review

Better decisions

ABB

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Better decisions

While it's a simple truism that the more you know the better your decisions will be, bringing them to fruition requires a complex, expert melding of experience with accurate, up-to-date data that's made available when and wherever it's needed to empower action. This issue of ABB Review explores how it's done and the successes it yields.

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Better decisions

Dear Reader,

Good decisions depend on good-quality data and on understanding that data. Traditionally, operators took decisions based on gut instinct, borne of long experience and formal training.

Today, data-mining techniques and artificial intelligence are helping operators take better decisions by making available a wealth of information that was previously inaccessible. Digital tools can recognize parallels between situations and provide an operator with solutions used by other operators who were confronted with similar situations. Rare or unexpected occurrences, which traditionally present the greatest risks, can be better managed, improving safety and reducing downtime and waste.

In this edition of ABB Review, "better decisions," we look at many different ways in which digital technologies are empowering the "human in the loop" to take better decisions for the benefit of their employers, customers and society as a whole.

Enjoy your reading,

Björn Rosengren
Chief Executive Officer, ABB Group

Better decisions

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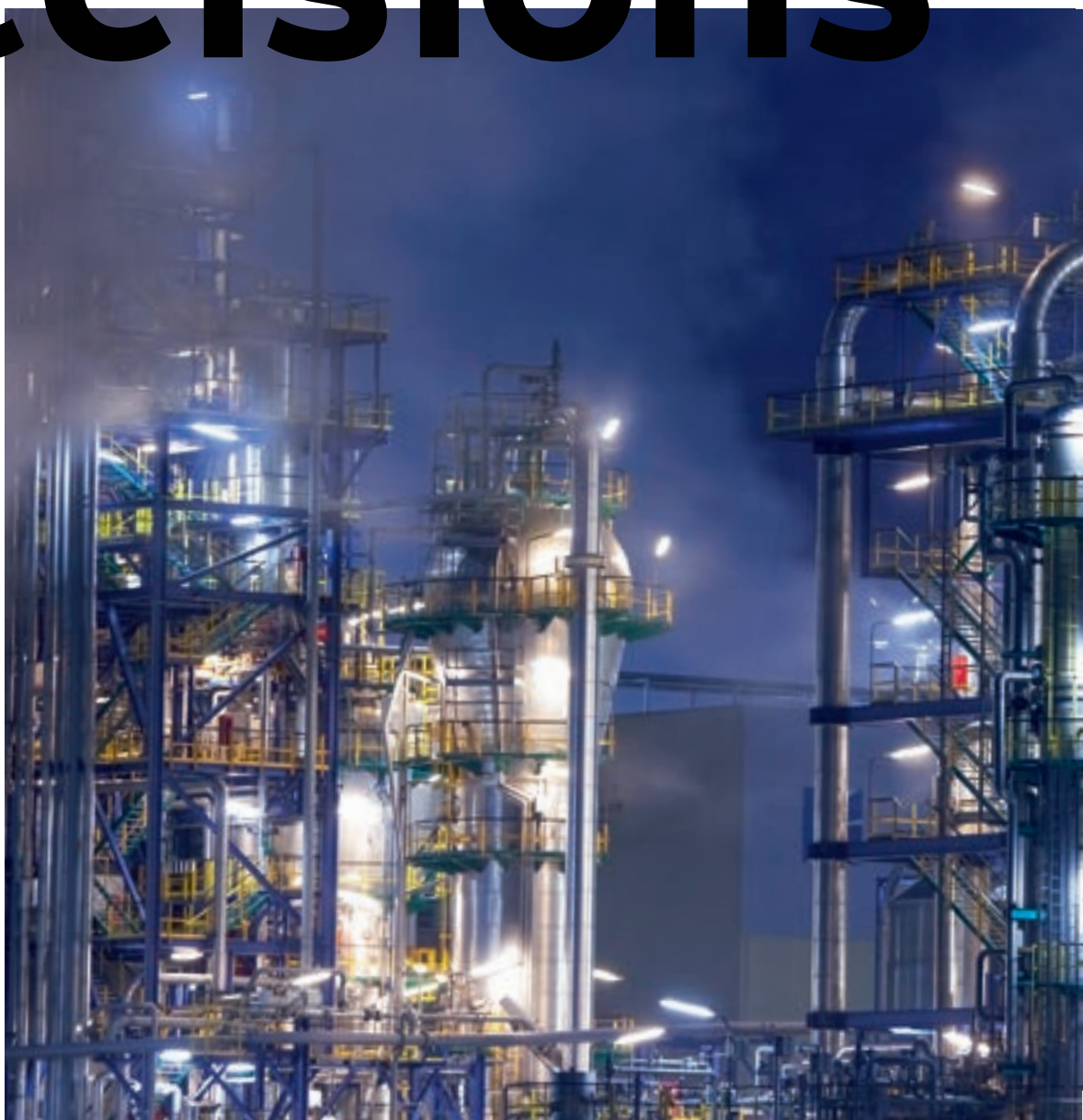
A "better" decision is one in which every relevant fact and possible outcome has been evaluated and included. This requires a combination of knowledge, situational awareness, and a profound understanding of the pro-cesses by which a broad array of variables can be trans-formed from data into insights. ABB works with customers every day to sup-port informed and actionable decisions.

01

AUGMENTED REALITY FOR PLANNING ROBOT INSTALLATIONS

RobotStudio® AR Viewer app

ABB's RobotStudio is the world's most-used simulation and offline programming tool for robotics. The RobotStudio AR Viewer app is an augmented reality (AR) application for mobile devices that visualizes, in the real environment, the industrial robots created beforehand in RobotStudio.

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01 RobotStudio AR Viewer: The robot setup shown on the table is a conceptual image of what the engineers see in 3-D on their mobile device.

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With more than 500,000 robot applications installed across multiple industries since 1974, ABB has impeccable credentials as a pioneer of robotics in industrial automation. Indeed, among its comprehensive range of digital offerings, ABB supplies the world's most-used simulation and offline programming tool for robotics, RobotStudio. This tool enables robot programming to be performed on a PC in the office, away from the production floor. RobotStudio provides the means to increase the profitability of that customers can gain from their robot systems, by allowing them to perform tasks such as training, programming and optimization, without disturbing production. The tool is built on an exact copy of the ABB Virtual Controller software that runs ABB production robots. This aspect allows very realistic simulations to be performed, using actual robot programs and configuration files identical to those used on the shop floor. RobotStudio comes with a full package of features and add-ons allowing for complete offline simulation, thus reducing risk, speeding start-up, shortening tool change-overs and, ultimately, increasing productivity.

To maximize the benefits that can be derived from the RobotStudio desktop application, ABB has now added the RobotStudio AR Viewer application to the PC-based RobotStudio offline programming software line-up.

RobotStudio AR Viewer
RobotStudio AR Viewer is an AR application for mobile devices, such as smartphones and tablets, that visualizes, in the real-world environment, the industrial robots created beforehand in the RobotStudio desktop application →**01**. The RobotStudio AR Viewer can be used to test

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The AR Viewer tool makes it even easier for customers to access the extensive capabilities of RobotStudio.

any model created in RobotStudio →**02**. The AR features enable precise positioning of a robot on the shop floor, which contributes to a better understanding of how it will fit into the space. It thereby accelerates the planning of manufacturing.

With RobotStudio AR Viewer, customers are presented with an exact copy of the ABB robot in a 3-D visualization in which the robot's movements are accurately reflected →**03**. Additionally, it is possible to resize the robot to the desired dimensions, adjust station rotation to see it from every angle and joint-jog (ie, move incrementally) robot parts →**04**. A timeline feature makes it possible to go quickly to a certain point in time in the animation, enabling the user to find ways to enhance performance or pinpoint a potential issue.

RobotStudio AR Viewer provides a quick and convenient way of using a smartphone or tablet to visualize where and how robotic automation could fit into a customer process. The AR Viewer is ideal for companies that are new to robotic automation or for those who have previously lacked the time or resources to start planning an installation.

The AR Viewer tool makes it even easier for customers to access the extensive capabilities of RobotStudio, helping them see how robots can be introduced into their production and how automation can improve the productivity and flexibility of the existing process before they commit to any investment. The app provides a

02

low-cost, safe and easy way for individuals or groups to visualize an installation, with none of the potential concerns over complexity, hygiene, or nausea that can occur with virtual reality-based alternatives.

The app is available free of charge on the Apple App Store and Google Play Store.

As part of its mission to pioneer and innovate in automation digitalization and help customers embrace and apply digitalization when and where it is needed, ABB is adding features to the app on an ongoing basis. A significant upcoming new functionality is the possibility to add a 3-D scanning capability so the mobile device can capture and record the topology and features of the prospective robot location. Such functionality will be especially beneficial for customers who want to replace a robot in an existing installation or integrate a new robot solution into a brownfield project. •

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02 Visualizations can
be presented on any
suitable mobile device.

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03 It is important to
know in advance the
3-D space in which
robot will move.

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04 The effects of joint-
jogs can be visualized
in the RobotStudio AR
Viewer app.
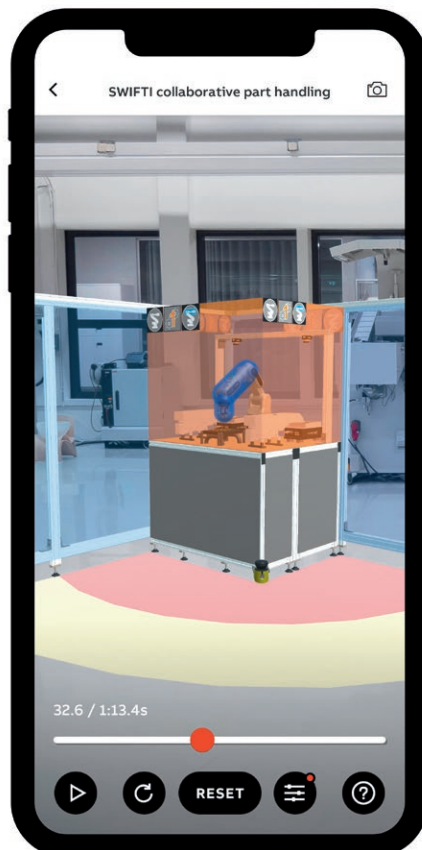
03

04

TOPOLOGY-BASED CONTEXTUAL ALARMS

Informed choice

Alarms are critical for control system operators and are usually displayed in tables, ranked by severity. However, alarm context has to be elicited by the operator. ABB now links plant topology and alarm chronology to provide a rich context for alarm interpretation, reducing operator cognitive load.

01

Industrial plants can have a large number of devices that receive or transmit signals associated with the control of production processes. The process control systems of these plants consist of networks of interconnected sensors, actuators, controllers and computers. Monitoring such a complex array of data and equipment and reacting appropriately to the events and alarms they produce is not a trivial challenge. Human operators on-site and in remote control rooms must pay close attention so that undesirable situations are quickly detected and their causes identified →01. Failure to rapidly detect and interpret alarms and remedy critical situations can lead to safety risks, unnecessary costs and environmental damage.

Traditionally, alarms and events are displayed in tabular form in an alarm list, allowing operators to monitor them as they occur and to perform operations in reaction →02. This task can place a considerable cognitive load on the operator since the number of alarms and associated parameters can be high.

While a traditional alarm list offers a comprehensive way to access information related to alarms, it lacks the context needed to identify topological and chronological relationships between them, often making it difficult for the operator to interpret a particular situation.

Response difficulties are exacerbated during an alarm flood – ie, situations where the rate of alarms arising exceeds the operator's ability to handle them. An alarm flood is often inevitable and is always serious. Such floods require opera-

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Monitoring alarms can place a high cognitive load on the operator.

tors to manually analyze the correlation of alarms in potentially complex process networks – eg, on operator screens that mimic the plant and process topology – in order to derive information on possible relations between alarms, including their chronology. This latter aspect necessitates the determination of start point for the analysis, the construction of a mental model representing the sequence of the topologically relevant

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01 Large industrial complexes can present an intimidating alarm landscape to the operator. ABB's novel context-rich, topology-based approach to industrial process alarms reduces the challenges in finding the information needed to make fast and correct decisions in alarm situations.

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On the other hand, a process or plant topology model is a formal model based on a domain-specific class library that captures the types of model elements, their semantics and their hierarchy. For example, a reference model for chemical plants will have special equipment

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ABB's approach enriches event and alarm history data with engineering information from a process topology model.

alarms and the identification of the alarm that started the cascade. In large, complex plants, this sudden, event-rich situation can quickly overwhelm operators, impairing their ability to react appropriately.

To improve the operator's alarm handling capabilities, ABB has developed an approach that enriches event and alarm history data with engineering information from a process topology model.

Process topology model
Process engineers use piping and instrumenta-tion diagrams (P&IDs) to create blueprints for industrial processes. These diagrams specify the equipment needed and describe directed relationships between elements. Some vendors of CAD tools are pushing for the digitalization of P&ID documents so computer algorithms can process them.

such as a "chemical reactor" that is a subtype of "tank." Having the P&IDs created as object-oriented models using these semantics opens the door to the automation of many engineering and operational tasks →03. Pending the support of CAD tool vendors in directly exporting P&IDs into topology models, research groups have themselves built tools to achieve this useful transformation [2,3].

Topology-based contextual enrichment – the smart alarm list
ABB's novel, dynamic, topology-based approach to industrial process alarms presents an effective alarm list summary enriched with contextual information, thus reducing the operators' challenge in finding the information necessary to make decisions. This method utilizes both engineering information (ie, the process topol-ogy model described above) and operational
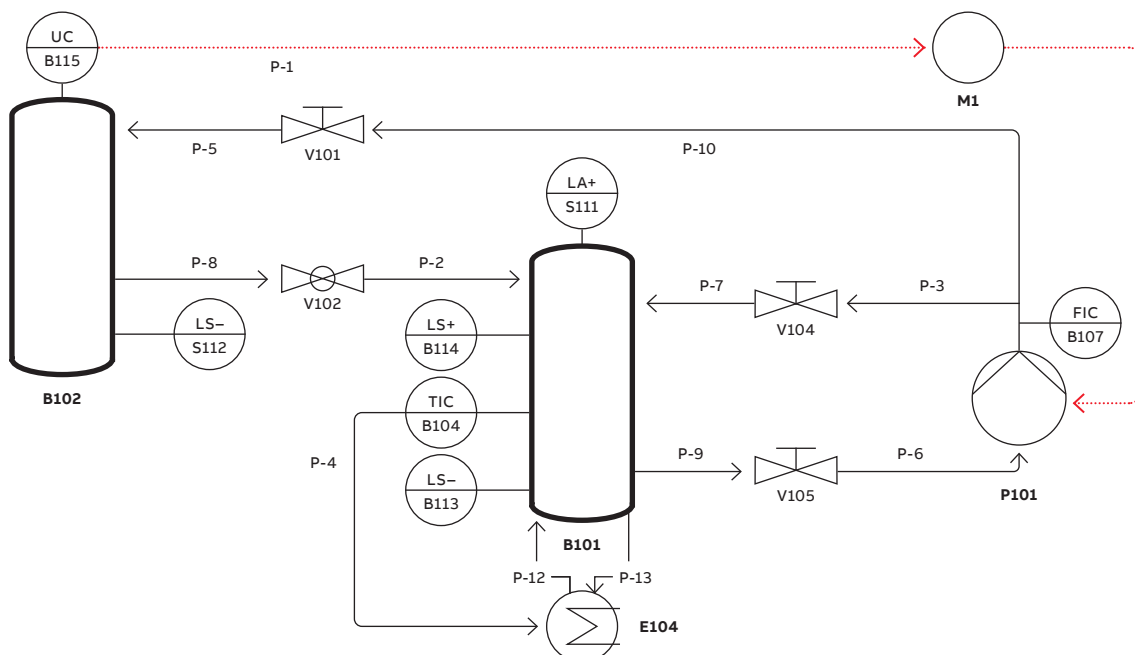
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information (ie, event and alarm history data) to derive the context for a set of triggered alarms. The "smart alarm list" so derived presents a simultaneous integration of both the alarms' topological relations and chronological informa-tion on the alarm summary view by:

• Utilizing the existing engineering artifacts – including the topological information about the controlled process (ie, P&IDs) – to infer the physical connections of the process equipment associated with the triggered alarms.
• Employing operational information (ie, event and alarm history data) to derive the chrono-logical order of the topology-connected alarms.

The result of this contextual analysis is presented on the user interface as a smart alarm list in which topology-connected alarms are linked and ordered over the timeline →04. The vertical dimension of the chart represents different objects that refer to an industrial component where the alarm was triggered. If different signals belong to the same object, they are displayed on the same row. The alarm proper-ties – active time, duration, acknowledged time, object name and priority level – are presented in a rectangle, whose width reflects the alarm's duration. One of the key features of the chart

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The contextual analysis shows a smart alarm list in which topolo-gy-connected alarms are linked and ordered over the timeline.
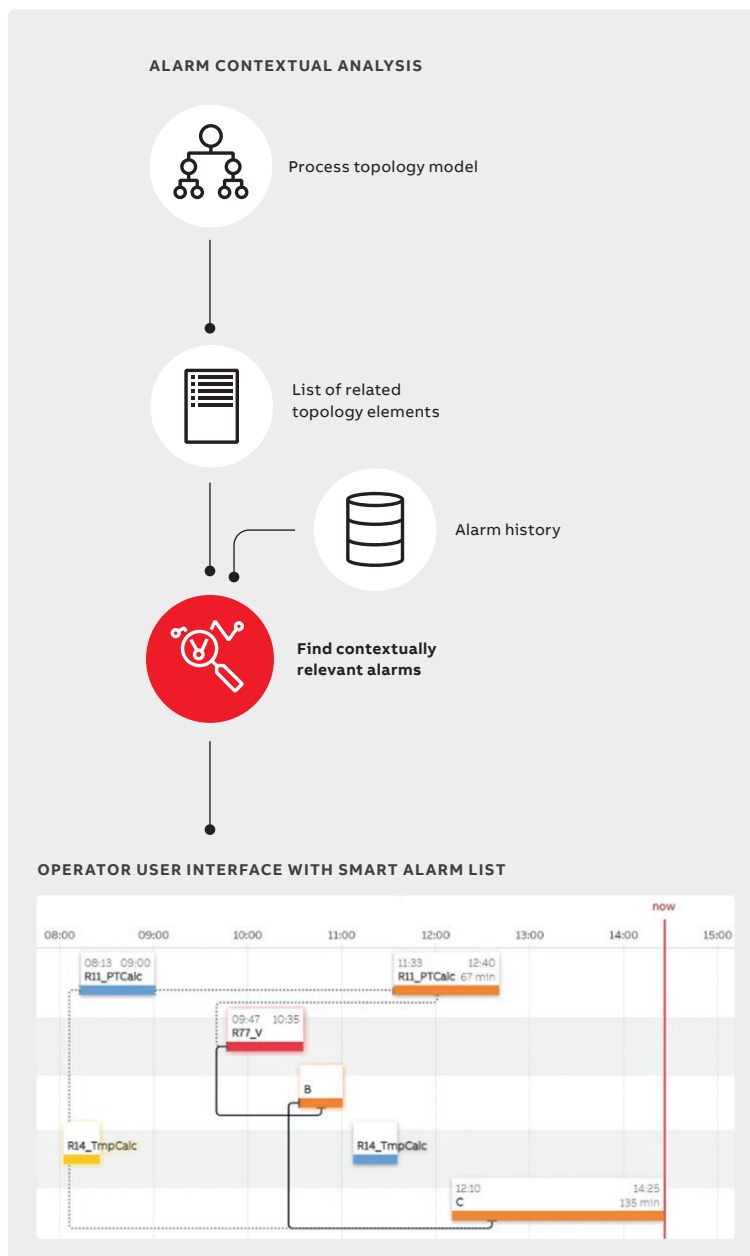
is the visualization, using connecting lines, of alarm relationships (dependencies) based on contextual alarm analysis. This visualization aids the user in distinguishing which alarms have topological and chronological relations – thus providing vital information for root-cause analy-sis – and decreases operator cognitive load. The presentation format is loosely based on cause-and-effect diagrams, also known as fishbone or Ishikawa Diagrams.

User scenario
→05 shows the user and system activities associ-ated with analyzing a specific alarm with the help of the smart alarm list. The starting point is the traditional alarm list. For example, the operator selects an alarm from a pressure transmitter, P4, in the water reinjection system on an oil rig →06. The Smart Alarm History application program-ming interface (API) queries the so-called Topol-ogy Navigator API for connected elements. The Topology Navigator API will perform its search across the plant topology model and will find other actuators and measurements upstream. The Smart Alarm History API combines the search results from the Topology Navigator API with the recent alarm history and finds that other pressure and flow transmitters (P1, P2, P3 and F3) show alarms. The Smart Alarm History API con-structs the alarm graph and returns it to the Web front-end, where the alarm graph is drawn. The operator can then see that a pressure problem originating from the booster pump in the suction side (P1) has propagated to the whole injection system, affecting the pressure at the well (P4).

ALARM CONTEXTUAL ANALYSIS

Process topology model

List of related
topology elements

Alarm history

Find contextually
relevant alarms

OPERATOR USER INTERFACE WITH SMART ALARM LIST

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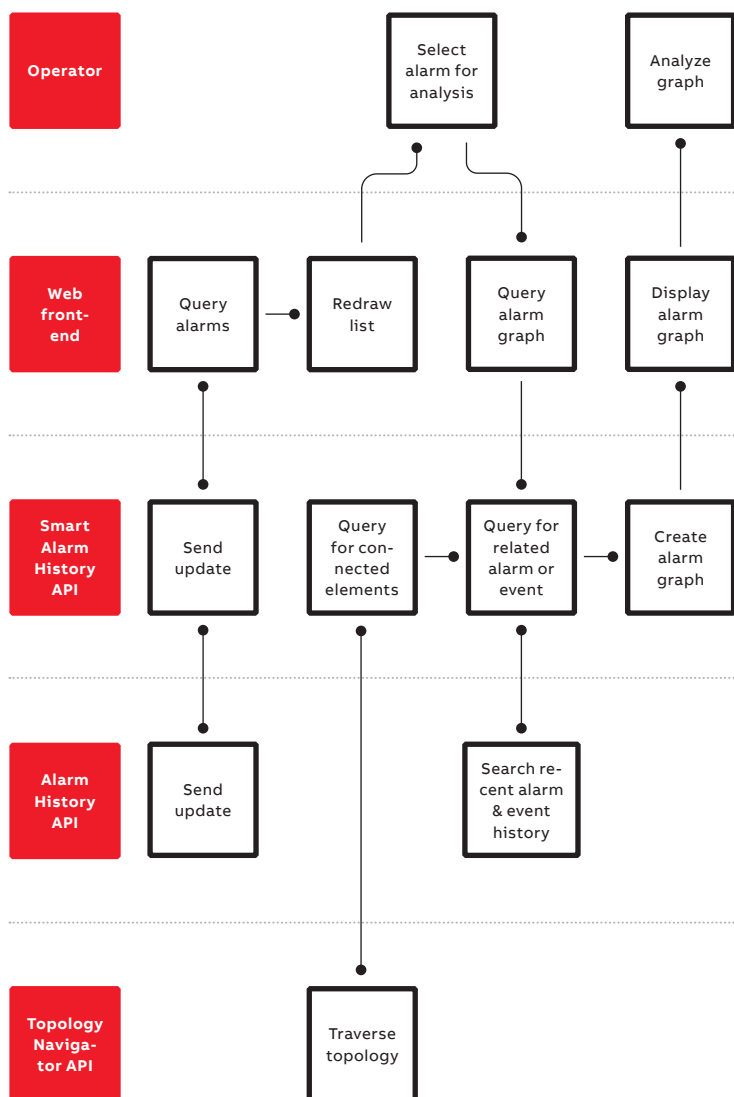
Validation
To validate the topology-based smart alarm list,
ABB designed and implemented both a proto-
type tool that interfaces with ABB's Extended
Automation System 800xA control system and
an importer that uses machine-readable P&IDs
to create a topology model. →07 shows the tool's
high-level software architecture as a Unified
Modeling Language (UML) component diagram.

The topology information, here stemming from
P&IDs created in Microsoft Visio, is converted to
a standard CAEX (a vendor-neutral data format)

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The topology-based smart alarm
list approach was successfully
validated in a real-world case in a
pilot plant.

plant topology format by the Topology Importer.
Other sources of topology information, eg, other
formats of P&IDs, or even information extracted
from the process representation and visualiza-
tion in the control system, can be used [2].

Using the prototype tool and importer, ABB's
topology-based smart alarm list approach was
successfully validated in a real-world case in a
pilot plant.

Context-rich alarm lists for any process industry
Context-rich alarm lists support the process
operator's reasoning concerning a triggered
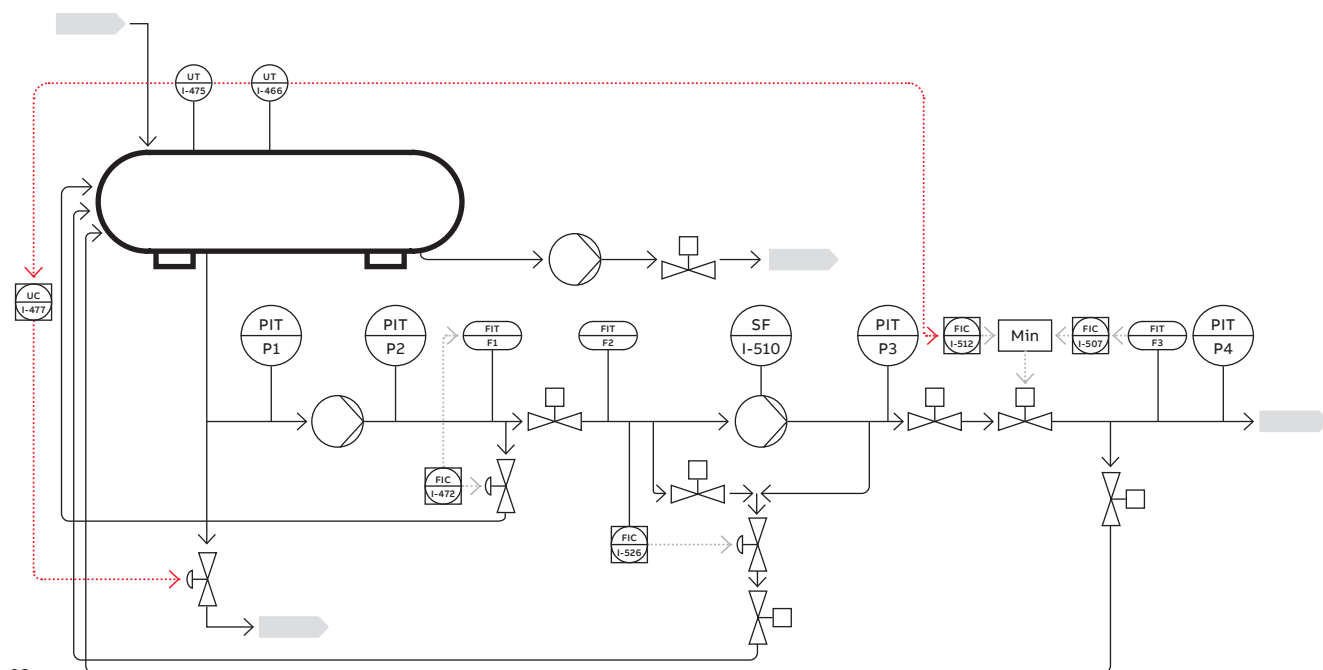
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05 Activities for smart alarm analysis.

06 Simplified process topology from a water reinjection system.

07 Components of the smart alarm list.
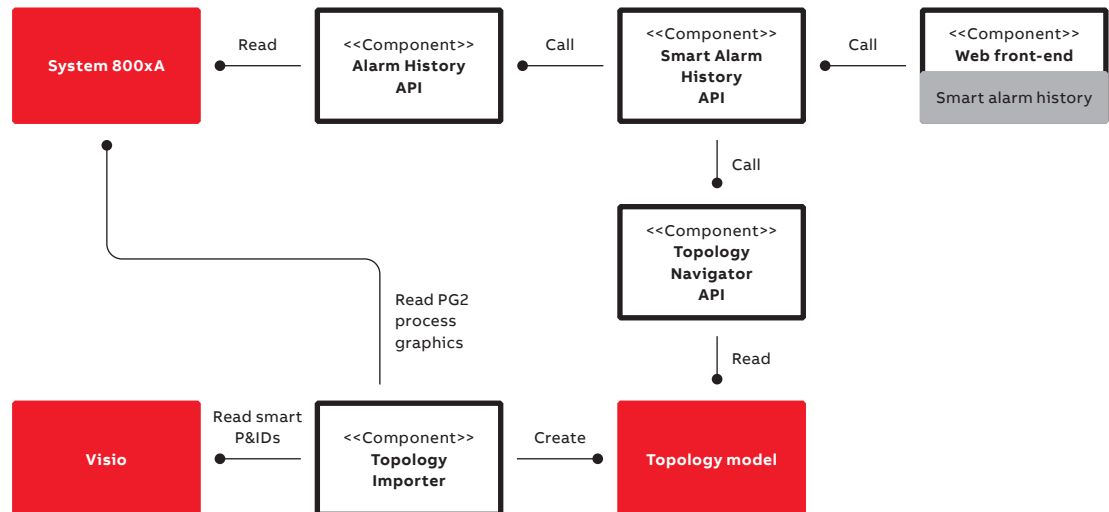
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alarm by putting it in a chronological relational context to other alarms that are topologically relevant to it. Compared to established alarm lists in control systems, this visualization approach

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The smart alarm list concept can be used for any continuous or batch process.

can, for example, bundle alarms caused by the same disturbance, such as a stuck valve. The approach informs postmortem alarm root-cause analysis and, because it is generalizable and does not depend on specific hardware, is applicable in all segments of the process industry.

The smart alarm list concept can be used for any continuous or batch process. ABB applied it to a water reinjection pump on an oil rig and achieved

a reduction of 95.5 percent in critical events presented to the operator when looking for causes of a pump trip alarm. This improvement significantly reduces the cognitive load on operators and boosts alarm management usability.

Future work will focus on, for example, integration of the alarm philosophy into future human-machine interfaces (HMIs), perhaps as a side-by-side display with a traditional alarm list. This approach would make it possible to leverage a conventional alarm list's filter and search capabilities to retrieve a particular alarm or event of interest and then explore alarm relationships in a smart alarm list. •

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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

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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

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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 indica-
tor and the process variables, thereby providing

Anomaly detection	Anything going wrong?
Topology-based root cause analysis	Why does it go wrong?
Workflow	What can be done?
What-if support	Will it work?
Knowledge Extractor	Has it happened before?
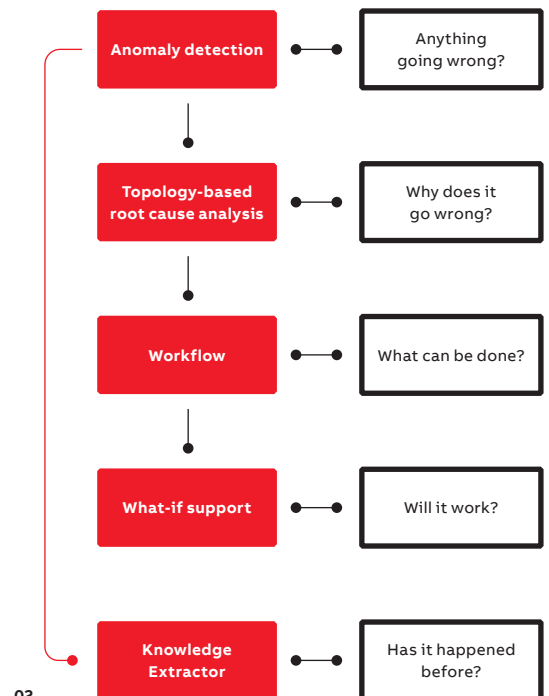
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information about the process performance in real-time →03.

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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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 clo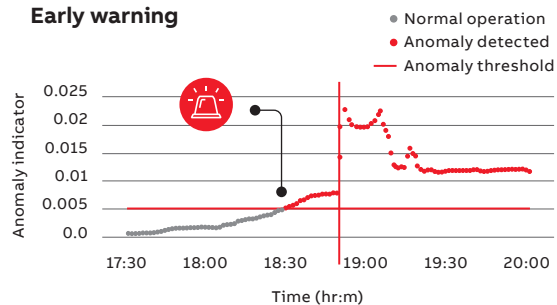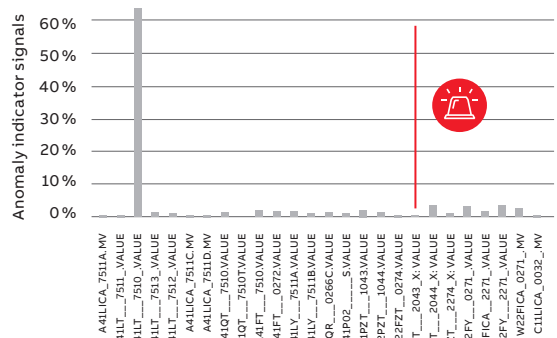sing of valves; overrides of systems and set point changes. By analyzing the temporal flow of the historical actions, reaction times and waiting times between actions can also be extracted. Using this information, workflow mining techniques allow blueprint processes for different plant situations to 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

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

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.

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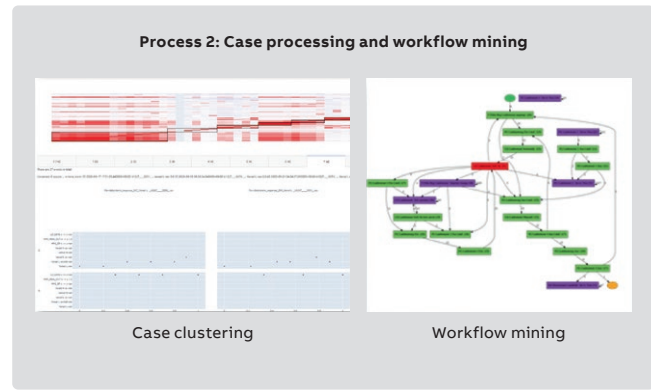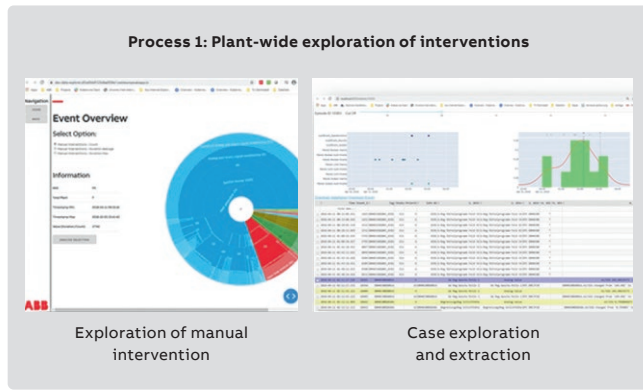
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transitions correctly, including aspects like overshot/undershot with regard to alarm limits or the time-lapses that occur until steady-state is reached following the implementation of an operator action.

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

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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.
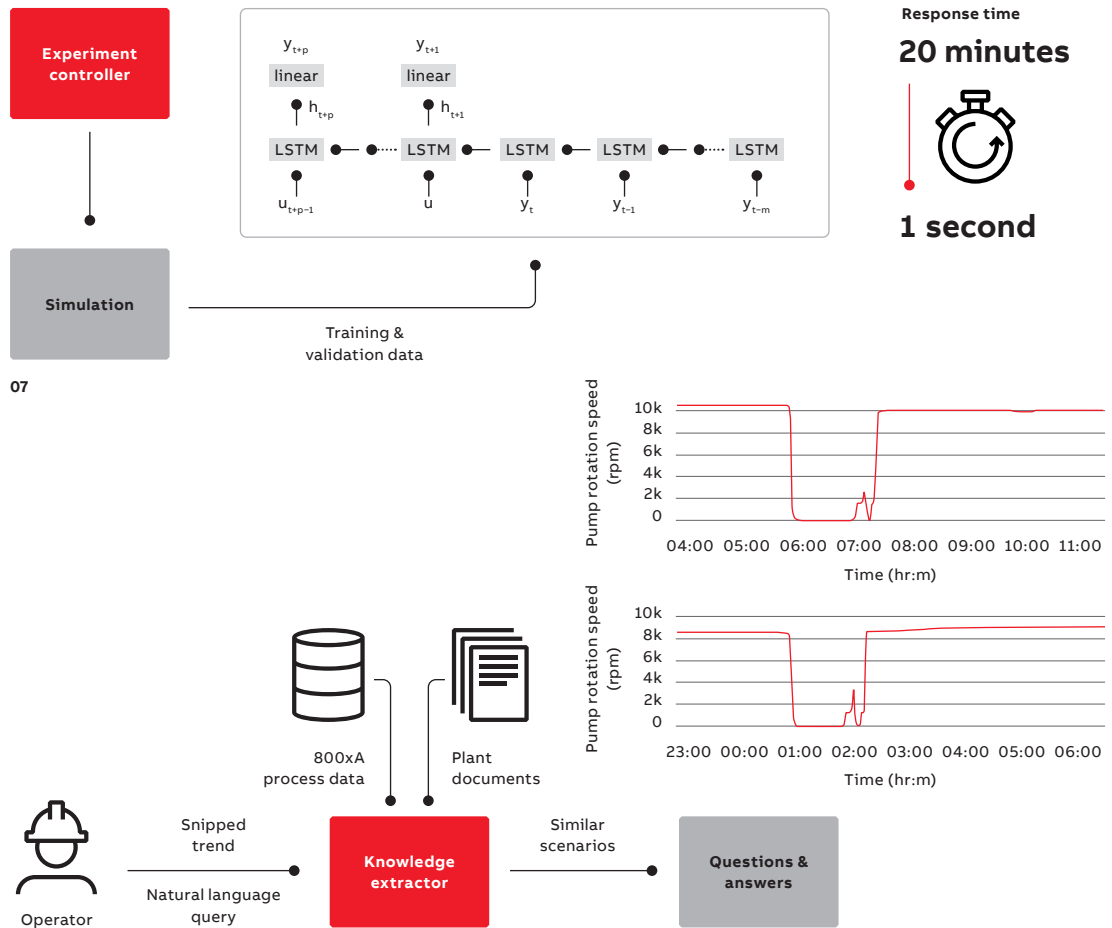
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This prototype was tested on the trip data from the real-world Draugen oil platform where it was applied to specific scenarios. For example, whenever gas pressure increases over a specific threshold, the pump trips, and the level of the feed-water 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

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

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. •

MODULAR PROCESS AUTOMATION PILOT PLANTS

Building blocks

Modularization helps overcome the challenges of changing production environments in process industries. ABB and partners have developed pilot applications to validate the new concepts in process automation communication and control that modularization needs. What are the results from these pilots?

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01 Modularization
can accommodate
fast-changing
process environments
that require highly
flexible approaches to
production.

Modular design approaches have been shown to bring substantial benefits to an astonishing variety of products and processes – from uninterruptible power supplies to software engineering, and much in between. Chemical and pharmaceutical processes, in particular, profit from modularization as it helps them overcome the challenges posed by the rapidly changing production environments that are characteristic of these industries →01. As well as catering for production capacity and product type changes, modular plants deliver a faster time to market and save time during engineering and commissioning (up to 50 percent in both cases) [1].

To exploit the advantages of process modularization, new process automation communication and control structures are required. Here, ABB is a leader and is recognized in the community as a standardization driver. Moreover, ABB has developed modular plant engineering prototypes. To ensure these prototypes perform well under real-world conditions, they must be tested in industrial applications.

It made sense, therefore, for ABB, in 2017, to join a third-party-funded enterprise: the

ENPRO-ORCA project [2]. In this project, plant owners and automation system vendors jointly develop pilot applications. Within these pilots, the engineering prototypes can be tested. The pilot applications also allow the project

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Modular production plants are, unlike conventional plants, assembled from predefined, pretested process modules.

participants to systematically validate the VDI/VDE/NAMUR 2658 standard upon which much of the modularization work is based. ABB's project partners are the TU Dortmund University, Evonik and Merck.

The project's findings so far have been very positive and to fully appreciate them, a basic description of modular process automation architecture is helpful.

Owner	Scale	# modules	Automation Suppliers	References
Namur Case Study	–	6	POL: ABB PEA: ABB, B&R	
TU Dortmund University (Distillation)	Lab	5	POL: ABB PEA: Wago, embedded, RasPi	[7]
Merck (Distillation)	Technical center	1	POL: ABB, B&R PEA: B&R	
Evonik (Membrane Test 1)	Lab	1	POL: ABB PEA: Wago	[8,9]
Evonik (Membrane Test 2)	Technical Center	3	POL: ABB PEA: Wago	[9]
Evonik (Reaction)	Technical Center	6	POL: ABB PEA: Phoenix Contact	[9]

02

Modular process automation architecture
Modular production plants are, unlike conventional plants, assembled from predefined, pretested process modules called process equipment assemblies (PEAs) [3] – sometimes referred to as packaged units or skids. PEAs fulfill a dedicated process function, such as tempering, and can be used in multiple applications. PEAs are described using the Module Type Package (MTP) standard, which is a vendor-neutral

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MTPs allow PEAs to be integrated into a supervisory control system: the process orchestration layer.

description of PEAs. For the automation of PEAs, a prototype of ABB's Module Designer is used that accommodates ABB and B&R automated PEAs. With this prototype, the automation engineering of the modules can be performed and the resulting automation system, eg, based on ABB Freelance, can be automatically generated. In addition, the Module Designer can automatically generate the corresponding MTP.

MTPs allow PEAs to be integrated into a supervisory control system: the process orchestration layer (POL) [3]. ABB's Extended Automation System 800xA is used as a POL. For engineering the pilots, a prototype of the ABB Orchestration Designer is used. From the Orchestration Designer, all parts required for the runtime are automatically generated in System 800xA and can immediately be used for supervisory control [4].

Every PEA has its own intelligence, often a programmable logic controller (PLC) or embedded or distributed control system controller [3]. The controller exposes the functions of the PEA using OPC UA. Functions are abstracted from the process device, eg, a valve, into so-called services. Services are controlled from the POL and execute the process functions provided by the module. A tempering module might, therefore, provide a service called "Tempering," which receives a start command and the setpoint for the required temperature so that the PEA internally executes the required functions of the devices.

The basic concepts, ie, integration using MTPs and service-based process design, have already been tested; it has been shown that modularization of process functions is possible. First concepts, architectures and prototypes have been developed by ABB for a modular automation system. Projects and previous initiatives [5] defined the automation system for modular plants and provided prototypes and demonstrators. The pilots described in this article are based on the previously developed prototypes [6,4].

Pilot applications
Several pilot applications were created in cooperation with ABB's customers Merck and Evonik, and the Laboratory of Equipment Design at the TU Dortmund University (Germany) developed a laboratory pilot →02–03. Only the laboratory pilot will be discussed in detail here.

TU Dortmund University (Distillation)
The pilot application at the TU Dortmund University is an existing laboratory environment that has been modularized by automating modules with a controller, providing an MTP for each of them and integrating them into the POL.

Basic structure
The distillation plant consists of five PEAs: distillation, feed, two thermostats and an analysis module. The analytical PEA is optional and can be used, for example, to determine continuously the concentration of the distillate or bottom product

03

stream. The two thermostats and the feed PEA are required to operate the distillation, but can also be replaced by any other PEA that fulfills the same function (heating/cooling or dosing). The distillation PEA as well as the feed PEA are each equipped and automated using PLCs.

The thermostats have an embedded control system. The analysis PEA is independently equipped with all necessary functionalities by the manufacturer of the software suite. For the other PEAs, the MTPs are provided by the PLC vendor. All PEAs can, therefore, be easily integrated into ABB's POL.

Services
The services provided by the individual PEAs developed in this project are used to operate the system from the POL. Different services are available from each PEA. The feed PEA, for exam-ple, provides a dosing function via the service "Dose."

The analysis PEA provides an "Analyze" service, in which Raman spectrograms are continuously recorded and then evaluated against a con-centration of a component. This concentration

value is communicated by the analysis PEA through System 800xA to the other PEAs, so that a module-to-module communication is achieved.

For each service, procedures specifying how the service should be executed are defined.

Usage of the laboratory plant
The distillation PEA is used to separate a mixture of substances into high- and low-boiling com-

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The services provided by the individual PEAs developed in this project are used to operate the system from the POL.

ponents with the highest possible purity. The basic operations required in this plant for this purpose, such as heating, level control, control of the spinning belt speed and similar further operations, can be combined and encapsulated
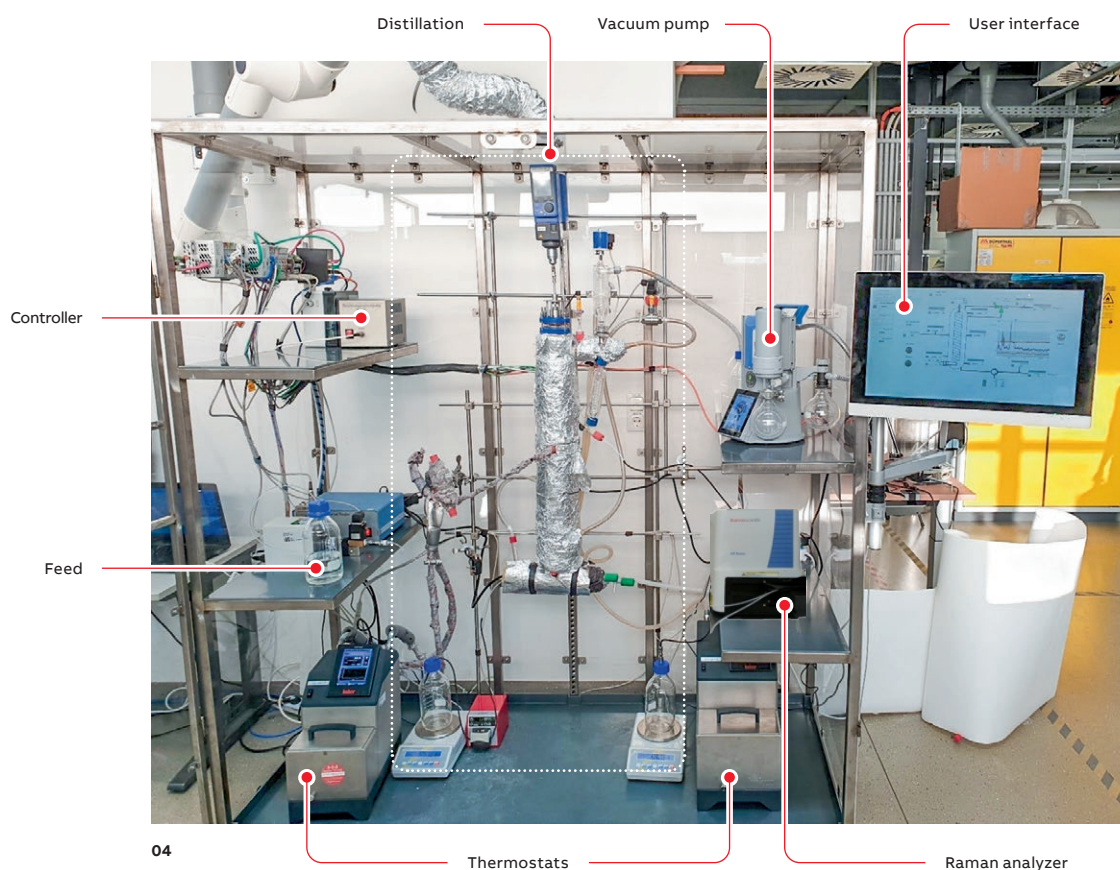
04

automatically in a "Distilling" service using a few operator specifications. Procedures are provided for startup and shutdown of the plant, which ensures automatic plant operation →04.

The Distilling service provides different procedures depending on how the user wants to operate the plant – for example, manually or automatically. In the "distilling_automatic" procedure, for instance, the operator has only to specify a heating capacity and desired head temperature (without analysis PEA) or head concentration (with analysis PEA). The distillation PEA then automatically and continuously adapts to this specification without operator influence.

The automatic "OP_testing" service enables a characterization of various unknown materials that, compared to a tray or packed column method, is 30 to 70 percent faster and uses 40 to 80 percent less material.

Lessons from the other pilot sites →02 expanded the team's experience in modularization for processes:

Namur pilot case study
The Namur case study was delivered from the

Namur working groups (Namur is an international user association of automation technology and digitalization in process industries) as a reference for the technological implementation and modeling of the MTP. In modular automation, the pilot is used as a reference example for the concept and prototypes; for ABB, it is the

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The pilot is the in-house testbed for new technology development in automation engineering and modular production.

in-house testbed for new technology development in automation engineering and modular production. Additionally, the pilot is used as a testbed for the pilot applications, since PEAs can easily be added to the demonstrator and the automation of PEAs, import of MTPs and PEA-to-PEA communication can be tested.

After Namur's seven PEAs are engineered using the Module Designer, the plant topology is developed using Orchestration Designer →05-06.

BP11

BPX	
Stickstoff2	Produkt
Stickstoff	Abfall
C0001In	Abluft
	Out
	P0008Out
	L0005Out

BP13

BPX	
Stickstoff2	Produkt
Stickstoff	Abfall
C0001In	Abluft
	Out
	P0008Out
	L0005Out

BP12

BPX	
Stickstoff2	Produkt
Stickstoff	Abfall
C0001In	Abluft
	Out
	P0008Out
	L0005Out

BP21

BPX	
Stickstoff2	Produkt
Stickstoff	Abfall
C0001In	Abluft
	Out
	P0008Out
	L0005Out

RP04

RPXX	
VEWasser1	Abfall
Heizmedium	ProduktOut
ProduktIn	Kondensat
ProduktRP21	Abwasser1
VEWasser2	Out
Stickstoff	HeizmediumOut
	Abwasser2
	Abluft

KW06

KWXX	
Kuehlmedium1	Kuehlmedium1Out
Kuehlmedium14701	Out3
Abfall	Kuehlmedium1469
Kuehlmedium1470	Abluft2
Product1457	Abluft
HeatingMediumIn	Out2
Product1308	Out1
Stickstoff30mBar	KuehlmediumOut
	O1773
	HeatingMediumOut

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04 Demonstrator plant distillation and interconnection with periphery/analysis PEAs.

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05 The plant topology is imported into System 800xA and the communication to the modules is automatically established.

—
06 The automatically generated operator workplace during operation. The sequence reached steady-state operation of the plant and each module executes the configured service.
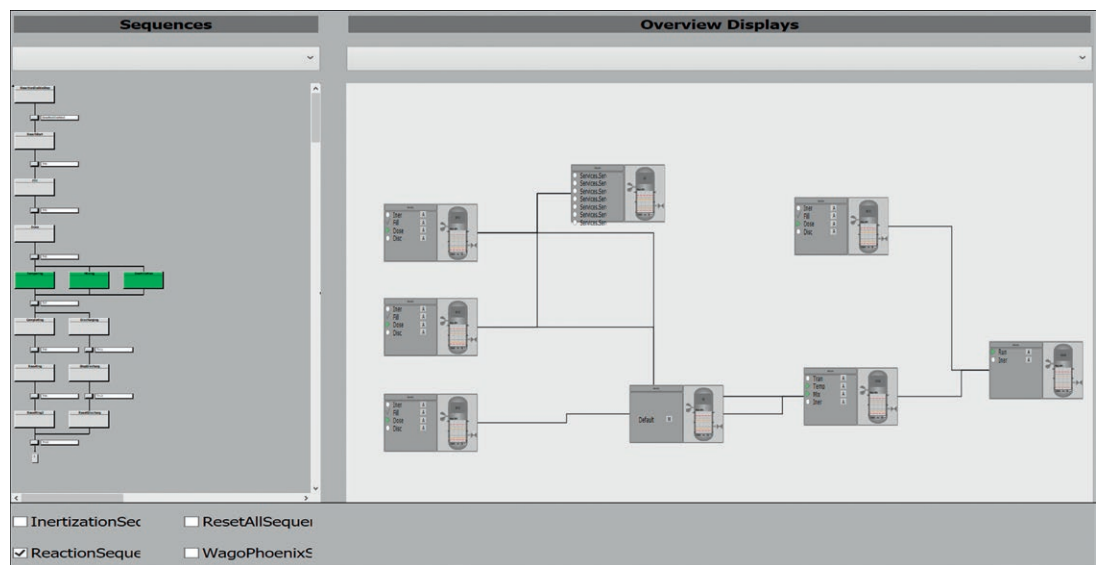
Merck

The Merck distillation pilot plant consists of a complex PEA that implements all the functionalities required to operate distillation. In this PEA, it is possible to show how services can be called from other services within the PEA and from the POL to demonstrate that a larger process can be realized at the PEA level. The PEA is "intramodular safe" and plant standalone operation is possible. Both manual control and automatic control via a recipe have been validated. Thus, it is shown that this technology is suitable for process automation, while important knowledge and experience were gained for the future operation of modular plants.

Evonik

In a close cooperation between Evonik, WAGO and ABB, HMI visualization, PEA tags, services and service-based recipe control were implemented and tested in this pilot →07. The services can be controlled manually via the POL, as well as via the recipe control (engineered in Orchestration Designer). PEA-to-PEA communication for analog and binary signals is prototypically implemented and tested.

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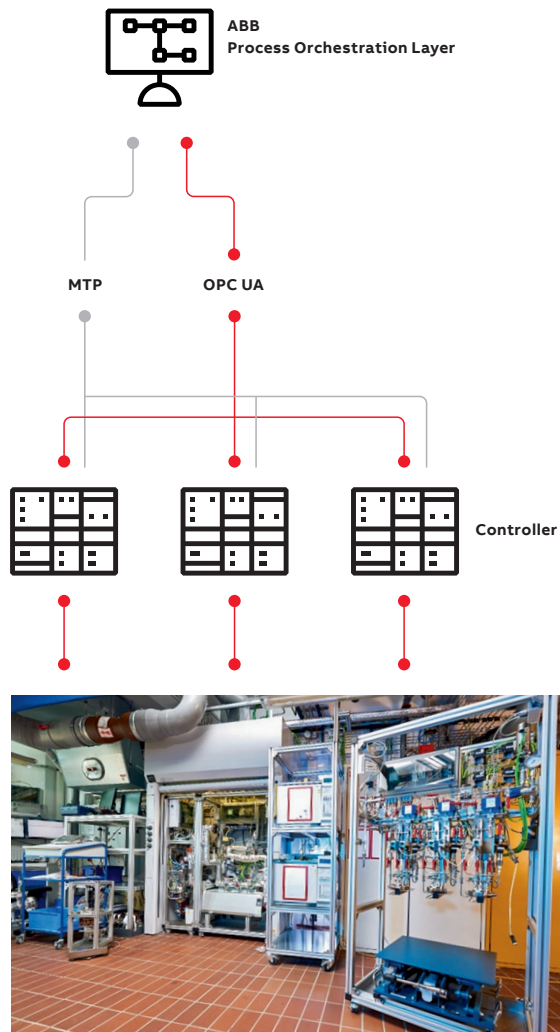
The tests with the ABB POL prototype show that it is possible to store and load different plant topologies and, thus, switch PEAs within a modular plant by a few commands within minutes. As

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MTP and the modular plant concept is a future standard as well as a potential game-changer for the process industry.

a result, use cases such as planning a new project and function changes are validated for ABB's POL based on System 800xA in an existing plant.

A second Evonik pilot plant consists of six PEAs and represents the first time that PEAs suitable for productive use are presented instead of a laboratory setup. Here, ABB's POL was validated for use cases such as services and

PEA-to-PEA communication and module-spanning control loops to reach the same functionality as existing plants.

A future of modularization
All pilot applications returned very positive results and it was demonstrated that the orchestration of modules using MTP works. The requirements of the pilots were met and the feasibility of MTP and modular automation was proven. All tag interfaces for equipment control and monitoring, services and service parameters have been successfully tested. The sequences for automatic operation were implemented and tested with positive results. In addition, cross-module control was successfully implemented and tested in the Evonik pilot plant.

MTP and the modular plant concept is a future standard as well as a potential game-changer for the process industry that addresses time-to-market and flexibility challenges →08. ABB is leading MTP development, implementing the latest standards and presenting a recipe engine based

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07 Pilot application
"membrane test 2"
schematics.

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08 MTP and the
modular plant concept
will improve production
in a whole range of
industries.

on the service concept and process orchestration
for modules from different suppliers.

Now that the feasibility of fully modular produc-
tion plants is proven, the next step is to leverage
the immense potential of this technology for
conventional plants. •

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Energy

52

ABB has deep experience in and understanding of the unique needs and circumstances of individual customers and of helps them put energy to productive uses. This starts early in the design phase and runs through operational management and day-to-day operation, extending to optimization, planning and upgrades. Better decisions mean getting more work done.

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BETTER POWER QUALITY FOR FOOD AND BEVERAGE PRODUCTIVITY

Quality control

Over many years, ABB has accumulated a wealth of process knowledge that helps the food and beverage industry become safer and more efficient. In particular, ABB power-quality products help prevent downtime due to power issues, thus keeping production running, cutting energy bills and improving productivity.

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01 Power quality issues
can have a significant
impact on food and
beverage production,
making a robust power
protection strategy
essential.

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In recent years, production and packaging methods in the food and beverage industry have undergone a dramatic transformation, driven both by a requirement to improve productivity and a move toward tighter food-safety standards. These shifts have introduced innovation into the industry but have also rendered food and beverage plants vulnerable to electrical power-quality events. The quality of electrical power is business-critical, because power outages, sags, swells, brownouts, or other voltage disturbances can cause critical equipment to trip or fail, resulting in:

- Failure of components such as contactors, release switches, fuses, etc.
- Unexplained breakdowns, faults and malfunctions in machinery.
- Overheating of transformers and motors, resulting in a reduced lifetime.
- Damage to precision equipment (computers, controllers, sensors, etc.)
- Communication interference between electronic sensors, devices and control systems.
- Higher levels of power losses in the electrical distribution system.

Depending on the particular power quality event, the costs related to production waste, downtime, or supply-chain disruption can be significant. Indeed, the Pan-European Power Quality Survey [1] reported that annual losses caused by power quality problems can amount to as much as 4 percent of business turnover in direct costs – incurred by the expense of replacing damaged equipment and the labor involved in troubleshooting, patching, cleaning, repairing and restarting the process – and indirect costs, for example, the financial impact of loss of market share or efforts needed to restore the brand value.

Food and beverage companies face additional challenges arising from adverse power-quality events as these may jeopardize the process, workers and even customers. For instance, dairy producers must precisely track the temperature of their milk throughout the whole process and even a minor power-system disturbance can trigger to the discarding of an entire batch of perfectly good produce, if temperature sensors fail. Further, unexpected power downtime can cause milk to spoil, resulting in the waste of production capacity, work hours and valuable dairy products after milk has already been sterilized. Moreover, across the food and beverage industry, consistency of product taste is a critical factor, which makes the flawless operation of machinery mandatory →01.

Alternatively, a power-quality event could cause a problem that could evade quality checks and result in a health issue. On the equipment side, excessive harmonics, for example, could cause a fire, shutting production and endangering employees.

The need for food and beverage companies to carefully consider a power protection strategy is why they bring in power quality experts like ABB to install power quality monitoring and protection solutions. For many years, ABB has worked

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ABB's solutions support power quality monitoring, conditioning and protection in food and beverage applications.

with food and beverage customers so they can be assured of reliable power and uninterrupted critical processes, with associated improved productivity and reduced operational cost →02. To deliver all these benefits, ABB has at its disposal a full range of solutions, software, digital tools and devices that support power-quality monitoring, conditioning and protection in

food and beverage applications. Quick and easy installation and commissioning, low maintenance requirements and guaranteed high reliability are further advantages of ABB's power quality systems. The mitigation of financial losses and equipment-lifetime extension also contribute to a high return on investment and short payback times.

Finally, ABB's high-efficiency solutions maximize sustainability by optimizing energy usage and reducing heat losses, thus taking steps towards the 2030 global target for CO_2 reduction.

Power quality monitoring solutions
The first step in solving power quality problems is to understand what is going on in the power network. For this task, there are the network analyzers embedded in ABB's Emax 2 and Tmax XT →02 circuit breakers, and in ABB's Ekip UP →03 and EKIP trip units, that monitor power behavior and detect anomalies, such as harmonics, micro-interruptions and voltage sags. An embedded unit eliminates the need for dedicated, expensive instrumentation and the Ekip UP digital unit can provide monitoring with no impact on the existing installation, either for ABB or third-party circuit breakers. Further, because these breaker and trip units are equipped with open protocols – such as Modbus RTU, Ethernet/IP, Modbus TCP/IP, SNMP, Profibus DP-V0 and BACnet/IP – retrofit is simple, allowing operators of existing automation or energy management system (cloud based or on-premise) to benefit from the embedded digital functionality the devices offer.

For complete power quality analysis in industrial facilities, ABB offers the M4M Network Analyzer range, which provides a selection of network analyzers that provide a complete evaluation of power quality →04. Compliant with the primary IEC standards, M4M analyzers capture and provide a full set of electrical parameters and power quality key performance indicators, from total harmonic distortion (THD) to individual harmonics.

Load immunity solutions
One strategy to adopt when power quality may be poor is to immunize the load against adverse power events. Here, ABB's AF contactor range is the optimal solution to keep loads immune to

shallow voltage sags as they include an option that guarantees compliance with SEMI F-47 (a voltage sag immunity standard) →05.

These contactors are offered as three-pole versions, from 9 A up to 1,060 A for three-phase AC, or up to 2,850 A for single-phase AC, with AC/DC coils with a wide operational range. They are also available as four-pole versions from 25 A to 525 A single-phase, with AC coils, DC coils or AC/DC coils, similarly with a wide operational range.

Power conditioning solutions
Whereas products such as AF contactors provide immunity at the device level, ABB's active voltage conditioner (AVC) range is designed to provide equipment with immunity from power quality events coming from the supply network itself.

ABB's AVCs cover from 150 kVA to 2,400 kVA and lower the cost of sag events, improve plant operation, limit damage to equipment and deliver a good return on investment. In addition to correcting standard voltage events, an AVC,

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ABB's high-efficiency solutions maximize sustainability by optimizing energy usage and reducing heat losses.

for instance, ABB's PCS100 AVC-40 or PCS100 AVC-20, offers power-quality functionalities such as correction of voltage unbalances, attenuation of flicker from the utility supply side and correction of phase-angle errors →06.

Power protection solutions
Industrial settings are notoriously tough environments for electrical and electronic devices due to the harsh conditions that may be encountered in terms of chemicals, dust, vibration, corrosion, humidity and heat. ABB's PowerLine DPA uninterruptible power supply (UPS) is specifically designed to withstand such harsh environments →07. This UPS protects against deep sags, power cuts and outages of several minutes. The PowerLine DPA has a high energy efficiency (up to 95 percent) and superior short-circuit and

02
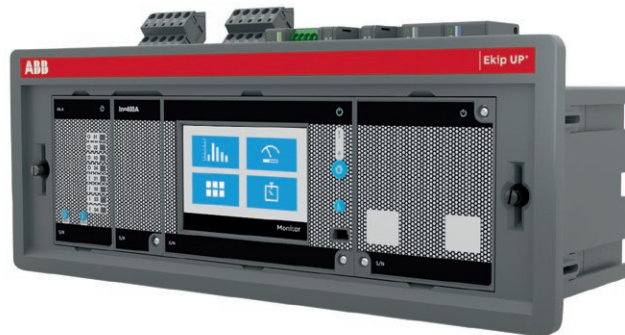
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02 Tmax XT circuit
breakers.

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03 Ekip UP.

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04 The ABB M4M
Network Analyzer.

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ABB's AVCs are designed to provide immunity from power quality events coming from the supply network itself.

overload capability. PowerLine DPA is based on ABB's decentralized parallel architecture (DPA). DPA is a modular architecture that, by its nature, provides not only the best availability but also the best serviceability, scalability and flexibility. Taken together, these features deliver a low total cost of ownership (TCO) over the UPS's lifetime.

Power quality from top to bottom
→08 shows the power protection solutions described above applied to a small-to-medium sized facility. Here, medium-voltage power supplied by an external utility is stepped down to

low-voltage levels. If a power interruption occurs, a UPS instantly steps in to keep power flowing to the load and a breaker-based automatic transfer switch (ATS) initiates the transfer of the load to the emergency generator, which can supply power for several hours. It can take up to 30 s for the generator to come online and once this is accomplished, the UPS reverts to standby, ready for the next power interruption.

For short interruptions and voltage fluctuations, loads can be divided into three categories from a power quality perspective. Each of these can be addressed by the power protection solutions described above:

• Non-critical loads. These loads do not require special protection and do not cause financial losses or safety concerns.
• Essential loads. If these loads are affected by frequent power interruptions, significant financial losses result.

- Critical loads. These loads must not lose power at any time and typically require continuous power operation or 24/7 availability.

Voltage sags and imbalances are the most common power events in an electric network. These disturbances can be easily countered with an ABB PCS100 AVC-40 →08. To prevent potentially deep sags and provide short-term backup for industrial process loads, the ABB PCS100 UPS-I should be used.

A UPS is best to protect sensitive loads – such as process controls or automation systems – and critical loads that must be available 24/7. ABB has a wide range of UPSs that are tailored for different applications. In the example in →08, the PowerLine DPA UPS can be the best choice for process controls and the DPA250 S4 UPS is optimal for IT server protection.

Upholding electrical distribution system reliability in the face of network events must be complemented with power quality monitoring to check the efficiency of the electrical system design and monitor energy consumption. Such monitoring allows optimization of the facility's energy efficiency and the detailed analysis of fault behavior.

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The PowerLine DPA UPS is specifically designed to withstand harsh industrial environments.

One way to implement a monitoring scheme is to deploy ABB circuit breakers with advanced metering and network analyzer functionalities that can monitor waveform characteristics up to the 50th harmonic order and measure the electrical parameters needed for asset health monitoring and performance optimization.

M4M meters can also be used to monitor and analyze the overall power quality performance of the facility. Because M4Ms have high accuracy and are certified for metering purposes, they can also be used for energy metering and bill management transactions with the utility.

Financially sensible and sustainable
ABB's power protection solutions maximize operational availability and are quick and easy to install and commission. Coupled with low maintenance requirements and high reliability, these solutions deliver a high return on investment and short payback period while helping food and beverage producers maximize the sustainability of their facilities and contribute to the reduction of global CO_2 emissions. •

05

06

07

NONLINEAR LOADS

Electric vehicle chargers

LED lighting

Emax 2

Tmax

M4M 20

NON-CRITICAL LOADS

PRE-PROCESS AND PROCESS LOADS

Packaging lines

Dryers and motor loads

Centrifuges

Robotic arms

Variable-speed drives

Generator   **Emax 2**

Emax 2   **PCS100 AVC-40**

Tmax XT

Embedded automatic transfer switch

ESSENTIAL LOADS

Medium- and low-voltage transformers   **Emax 2**

M4M 30

PROCESS CONTROL LOADS

Programmable logic controller and controls

Distributed control system

Sensors

Tmax XT

PowerLine DPA

CRITICAL LOADS

CRITICAL POWER LOADS

Building services

Security

IT services

Tmax XT   **DPA250 S4**
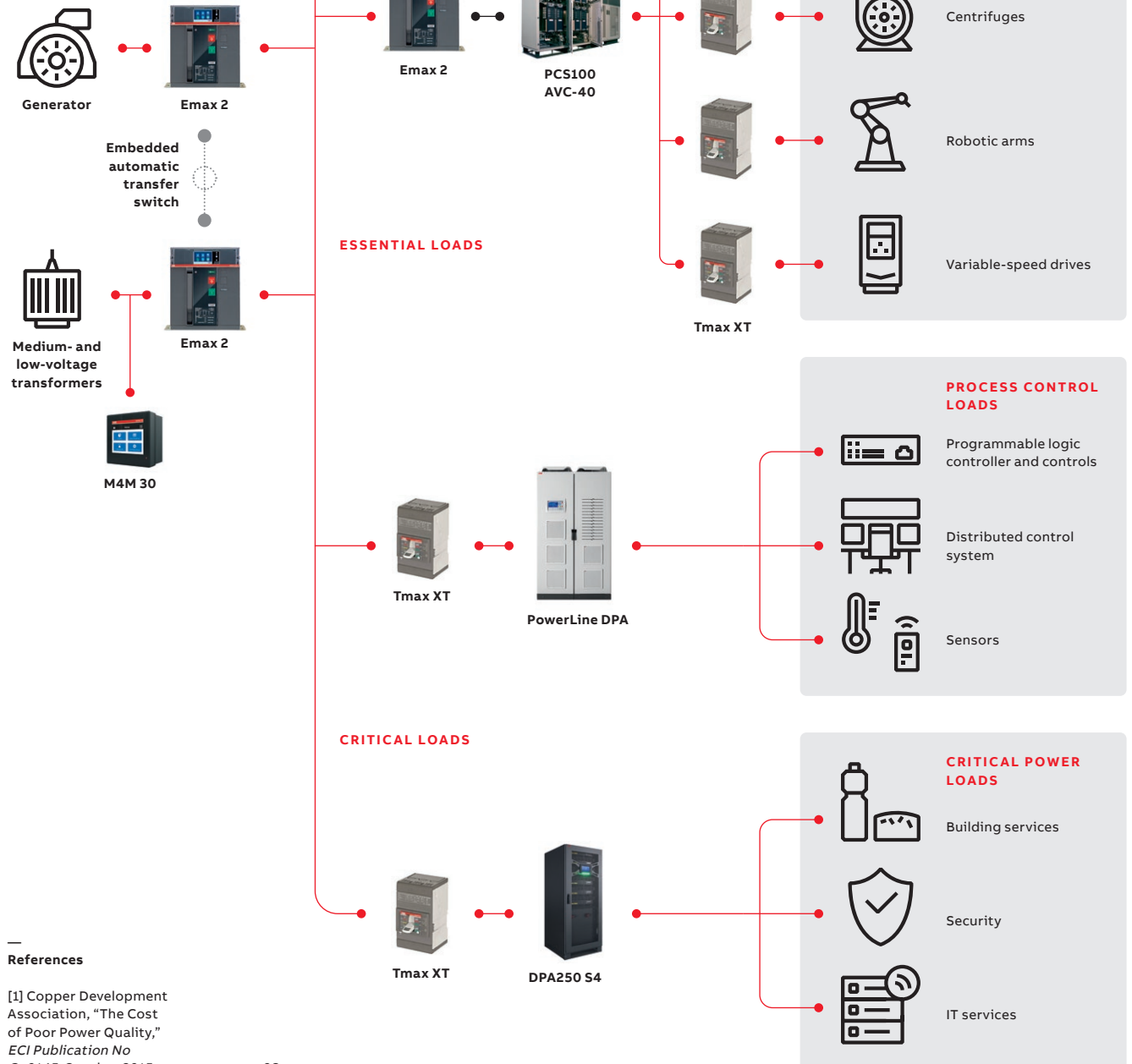
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08

IT ALL ADDS UP TO MEASUREMENT ACCURACY

Data center energy efficiency

How can a data center operator be sure that a facility's measured power usage effectiveness (PUE) – the key parameter defining energy efficiency – reflects reality? The profound risks associated with even minor discrepancies in this area can be avoided by implementing ABB's modular and scalable solutions. Such solutions meet all measurement requirements, ensure the highest level of accuracy, improve energy efficiency, and can translate into as much as a 36 percent reduction in maintenance costs after upgrading electrical systems.

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It may not be much of a surprise to hear that Internet traffic has grown by leaps and bounds over the last few years. But what may raise many eyebrows is that dire predictions about an expected explosion in data center CO_2 emissions

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Between 2010 and 2019 data center energy usage remained steady at about one percent of global electricity demand.

have not come close to being realized. Since 2010, Internet traffic has grown 12-fold. This trend has been driven by factors such as the rapidly growing number of interconnected devices, the replacement of physical applications with virtual ones, and a doubling of Internet users.

Nevertheless, between 2010 and 2019 data-center energy usage remained steady at about one percent of global electricity demand, or about 200 TWh →01 [1]. Furthermore, this energy-stingy trend appears to be continuing. According to the International Energy Agency (IEA), "If current trends in the efficiency of hardware and data center infrastructure can be maintained, global data center energy demand can remain nearly flat through 2022, despite a 60 percent increase in service demand." [2]

Behind these encouraging figures is the fact that data centers have consistently invested in technologies designed to reduce energy demand and CO_2 emissions. Here, the most important parameter defining data center energy efficiency is Power Usage Effectiveness (PUE), a term developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and The Green Grid [3]. In essence, PUE refers to how much energy is used by a data

center's computing equipment in contrast to total data center energy consumption, including cooling, lighting, and other non-IT-related equipment →02.

As essential as PUE is to determining a data center's energy efficiency, the data upon which PUE is based and the measurement systems

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PUE is only as good as the data it is based on and the measurement systems that contribute to that data.

that contribute to its determination, are every bit as important. Here, accurate and correct measurement of key electrical parameters, such

as voltage, current, power, energy, and power factor depend on the correct use and placement of measurement devices [3]. The EN50600-2-2 standard for data centers requires the measurement of these parameters to an accuracy of 1 percent. Additionally, it recommends the measurement of current and voltage total harmonic distortion (THCD and THVD), stipulates that acquisition of such data must be performed rapidly and simultaneously, and that the resulting data must be analyzed and represented correctly. Only under these circumstances can the owner of a data center be sure that a measured PUE value reflects reality.

Several consequences can follow if there is even a small discrepancy in a facility's measured PUE value. At risk, for instance, is the ability of a data center to accurately measure its energy efficiency, its ability to allocate power to IT loads, and its ability to plan installation upgrades effectively.

Global trend

— Internet traffic
— Data center workloads
— Data center energy use
······ Server virtualization

12x

8x

1x

2011   2013   2015   2017   2019

Electricity consumption by segment

Traditional

Other cloud

Hyperscale cloud

2011   2013   2015   2017   2019

01

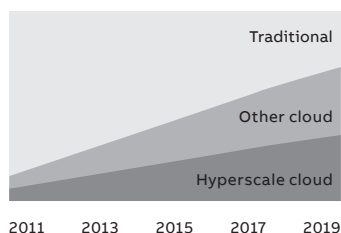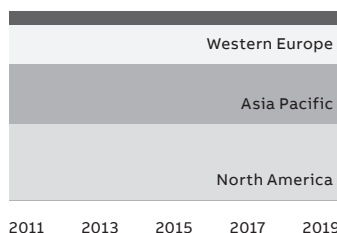**Electricity consumption by region**

Western Europe

Asia Pacific

North America

2011   2013   2015   2017   2019

Data centers account for

1%

of global electricity demand.

Global **data center electricity demand** in 2019

200
TWh

Accurate information is everything

The above-mentioned risks can be avoided by implementing ABB's unique and flexible solutions. Such solutions meet all measurement requirements, ensure correct class 1 accuracy, and make power monitoring and capacity planning easy, while improving energy efficiency.

In addition, exceedingly efficient ABB devices ensure the highest efficiency for power distribution equipment, including transformers, UPS systems, cables, and protection and switching

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Power distribution losses, which usually average 20 percent, can be cut to just five percent.

devices. Thanks to a UPS efficiency of 97.4 percent on system level in double conversion mode, efficient power distribution products, and the right power distribution design, power distribution losses, which usually average 20 percent, can be cut to just five percent.

Additional efficiency increases can be realized through the implementation of ABB's measurement, monitoring and control solutions. For instance, ABB's Ekip devices with embedded metering are capable of measuring and

controlling all electrical parameters on all distribution levels with a high level of flexibility and class 1 accuracy according to the IEC 61557-12 standard. Having embedded functionalities offers the following advantages:

• No need for additional relays and measurement devices, thus enhancing simplicity and saving time
• High level of flexibility thanks to a choice of several communication protocol modules
• Simple and effective cloud connectivity
• Increased reliability thanks to fewer devices and connections
• Fast design, installation, and integration.

Furthermore, most of the important information from ABB's embedded metering devices can be easily visualized and monitored from the ABB Ability™ Energy and Asset Manager, which is available as a local or cloud-based solution.

Modular and scalable

Since data centers come in all sizes, ABB offers modular components →**03** designed to make it easy to realize three scalable solution levels:

• **Essential monitoring** is a basic solution that provides the ability to monitor a data center's PUE. It is ideal for small installations.
• **Enhanced monitoring** provides a wider and more accurate view of power consumption, enabling analysis of energy efficiency and the possibility of monitoring UPS status.

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01 Global trends in internet traffic and data center energy use, 2010-2019, courtesy OMDIA [1].

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02 The most important parameter defining data center energy efficiency is Power Usage Effectiveness (PUE).

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03 ABB offers modular components designed to make it easy to realize scalable solutions.

- **Advanced monitoring** is a complete package designed for very detailed metering and providing predictive maintenance. It is suitable for larger data centers or data centers with the highest energy efficiency and sustainability requirements.

The above-mentioned scalable solution levels offer many advantages. They reduce project design time by up to 80 percent, cut project risk because digital connectivity is tested by ABB, are easily adapted to different projects, and offer the possibility of being upgraded at any time, without the need to change hardware, by adding advanced functionalities available on the ABB Marketplace™. This can translate into as much as a 70 percent reduction in costs when upgrading electrical systems compared to traditional replacement.

Essential monitoring solution
ABB's Essential level solution is based on two Emax 2 or Tmax XT circuit breakers. These measure all the electrical parameters (current; voltage; frequency; active, reactive, and apparent power and energy; power factor; peak factor; THVD; THCD) of a UPS output and a facility's input. The two circuit breakers are connected through the Modbus TCP communication protocol.

Measurements are collected through the ABB Ability™ Edge Industrial Gateway and stored either

DATA CENTER PUE
(Power Usage Effectiveness)

$$PUE = \frac{\text{Total facility energy}}{\text{IT energy}}$$

Total facility power

Power losses
- batteries
- transfer switch
- UPS
- PDUs
- transformers
- rack distribution units
- breaker panels
- distributed wiring
- lighting
- generators
- etc.

Cooling
- chillers
- chilled water pump
- cooling towers
- condenser pumps
- dry coolers
- CRACs & CRAHs
- fans
- humidifiers
- in-row coolers
- in-rack coolers
- in chassis cooling
- etc.

+

IT equipment
- servers
- storage
- Telco
- etc.

04

in the local Gateway or transferred to the cloud. If the latter is chosen, all the information is available from the new ABB Ability™ Energy and Asset Manager cloud platform and is accessible from any location and any device with internet access.

In addition to a cloud connection, it is also possible to connect the measuring devices (circuit breakers) to the local DCIM installed and configured on the premises and to use available information in a customized way.

Although this solution is simple and has a low initial cost, it provides very little information about the energy consumption of the data center, since only two measurement points are installed. Consequently, there is little room for improving the overall efficiency and reliability of data center.

Enhanced monitoring solution
Here, the same considerations regarding measurements, software and communication

outlined in the Essential solution apply. However, in the Enhanced solution the measurements are performed by more protection devices and the new System pro M compact® InSite, thus reaching more data.

Information is available in the cloud and/or locally. The safety of the data is ensured thanks to a high level of cybersecurity, developed in collaboration

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The safety of the data is ensured thanks to a high level of cyber-security, developed in collaboration with Microsoft.

with Microsoft. This allows very flexible, easy and precise computation of the PUE value. Thanks to

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04 ABB components are designed for maximum flexibility.

the grouping of the load feature, it is possible to customize the plant overview in a fast and flexible manner →**04**. For example, all protection devices protecting the cooling load can be grouped together so that the values of the cooling load consumption can be seen, while keeping the visibility of the individual values as well.

With higher precision, numerous measurement points, and information about equipment status, the equipment that consumes the most energy can be easily identified and corrective action can be taken. In this way, it is easy to make cost-effective changes that improve the overall efficiency of the data center and, thanks to a unique predictive maintenance feature available on air circuit breakers, maintenance can be planned in advance. Furthermore, thanks to UPS Insight, the major UPS parameters can be monitored. These include real-time current and voltage, temperature and battery charge status, as well as alarms and other events.

Advanced monitoring solution
A much more advanced monitoring system is also possible. This solution offers capillary metering architecture that is not limited to IT land mechanical loads and covers a range of additional load types. This advanced solution can be applied to any type of data center type, regardless of size. But it goes without saying that the larger and more complex a data center is, the more important it is to reduce costs without compromising energy efficiency or reliability.

Taking typical costs into account, ABB's calculations show that the Advanced solution can save up to 36 percent of maintenance costs for some devices such as Emax 2 air circuit breakers. Additionally, with precise information regarding the health of each device and regular maintenance, the reliability of an entire plant increases dramatically, thus reducing the chances of data center outages, which can cost as much as $2.4 million [4] per incident. The probability of encountering an unplanned maintenance situation is further reduced by the fact that all monitored devices continuously perform self-checks. If a device detects any abnormality based on the upper and lower thresholds set by the customer, it issues an alarm.

Cutting distribution losses
In addition to improving a data center's efficiency through increasingly precise energy use monitoring, operators can turn to technologies

for reducing distribution losses. ABB offers equipment that can decrease power distribution losses down to five percent. Furthermore, this approach is ideally suited to installations with large numbers of measurement devices, which can provide insights into the causes of distribution losses, and thus support distribution

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Calculations show that ABB's Advanced solution can save up to 36 percent of maintenance costs when upgrading electrical systems.

efficiency optimization. This approach is applicable to data center IT equipment as well. Such equipment can produce power quality issues that cause harmonic distortions in a network. These issues can be overcome by placing suitable filters inside a network. However, to correctly select and locate the filters, operators must identify the sources and levels of the distortions.

ABB equipment can perform measurements up to the 50th harmonic without additional devices, providing the right information and enabling these improvements. Additionally, the same equipment, all of which is outfitted with embedded power quality meters, can monitor other aspects of power quality, such as average voltage, spikes or short interruptions in voltage, voltage imbalances between phases, etc. that, when identified and rigorously managed, can further increase energy efficiency and reliability. •

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DIGITAL SOLUTIONS FOR ELECTRICAL ROTATING
EQUIPMENT PERFORMANCE

Better decision making

Digitalization gives all industrial companies the means for better operational decision making and cost management. Basing decisions on accurate data and its expert analysis leads to improved health, performance and energy efficiency, and reduced CO_2 emissions from electrical motion equipment.

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01 Digital solutions now enable continuous optimization of energy efficiency.

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Globally, there are about 300 million systems that are driven by electric motors and this number is likely to increase. Improving motor system efficiency is of growing importance. Indeed, it is estimated that if all the motor systems currently in use were replaced with higher-efficiency equipment, global energy consumption could be reduced by up to 10 percent [1].

One way to improve efficiency is to modernize older and less energy-efficient equipment. However, one-off modernization is only one possible step in the improvement process: Digital solutions now enable energy efficiency to be assessed and optimized on an ongoing basis →01. To enable these digital solutions, the equipment and processes concerned must be connected. Connection enables actual energy use data to be gathered, monitored and analyzed. Using the insights gained, service experts – either from the customer or their service partner – can then identify inefficiencies and opportunities and make recommendations for continuous improvement in energy use. One significant contribution to energy efficiency

comes from keeping equipment in good working order. Here, data from digital solutions helps the operator choose the best maintenance strategy.

Better decision making with connected assets
To decide how to optimize energy efficiency on an ongoing basis, data about actual energy use and equipment performance must be collected. However, merely accumulating raw data is not enough: Relevant data needs to be identified

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Digital solutions now enable energy efficiency to be optimized on an ongoing basis.

and this is where a trusted service partner can be very valuable. There must also be access to the internal or external experts who can analyze and interpret results to identify effective ways to improve energy efficiency →02. The type of expertise required includes an understanding of

01

the technology involved – for example, brand-agnostic motors, or ABB drives.

Data gathering in practice
Connecting to devices to collect data and provide remote services has become much more straightforward since the advent of secure cloud platforms. Here, specially developed solutions – such as ABB Ability™ Condition Monitoring – can gather data from connected devices for use, even in remotely based facilities. Customers can then benefit from cloud-based analytics and insights without building or supporting data

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Data gathering is increasingly being applied to whole processes and process areas.

storage or computing facilities on their site. ABB Ability Condition Monitoring for power-trains, for example, is enabled through sensors that can be added to motors, generators, bearings and pumps or via sensing functions that are an integral part of the equipment, as with ABB drives. Parameters such as usage patterns, cooling, stress levels and power consumption can then be measured and tracked.

Data gathering is increasingly being applied to individual pieces of equipment as well as to whole processes and process areas. For example, it is possible to assess an entire powertrain's condition and maintenance needs, rather than just those of the individual motors →03.

Continuous monitoring and condition-based maintenance
In condition-based maintenance, data is continuously gathered from equipment to monitor its status. The data is transmitted securely to the cloud, where the customer or authorized partners access, process and analyze it. An engineer will then interpret the data to assess the condition of the equipment, identify maintenance needs and recommend maintenance actions to their customer. This approach improves equipment reliability and performance and enables better maintenance scheduling while avoiding unnecessary maintenance work and reducing the need for manual inspections. Because the system

monitors the equipment continuously, it can also provide alerts and alarms automatically if an unexpected deviation occurs.

In services that focus on energy efficiency, data about energy use is continuously gathered from connected motors and drives. Service experts can examine the data to gain insights into where energy could be saved, where the greatest inefficiencies are and where the most significant opportunities for savings can be found. Using this information, they can then advise on the options available and recommend the most effective course of action to improve energy efficiency. Once any changes are made, continuous monitoring enables the experts to follow up and verify the efficiency gains and to ensure that all motor systems continue to run as efficiently as possible in the long term.

Digital solutions in operation
At SCA's kraftliner mill in Munksund, Sweden, the move to a fossil-free future is facilitated with the help of ABB digital solutions. Sustainability is at the core of the Swedish SCA Group's operations, with a long-term goal of establishing a fossil-free value chain. SCA's industrial processes are already 95 percent fossil-free thanks to bioenergy production. ABB Ability Condition Monitoring allows SCA to conduct secure collection of data, tailored to a specific operation, including indicators such as temperature or operational patterns.

The deeper insights into production processes that are realized through analysis of the collected data helps identify long-term trends in performance, thus improving equipment energy efficiency, reliability and uptime, and facilitating predictive maintenance.

Predictive maintenance
Predictive maintenance uses data to identify potential issues before they become a problem, which helps ensure process stability and maximum uptime. With predictive maintenance, service experts analyze current and historical data from motors and drives. With this longer-term overview, optimal maintenance intervals can be established, deviations in performance can be pinpointed and problems can be prevented →04. In addition, bottlenecks and opportunities for improvement can be identified.

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02 Expert analysis of data is critical to performance optimization.

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03 ABB Ability Condition Monitoring for powertrains is a solution that gathers data from drives, motors, pumps and can also be applied to applications such as compressors, conveyors, mixers and extruder main shafts.

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Using ABB's preventive maintenance solution, Mokrá identified potential failures in advance.

ABB's predictive maintenance approach was used in a cement factory operated by Mokrá in the Czech Republic, where there were difficulties tracking down the source of repeated, unplanned outages [2]. Using ABB Ability Condition Monitoring for drives, ABB personnel monitored the condition of Mokrá's variable-speed drives continuously. The knowledge gathered from this data allowed ABB to identify the cause of the failures and recommend areas to investigate. This information enabled Mokrá to change from schedule-based maintenance to an approach in which they concentrated maintenance actions on the right equipment at the right time. By using ABB's preventive maintenance solution, Mokrá can now also identify potential failures in advance, thus preventing unplanned shutdowns →05. In just three months, Mokrá saved over $210,000 and improved the performance and efficiency of their smoke fans without needing to make unplanned investments.

Outcome-based business models
Digitally enabled solutions can also be exploited to approach customer relationships in entirely new ways. For example, with traditional services, equipment manufacturers and service partners focus on responding to needs and finding solutions to any problems that arise. In contrast, with outcome-based business models, the idea is to shift risk from the customer to the service

04

partner. The customer and their service partner work together to define critical outcomes and how these can best be achieved. The service partner then commits to the agreed objectives. For example, a customer might pay their service provider to ensure a guaranteed production

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With outcome-based business models, the idea is to shift risk from the customer to the service partner.

availability or continuous energy efficiency. The service provider will then monitor the customer's equipment remotely and take proactive main-tenance actions to ensure the agreed outcome. Similarly, in the future, a customer might pay their service provider to improve their energy efficiency and optimize their energy use.

ABB already has such outcome-based business models in place. For instance, ABB has signed a 10-year service contract with Statkraft, Europe's

largest generator of renewable energy. This turn-key contract includes the design, manufacture and installation of two high-inertia synchronous condenser systems for the Lister Drive Greener Grid project in the UK [3]. As part of their service, ABB will ensure round-the-clock availability for the condenser system. With this outcome-based service, Statkraft will get a guaranteed level of uptime, together with maintenance from ABB. ABB will continuously monitor the equipment and take proactive maintenance actions to ensure that breakdowns never occur.

A digital and energy-efficient future
As industrial electrical motion equipment becomes increasingly connected, ABB is partner-ing with customers to deliver new digital solu-tions and service models that help them exploit digital data to enable better decision making. ABB's digital services – such as condition mon-itoring and condition-based maintenance – use data to improve process reliability, maintenance optimization and energy utilization. Planned services, like predictive maintenance, look deeper into the data to reveal trends, enabling upcoming maintenance needs to be predicted well in advance. Both types of service help equipment run more efficiently and save energy and costs.

05

ABB is leading the way in digital solutions for energy efficiency for motors, generators and drives and offers digitally enabled services accessible to almost any business. These powerful new technologies can be adopted in small steps as customers digitalize their business. In the future, digital, outcome-based business models are expected to be a regular part of business life. ABB has the expertise and the technology to make the transformation to a digital and energy-efficient future easier than ever before. •

These powerful new technologies can be adopted in small steps as customers digitalize their business.

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04 Predictive maintenance on electrical rotating machines prevents small issues becoming big ones.

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05 ABB Ability Condition Monitoring for drives solved an issue Mokrá had in a cement factory.

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AUTOMATED SEABED DRILL TECHNOLOGY FOR EXTREME CONDITIONS

Drilling down

B&R provided an automation solution for MeBo200, a seabed drill rig that cores up to 200 m at a water depth of 2,500 m. The result is a reliable and efficient remote-controlled seabed drill rig that fulfills all automation, communication, diagnostic and maintenance requirements for commercial use in ultra-deep waters.

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Penetrating the darkness, four plate-footed legs extend in preparation for landing the ten-ton apparatus securely below. Once established on the targeted unexplored landscape, the integrated robotic drill begins probing the terrain [1].

What could be a rendition of a mission to Mars, is actually a description of a deep sea drilling research mission in which a drill rig was once lowered through the ocean to rest on the sea floor 2,500 below, where a remote-controlled robotic drill rig samples the seafloor 200 m below. This amazing feat is possible in part thanks to the automation, control and communication technology supplied by B&R Industrial Automation (a company acquired by ABB in 2017

that now acts as ABB's division for machine automation) at the request of Bauer Maschinen GmbH.

A challenging setting
The ultra-deep sea is largely unobserved, unexplored, and unmapped, yet, holds one of the

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At water depths of 2,500m, a remote-controlled drill rig samples the seafloor, thanks to B&R's technology.

02

is problematic yet essential, requiring resilient technology.

A collaborative solution
This is where business and academics join forces to develop robust technologies to operate reliably under such adverse conditions. The newest generation of the seabed drill rig, MeBo200,

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The robotic drill rig MeBo200 rests on the sea bed, where it can sample and probe the sea floor to depths of 200 m.

developed by the Center for Marine Environmental Sciences (MARUM) and Bauer in 2014, is just such technology →01. The drill rig can be deployed through 2,500m of ocean to rest on the seabed where it can sample and probe the sea floor to depths of 200m →01. Such a phenomenal achievement owes its success to another long-term collaboration between experts at Bauer and B&R. After many successful years of research-based drilling, Bauer asked B&R to supply the

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01 Built to perform at a depth of 2,500 m: The remote-controlled seabed exploration drill rig MeBo200 is the second generation drill rig built by MARUM and Bauer.

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02 A water-cooled winch is used to wind and unwind the 35.5 mm thick steel-armored cable. An X20 module from ABB's B&R seamlessly integrates this winch into the automation of architecture of MeBo200.

keys to understanding Earth's climate; it is also a source of energy, sustenance and commerce. Understanding these phenomena requires drilling under difficult conditions in a physically challenging environment – as challenging as exploring space.

Here, enabling technology depends on water depth, sediment type, potential foundation depth and soil properties [3]. For instance, at water depths of 4,000m, temperatures are below 4°C and the ambient pressure is 40.0MPa. Typically, soft fine-grained clays are encountered with undrained shear strengths of 5–30kPa at 45m depth [2]. Taking measurements and obtaining undisturbed samples under such conditions

03

not assembled from the ship to the seabed [4].
For cost and time effective strategies, robotic
seabed drill rigs are widely and successfully used
for exploration today.

Reaching the Seabed
One such rig, MeBo200, is a second generation
seabed drill rig built on the success of the first
MeBo drill rig, operating since 2004 and capable
of drilling down 70m →**01**. MeBo200 extends
drilling capability to 200m. Successfully tested in
the North Sea during 2014, not only can MeBo200
work at water depths of up to 2,500m, it can
drill into sediments, rock, and gas hydrates with
generally less sample disturbance than drill rigs
operated from drillships can achieve [2].

Modern automation technology
Despite the success of the first two MeBo
generations to deliver valuable results to the
research community, further improvements were
necessary to enable widespread commercial use
in accordance with DNV standards. Bauer, who

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Bauer GmBH sought B&R to en-
hance MeBo's automation, con-
trol, and communication capabil-
ity to enable commercial drilling.

developed the drilling technology, mechanics,
hydraulics and launch and recovery system of the
MeBo200, asked B&R to enhance the drill rig with
the following elements to enable commercial
applications:
• State-of-the-art control technology
• An extended communication network
• Interfaces for external automation components
• An updated diagnostics and maintenance
  system

B&R was an obvious partner for upgrading the
automation architecture. "We've been working
successfully with B&R for a very long time, and
have been using their technology in our deep
drilling rigs for decades," according to Bauer's
Lothar Schirmel.

Performance under harsh conditions
MeBo200 is mounted in a frame and weighs 10
tons in air (eight tons in water). The entire MeBo
has 20-foot container dimensions and is carried
by an available research vessel to the location

automation, control and communication technol-
ogy needed for remote-controlled robotic drilling
operations in extreme environmental conditions,
in order to open up MeBo200 for commercial
drilling use [1], eg, test drilling in subsoils ranging
from loose sediment to hard stone, geotechnical
exploration for offshore foundations; for mineral
exploration; offshore gas or oil drilling explo-
ration of underwater sulfide reserves and for
exploration of marine gas hydrates.

Drilling options
Although specialized drillships are traditionally
used to explore the sea floor, reduced availability
and high costs, due to the impacts of wind,
waves and current on the ship- and drill string
motion and the properties of soft fine-grained
sediments encountered, make this drilling pro-
cess in ultra-deep waters logistically challenging
[2]. Robotic seabed drill rigs, however, reduce
and even eliminate some of these difficulties:
in situ coring diminishes sample disturbance,
drilling quality remains intact as wind, waves
and current are irrelevant for the drilling process,
in situ coring mobilization costs are reduced
as multi-purpose ships can deploy the rigs,
drilling costs are lower because drill strings are

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03 An explanation of ABB's acquisition of B&R is outlined.

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04 The X90 mobile controller system is resilient enough to withstand the extreme conditions at depth.

04a The X90 mobile controller unit is shown.

04b The X90 mobile controllers are housed in sealed pressure vessels that protect the electronics from seawater.

of interest →01. When it arrives, the exploratory drill rig is lowered to the seabed by 2,700m of steel-armored umbilical cable →02. The cable is MeBo200's lifeline to the ship, supplying it with both power and control commands. It is remotely steered shipboard.

In order to reliably collect data from the seabed and send it to the ship kilometers above, MeBo200 required extremely resilient technology →03. Schirmel notes, "At 2,500m below sea level,

04a

04b

conditions are extreme, so all the components used must be robust and reliable. That's why we chose B&R's X90 mobile control system, which easily withstands these extreme conditions."

The X90 controllers are easy to adapt to different requirements using option modules due to their standardized components →04. The heart of the system is an ARM processer. For the MeBo200, these were configured as intelligent POWERLINK bus controllers with numerous integrated I/O connections. The POWERLINK protocol is transmitted on single-mode fiber cable via wave-division multiplexing media converters and converted back when it reaches the ship. "Operating a reliably functioning real-time network under these extreme conditions is a major challenge – but together with B&R it was

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Operating a reliably functioning real-time network under extreme conditions is a major challenge, but with B&R it was possible.

one we were able to solve. They provided expert guidance in the selection of converters, and they knew just how to tweak the network settings to get the initial communication interruptions under control. That's exactly what you want from an automation partner," affirms Schirmel.

Software updates on deck
The integrated Ethernet interfaces on the X90 controllers are accessible from the ship's deck via fiber optics. "That's important for us, because it allows us to update the software on the rig as needed without having to bring it up to the surface or open the pressure vessel to access the controllers," Schirmel explains.

Electric signals into the pressure vessel are secured with special plug-in connectors able to easily withstand 40.0 MPa of pressure, conditions that are encountered at water depths of 4,000m. In this way, nearly 100 proportional valves, absolute encoders, displacement sensors and more are connected to the I/Os on the X90 controller devices.

All-around control and views
The drilling unit is easily controlled remotely from a container on the deck of the research vessel.

The completely revamped operator station features a seat with joystick controls mounted on the armrests, similar to what one would find in the cab of a crane →05. Additional controls are found on three 19-inch touchscreen monitors, which were selected from B&R's Singletouch

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The up-dated drilling unit is easily controlled remotely from a container on the deck of a research vessel.

Automation Panel series, with three panels with analog resistant single touch screen (wide screen formats) available, this highly flexible system allows upgrades to be made while continuing to use the HMI application →05.

The three panels display all the critical information needed to control the MeBo200 drilling rig and all other auxiliary equipment. Above them, two more monitors display live video feed from the eight installed underwater cameras. The operators can monitor closely the largely manual drilling process.

The data coalesces in the B&R APROL process control system, which runs on two redundant Automation PC 910 units →06. Three more industrial PCs from the Automation PC 3100 series are used as remote Human Machine Interface (HMI) servers.

"We've been using APROL as a powerful HMI, data acquisition and data management solution in our oil and gas deep drilling rigs since 2005," Schirmel explains →06, "A key element is the high-performance data storage and long-term archiving that APROL offers. That includes the Trend Viewer, which lets us visualize the recorded data and analyze error causes."

Progressive commissioning
MeBo200 control solution runs on a PLC from the B&R X20 system, a complete and detailed control solution with a sophisticated ergonomic design. The X20 system expands the possibilities of any standard control system, The seamless integrations with other B&R components, allows the implementation of applications with unimagined performance and flexibility.

Because the control and HMI can run separately, the operators are able to start up, test, or/and operate the drilling rig and auxiliary units progressively, even without an APROL server.

05

Furthermore, the B&R X20 system is used to integrate a variety of auxiliary units, including a hydraulic power unit, a radio remote control for deck-based operation of MeBo200 and the power center with transformers for the high-voltage supply of the drill rig.

Connecting third-party components
"Some of the auxiliary units are bought-in parts," Schirmel says. "For those, we have no say in what fieldbus is used. That's why we really appreciate that B&R offers interfaces and libraries for all common fieldbuses." This setup has made it easy for Bauer's Schirmel and his team to connect the remote control receiver, the joysticks and the associated control panel for the full benefits of this automation system.

A dependable partner
"The flexibility and consistency of everything in the B&R world allows us to seamlessly capture all necessary data and transfer it to the HMI and data management systems without having to define or implement all the different interfaces ourselves," praises Schirmel. "Together with the openness and size of the product portfolio, those are the reasons we rely on B&R as an automation partner – especially for particularly large or unique automation projects like our new offshore applications."

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05 The drilling process is controlled via joystick, control panel and touchscreen operation from a container on the ship's deck. Live video streams from eight underwater cameras help operators monitor the drilling process.

06 An ocean of computing power: Five industrial PCs from B&R guarantee that HMI operation and data storage always function reliably.

Expanding the future of drilling

Thanks to B&R, the newest automated MeBo200, benefits from the highest industrial quality, a powerful and open architecture, comprehensive connectivity, consistent data management and seamless data storage. Working through ideas to create products to achieve automation, control, connectivity and communication goals, B&R is helping to expand MeBo200's application range so that Bauer can target commercial drilling communities who now have another way to drill in ultra-deep waters. •

By achieving automation, control connectivity and communication goals, B&R is helping to expand MeBo200's application range

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Trans-portation

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The purpose of transportation is typically the physical movement of goods or people from point A to point B. The effective and efficient delivery of such a transportation service, however, relies on the transportation of data between a far larger number of points, as well as their analysis and processing. Here are examples from EV charging, railway traction and cargo shipping illustrating just a small selection of the ways in which ABB can support and enable just that.

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Tracking analytics

Understanding the wear of locomotive wheels is a key ingredient to accurate predictions of degradation and maintenance needs. Swiss Federal railways (SBB) and ABB have jointly launched a data collection and analysis activity to better understand wheel wear and the degradation of wheelsets on Re 460 locomotives.

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To transport passengers or cargo, a locomotive must apply a tractive force. This force can only be exerted if the wheels "grip" the rail. In other words, the tractive force that accelerates the train must be matched by adhesive forces between wheel and rail. Should the tractive force exerted rise above the adhesive limit under normal conditions, this adhesion is lost, the wheels spin without gripping the rail, and the train cannot accelerate. This phenomenon is known as wheelslip. The wheelslip is determined by multiple factors, including the weight pressing down on the wheel-rail interface, the gradient of the rail, the behavior of a locomotive driver, and ambient conditions (such as moisture, weather conditions, contamination of rail surface) limiting the tractive effort that can be utilized.

Wheelslip is not just a nuisance, but is also a cause of wear and degradation to both rail and wheel. Wear and degradation are also affected by

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The project sought optimization of the drive train and adhesion control.

other aspects of train-track interaction including torsional oscillations and acceleratory and braking forces.
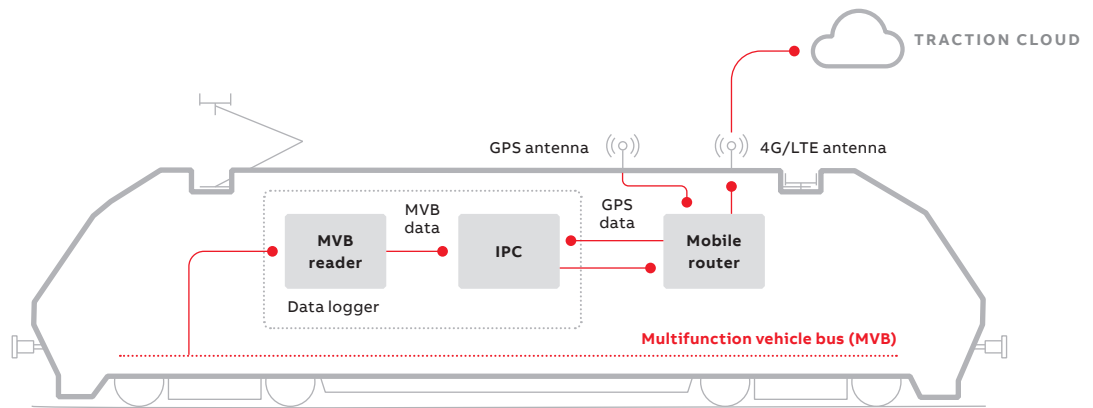
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Interaction of wheel and rail
The performance, safety, operating costs and
reliability of railway operations depend to a large
extent on the mechanical interaction at the inter-
face between wheel and rail. This is described in

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The interactions between
wheel and rail are significantly
influenced by variable adhesion
conditions.

[1]. A detailed overview of prognosis and health
management is provided in the referenced article
[2]. Over the past decades, numerous research
projects have added to the understanding of
mechanical properties of wheels and rails, the
maintenance of wheel and rail profiles, the
mechanical properties of bogies (rigidity, etc.)
and the damping properties of rail pads.

In practice, however, the interactions between
wheel and rail at the contact surface are highly
complex and are significantly influenced by
variable adhesion conditions, which cause
interactions with the powertrain, especially for
driven axles. Deeper understanding of these
effects is needed to be able to optimize the
drive train and adhesion control and to improve
the overall system.

Partnership
Swiss Federal Railways (SBB) and ABB partnered
up in a co-creation activity using digitalization to
gain a better understanding and new data-driven
insights of wheel wear in the Re 460 fleet [3].

The 119 locomotives of the Re 460 class were
originally built in the 1990s, with electrical equip-
ment supplied by ABB [4]. The fleet has recently
undergone a major refit program, implemented
jointly by SBB and ABB, including the fitting of
new state-of-the-art converters [5].
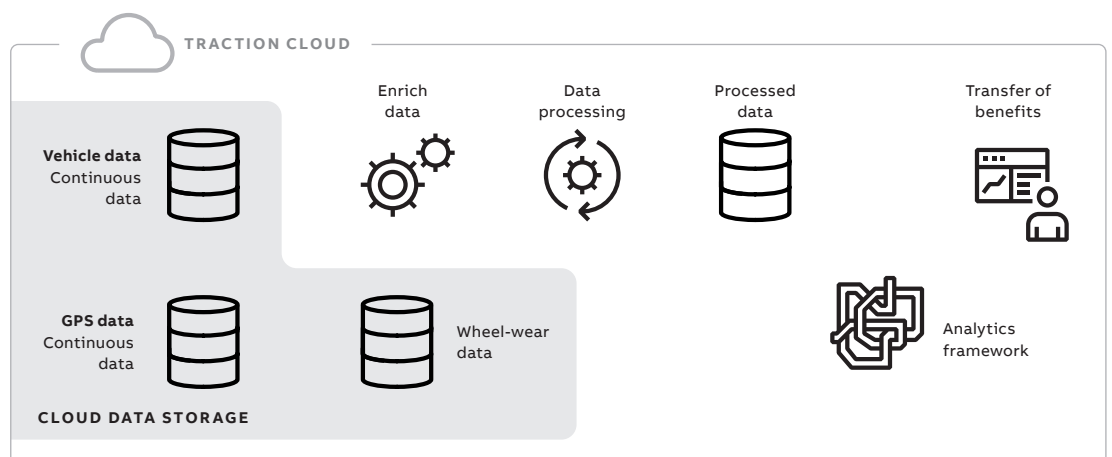
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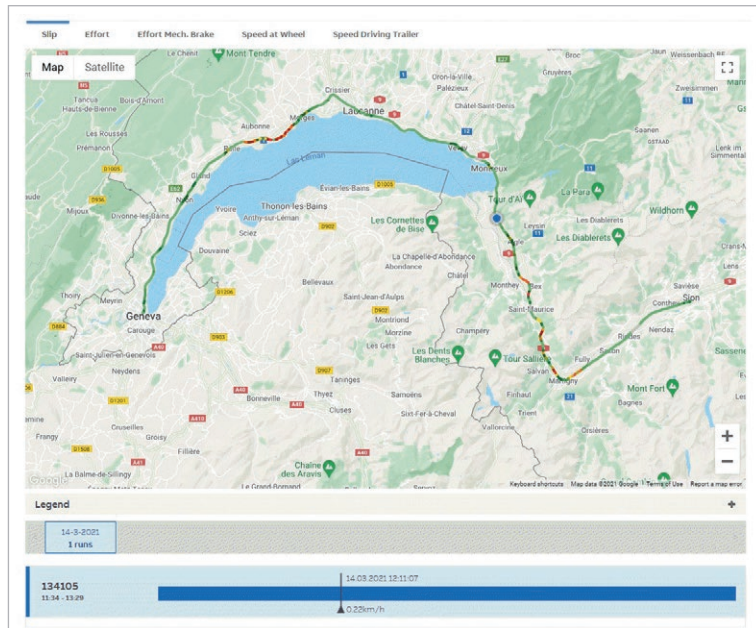
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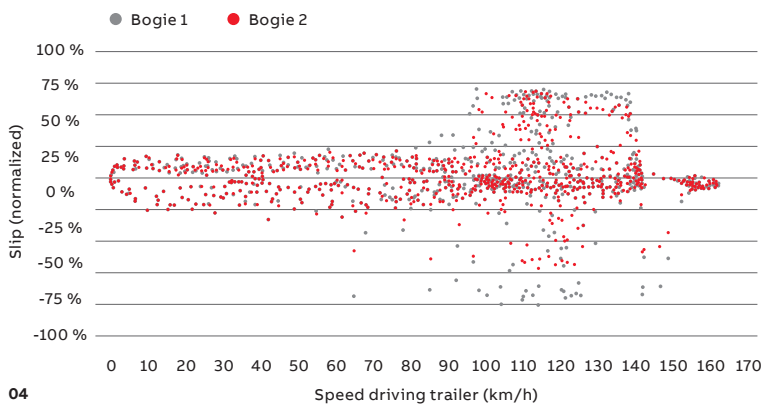
04

Among the fields of investigation included in this activity are the behavior of traction control under challenging conditions of adhesion, and the use of the sling brake, emergency braking and sanders. In connection with the Re 460 retrofit, special attention was paid to understanding the torsional oscillations of the wheel sets [6].

Collecting the data
The five class Re 460 locomotives used in this study were fitted with a railway-compatible industrial PC (IPC) reading read data from the multifunction vehicle bus (MVB), via an MVB Reader →01.

The MVB Reader is configured to read all relevant signals for wheel-rail contact at a sampling rate of 20 Hz, and transmit them to the IPC. Captured signals include, for example, the tractive effort, the air pressure in the main brake pipe and brake

cylinders, the intensity of torsional oscillations of the axles, the rotational speed of the four driven axles and the vehicle speed.

A second data channel captures the geographic position of the locomotive every second. This data is provided by a mobile router, a component that is installed as standard in every Re 460 locomotive. The same router also provides a secure data transmission channel between the

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The web portal permits the identification of unusual or special incidents or situations.

IPC and the Traction Cloud by way of the mobile network. This connection is used to transmit the collected data →02.

Data to knowledge
After the data ingestion, the Traction Cloud processes and stores the data using data pipelines. Typical tasks of data pipelines are merging of data sources (eg, offline wheel-wear data), aggregation of data, calculation of different statistics and performing data analytics. The customer benefits are finally transferred using visualizations, generated reports, data interfaces, and serve as the basis for analytics workshops in a co-creation setup.

As an example of benefit transfer, a tailor-made web portal was developed to visualize the processed data. It can provide a quick overview of the historical utilization of the locomotives. In addition, it permits the identification of unusual or special incidents or situations, so that they can be analyzed in more detail.

Beyond displaying the most important signals in the time domain, the web portal offers a selection of different views for inspecting the data. For example, two signals can be displayed in a scatter diagram (as a cloud of points) or in a two-dimensional histogram as a frequency distribution. The portal can also overlay data on a geographic map, identifying locations on which, for example, have excessive wheelslip →03.

The web portal offers different filtering capabilities to focus only a subset of the data. For example, the data of either one or of both bogies can be displayed. Moreover, the user can filter the data by train configuration. For example, only journeys in which the locomotive

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03 Wheel-rail slip by
GPS position. Low slip
values are visualized
in green and high slip
values in red.

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04 Scatter plot of wheel
slip versus vehicle
speed for a journey
under difficult adhesion
conditions.

—
05 Comparative
visualization of two
trips on the same line
with difficult adhesive
conditions (left) and
dry conditions (right).

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06 The tool permits
statistical comparisons
of the operation of the
different locomotives
for which data is
collected.

is pushing rather than pulling with a specific bogie in front.

Case study: difficult adhesion conditions
The following example illustrates how the web portal is used to better understand the locomotive's behavior under given conditions. In →**03**, the wheel-rail slip is shown in color on the map for a rainy day on the route section between Sion and Geneva (Switzerland).

The data reveals there were difficult adhesion conditions over longer stretches of the line (visualized by the red and orange and colors highlighting increased slip conditions). The user can visualize the same journey in a scatter diagram, selecting any signal combination. For example, in →**04**, velocity is plotted against wheel slip. The diagram shows that the increased wheel slip on this journey occurred primarily at higher speeds. Furthermore, the data shows that the front bogie, "Bogie 1", tends to have higher wheelslip than the following bogie. This effect

can be frequently observed under difficult adhesion conditions. The traction control optimizes the overall traction of the locomotive by inducing

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Optimizing wheel wear offers considerable potential for cost savings.

higher wheelslip on the leading bogie, thereby conditioning the rail surface for the second bogie.

Another interesting comparison is shown in →**05**. Here the tool displays two journeys on the same railway line. The plot on the left was recorded under difficult adhesion conditions, and the plot the right under favorable conditions.

Statistics
Besides detailed insights, the tool can also be used to generate quick overviews. This is done using two types of statistics: general statistics, which present overviews of locomotives, and geographic statistics, which aggregate data with respect to GPS coordinates.

The general statistics make it easy to compare data from different locomotives. It offers visualization of data and events over different time scales, such as monthly or yearly. For example, bar plots of operating hours and operating kilometers reveal basic information on deployment of different locomotives →**06**.

It is also possible to combine such data and, for example, look at different operating-speed classes.

The geostatistics are displayed as pie charts on a map, with the size of the pie showing the whole value for any given parameter, and the pie sectors showing the values per GPS coordinates. This enables the interpretation of locomotive data in relation to specific locations. It can identify, for example, areas where there is a lot of sanding →**07**, or where there are high torsional oscillations. It is also possible to capture correlation with weather data, for example slip caused by wet track conditions.
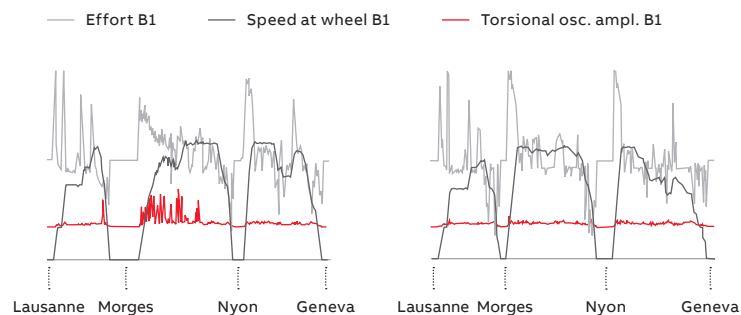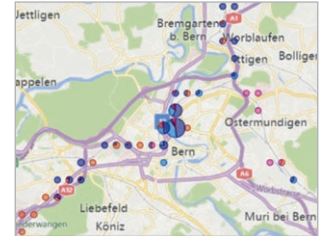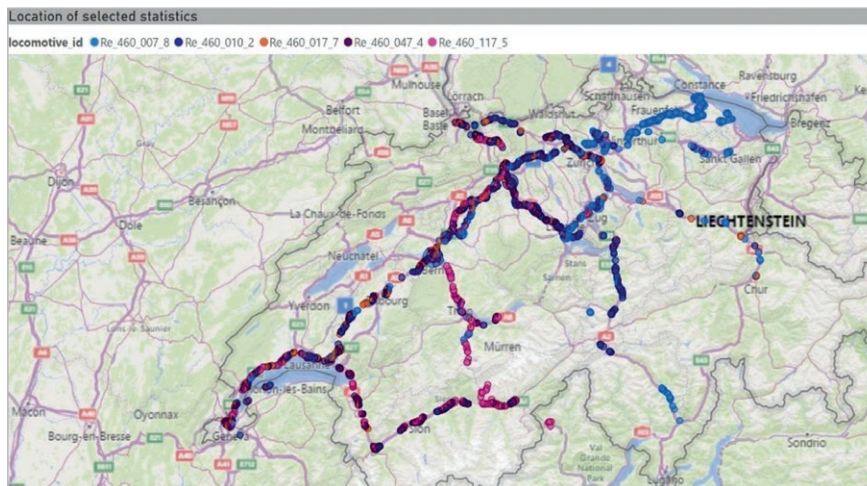

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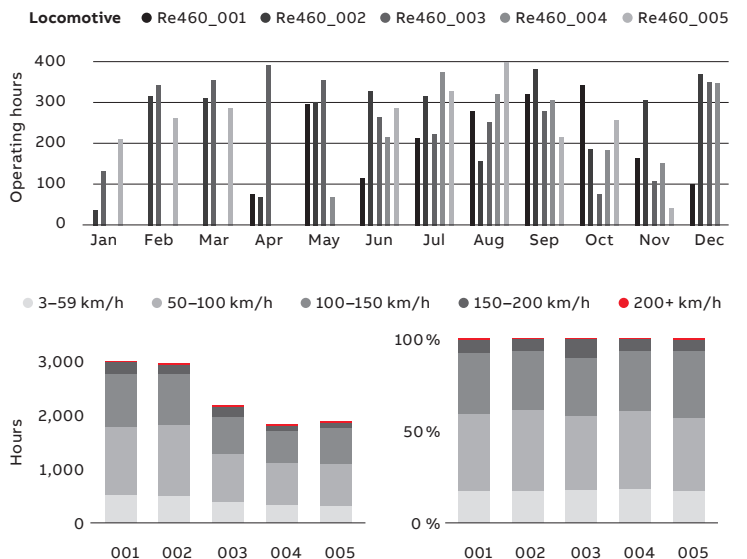
06   **Operating time in speed zones**   **Percentage of operating time in speed zones**

07

Wheel wear
Wheel wear is checked periodically to determine whether a wheelset needs to be replaced or re-profiled. Replacement is a tedious process, but even measurements and reprofiling of the wheel profile requires downtime (including the need to take the locomotive out of normal operation). Optimizing maintenance and wheel wear thus offer great potential for cost savings.

The aim of the data analysis on wheel wear is, on one hand, to predict wheel wear so that wheel measurements are performed only when neces-

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The understanding of numerous physical interactions could be increased.

sary, and on the other hand, to identify the most important wheel-wear factors, and hence introduce optimizations that extend the life of the wheel.

In the performed analysis, a list of train signals that potentially influence wheel wear is created from the recorded data and from prior knowledge. These signals are then fed into a feature selection process to identify the best model inputs. First, constant signals are removed.
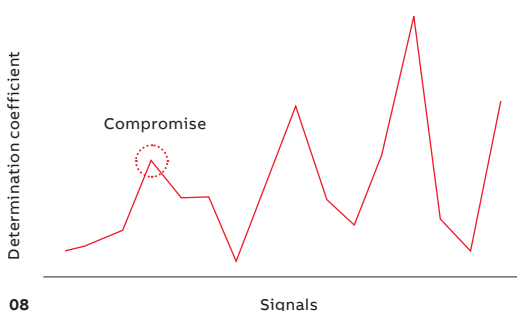
Then the model is trained with decreasing subsets of the remaining signals. On each pass, the signal whose important score is the lowest gets removed. The reduced model is then evaluated using its determination coefficient →08. The determination coefficient states how much variance in the data is explained by the model (the higher the better, maximum 1.0). Based on the determination coefficients, the smallest group of signals representing the best compromise in terms of model performance is selected (five in the illustrated case). These signals are used as inputs to the data-driven model.

Wheel wear is often predicted using simple linear regression models based on mileage. Using the additional data and exploring different machine learning algorithms, it is possible to build a more accurate model. To give an idea of the model accuracy, →09 plots measured values (x-axis) against predicted values (y-axis). Ideally, all points should lie on the diagonal, implying that the predicted value is equal to the given value.

The random forest model (right) uses the five signals from →10 to improve the mean absolute error by 22.8 percent compared to the simple linear regression model (left).

Actionable results
Thanks to the data collected and analyzed in this project, the understanding of numerous physical interactions and the transparency of the drive train and wheel-wear mechanisms have been increased. This permitted software adjustments to be implemented in the area of the drive chain, leading to increased mileage of wheelsets.

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Linear regression (driven km) / Random forrest (5 signals)

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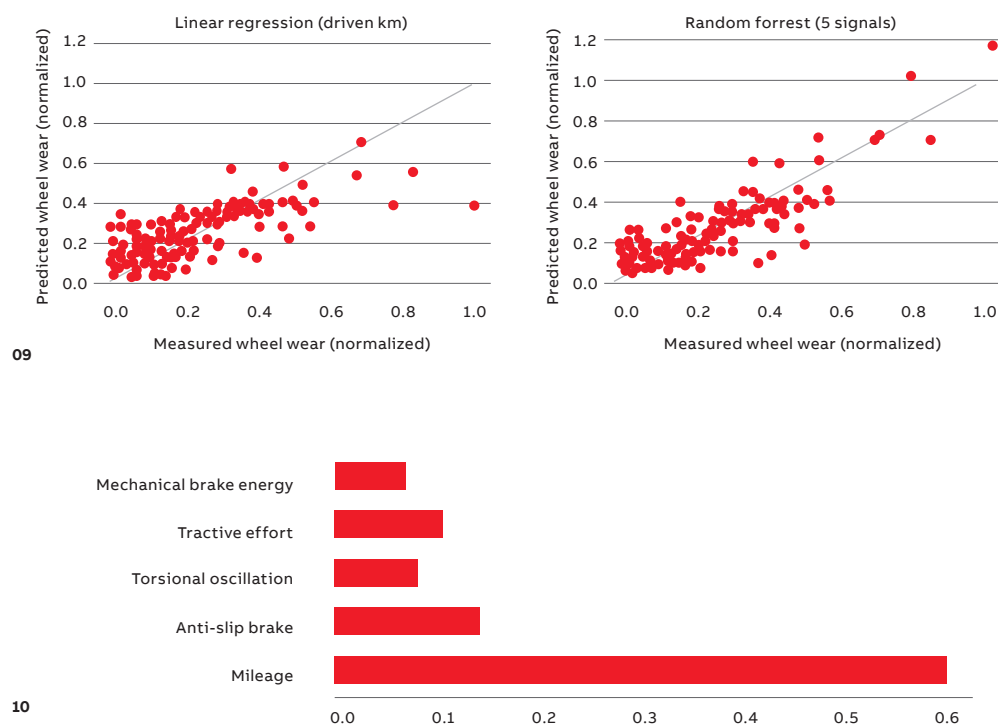
In addition to the fields of investigation initially defined in the collaboration, it was found that the recorded data could also be used in further areas of interest. Examples of this are supporting the proof of axle fatigue strength with respect

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In addition to the fields of investigation initially defined, the recorded data could also be used in other areas of interest.

to torsional oscillations, the detection of sensor problems prior to test runs, the understanding of pantograph bounces with fixed overhead lines, and more. This shows how data can be used in a versatile way to unlock hidden potential can

be exploited when the data is made available in a processed and structured form. The knowhow gathered using this project will also be used in future converter designs and converter controls.

Finally, no major project runs without a few "lessons learned". Especially in the early phases of the project, significant effort was required until the data could be reliably recorded and well structured in a database. The data itself also presented several challenges: from consolidating very slow and very fast time series to data quality issues – not to mention avoiding the ubiquitous trap of mixing correlation with causality.

The project was also a valuable showcase for co-creation, in which the product was not simply a deliverable but in which ABB and the customer jointly set goals, shared observations and stewarded the development from beginning to end. •

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AN ELECTRIC EXPERIENCE TAKES SHAPE

Reimagining vehicle charging

ABB, the global leader in EV charging infrastructure (EVCI), has streamlined its connected cloud services in this area. The company's new Asset solution enables EV charging infrastructure operators to optimize their processes and reduce operational costs based on real-time, data-based insights. Its Styling solution, on the other hand, is designed to bring brands to life on the EV charger display through a flexible, easy-to-use and remotely controlled solution.

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More and more electric cars are rolling off production lines. According to the International Energy Agency (IEA), a decade of growth has already produced more than 10 million electric cars. Furthermore, experts predict an annual average growth rate of nearly 30 percent, and EV

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According to a study by Roland Burger, by 2030 there will probably be about 140 million EVs in circulation.

sales reaching almost 15 million by 2025. Indeed, according to a study by Roland Berger that was commissioned by ABB, by 2030 there will probably be about 140 million EVs in circulation →01.

Growing hand in hand with the population of electric cars is the need for a supporting EV charging infrastructure. As of 2021, there were 1.8 million chargers around the world →02 [1].

As EVs have grown in popularity, OEMs and charging network operators have, until now, assumed that their goal was to make the

charging process as comparable to fueling an internal combustion engine vehicle as possible. But today, given the level of innovation in the charging field, the industry is asking: is that objective ambitious enough? With extensive digital capabilities, the EV charging stations of today and those of the future can and will not only outperform the traditional fueling experience for drivers but will also support greater efficiency and be more cost effective for the charger operator.

Redefining web solutions
As the global leader in EV charging infrastructure (EVCI), ABB is at the very heart of this digital charging revolution. Committed to continual innovation of its hardware and software solutions, ABB has redeveloped its connected services →03 for EVCI. The new offering, which launched globally in April 2022, has been specifically designed with customer feedback in mind to create a simplified, more flexible and more cost-effective range of web solutions.

The previous offering from ABB for its portfolio of DC chargers included four separate web solutions:
• Driver Care – for non-commercial charger networks to monitor and operate their chargers
• Charger Care – an extended service solution

for experienced charge point operators to gain insights into charger operations with the ability to diagnose and troubleshoot hardware issues and streamline their service operations

- Case management – a functionality provided with Driver Care and Charger Care to request ABB Service support
- Payment – a functionality that enables charge point operators and/or e-mobility service providers to commercialize their charger network via payment terminal devices to generate additional revenue by opening up the charger network to non-members
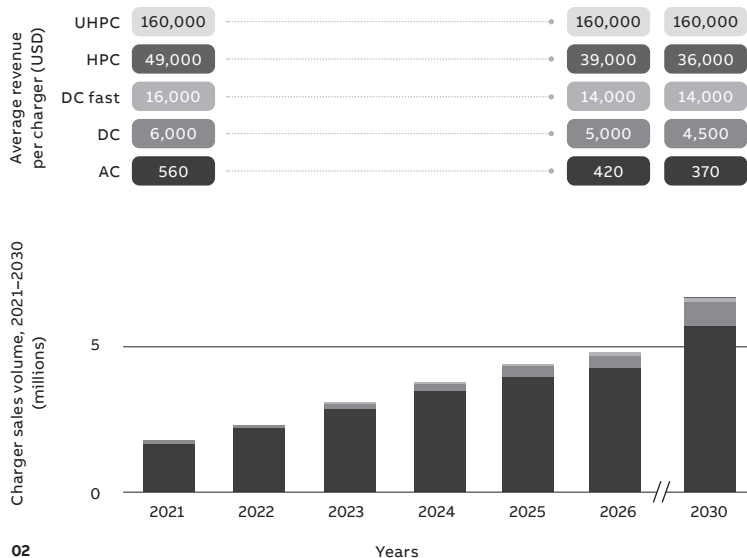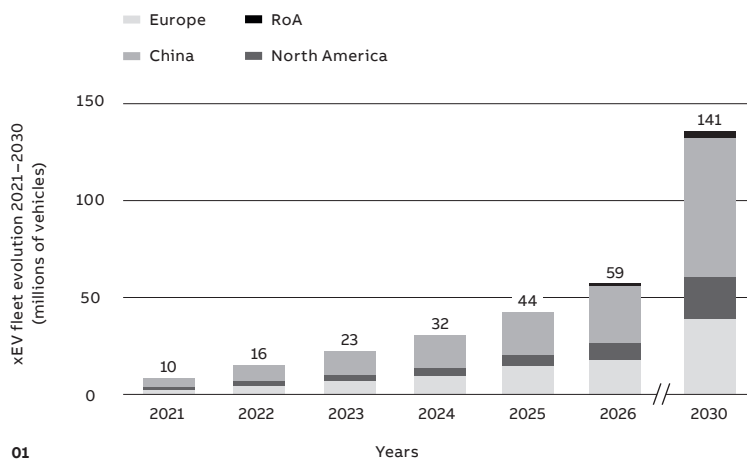
While retaining many of the popular features of the above-outlined web solution range, the new modular offering →04, which is part of the ABB Ability™ portfolio of connected solutions, has been streamlined to include two main cloud services: ABB Asset and ABB Styling. Both are based on SaaS pricing policy standards and will include tiers of functionality with varying

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The ABB Ability™ portfolio now includes two main cloud services: ABB Asset and ABB Styling.

monthly fees and optional 'add-ons' to maximize value for customers. Below is an outline of the new offering's key customer benefits.

ABB Asset
ABB Asset enables EV charging infrastructure operators to optimize their processes and reduce operational costs based on real-time, data-based insights. Its flexible three-tier offering (Essentials, Professional and Enterprise) allows customers to select exactly the capabilities their operation needs.

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ABB Styling

Meanwhile, ABB's Styling solution will launch with a professional tier supporting e-mobility service providers. This will enable providers to build customer loyalty by creating a distinctive brand experience at the charger. The web solution's unrivalled flexibility brings brands to life on the EV charger display and creates unique advertisement capabilities and brand experiences, further maximizing opportunities for revenue generation.

Different styling sets to suit different site locations can be designed and deployed via an easy customization and update process. The end result is a flexible, easy-to-use and remotely controlled solution that gives ABB's customers full control over their charger branding. This will

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ABB Asset's flexible three-tier offering allows customers to select exactly the capabilities their operation needs.
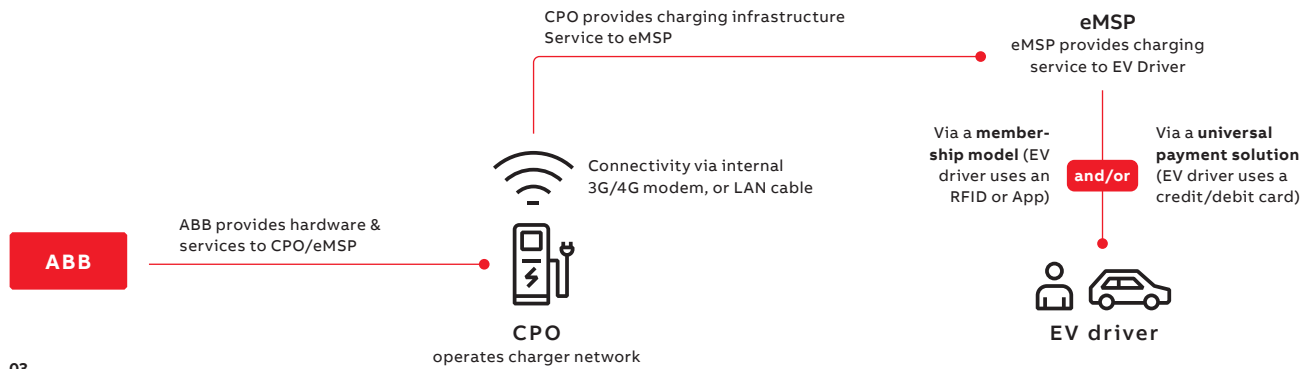
not only enable them to strengthen customer engagement and retention but also to improve profitability to help develop a sustainable business for the future. Looking ahead, additional tiers will be added to the HMI styling solution to further maximize flexibility for the customer.

Optional add-ons

With maximum flexibility for the customer in mind, optional upgrades have been created to supplement the two main services. Both ABB Asset and ABB Styling can be upgraded with a User Management add-on, enabling users to be added to the portal. In addition, customers can use the Charger Group Management add-on to group the management of chargers through the ABB Asset and ABB Styling solutions, for example by restricting access rights across certain groups of chargers.

ABB Asset customers can also benefit from the following extra upgrades:
- Alerts (available through all tiers), which send notifications for a number of pre-configured criteria
- Card Payment Analysis (available through all tiers), which provides additional insight into revenue generated from charger payment terminals
- Charging Authorization (available through all tiers), which allows the authorization of charge sessions via RFID or PIN

Insights into charging patterns, cost predictions, and opportunities to optimize charging networks are examples of ABB Asset's available features that do not require investment in an external operations management software platform. Furthermore, even more efficient servicing and higher system availability can be achieved with remote troubleshooting. What is more, with the Essential tier, charger monitoring and charging session monitoring are included in the hardware purchase, with the option to easily upgrade to higher tiers or add-ons as required.

Ultimately, ABB Asset will help its customers build trust and loyalty through increased uptime and reduced operational costs, while improving profitability and the predictability of expected revenue.

CPO provides charging infrastructure
Service to eMSP

eMSP
eMSP provides charging
service to EV Driver

Via a **member-ship model** (EV driver uses an RFID or App)   **and/or**   Via a **universal payment solution** (EV driver uses a credit/debit card)

Connectivity via internal
3G/4G modem, or LAN cable

ABB

ABB provides hardware &
services to CPO/eMSP

CPO
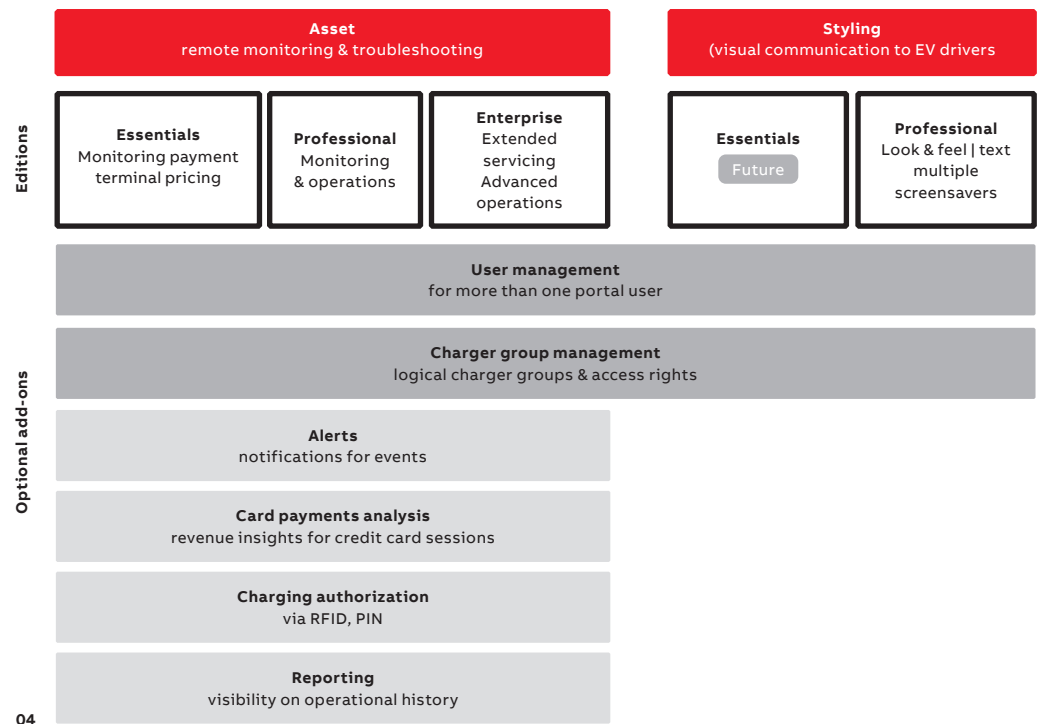operates charger network

EV driver

03

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01 Global electric vehicle stock by region [1].

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02 Estimated world-wide charger sales volume and revenues 2021–2030. UHPC: Ultra High Power Charging. HPC: High Power Charging [2].

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03 ABB has redeveloped its connected services for EV charging infra-structures for charge point operators (CPO) and e-mobility service providers (eMSP).

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04 The ABB Ability™ portfolio of connected solutions has been expanded to include two main cloud services for EV charging: ABB Asset and ABB Styling.

Asset remote monitoring & troubleshooting			**Styling** (visual communication to EV drivers	

Editions

Essentials Monitoring payment terminal pricing	**Professional** Monitoring & operations	**Enterprise** Extended servicing Advanced operations	**Essentials** Future	**Professional** Look & feel | text multiple screensavers

Optional add-ons

User management
for more than one portal user

Charger group management
logical charger groups & access rights

Alerts
notifications for events

Card payments analysis
revenue insights for credit card sessions

Charging authorization
via RFID, PIN

Reporting
visibility on operational history

04

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• Reporting (available on the Professional and Enterprise tiers), which provides visibility into operational history

The era of digital transformation necessitates change and innovation across many walks of life. Transportation is no exception. As the world increasingly embraces new forms of mobility, the automobile industry and related OEMs not only have an opportunity to transform the driving experience but a full range of related experiences, such as EV charging.

Driver expectations are undoubtedly higher than they have ever been before. But with intelligent and connected solutions such as ABB Asset and ABB Styling, the ability of charge point operators and e-mobility service providers to both meet and exceed those expectations is already at

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ABB Asset will help its customers build trust and loyalty through increased uptime and reduced operational costs.

hand. ABB is committed to supporting its e-mobility customers on the road to digitization by developing technologies that have the power to drive a new and elevated customer experience for all. •

ABB TECHNOLOGIES ENSURE THAT SHIPS ARE NEVER ALONE

Remote voyages

Shipping cargoes across the world's oceans has always been a balancing act between technology and risk – and even today's high-tech vessels are no exception.

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They routinely travel routes that are far from expert assistance, carry huge, unwieldy cargoes that are subject to extreme accelerations and stresses, and operate on strict schedules that leave little room for error. Making this possible

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Factors such as wave direction and the distribution of wave periods can have a significant impact on a vessel's safety.

are ABB technologies such as remote diagnostics systems, real-time decision-making support in voyage planning and execution, and vessel motion risk management.

Today's biggest ships, which can reach nearly half a kilometer in length, may seem to be virtually impervious to the forces around them. But they are not. Ocean-going vessels such as container and cargo ships are routinely exposed to high waves, lashing winds, currents and tides, as well as other, less obvious phenomena, such as the distribution of wave periods and wave direction relative to a ship's heading – factors that can have a significant impact on a vessel's safety, maneuverability, and fuel use. Furthermore, the magnitude of the influence that these forces

have on ship handling depends on ship size, speed and draft – not to mention rapidly developing weather systems that may require quick changes of plan.

Added to all this are the extreme accelerations and stresses that can affect huge, bulky cargoes such as wind turbine parts, jack-up rigs and even container stacks. Ideally, when adjusting a vessel's speed and heading, all of these factors should be considered with a view to their influence on motions such as roll and pitch.

Whether a vessel is transiting the North Sea to deliver components to a new wind farm, negotiating the narrowest sections of the Suez Canal, or attempting to avoid a rapidly developing storm surge in the East Indies, ships and their cargos need all the support they can get. The following sections take a look at what such support means in practical terms. In particular, the sections examine the ABB Ability™ OCTOPUS Marine Advisory System, a ship operations performance management package; the ABB Ability™ Remote Diagnostic System for Marine, and the company's new online platform, ABB Ability™ Marine Fleet Intelligence.

OCTOPUS: Widening the operational window
According to the International Energy Agency, global offshore wind capacity may increase 15-fold and attract around $1 trillion of cumulative investment by 2040 [1]. As this trend

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01 Module deck carrier VestVind will be able to increase its operational window with ABB software.

01

accelerates, demand is increasing for vessels servicing this growing segment. With its wide portfolio of electric, digital and connected solutions, ABB has a long history of supporting wind turbine installation vessels, service operation vessels and cable laying vessels.

One key way in which the safety of such vessels can be maximized is the reduction of unwanted vessel motions and accelerations. In this connection, ABB Ability™ OCTOPUS – Marine Advisory System software helps protect high-value payloads in transit, while at the same time boosting vessel efficiency by optimizing the route, based on vessel motions resulting from weather and wave conditions.

Heavy lift operators such as United Wind Logistics are increasingly turning to OCTOPUS for enhanced voyage planning and execution →01 [2], with ABB estimating that the easy-to-install

or retrofit platform supports 90 percent of the semi-submersible heavy lift ships in operation worldwide.

A recent example is United Wind Logistics' module deck carrier VestVind, which will rely on the OCTOPUS System to support real-time

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Ideally, when adjusting a vessel's speed and heading, factors such as extreme accelerations and stresses should be considered.

decision making as it transports large windfarm components such as turbines, foundations and blades to offshore installation sites. Indeed, the

02

REMOTE SERVICE: HELPING COMPANIES SURVIVE A CRISIS

When ship operations were disrupted by grounded flights and closed borders, many customers were quick to realize that remote services were essential to keeping their ships running. The ABB Ability™ Remote Diagnostic System for Marine ensured that customer data in the cloud was available both to ships' crews and to personnel ashore. Customers were reassured because they were able to get answers to their questions on the spot because ABB's digital portfolio is designed to reinforce the monitoring and maintenance of assets while, at the same time, optimizing day-to-day operations.

Although ABB's remote support systems, particularly its Collaborative Operations Centers, have been operating effectively for years, the Covid-19 pandemic has demonstrated the true value of the company's remote monitoring and cloud-based data management systems, which have helped to streamline customer maintenance, cut costs, support decision-making and ensure the best through-life asset care [3].

03

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technology will allow the module deck carrier to increase its operational window, during which it will be able to perform tasks safely and efficiently even during weather-sensitive operations.

Installation of ABB's market-leading solution on board the 130-meter, 10,238-DWT VestVind follows successful application on board United Wind's module deck carriers BoldWind and BraveWind, both of which were delivered in 2020. The technology is seen as having growing significance due to the fact that offshore wind power installations are being outfitted with larger, more expensive wind turbines, which require larger, more sophisticated vessels. As this process evolves, the importance of motion monitoring and forecasting is increasing steadily.

Digital Journey
ABB's digital portfolio is designed to reinforce the monitoring and maintenance of assets while, at the same time, optimizing day-to-day operations, all of which can extend intervals between equipment overhauls. ABB Ability™ Remote Diagnostic System for Marine, for example, is capable

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The VestVind will rely on an OCTOPUS system to support real-time decision making.

of reading data from a wide range of ABB devices and providing a holistic view of a vessel's entire powertrain. The results are increased uptime, lower service costs, and 24/7 access to technical support engineers and the global network of round-the-clock ABB Ability™ Collaborative Operations Centers →02 – all of which turned out to be immensely valuable during the Covid-19 crisis →03.

Furthermore, ABB's Remote Diagnostic System and the services built around it are both proactive and reactive. In other words, ABB experts may pick up an anomaly in the condition-monitoring process; or an engineer aboard a ship may seek advice on a specific issue. For example, an ABB duty engineer in an ABB Ability™ Collaborative Operations Center recently picked up a critical trip notification from a tanker. The engineer

04

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02 ABB Ability™
Collaborative
Operations Centers
around the world
providing 24/7 support
to customers.

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03 ABB's remote sup-
port systems help to
streamline maintenance
and cut costs.

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04 ABB Ability™ Marine
Fleet Intelligence
provides insights
and advice on fleet
performance to ship
operators.

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analyzed the data, contacted the ship, informed staff that the data pointed to a faulty power supply and provided troubleshooting instruc-tions. The crew found the faulty power supply in an inverter unit and replaced it with a spare. The ship's operations were not interrupted, no time was lost, and no expenses were incurred.

Examples like this illustrate how ABB's goal is to reduce its customers' total cost of asset ownership by 30 percent through partner-ships designed to steadily improve lifecycle maintenance.

Fleet intelligence
A new online platform, ABB Ability™ Marine Fleet Intelligence – Advisory →04 [4], combines the power of cloud-based analytics and reporting with user-friendly visualizations to help ship-owners, managers and charterers optimize ship performance fleet-wide. The platform is being offered as a Software as a Service (SaaS), which can collect data from a wide variety of vessel sys-tems. The solution provides a complete overview of all data collected from shipboard systems, making it possible to compare the operational performance of ships built to the same specifica-tions in an entire fleet.

ABB Ability™ Marine Fleet Intelligence – Advisory is a single platform featuring uniform reporting for customers seeking a robust analytics service capable of fleet-wide data collection. For instance, the platform provides verifiable emissions data, thus making onboard energy use transparent and supporting compliance with tightening greenhouse gas regulations.

The platform draws on system data points on navigation, propulsion, fuel consumption, loading conditions, weather and speed logs. Based on all of this, it delivers an integrated evaluation of a ship's fuel, energy and emissions efficiency,

its operational availability, technical condition and safety, and compares results to fleet performance.

In addition to integrating with ABB's onboard systems, the platform can combine other data retrieval solutions to support analytics, reporting and display. Users can access operational per-formance information by signing into the ABB Ability™ Marine Fleet Portal. Based on Microsoft Azure and integrated Power BI business analytics from Microsoft, the online platform offers inter-

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ABB's goal is to reduce its customers' total cost of asset ownership by 30 percent through partnerships.

active visualizations and business intelligence capabilities with an intuitive interface that allows end users to create customizable reports and dashboards. In short, ABB's new Advisory platform puts operational vessel data in the context of smart KPI dashboards and reporting functions, thus opening the door to valuable insights that help to optimize vessel maintenance scheduling throughout a fleet. ●

Edge vs. cloud computing

During the previous decades, an increasing number of industries benefitted from bringing their IT applications into the cloud, leveraging its scalability as well as its power for big data processing.

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However, in many cases, more local solutions have benefits as well, eg, in terms of end-to-end latency, or data privacy. This is why edge computing is seen as a promising technology in many areas nowadays [1,2].

Edge vs. cloud computing

Response time
Scalability
Integration
Sustainability
Availability/reliability
Cyber security & data privacy
Costs

In edge computing, data processing tasks are executed close to where the data is generated, in order to enable fast response times. At the edge, the data can be preprocessed, filtered, or aggregated, such that a smaller amount of data needs to be sent to the cloud.

When comparing the benefits of edge and cloud computing, there are many aspects to consider →**01**:
- Performance: With edge computing, it is easier to achieve low latency and high bandwidth due to the physical proximity of the computing nodes to the source of the data. This also means that higher volumes of data can be processed at faster response times.
- Scalability: Scalability and elasticity, however, are among the big advantages in favor of cloud computing.
- Integration: When connected to an edge device, legacy and very resource-constrained devices can also be integrated into an advanced OT-IT system architecture [3].
- Sustainability: There are many different opinions regarding whether edge computing contributes to a low-carbon society. Edge
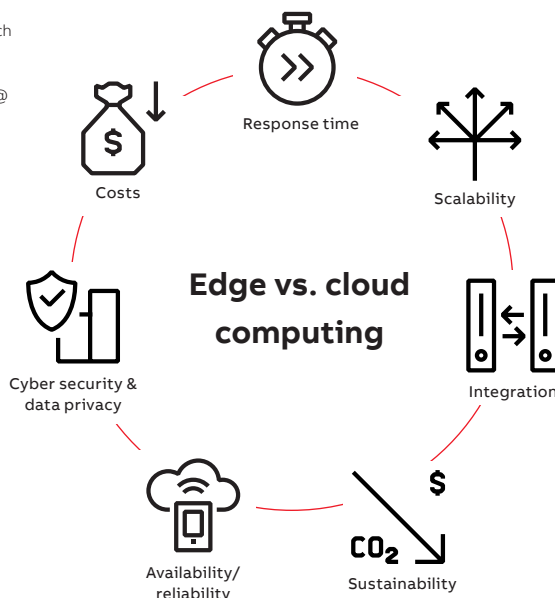
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01 Aspects to consider when comparing edge and cloud computing benefits.

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computing helps to reduce traffic to the cloud as well as cloud storage and cloud operations, however, the providers of the big public clouds also have strong sustainability strategies [4].

- Availability/Reliability: The edge can operate even during times of unavailability of cloud services.
- Security/Privacy: On the edge, it is usually easier to protect applications and data. Having a secured edge gateway channeling the communication to the cloud, the attack surface is smaller, compared to a system with many devices establishing their own connections.
- Costs: Depending on the application, edge resources can be less expensive than cloud resources. Often, edge computing adds to a higher CAPEX, but has a lower OPEX if used in a continuous monitoring case.

All in all, both edge computing and cloud computing have their benefits and there are always trade-offs when deciding between these deployment alternatives for a specific application. Edge computing is not to be understood as an alter-

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Edge computing is seen as a promising technology in many areas nowadays.

native to cloud computing but as a complement. Industry investment in edge computing has grown a lot within recent years, including efforts for industrial edge computing reference architectures and standardization eg, [5,6], accordingly, edge computing is well on its way to becoming a leading digital technology. •

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