called stagnation-point flow pattern of gas around the arcing zone. Further, because weak dielectric strength in both cold and hot zones in the LBS may cause restrikes, innovative solutions have been implemented to tailor the flow pattern of the hot gas to prevent arc re-ignition. Although interruption capability is the main challenge, the functionality of a new LBS also has an optimized dielectric and thermal design. Advances made in these respects allow a compact LBS to be created that uses eco-efficient insulation gas alternatives while maintaining the established ratings and footprint of SF_6 GIS.

Thermal interruption

Different topologies of the flow around an interrupter arcing zone are shown in →03. The common flow pattern utilized in SF_6 medium-voltage (MV) puffer interrupters is called “simple flow.” Here, the gas flows straight through the moving contact and nozzle system toward the fixed contact. Experiments with a simple flow puffer interrupter under different gas pressures and loads have indicated that the interruption performance is not sufficient for SF_6-free MV applications [3].

Two alternative designs were explored: Single-flow and double-flow designs, which both feature a “stagnation point” that is found to improve the interruption performance significantly for air compared to the simple flow design →03. A stagnation point is a point in a flow field

— The principle is to “blow out” the arc using the overpressure generated by compression of the gas by the piston.

where the local velocity of the fluid becomes zero and all the kinetic energy is converted into pressure energy. The stagnation-point type of flow is commonly utilized in high-voltage circuit breakers, but no applications are known for commercial MV LBSs.

During the opening operation in stagnation-point type designs, the piston attached to the moving contact compresses the gas, which results in overpressure in the compression chamber. At the same time, the arcing tulip contact is pulled away from the arcing pin, which consequently generates an arc →04. The arc initiation heats the gas, which partly “clogs” the critical cross-section of the nozzle, resulting in an even higher pressure

—
02 Schematic drawing of the gas puffer interrupter.

—
03 Simple flow and two stagnation-point type flows – single flow and double flow.

—
04 Opening operation of a puffer switch based on double-flow geometry.

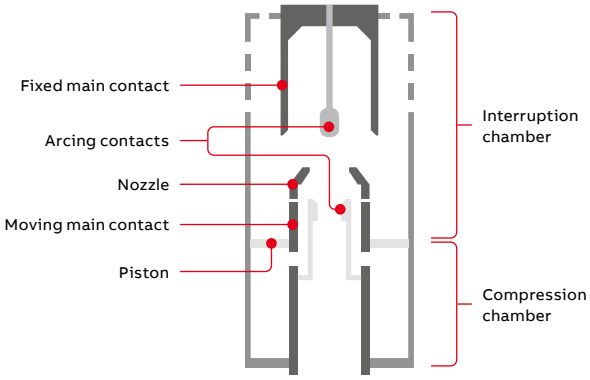
The specific arrangement of the flow pattern chosen significantly improves interruption performance.

in the compression volume. Eventually, the pressurized gas from the compression volume blasts into the arcing zone and helps to extinguish the arc. The arc extinction should preferably occur at the first CZ crossing, and, therefore, enough gas pressure is needed to blow out the arc at that point. As a part of the new design, customized ports are made around the arcing zone. Fresh gas can then enter via these ports to quickly replace the ejected hot gas.

Many parameters of the puffer design influence the gas flow and pressure buildup in the system and lead to different interruption capabilities. In the switching device discussed here, the gas is used as both an arc interrupting and a dielectric medium. The specific arrangement of the flow pattern chosen in the arcing zone significantly improves the interruption performance.

Dielectric restrike

The dielectric phase – around 10 to 100 µs after CZ and characterized by a residual current close



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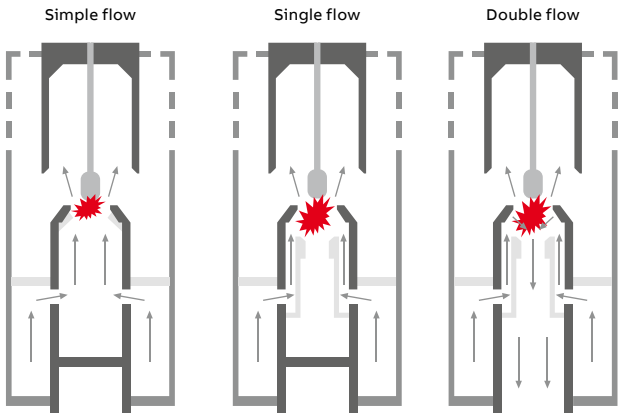

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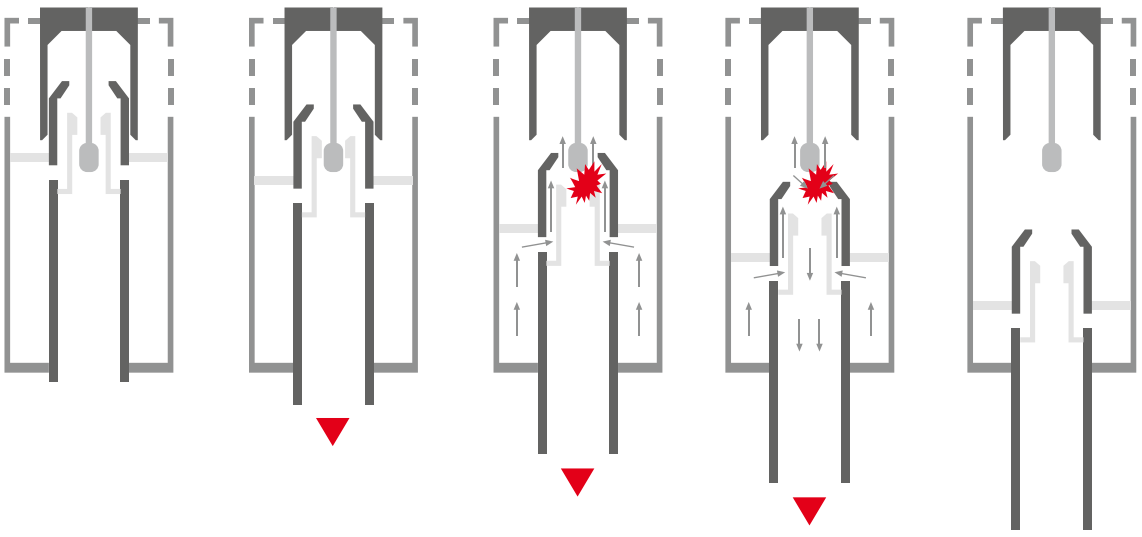


04

05

—
05 A hot cloud from the arc settling around the moving main contact, which resulted in restrike to it. Design changes can push the hot gas away from the moving main contact and prevent the dielectric restrike.

—
06 Temperature distribution just after CZ crossing. The arrows indicate the gas that is pushed away.

06a Arcing time = 5.25 ms.

06b Arcing time= 13.3 ms.

—
07 Effect of the outlet at the end of the tube on the accumulated hot gas around the main contact just before the CZ. Double-flow design reduced the accumulated hot gas around the main contact.

07a Double flow.

07b Single flow.

to zero – may generate restrikes if a hot gas and metal vapor mixture generated by the burning arc remains around the contacts. This mixture has lower dielectric strength than cold insulation gas and when the TRV increases, restrikes may take place within or away from the original plasma channel. To quantify the robustness of the new switch design in this respect, experiments were conducted at different development stages →05.

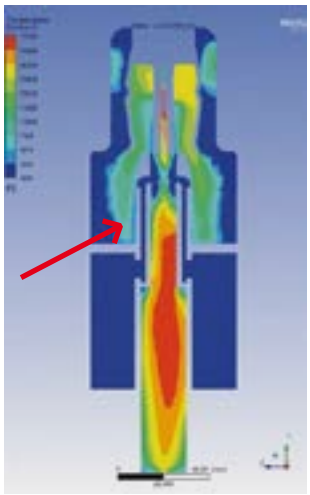
In addition to full-scale experiments, computational fluid dynamics (CFD) modeling is another major tuning tool for both root-cause analysis and sensitivity analysis of new switchgear design concepts. →06 illustrates CFD modeling of the cloud of accumulated hot gas around the contacts in the double-flow design for two different arcing times. The ideal situation would be to push this hot gas away from the moving main contact – ie, it is essential to tailor the flow pattern of the hot gas generated during the interruption event in such a way that reignition in the dielectric phase is prevented. The flow pattern can be controlled by splitting the fixed arcing contact (arc pin) and giving the fixed main contact multiple contact members with pressure-release openings. Further, the gas outlets should be large enough to avoid the flow of hot gas toward the main contact and any change in the contacts should not sacrifice the required cross-section of the main current path →07.

By implementing some openings on the field controllers around the interruption chamber, the hot gas, vapors and exhaust generated during the arcing event are transported away from regions with high electrical field stress, which not only assists cooling but also helps to maintain the dielectric strength of the gas at the level needed between phases.

—
CFD modeling is another tuning tool for both root-cause analysis and sensitivity analysis of new switchgear designs.

Dielectric design

Although the dielectric withstand of air in, say, a ring main unit (RMU) application is almost one third that of SF_6 [3], the footprint of a new air-insulated switching unit should not be greater. Therefore, substantial effort has been made to reduce the electric field stress near compo-



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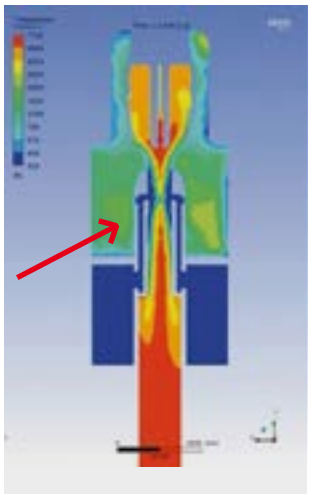

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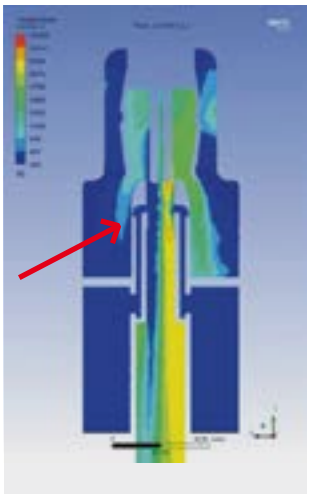

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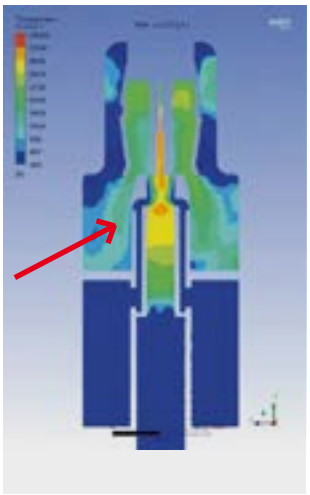

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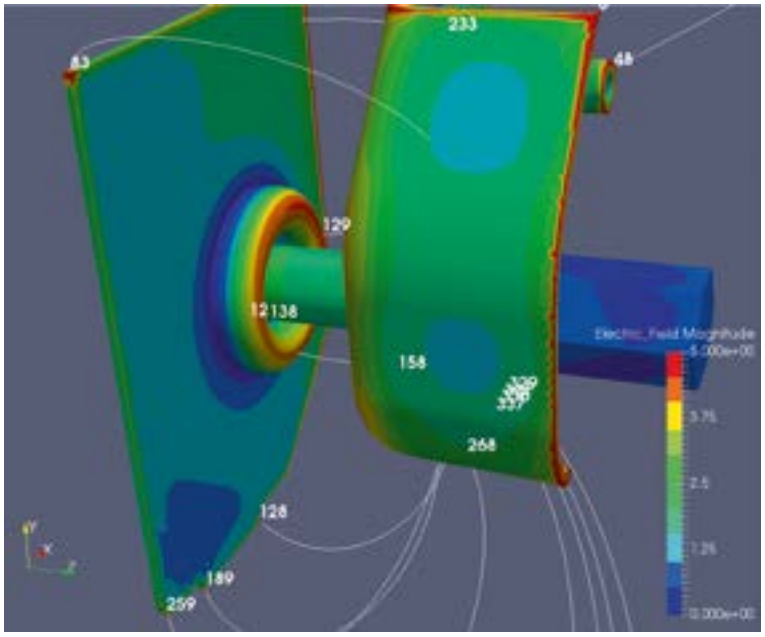

08

— 08 Electric field stress at a critical region. The numbers identify the critical points that are used to extract the data, colors show the electric field magnitude.

nents [3]. This action has resulted in very smooth parts that are, in effect, field shields →08. Novel designs have been implemented to overcome high-stress regions at triple points, where conductive solid, insulating solid and insulating gas meet [4]. Finally, the sophisticated design of the puffer interrupter fulfilled all dielectric requirements based on common standards such as IEC 62271-1 [5].

Full-scale testing

Full-scale interruption type tests were conducted on a commercially available ABB SafeRing/SafePlus Air unit, according to the "active load" test duty classes E3 and C2 of the IEC standard for a rated voltage of 12 kV at a nominal current of 630 A [6].

The same interruption principle has been also successfully tested for "active load" and "switch-fuse" transfer current according to the IEC standard for 24 kV in High pressure dry Air, from 2.0 to 2.5 bar abs. The switch-fuse test duty is challenging due to the much higher rate of rise of recovery voltage compare to the "active load" test duty.

A cost-effective and easily operated alternative to a vacuum LBS

Puffer interrupters, which use the gas blast produced by the relative movement of moving and fixed contacts, are widely used in SF_6 switchgear due to their compact size, simple structure and excellent interruption characteristics. In a puffer switch, the interrupting capability depends on the interaction between arc, gas properties, flow pattern, pressure buildup and geometry. The stagnation-point type of flow improves the interruption performance compared to simple flow in non-SF_6 gases. The successful performance of the new interrupter design described here makes it a cost-effective and easily operated alternative to the LBSs using vacuum interrupters and paves the way for the next generation of environmentally friendly RMUs. •

— Novel designs have been implemented to overcome high-stress regions at triple points.

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BETTER DECISIONS FOR SMART CITIES

Integrated infrastructures

The United Nations estimates that by 2050 almost 70 percent of the world's population will live in urban areas.

— ABB offers solutions for cities in five key areas: electric grids, water, transport, buildings, and district energy.

In view of this, city planners are scrambling to ensure that growing numbers of people in increasingly dense settings have affordable and equitable access to reliable and sustainable energy, clean water, sanitation, transport systems, and housing.

Particularly in terms of operations and maintenance, these massive infrastructures can benefit significantly from the digitization and optimized lifecycle performance offered to businesses and individuals by ABB Ability™ solutions. Specifically, these solutions are concentrated in five key areas: electric grids, water, transport, buildings, and district energy.

In terms of electric grids, ABB's major areas of expertise are grid connections and power distribution, automation, solutions for integration of renewable energy sources, and energy storage. To meet customer demand in these areas, ABB provides electrical equipment, primary and secondary distribution substations, containerized substations, smart control cabinets, and protection and control devices.

In the water management area, ABB offers solutions that result in up to 25 percent improved water cycle efficiency. These include electrification, automation, and motors and drives for pumping stations, water and wastewater treatment stations, desalination facilities, and technologies designed to protect coastal areas and waterways.

Transporting large numbers of people efficiently, affordably, safely and sustainably is another key challenge for cities. In this connection, one of ABB's major areas of expertise is EV charging, including roadside stations, commercial parking, and asset and fleet management. The company also offers a range of automation and electrification technologies that support electric buses and rail systems, as well as shore-to-ship technologies. These include ship and boat electrification, power solutions for ports, and crane control and motion technologies.

Technologies for buildings are a fourth major area of expertise for ABB, which offers efficient energy management and control systems for residential and commercial buildings, industrial facilities, and data centers. Here, the company offers solutions in areas such as power quality control, UPS and storage, building automation, atmosphere and lighting control systems, metering and submetering, HVAC controls, entry and security systems, as well as a range of smart home technologies.

With regard to data centers – an increasingly important part of urban administration because of their ability to support all other services – ABB offers expert knowledge in areas such as power distribution and protection; cooling systems; building, energy, and automation management; as well as its Secure Edge Data Center (SEDC) for industrial and telecommunications environments.

ABB also provides district heating and cooling as well as management of waste energy. Here, areas of specialization include gas distribution and control, process optimization, and collaborative operations centers. Collectively, these systems can result in up to 30 percent in energy savings. •

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— **Originally published in ABB Review 02/2022, p. 69.**

—
01 The ABB Megaflex DPA UPS. Here, a 1.5 MW configuration is shown.

01

AN EFFICIENT AND RESILIENT UPS FOR HIGH-POWER DATA CENTERS

Megaflex

ABB's new MegaFlex uninterruptible power supply (UPS) is aimed at applications such as data centers that have high power demands. MegaFlex is simple, compact and resilient – and delivers the excellent availability, reliability and efficiency that is a hallmark of all ABB's power protection products.

The quantity of data added to data centers around the globe each minute of every day is staggering. This deluge of data has to be stored in a safe and rapid way and has to be retrievable just as quickly – 24/7 and 365 days a year – so it can be utilized in one of the many applications uopn which day-to-day life depends. The dawning of this new era is the reason why data centers are proliferating around the world. Growth in the sheer number and size of data centers is accompanied by another trend: a move toward a sophisticated world of cloud-based, hybrid and distributed data centers. The single, standalone data center concept often cannot provide the replication, data traffic, reliability and resiliency capabilities demanded by some customers.

—
Growth in the number and size of data centers is accompanied by a move to cloud-based, hybrid and distributed data centers.

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Data center requirements
Data center operators have many requirements in common, the most important being:

- Business continuity and zero downtime: All systems have to be always up and running – and whatever happens on the infrastructure side, load-drops are not an option. This is to guarantee safe data transaction, storage and recovery. It is not uncommon for data center outages to cost tens to hundreds of thousands of dollars, and cases that incur costs in the tens of millions of dollars are no rarity.
- Reduction of investment and operating costs through higher energy efficiency: Better efficiency not only reduces energy losses and operational costs but also eliminates

the capital investment that would be needed to purchase higher-performance temperature-conditioning systems. Such investments profoundly impact upfront investment.

A data center has to store data in a completely safe and reliable way. For this reason, the ability to provide an unbroken supply of good-quality power to the data center is critical. Indeed, when they do occur, the most common cause of outages in data centers is a power supply problem.

ABB is a market leader in the UPS technology that ensures power keeps flowing no matter what. The company has pioneered many advanced concepts in modern UPS design – for example, distributed parallel architecture (DPA™).

DPA has worked well for ABB: Users whose power requirements increase can simply add modules to reach power capacities of several MW. However, as larger data centers drive UPS power requirements ever higher – to 30 or 40 MW – the need has emerged for a UPS that has a base power level of at least 1 MW and that can be expanded or configured to cater for applications requiring up to 6 MW. Five such installations can cover the energy needs of a 30 MW site.

Further, as data centers evolve into larger facilities that are denser, scalable, more networked and more converged, operational costs can increase. An appropriate choice of UPS and associated power infrastructure helps control these costs.

> Customers seek a power distribution solution that is highly efficient, scalable, flexible and easy to install and maintain.

Other considerations involve the move away from the standalone data center toward geographically distributed facilities, global traffic management, critical data replication, virtual storage, cloud computing and other complicating factors. This evolution places new demands on resiliency, provokes new thinking and, most importantly, motivates customers to look for a power distribution solution that is highly efficient, scalable, flexible and easy to install and maintain.

—
02 Space in data centers is usually limited, so the flexibility of the Megaflex DPA UPS is valuable when it comes to layout.

02a 1,000 kW, system with four power modules, connection frame on left.

02b 1,000 kW, system with four power modules, connection frame on right.

02c 1,500 kW, six-power-module system with connection frame in center.

—
03 Compared to an ABB DPA 500 UPS solution, the Megaflex DPA has a footprint around 45 percent smaller.

02a

02b

02c

03

04

—
04 The operator has a comprehensive overview via a HMI but can also access the same information via a Web page.

To satisfy these evolving customer demands, ABB has developed the MegaFlex UPS for the UL and IEC markets →01.

ABB's MegaFlex DPA IEC UPS
The MegaFlex DPA design brief included the following basic tenets:

- Develop, manufacture and sell a high-efficiency UPS with a rated power of 1 MW, 1.25 MW, or 1.5 MW that is suitable for large data center facilities.
- Standardize power distribution architectures in compliance with the Uptime Institute classification system and EN 50600.
- The UPS must be compact, highly energy-efficient, flexible, easy to install and maintenance needs must be predictable.

The result was a transformer-less UPS consisting of 250 kW power blocks, a central static bypass with a rated power of 1,000 kW or 1,500 kW and an I/O connection frame with power ratings of 1 MW and 1.5 MW. The input feed can be single or dual (option). The MegaFlex DPA UPS can use lithium-ion or valve-regulated lead-acid (VRLA) batteries as external storage. Backfeed protection is provided as standard. An option provides redundant power capacity: 1,000 kW N+1 or 1,250 kW N+1. A product variant – which will be released first – features distributed bypass switches, resulting in a smaller footprint.

—

An option provides redundant power capacity of 1,000 kW N+1 or 1250 kW N+1.

Further salient MegaFlex DPA features include:

- High-efficiency converters – in VFI mode (see below) > 97.4 percent.
- Optimized footprint and flexibility in component layout →02–03.
- Simple, safe and quick installation with high adaptability to the building infrastructure.
- Enhanced power measurement that provides comprehensive information to the data center operator so that energy consumption can be tracked.
- Intelligent predictive maintenance program to plan and reduce maintenance throughout the product life.
- Enhanced self-diagnostics to minimize human intervention during maintenance and start-up.
- Full lifetime service provision via local ABB-trained specialists.

Intelligent energy management
Due to the vast amount of energy large data centers consume, energy efficiency is a particularly important topic. Every percentage point improvement in efficiency brings with it significant cost savings. The default operating mode for the MegaFlex DPA is voltage- and frequency-independent (VFI) double conversion mode, which has an efficiency of up to 97.4 percent. Alternatively, the UPS can operate in its voltage- and frequency-dependent (VFD) ECO mode to attain 99 percent efficiency.

When a UPS is operating significantly under capacity, its energy efficiency can be negatively impacted. ABB's Xtra VFI operating mode is a smart way to minimize losses and improve efficiency safely when running in double conversion mode.

When the MegaFlex DPA UPS runs with Xtra VFI mode enabled, the UPS automatically adjusts the number of active modules according to the load power requirements. Modules that are not needed are switched to a standby state of readiness, primed to transfer back to active mode if the load increases. The efficiency improvements

To increase reliability, extend service life and equalize aging, the system rotates modules between active and standby mode.

achieved by this mode of operation are especially significant when the load is less than 25 percent of full UPS system capacity – an operating regime in which traditional UPS systems fare poorly. The switching scheme parameters can be configured by the user. To increase reliability, extend service life and equalize aging, the system rotates modules between active and standby mode at fixed intervals. Should there be a mains failure or other abnormal situation, all modules revert to active mode within milliseconds.

Control and monitoring

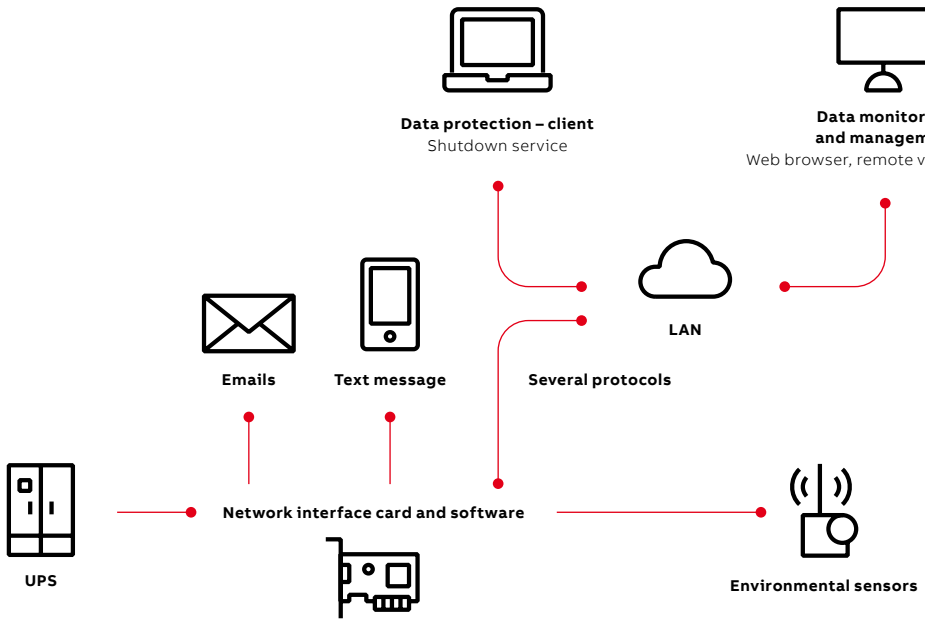
The MegaFlex DPA human-machine interface (HMI) allows the operator to display measurements, events and alarms (primary input failure, battery status, overtemperature, overload, input and output protection status, etc.) as well as the UPS status and primary component status →04. Also measured and displayed are:

- Input, output and battery voltage and currents.
- Output kW/kVA.
- Thermal monitoring for the main converter and critical components.

Connectivity is accomplished via two slots for optional communication boards, eg, SNMP, Modbus TCP/IP or Modbus RS-485. These ports can make measurements and alarms available to the electrical power monitoring system (EPMS), the building management system (BMS) and the data center infrastructure management (DCIM) – all of which integrate with ABB Ability™ Data Center Automation via, for example, the local area network (LAN) →05. The UPS is also equipped with dry inputs for remote shutdown, generator operation and external switchgear; I/O dry ports; a Castell interlock function; and a preconfigured (battery) temperature sensor input.

Resiliency

Resiliency refers to the ability of the entire power structure to prevent failure – and to recover quickly and fully from failure – or to keep running even with a certain level of faulty equipment or software. A system-wide approach becomes essential if resiliency is to be maintained as the concept of the standalone



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05 Example of Megaflex DPA connectivity.

06

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06 The Megaflex DPA. Power modules slide in on integrated wheels and lock in place using docking connectors.

data center is overtaken by new trends – for example, hybrid and distributed architectures and advances in virtualization; strategies that shift data from one geographical location to another to take advantage of cheaper energy tariffs; and real-time data replication in different sites for hyper-critical applications.

ABB's MegaFlex DPA UPS and associated ABB support infrastructure – such as intelligent switchgear, smart sensors, cloud-based predictive maintenance algorithms, enterprise-wide and site-specific monitoring, transformers, smart sensors, short-circuit isolation selectivity, etc. – help deliver the high level of system-wide resilience needed.

Measures taken to improve resiliency can also have other benefits. For example, a good monitoring strategy creates a predictive insight that not only flags a component replacement need (rather than unnecessarily replacing it after a prescribed period) but also increases availability while reducing energy consumption. Here, emergency maintenance is also reduced and customer satisfaction increased. This approach also allows remote monitoring of energy consumption and costs, making the implementation of energy management strategies easier and faster.

Another critical aspect of resilience lies with ease of maintenance and the elimination of human error. The design of the MegaFlex DPA UPS has placed great emphasis on these factors. For example, module cabinets can be easily moved to the UPS location using a palette truck and then slid into place on their integrated wheels →06. Connection is made via docking connectors so cabling faults cannot arise during the procedure.

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For mains cabling, there is entry top and bottom and the cabinet is IP20 protected. Further, the fan array is located on a pull-out drawer for easy access. Fan failure detection and speed regulation are provided as standard. Timely indication is given of the need to replace consumables such as fans and AC and DC filters, thus improving reliability. All in all, continuous UPS monitoring, smart design and intelligent diagnostics lengthen the UPS lifetime significantly.

—

A predictive insight flags component replacement need, thus increasing availability while reducing energy consumption.

MegaFlex DPA – a UPS for tomorrow's data center

High power, simplicity of use, efficiency, reliability, availability and resiliency are the watchwords that underpin ABB's high-power MegaFlex DPA UPS. MegaFlex DPA is designed to work with the rest of ABB's power infrastructure products to ensure a continuous flow of clean power to a data center and provide the system-wide resiliency needed for modern data storage solutions that implement distributed, cloud or hybrid approaches. By paralleling units, MegaFlex DPA can provide up to 6 MW and the UPS satisfies the "six-nines" requirement of the most demanding data centers.

Most important of all, MegaFlex DPA provides peace of mind for customers with the assurance that their power is guaranteed by the very best power protection technology on the market. •

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BETTER DECISIONS FOR ENERGY MANAGEMENT WITH ABB ABILITY™ ENERGY MANAGER

Smart energy management

Aggressive energy standards and new initiatives tightly regulating sustainability reporting are advancing in tandem with the digitalization revolution. The result is real-time data-driven energy management solutions.

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—
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With its vast number of electric assets and around-the-clock energy requirements, the global energy management system market is a key value leader – valued at an estimated USD 31.76 billion in 2023, it is forecasted to grow and reach USD 112.32 billion by 2032 [1].

Organizations that recognize the significance of energy management, will benefit by visualizing their energy consumption, tracking and reducing it. ABB Ability™ Energy Manager – whether cloud-based or on-site, provides any organization with the ability to do just that.

Defining energy management

"Energy management" viewed as a buzzword, summarizes the competences required to understand energy flows and performance actions necessary for improvement. However, upon examination, this broad term describes smaller, inter-linked functions that are a critical part of a stepwise digitalization transformation.

The ability to gather accurate, real-time data, leveraging digital technologies, supports the implementation of energy management initiatives and enables companies to make faster decisions.

Operator decisons impact a plant's energy and emissions footprint.

ABB Ability™ Energy Manager improves scheduling and coordination.

A food facility that installed the system reported saving 30 tons of carbon.

Organizations that recognize the significance of energy management will benefit by visualizing their energy consumption.

ABB designates five functional stages that constitute essential best practices for energy management, where digital tools play a fundamental role: detect, monitor, analyze, optimize and control [2].

Through detection, facility owners and managers use data from utility bills and available building information to benchmark, virtually disaggregating the energy costs to identify areas of excess energy consumption. Large datasets and Artificial Intelligence (AI) algorithms support this process.

Once a benchmark is set, monitoring follows. By leveraging device connectivity to visualize the historical and real-time energy data of key assets, facility owners and managers build a clearer picture of the issues to be resolved. Products, eg, circuit breakers, meters, relays, EV-chargers, inverters and sensors, linked to an on-site connectivity infrastructure or dashboard with widgets, are critical.

Once gathered, data is analyzed – especially for Key Performance Indicators (KPIs) and output reports are created; enabling saving actions aligned with benchmark targets. Energy forecasting analytics make this stage easier and more accurate.

Next, asset setpoint scheduling is used to optimize targeted KPIs. Here, smart connected products, power quality converters, uninterrupted power supplies (UPS), transfer switching and advanced relays, feed into an optimization engine, enabling those charged with delivering energy reductions to improve outcomes.


ABB Ability™
ABB SACE Building
Dashboard:
Overview
Energy
Assets
Real time currents
Site locator
Group peak monitoring
Power generation
11,25%
Power Generation
Site generation capacity
80,0
Generated power
9,0
Energy monitoring
212.387,0
363.780,0
Power demand
72,25%
Power demand
Contractual power
400,0
Active power
289,0
Power factor
Today
0,97
Power Factor
Real time power
Real time voltage
Peak monitoring
Energy cost
Analog data monitoring
Energy mix group
Total Income
270

01

With energy management systems and processes in place, control allows the asset setpoint to be carefully adjusted for energy efficiency or service continuity strategies. Pre-engineered reference architectures with Edge controllers and smart connected products, plus on-site distribution energy resources, microgrids, BESS and renewable technologies, should be considered.
By following these stages, organizations can continuously improve energy efficiency practices.

Energy management benefits
With the need to manage and lower energy usage across the industrial landscape more regulated now than ever (the basis for IEC 60364-8-1 and ISO 50001 for Energy Management Systems – Requirements with Guidance for Use) [3], compliance and avoidance of penalties for non-compliance is paramount. Nevertheless, energy management should be embraced, not out of necessity, but because it demonstrates a company's willingness for accountability.

Today's market-leading EMS solutions, such as ABB Ability™ Energy Manager, simplify this process as engineering requirements are minimal and system commissioning is quick (usually within one day). Available as Software-as-a-Service, it is ready-to-use.

Energy management monitoring helps industrial facilities fulfill sustainability targets, thereby reducing CO_2 emissions and unlocking further energy savings more easily than systems without digital capabilities; savings can lead to ISO 50001- and LEED certification.

Additionally, operating expenses (OPEX) can be reduced. Data insights help forecast energy usage, thereby increasing efficiency by up to 30 percent and reducing costs. ABB Ability™ Energy Manager delivers a potential payback in less than three years.

Getting started
Organizations, single- and multi-site facilities, that want to initiate steps toward energy management benefit from a concise assessment of energy usage. Energy service companies (ESCOs) typically perform audits and start creating actionable reports. Enlisting the support of an expert service provider, such as ABB, early on can pay dividends by maximizing energy management rapidly. Usually, all available historical site data is requested, data from facility utility bills, building information systems and field sensors.

ABB's Energy Manager, with add-on and premium service available, has provided valuable data-driven insights to a variety of industrial facilities →01 [1-4]. Recently, ABB Ability™ Energy Manager helped an international food facility

ABB Ability™ Energy Manager has helped a variety of international facilities control electricity costs and reduce emissions.

control electricity costs and reduce emissions while maintaining reliability and efficiency. By analyzing energy consumption, production costs could be optimized – the facility could save 30 tons of carbon by making additional use of ABB's EKip digital controllers to deliver power peak shaving [1].

In 2021, ABB initiated an EMS solution for a technology campus with multiple facilities and buildings. By monitoring power equipment in real-time and sending alarms via mobile devices, ABB Ability™ Energy Manager has helped this campus reduce energy consumption by 20 percent. In these ways, ABB demonstrates their ability to help an organization of any size roll out their energy management initiatives and secure their energy and cost targets [1-4]. •

01 Screenshot of analyzed data for connected products

Footnote
[1] Global energy management market size by sector 2025 Statista

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BUZZWORD DEMYSTIFIER

Hybrid

This quarter we have less of a demystifier article and veer more towards philosophy. Because we all know what the word hybrid means, right? Or at least we think we do and therein lies the challenge for the word hybrid in 2019: it's become a buzzword.

01

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01 A hybrid – the Chrysler Imperial hybrid tea rose.

—
02 Not a hybrid – the Chrysler Imperial car.

Type the word hybrid into google and the first thing that comes back is a definition for a hybrid vehicle. In fact, I conducted a small informal survey for this Buzzword Demystifyer. I asked people "What's the first thing that comes into your head when I say hybrid?" and nearly everyone replied "cars".

But hybrid is so much bigger than that. The trigger for hybrid as a buzzword topic came from your author walking past a bicycle shop and seeing some e-bikes labelled "hybrid bikes". As an owner of both a hybrid car and an e-bike the labels caught my eye. I excitedly deviated from my intended food shopping objective to find out more. I was expecting to be amongst the first to see e-bikes with energy recovery, a hybrid of my car and my bike in fact. Instead, I found out that the hybrid aspect of these hybrid e-bikes was that they are a mix of a road bike and a mountain bike.

I haven't even defined my hybrid car correctly above. Despite the very nature of the technology demanding that my car be quite light, it's a "heavy hybrid" that has a petrol and an electric motor and uses energy recovery to charge the battery. As opposed to a plug-in hybrid, which is helpfully named to clarify that it must be plugged in to charge its battery. So I made a heavy hybrid assumption about the hybrid e-bikes. A plug-in hybrid owner may not have jumped to the same conclusion. And the word hybrid means something else entirely to keen gardeners. The roses at the start of this article are hybrid tea roses →01.

From the Latin hybrida, a variant of ibrida "mongrel," specifically meaning "offspring of a tame sow and a wild boar", the word hybrid seemed to first emerge in c. 1600 and was used to refer to the "offspring of plants or animals of a different variety or species". Around about 2002 hybrid started being used as a short form of hybrid vehicle [1].

The Merriam Webster dictionary [2] defines Hybrid as:

1 an offspring of two animals or plants of different races, breeds, varieties, species, or genera a hybrid of two roses
2 a person whose background is a blend of two diverse cultures or traditions
3a something heterogeneous in origin or composition: composite
3b something (such as a power plant, vehicle, or electronic circuit) that has two different types of components performing essentially the same function

To be fair to the bicycle sellers, who I thought were perhaps being rather cheeky and jumping on the hybrid bandwagon to lure people in, perhaps I should have checked Wikipedia first [3]. There, in addition to the expected definitions of hybrid for biology (think of the tea roses above) hybrid vehicle, plug-in hybrid and hybrid train there, indeed, was hybrid bicycle, defined as "a bicycle with features of road and mountain bikes". But in addition was a fascinating list including, for example, hybrid library, hybrid market, hybrid gemstone and, of course, hybrid word. All perfectly valid uses of hybrid, but since 2002 becoming increasingly overshadowed by the shortening of hybrid vehicle to just hybrid.

And therein lies the modern challenge for the word hybrid. No longer restricted to sows and boars it is now, either overused or the victim of

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Photo 01: wikimedia, Yoko Nekonomani; photo 02: Wikipedia, AlfvanBeem

Buzzword Demystifier

02

a narrow assumption. In the world of technology hybrid has, in some ways, fallen victim to the “apple phenomena”: first there was the iMac, then the iBook, followed by iPod, iPhone and iPad. Now, businesses who’d like to imply the same innovation and design chic put i in front of their product name, technology based or not. I’ve even seen an iUmbrella. In the technology arena some use the word hybrid to imply environmental

The centuries-old term “hybrid” is no longer restricted to sows and boars, it’s become a buzzword.

benefit, true or otherwise, and at the same time some of us see the word hybrid and make assumptions about the product, its behavior and benefits. As always in life hybrid now essentially boils down to “always check the small print”. Otherwise you may take delivery of a bargain Hybrid Chrysler Imperial that you have to plant in your garden, rather than park in your garage →02. ●

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