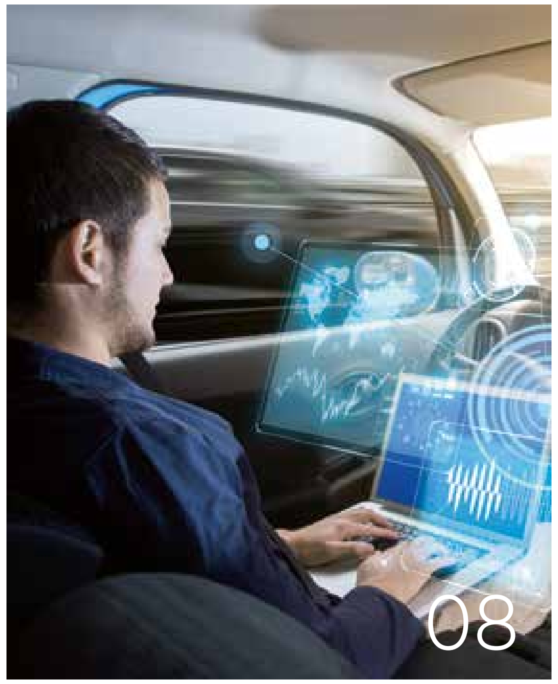
ABB
review
03|2019 en

Autonomous systems

Data analytics tools
for industry

Smart visualizations



From automation
to autonomous systems

The fuel cell – a green
powerhouse

Autonomous systems

Energy

Buzzword demystifier

An autonomous system can make a machine, factory, network, or even an entire city run more efficiently, reliably, and safely without direct human control; building one requires novel visualization tools, innovative construction and coding, and new approaches to forecasting and management. It is where digitization and deep industry experience meet. This issue of ABB Review explores some of the latest technologies the company is developing with customers.

EDITORIAL

Autonomous systems

Dear Reader,

In a world characterized by unpredictability and constant change, our ability as humans to be successful relies on our natural capability to learn, adapt and think contextually. Increasingly, industrial systems are also acquiring such skills. The automation system of the past, in which a limited set of rigid instructions produced optimal results only within a narrow set of boundaries, is being replaced by autonomous systems, able to continuously adapt, learn and even create their own rules.

This issue of ABB Review looks at examples from across the company in which increasing levels of autonomy are unleashing new capabilities in the gathering, interpretation and processing of data as well as their use in taking or informing decisions.

Enjoy your reading!

Bazmi Husain
Chief Technology Officer

Photo: MF3d, istockphoto.com

Autonomous systems

A system that learns is more than just a sum of its parts, as it doesn't only carry out programmed actions or respond directly to sensor inputs, but instead yields insights and actions that address and adapt to the variability of experiences. It represents the leap from simple automation to autonomous functions. ABB goes deep on the research and development required to bridge that gap.

AUTONOMOUS SYSTEMS

The road from automation to autonomous systems

Photo: metamorworks, istockphoto.com

Data is often referred to as the oil of the digital economy; but in the context of the Fourth Industrial Revolution, self-learning algorithms for autonomous engineering, operation and control are likely to be the key to success. Tomorrow's market leaders will be those who have the domain expertise to develop the industry-specific machine learning algorithms that improve the productivity of their customers.

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Everybody is talking about autonomous cars →1. Indeed, the progress this technology has made during the last few years is so impressive that it's way ahead of what is happening in the field of industrial automation. So, to better understand what is going on, ABB has taken a close look at how the automotive industry defines the five levels of autonomous driving [1,2,3] in the context of today's industrial automation systems →1.

Level 0. This is where we are today, ie, where a human, controls it all. In the context of industrial automation, level zero is how operators run their plants during the startup phase; this is when they configure and optimize processes.

Level 1. According to the US National Highway Traffic Safety Administration (NHTSA), this level is characterized by "an advanced driver assistance system (ADAS)… that can sometimes assist the human driver with either steering or braking/accelerating, but not both simultaneously."

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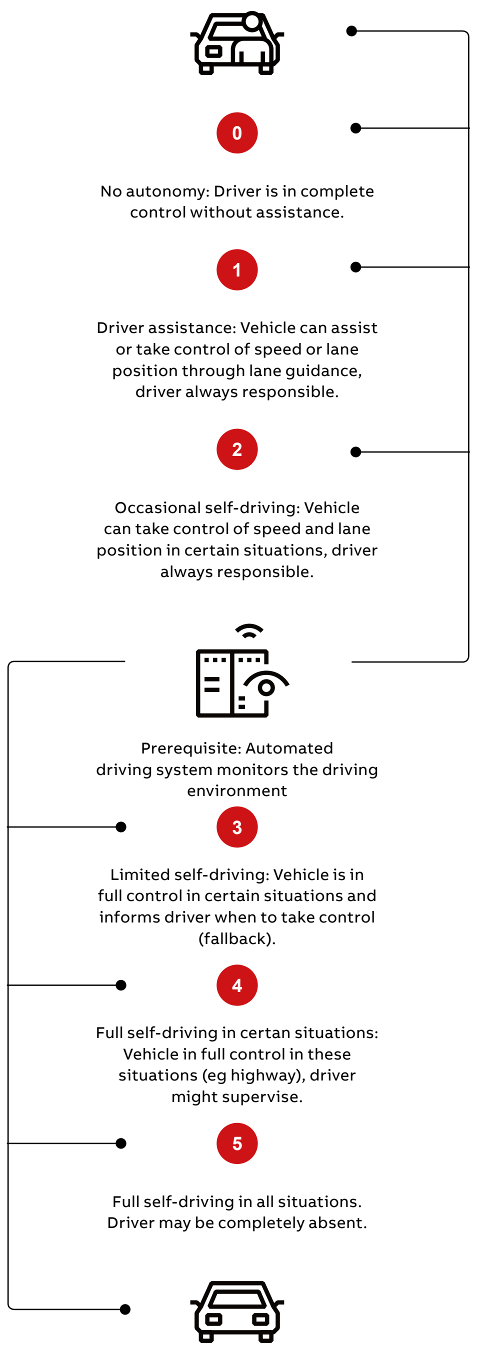
Today's plant operation technology has reached a level of autonomy somewhere between levels 2 and 3.

In the context of industrial automation, this is replicated by control loops that keep particular process variables at set points based on feedback from sensors.

Level 2. The NHTSA describes this level as "an advanced driver assistance system (ADAS)… that actually controls both steering and braking/accelerating simultaneously under some circumstances. The human driver must continue to pay full attention at all times and perform the rest of the driving task." In the context of industrial automation, this is how most operators run their plants. They are in the control room to observe production and step in only if an alarm indicates that specific process variables have drifted in an undesired or unexpected direction.

Level 3. According to NHTSA, this level is characterized by "an Automated Driving System (ADS)… that can itself perform all aspects of the driving task under some circumstances. In those circumstances, the human driver must be ready to take back control at any time when the ADS requests the human driver to do so. In all other circumstances, the human driver performs the driving task." In the context of industrial automation, this is roughly equivalent to a plant with continuous production and only a handful of service personnel on site to keep the operation running.



01

	Level 1	Level 2	Level 3	Level 4	Level 5
Control		×			
Operation		×	×		
Engineering	×				

02

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01 Levels of autonomous systems as exemplified by self-driving vehicles.

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02 Levels to which autonomy has been achieved in industry.

Level 4. This level refers to an "Automated Driving System (ADS)… that can itself perform all driving tasks and monitor the driving environment – essentially, do all the driving – in certain circumstances. The human need not pay attention in those circumstances." Today's automation technology is still far from this level in most industries.

Level 5. Here, an "Automated Driving System (ADS)… can do all the driving in all circumstances. The human occupants are just passengers and need never be involved in driving." We expect it to take quite some time before even the automotive industry reaches this level.

Three views of industrial autonomous systems
Having examined the autonomy levels of self-driving cars, we now need to consider at least three views of industrial autonomous systems →2.

Autonomous engineering.
Most discussions on autonomous systems center around autonomous operation. However, a pre-condition for autonomous operation is autonomous engineering. Using the vision of the Fourth Industrial Revolution [4] as guide, the development of industrial automation can be interpreted as parallel to the five levels of autonomous driving. Considering the production and optimization of smartphones, for instance. These devices are characterized by hundreds of configuration parameters designed to allow users to customize their communication experiences. However, although more than ninety percent of all settings are kept at default values, some users take the time to tweak their devices and applications for optimal performance. And in those cases where the tweaks can be shared with the supplier the information can be used to improve the product, reduce troubleshooting costs and optimize default parameters.

A further step could be a scenario in which all smartphones can upload their improved configurations into a vast data lake that would be available to all. By the same token, today's industrial automation technology already connects millions of devices. This, along with the knowledge of how devices associate with each other, in which industrial applications and under which environmental conditions, is the foundation for autonomous engineering!

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The probabilistic responses generated by machine learning-based AI could profoundly alter tomorrow's industrial control systems.

Using the capabilities of big data analytics, one can derive device and application settings that are much better than the default settings. The data model continuously refines the settings. For guidance similar to that provided by an advanced driver assistance system, engineers can then either choose default parameters given by the product owner, or the settings most of the engineers around the globe have chosen in a similar setup for a similar application in a comparable environment. This combination of human and machine resources would move autonomous engineering from level one to two. Once this becomes mature, it would allow moving to level three, where a plant could autonomously change its configuration, for instance based on environmental changes between summer and winter. This is the reason why autonomous engineering is to some extent a precondition for autonomous operation.

Autonomous operation.
Today's plant operation technology has reached a level of autonomy somewhere between levels 2 and 3. But it will take much more than just autonomous engineering to reach full autonomy. To achieve this, systems will have to combine device and application settings, as well as process values. A good starting point is an analysis of data from decades worth of alarms and events

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03 Control loop-based automation.

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04 Operational risk management blueprint for AI.

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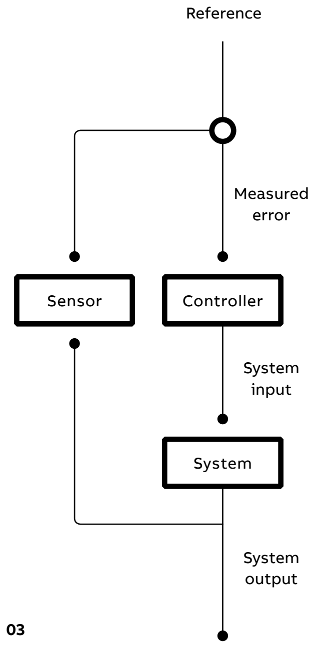
05 An ABB industrial robot palletizing meats in a frozen food area. ABB is investing heavily in increasingly autonomous production technologies.



03

that tell operators how production systems have performed under a vast range of conditions.

It must, however, be kept in mind that human error is still the main cause for production failures and plant shutdowns [5]. In view of this, the availability of plant-wide data is obviously at the core of autonomous operation and is a prerequisite for unlocking the potential of today's technology and data analytics. Machine learning, with its unlimited storage and computational power, allows us, for the first time, to take advantage of this. But to become fully autonomous, such a system must be able to automatically change a configuration if it detects a novel fault situation; in other words, it must be able to go beyond what it has learned from a vast data set of previous situations and be capable of triggering and configuring new alarms by itself and reacting to them. This new setting is far more complex than anything engineers have configured to date. Here, data is the beginning of autonomous operation, while self-learning algorithms lead to the next level of autonomy.

Autonomous control.
This leads us to the concept of autonomous control, which is probably the most controversial part of autonomous systems. The most persuasive argument used against machine learning replacing today's control-loop-based automation →3 is that the response of a control loop is deterministic while machine learning is probabilistic. One can hardly doubt that a single control loop is deterministic, but one should question whether a control system based on hundreds or even thousands of control loops is also deterministic.

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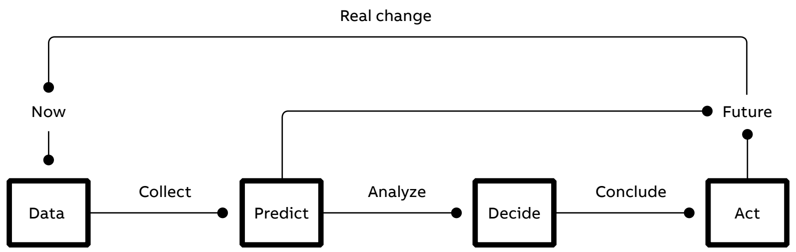
The next level of autonomous control will have to holistically address entire industrial automation systems.

In view of this, the probabilistic responses generated by machine learning-based AI could profoundly alter tomorrow's industrial control systems. While it is true that control systems based on Third Industrial Revolution technologies have reached very high reliability and performance standards, the capabilities of those that will be based on Fourth Industrial Revolution technologies will accelerate at a speed the industry has never seen before. A probabilistic response of eighty percent today might become ninety-nine percent soon, which would be close to those of a deterministic system if we consider a whole process area or plant.

In coming years artificial intelligence will change today's control paradigm from signal marshalling to process data analytics, from feedback loops to prediction, and from process calibration to



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self-optimization →4. Artificial intelligence-based systems will also soon be far better than traditional control loop systems because machine learning can correlate hundreds and thousands of parameters instead of just comparing a variable with a set point. In order to take advantage of this, the next level of autonomous control will have to holistically address entire industrial automation systems →5. This will call for feeding all engineering data, device parameters and their operations, as well as process and environmental data into a machine learning-based system and training it based on physics, feedback from the quality assurance system, and the experience of operators and plant engineers. Once these steps have been taken, control loops will no longer be needed to determine process input parameters for devices. Product-wise this will initially cause a disruptive transition because industrial automation devices in the installed base are not capable of hosting machine-learning engines; but it can be expected that the next generation of industrial devices will be much more powerful.

Technology-wise, artificial intelligence-based control systems will probably completely replace today's distributed control systems. First, because they will deliver better results faster. Second, the architecture of today's control systems is outdated. Distributed control systems have their roots in the Third Industrial Revolution where computing power and storage capacity were scarce and real-time communication required the proximity of control to equipment. All these constraints are no longer valid, particularly with the upcoming advent of 5G wireless communication.

Market-wise, the good news is that this transition will be relatively slow because of the enormous size of the installed base, thus giving users time to implement and familiarize themselves with new systems.

Roadwork ahead!
Successful players will need to be agile and fast in terms of service development. They will accomplish this by limiting the role of proprietary hardware to a minimum and shifting their focus to cloud-based software-as-a-service solutions. Finally, they will need to transition to control systems that are based on architectures and designs built from the ground up with autonomy in mind.

The architecture and design of tomorrow's autonomous industrial systems will have to support autonomous engineering, operation and control.

Technology-wise, artificial intelligence-based control systems will probably completely replace today's distributed control systems.

To accomplish this, future autonomous control systems will have to start bottom-up because the control layer and the underlying field layer provide the process and device-specific data for data analytics and new AI-based solutions. Starting from the control layer also explains why it cannot be an extension of today's hardware because today's industrial controllers lack the power to compute or the memory to run additional analytics or AI processes. Nevertheless, the first step will obviously be to maintain today's software while migrating it to a more powerful platform – a virtual controller running in a cloud environment.

Starting with the architecture from a virtual controller →6 solves many requirements on the way to fast and agile data analytics, AI-based solutions, and autonomous systems. First, all data will be easily accessible for data analytics and AI applications within the same cloud environment. Second, unlimited computational power and memory can enhance the control software with new features and interfaces. And finally, new features can be quickly deployed within the cloud and do not require any hardware changes or extensions, thus maximizing speed and agility.

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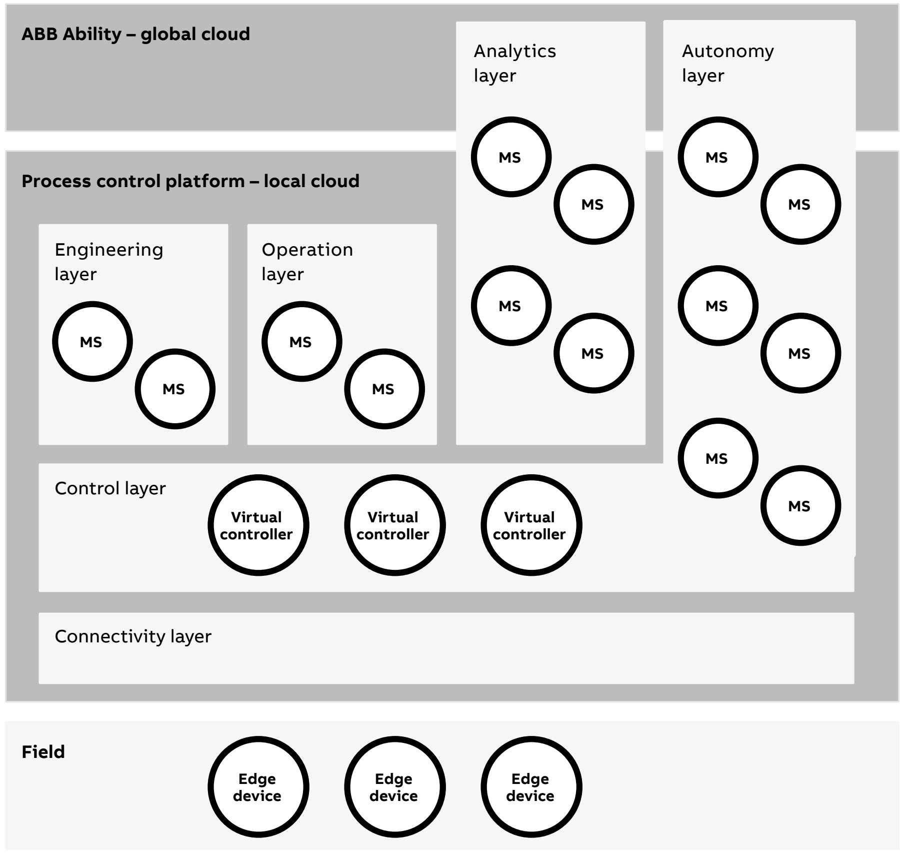
06 Architecture for autonomous operation.



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Autonomous industries need ABB Ability
Connecting a process control platform with ABB Ability provides the data lake for new analytics services and paves the way to bringing today's industries to a new level of productivity. In this architecture, an autonomous system with input from ABB Ability, can run microservices for analytics and enable autonomous engineering, operation and control. In the data analytics layer, the microservices in the process control platform collect the data and decide whether it can be used for local optimizations or fleet management. This built-in intelligence in the process control platform optimizes the data volume transferred to the global cloud.

The architecture and design of tomorrow's autonomous industrial systems will have to support autonomous engineering, operation and control.

That said, autonomous control will take time to realize and will call for many intermediate steps. Here, it is to be expected that connectivity to ABB Ability will speed up machine learning. For instance, microservices that learn from virtual controllers within the same process control platform could also learn from other industrial systems in similar environments.

Moving toward autonomous systems is certainly a challenge, but it is attainable with this stepwise approach. The key to agility and speed is to change the mindset from a transactional product business to software-as-a-service and minimize the development of proprietary hardware. The key to success is two-fold: On the technology side development must start from a base architecture build on a vision of autonomy; on the business side, an early and stepwise business model must be created in which this new development adds to the top line while the existing business continues. •

AUTONOMOUS SYSTEMS

User-centered power network visualizations empower digital twins

ABB's novel visualization display design will allow engineers to quickly grasp State Estimator digital twin function. Grid problems might be solved more efficiently, thereby creating a more reliable power network system for the future.

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Electric transmission and power distribution network systems are increasingly smart and vastly complex. These systems must boast real-time predictive monitoring capabilities that support system operators to manage their interconnected power grid in compliance with international regulations. The massive Eastern North American black-out and the Italian black-out, in 2003, brought vulnerabilities to light. Consequently, regulation authorities now require transmission network operators to monitor their neighbor's networks in addition to their own – a herculean task [1].

ABB's Ability™ Network Manager (NM) offers a combined Supervisory and Control Data Acquisition system (SCADA) and Energy Management System (EMS) to provide advanced monitoring and operation support applications to customers.

The Network State Estimator (SE) is at the heart of the EMS and relies on a digital twin, or virtual model, of the customer's complete electric network – generators, transformers, circuits, etc. The SE predictive model runs in real-time to smooth over noisy or missing data using a weighted least square estimation algorithm with augmented blocked matrices. Furthermore, gaps in electric network visibility can be filled-in, thereby easing recognition and decision-making for both human operators and EMS applications. Hence, SE fulfills critical functions and supplies exactly those features that customers depend upon.

Maintaining the State Estimator
Nevertheless, crucial challenges exist:
The State Estimator must operate within varying environments. Over time, grid equipment is replaced and network connections are altered but the quality of the solution must be maintained. This is especially problematic if enough model mismatches combine with corrupted data from failed telemetry or cyber-attacks. In these instances, the State Estimator algorithm might be unable to forge solutions in either part or all of the network resulting in degradation of automatic monitoring, eg, contingency analysis, and risk of violating regulations. Such SE failure eliminates the tools that EMS engineers depend on to maintain situation awareness and solve grid problems.

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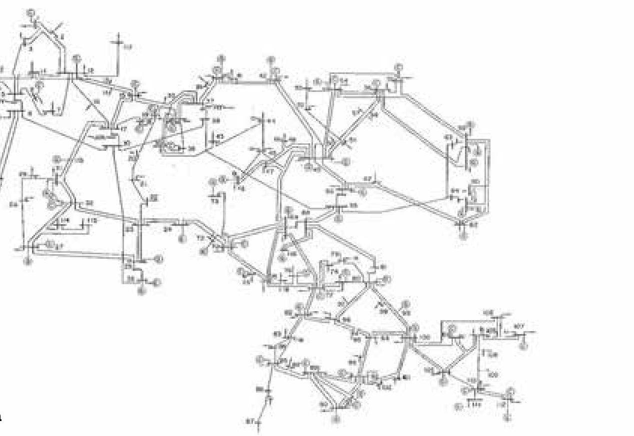
The Network State Estimator (SE) is at the heart of the EMS and relies on a digital twin, or virtual model, of the customer's complete electric network.

Additionally, the requirement to monitor neighboring networks can increase exposure to anomalous models or data. For instance, the majority of the 113 SE outages that occurred in eastern North America between 2013 and 2017 resulted from modeling or communications issues [2].

Commissioning and monitoring of the SE to maintain reliability in the face of these challenges is costly and time- and labor-intensive. To rectify this situation, ABB investigated visualization methods to help SE engineers, experts and non-experts alike, to easily and efficiently monitor SE model health and diagnostics, eg, solution residuals and convergence iterations.

Currently, SE monitoring displays show data inputs, estimated results and rely heavily on numbers and tables. Displays are designed for maintenance by advanced network tuning experts who are few in number and high in demand. Such design is challenging for non-experts to use; demands time and labor and impedes the monitoring and diagnostics of model health – critical for utilities to maintain a competitive edge in today's market.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01c

Project inception and methods
In 2018, ABB initiated a research project to investigate ways to visualize just where the SE model might be encountering problems: mismatches between model and data. The fashioning of displays that intuitively help experts and non-experts make sense of problems would allow staff to efficiently and pro-actively reduce risks to solution reliability by:

- Pin-pointing faulty telemetry or measurements to block faulty data
- Locating aspects of the model that are obsolete
- Assessing model tuning and how to improve it

ABB validated the visualization through design workshops and interviews with ABB experts, and by eliciting external reviews (four Network Manager customers: two in Europe and two in North America reviewed the concept).

Mapping the electric connectivity
In order to create an agreeable visual analytics solution best suited to SE diagnostics, the design team evaluated conventional maps of electric network connectivity, typically employed for different purposes [3]: geographic view and transmission schematic overview →1.

Power distribution companies send maintenance crews into the field and troubleshoot physical damage to equipment. Geographic views show the physical location of assets and are easy to interpret and so are well-suited for these tasks (navigation by continuous plan with zoom features) →1a. Nonetheless, physical location is irrelevant to the functionality of the SE model, making geographic views alone unsuitable.

—
ABB investigated visualization methods to help SE engineers, experts and non-experts alike, to easily and efficiently monitor SE model health and diagnostics.

Schematic views show the logical electric connectivity of network circuits and stations and are therefore standard for transmission companies →1b. The schematic representation style is more abstract than the geographic view: it displays buses as straight lines and navigation occurs by discrete steps along lines. Essential for planning, the schematic view enables grid operators to readily discern all the possible connections that circuit breakers and switches can be used to create. This is invaluable knowledge and yet the SE only solves the present situation: a tiny visual difference on a schematic could greatly underrepresent the impact of an event on the SE modeled solution, eg, closing a circuit breaker.

Because State Estimator model troubleshooting is dissimilar to distribution- or transmission network operation, a new approach is required. Based on previous academic schemes [4], ABB applied standard graph theory with visual formatting, landmarks and navigation aids to create a network visualization that is abstract, intuitive to use and displays the underlying structure of the network model →1c–2 [5]. Ultimately, this visualization, if proven useful for SE, might also be effective for monitoring power grids of the future.

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Title picture: Visualizations are designed according to the job.

01a Geographic views show where physical assets are located and have been in use since the 1970s.

01b Standard diagrams for transmission networks show the location of connections logically. Here, Nominal voltage is mapped to line thickness after [5].

01c Power balance shows network function based on Cuffe and Keane's academic work and include ABB's design modification [4].

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02 ABB designed a Network Topology visualization for Power System Explorer's State Estimator. The result complements the existing interface for the transmission network digital twin.

Even though network graphs are successfully employed for analytics in many fields today, eg, social sciences, logistics, etc., ABB's challenge was to design this demanding application to be user-centered for power network applications.

Design evolution
Because SE model health indicator visualizations must scale up to be useful for large network models, a minimalist graph design approach was chosen. This allows space for data and a 'global' visual effect style, one that relays overall network and model properties.

Accordingly, ABB incorporated features of basic network graph design: node circles as stations, and edge lines representing electric circuits. Three main visual factors were used: node size, line width, and line length. Node sizes encode the difference between station power generation and power load. So, larger circles indicate important stations: either large generators or large loads, eg, cities. Smaller circles represent self-sufficient cities, or transmission stations, and small junctions (circles are hidden). Line widths visualize circuit capacity or voltage level; a thicker line denotes higher power flow rating. This style distinguishes strong from weak circuits and visually separates networks of different voltage levels →2,3.

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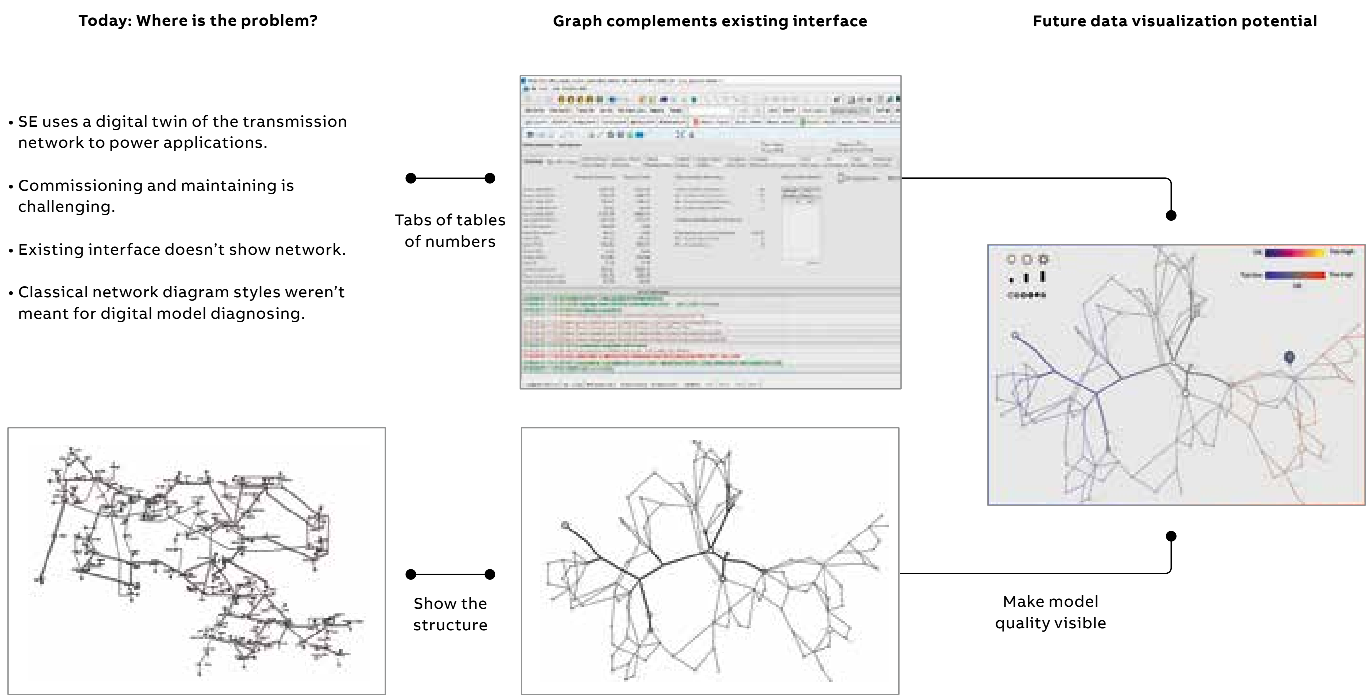
Based on previous schemes, ABB applied standard graph theory to create a network visualization that is abstract and intuitive to use.

Although operators often use color for network voltage, color coding is better suited to represent data – the key to comprehending the quality of the SE model solution.

Typically, line length represents distance or km, but, since distance is not directly relevant to the SE, line length was drawn using impedance-derived Net Power Transfer scaling [4]. Hence, line length supports a visual metaphor of "power travels in straight lines" and results in the least distortion of the



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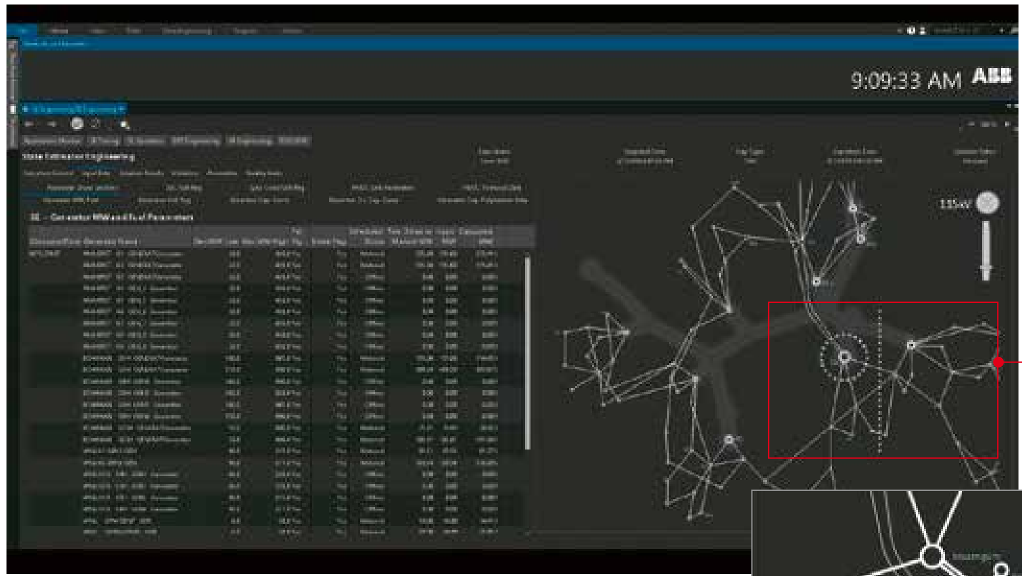

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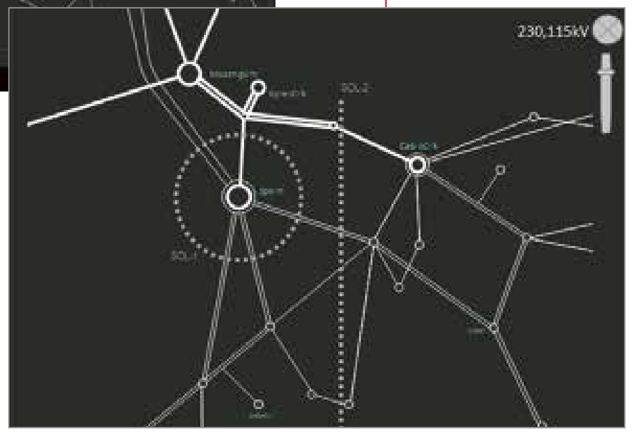

03b

network structure [4]. Furthermore, this device helps SE engineers visualize the "path of least resistance" and the underlying electric model. Longer lines represent less direct power flow paths →3,4.

Vitally important major boundaries in the SE model solution (eg, between the customer's network and neighboring networks, or between what is "observable" and "unobservable") are visualized by extending line lengths slightly to create blank space, thereby forging separate areas.

The resultant visualization is an insightful view of how the SE sees the current network configuration – how power flows from large generators to large loads, and which aspects of this flow are solved properly by the SE →3,4.

Fostering visualization
Important questions remained, however, once the design concept was complete: How can EMS engineers relate to this visualization design in terms of what they know about their network and their region? Which features foster the usefulness of network-centered visualization?

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Recognizable visual features allow users to apply their knowledge and experience to steer and search through the network representations.

Many challenges can affect visualization acceptance. The use of consistency and conventions help avoid misunderstandings that can lead to hazards. Consequently, ABB is developing the network-centered design for EMS SE model maintenance staff (either IT or electrical engineers) to complement traditional representations →2.

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03 The SE network visualization concept complements existing tabular data structures and can support intuitive user navigation by pan, zoom, voltage layers, selection in tables, or station/landmark search.

03a Network visualization shows tabular structure.

03b The visualization concept allows users to zoom in on structures of interest.

—
04 By using monochrome visual design to show network structure, color visualizes SE health indicators eg, solution residuals or convergence iterations. By designing color scales so that significant deviations are shown in higher contrast, the eye is drawn to the source of the problem.

Another barrier to acceptance is the risk of user-disorientation. To avoid this, conventional design features are included, eg, north-up, west-left. The graph was decluttered by bundling minor junctions and line segments inside the circuit lines and progressively revealing text labels →3. For smaller stations, this is accomplished with a zoom-in feature. Network landmarks, like groups of lines in a System Operating Limit (SOL), are represented by large background visual features, eg, a load "pocket" in a city is denoted as a boundary circle (the SOL describes a limit to the total power flow on electric circuits that the boundary circle crosses). SOLs for regional transfers like an East-West flow are shown as boundary lines. Here the boundary lines are drawn vertical. →3b.

—
ABB designed an attractive user-centered visualization scheme: color can be used to represent data like SE model health indicators.

To zero in on modeling problems, different network voltage levels can be navigated as "layers" that can be brought to the forefront, while the user can view the rest of the network as background. Instead of trying to include all details within stations, the design helps users navigate to the existing diagram display once they have located the modeling perturbation →3.

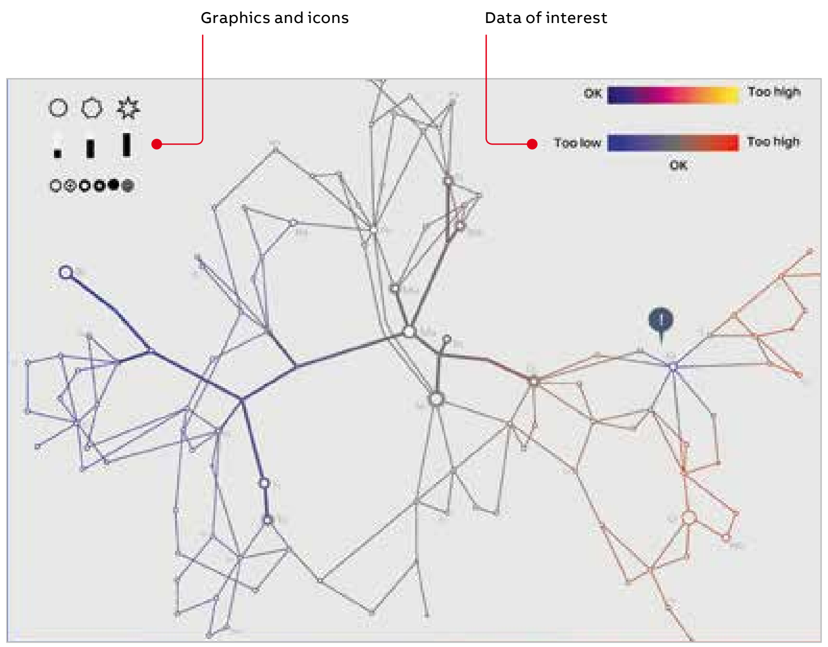
Recognizable visual features allow users to apply their knowledge and experience to steer and search through the network representations; this user-centered design helps SE engineers diagnose SE model health stress factors.

Color aids interpretation
ABB designed an attractive user-centered visualization scheme that employs scalable styles to reveal the structure of the network model. Because the display functions successfully in black and white, color can be used to represent data such as SE model health indicators →4.

Continuous color scales can show ubiquitous analog data, eg, model residuals and model convergence times. By increasing brightness to draw the eye to the model area showing signs of stress, the user can immediately grasp patterns in SE health issues. Concomitantly, discrete indicators, eg, last bus converged or bad topology detected, can be shown with pop-up pins →4,5.

To make the system even more user-centered, ABB embraced customer feedback for extended functionality, eg, animated particle flow trails could show patterns of real or reactive power →5.

Power network future is visual
Once the visualization scheme is approved for SE monitoring and diagnosis, it could be re-used for other critical future applications. For instance, the consequences of the highest risk contingencies could be visualized or the visual representation of a network following an outage could be displayed



Visualizing State Estimator

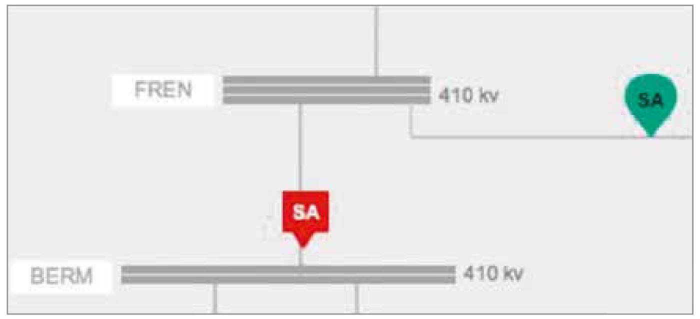
Key data can be overlaid using visual style or icons

Working in grey-scale saves color to show data patterns:
- Solution residuals
- Convergence iterations
- Estimated vs. assumed

Applications can be developed to suit user needs.

Use pins/pop-ups sparingly
- Last station converged
- Bad topology?

04



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05 Data visualization overlays on the core network can be used in the future to compare different grid states according to customer needs eg, time history, power-flow studies and simulations. In this screenshot, pinned points are shown.

along with the consequent overloading spread. Changes in a neighbors' network situation throughout a busy day or large changes in flows or redundancies could be summarized.

The ability to quickly and easily evaluate queries visually will help power network operators maintain reliability and security efficiently. Furthermore, the same features needed to monitor the SE will help ABB commissioning experts set up the model, demonstrate acceptance tests, and train customer staff.

Commonly used, but rarely maintained to a high level, SE requires continuous fine-tuning from experts for full functionality. And yet, the ongoing energy revolution will undoubtedly continue to increase the demand for greater situational awareness of power network systems. Consequently, more effort will be devoted to SE development and expansion. The current growth of renewables and the need to maintain capacity are potential drivers. SE technology has yet to be included in the small distributor market and this market sector is expanding [6]. Improvements in infrastructure and control systems enable expansion of SE in the balanced network market, ie, the high and medium voltage market, and allow entrance to the low voltage market.

By improving SE model solution capability and usability, ABB aims to enhance profitability: ABB's SE visualization design is a first step.

The US power transmission and distribution markets are expected to grow significantly by 2023 [6]. By improving State Estimator model solution capability and usability, ABB aims to enhance profitability: ABB's SE visualization design is a first step. •

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AUTONOMOUS SYSTEMS

Visualizations for a smarter municipal community

Relying on user-centered design, ABB created intuitive data visualizations for two essential community systems: district heating and health-care. Promising results set the stage for further research into smart visualization and artificial intelligence.

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01 ABB works closely with public and private stakeholders to explore digital visualization solutions that could help cities like Västerås, Sweden to increase efficiency and sustainability.

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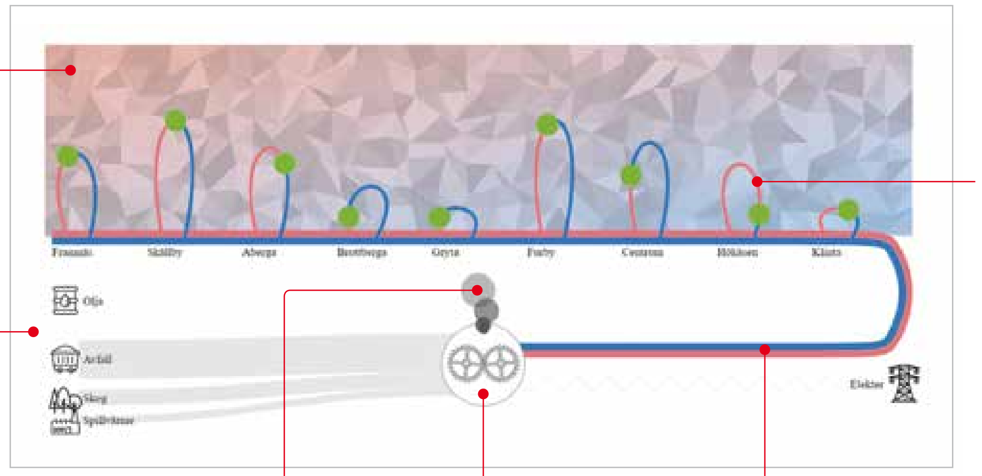

An animated background, depicts the weather conditions: the colder the area, the bluer is the background.

Raw materials that are employed for heat production.

The delivery end-points, ie, residential areas, are presented as curves. The shape of the curves represents the consumption process eg, the height of a curve shows the amount of delivered energy and the color ratio depicts the balance between the delivered and the consumed energy.

Black smoke extending outward portrays waste or pollution.

The number of gears depicts the number of boilers that are involved in the production process.

The delivery process is represented by red and blue pipes, which symbolize hot and cold water flows, respectively.

02

Advanced analytics and information visualization can foster awareness and a better understanding of a community's industrial processes, thereby creating guidelines and contributing to increased productivity and energy savings. For example, well-designed visualizations can help uncover bottlenecks in the patient flow of a hospital, potentially increasing efficacy of the healthcare system. Effective data visualization of a district heating system can help industrial operators run the energy production process more efficiently, leading to more satisfied community residents while lowering regional environmental impact.

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ABB's experts utilized the user-centered design paradigm to develop several innovative visualizations for community hospitals and district heating systems.

However, presenting essential data in a comprehensive visual form to the right users is a non-trivial task. Relying on collaborations with multiple stakeholders, ABB's technology and domain experts, researchers utilized the user-centered design paradigm¹ to develop several innovative visualizations for Swedish community hospitals and district heating systems that can do just that.

District heating and cooling (DHC) is an efficient, fuel-flexible, and sustainable way to produce and deliver energy in today's market →1. In Sweden, for example, this popular heating process serves more than 50 percent of all homes [1].

ABB, a pioneering technology leader in automation and control systems, contributes to the efficiency of district heating systems with state-of-the-art SCADA (Supervisory Control and Data Acquisition) systems, intelligent pump control (IPC) for drives, and communication and interface solutions.

The control of a district heating production and delivery system is a consequential task: To control the district heating system, operators rely on process graphics and a myriad of numerical parameters. Dependence on weather conditions introduces uncertainties and unpredictability and non-user-friendly legacy interfaces, overloaded with numerical data and process graphics, do not alleviate the challenge. As a result, industrial operators often run the production process with their "gut feeling" or previous experience.

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02 The display makes an attempt to visualize the cornerstone constituents of a district heating system: production, distribution and consumption.

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03 The main overviews are: patient flow overview, patient cases overview and patient transitions between departments overview.

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04
The patient flow overview display shows the hospital structure and number of patients being served. Users can filter according to diagnosis- and time-related attributes. Histograms provide visual representations of patient waiting time.

To research the design space of user-interfaces (UI) for industrial operators, ABB collaborated with several Swedish energy companies, Sweden's independent state-owned research institute, RiSe, and others, eg, PiiA (Process Industrial IT and Automation Agency). Experts from ABB Corporate Research and RiSe employed the user-centered design paradigm¹ to investigate ways to transform runtime data of DHC processes to insightful and aesthetically pleasing visualizations to foster understanding of the DHC system status.

Initially, extensive field studies (interviews with operators, production planers, service technicians, environmental engineers, private customers and related companies) led to gains in domain knowledge. Multiple analytical techniques applied to collected data allowed researchers to identify operators' challenges.

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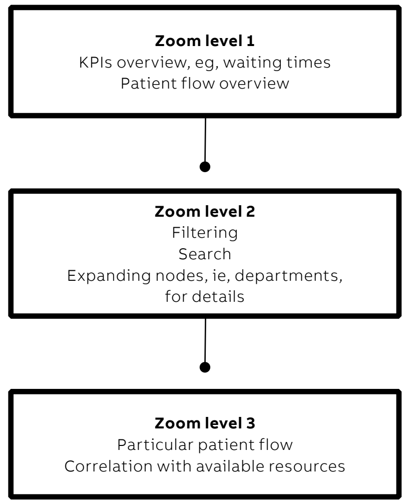
ABB conducted interactive workshops with operators and business stakeholders to generate ideas for potential solutions.

By conducting interactive workshops with operators and business stakeholders alike, ideas for potential solutions could be generated. Subsequently, iterative low- and high-fidelity prototyping occurred: designers could continually refine the development process through qualitative user-evaluation sessions in which feedback was incorporated in the development process.



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Many ideas and concepts were considered initially; those that intended to help industrial operators obtain an instant overview of the district heating system status were, however, strongly favored. The development of such visualizations requires the aggregation of large amounts of data to form a meaningful summary represented visually as aesthetically expressive and pleasant metaphors and symbols.

The resultant pipeline visualization is a lightweight web solution that runs in a modern browser. It displays the three main constituents of a district heating system: production, distribution and consumption →2.

—
Footnote

1) Please refer to "User-centered power network visualizations empower digital twins" on page 16.

04

05

— 05 User-friendly visualizations with advanced data exploration and analytics capabilities could help hospital staff uncover the reasons for the formation of patient queues.

Photo: vm, istockphoto.com

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AutoMed is a long-term research project to investigate how process automation, simulation and modeling can lead to smarter resource allocation and patient flow organization.

The visualization is intended to serve as the starting point of the operator's workflows, who should then be able to quickly grasp whether the district heating system is performing properly or malfunctioning. Moreover, the operator can drill down into any aspect of the visualization by clicking on the corresponding UI elements, which will switch to a more detailed process representation, eg, process graphics or the city map view.

Several industrial operators who evaluated the pipeline visualization were clearly interested in the potential of future visual solutions and fascinated by the animation and use of bright colors. Although some individuals were skeptical that such a scheme could be useful in the near future, most could envision the visualization as an overview screen in the industrial control room. These preliminary results are indeed promising.

Quality health-care gains through visualization
The projected demographic boom and limited medical resources stress healthcare systems. In Sweden, as elsewhere, medical personnel dedicate time and effort to administrative and maintenance work, eg, paperwork, scheduling, cleaning and sorting medical instruments, working with contagious bacteria or hazardous substances, etc. [2]. Such necessary routine work is repetitive, monotonous and potentially dangerous. Time is squandered that is better spent elsewhere.

What if hospitals could find more efficient means to perform this work? ABB is convinced that robots and algorithms can improve organization to minimize the need for people to perform hazardous and monotonous tasks. Seizing on their expertise in robotics, automation and control systems, ABB explored visualization solutions that could free staff to do what they do best – provide expert medical care and service to patients.

AutoMed: Collaboration is the key
Initiated in 2015, AutoMed is a long-term collaborative medical domain research project funded by the government agency, Vinnova. ABB joined forces with two Swedish hospitals and multiple industrial and academic partners to investigate how process automation, optimization, scheduling, simulation and modeling approaches can lead to smarter resource allocation and patient flow organization.

In the scope of the collaboration, ABB researchers, due to the lack of real-time data, worked closely with Swedish hospitals to obtain historical data of patient flows to identify potential bottlenecks and develop a simulation tool capable of their prediction. A key feature for this purpose is the creation of a UI for extensive data exploration and analytics.

Furthermore, by visualizing waiting times, ie, how long patients have to wait before receiving the necessary medical service, staff could identify bottlenecks in the patient flows that result in overall medical care system delays. Unfortunately, it was impossible to obtain a complete picture of patients' waiting times due to a lack of reliable data. Extra effort was, however, invested to approximate waiting times for each department by assessing mean times, standard deviation and identifying outliers, ie, patients who waited longer or shorter than normal.

ABB also explored visualizations that would help identify a unique process flow for specific diseases. Surprisingly, when a person receives a diagnosis, their treatment plans can vary from case to case, ie, the departments to be visited and procedures to be followed depend in some degree on the judgement and spontaneous decisions of the doctor(s) responsible for the patient's case. It would be helpful to have a relatively common flow for each disease: currently the flow differs from patient to patient. Researchers found some commonalities and approximated, somewhat, such a flow for certain diseases.

Innovative visualization design for healthcare
A web-based portal with several views was designed and created to enable interactive medical data exploration: patient flow overview, patient cases overview and patient transitions between departments overview →3.

—
ABB explored visualization solutions that could free hospital staff to do what they do best – provide expert medical care and service to patients.

The patient flow overview is a hierarchical data visualization showing the structure of the hospital and how many acute/scheduled patients visited each department over a selected time →4. The interface allows filtering capabilities according to diagnosis- and time-related attributes. Each department can be expanded or compressed through mouse interaction. The spectrum of waiting times is displayed as histograms around each department (waiting time increases in a clockwise direction). The higher the column, the greater is the number of people that have waited. By hovering with the mouse over a column, a pop-up will appear that explicitly shows this information. Histogram bars are color-coded based on whether the waiting time is shorter, slightly longer or greatly exceeds an estimated threshold. By clicking on a bar, the user is redirected to the overview of the patient cases represented by the histogram column.

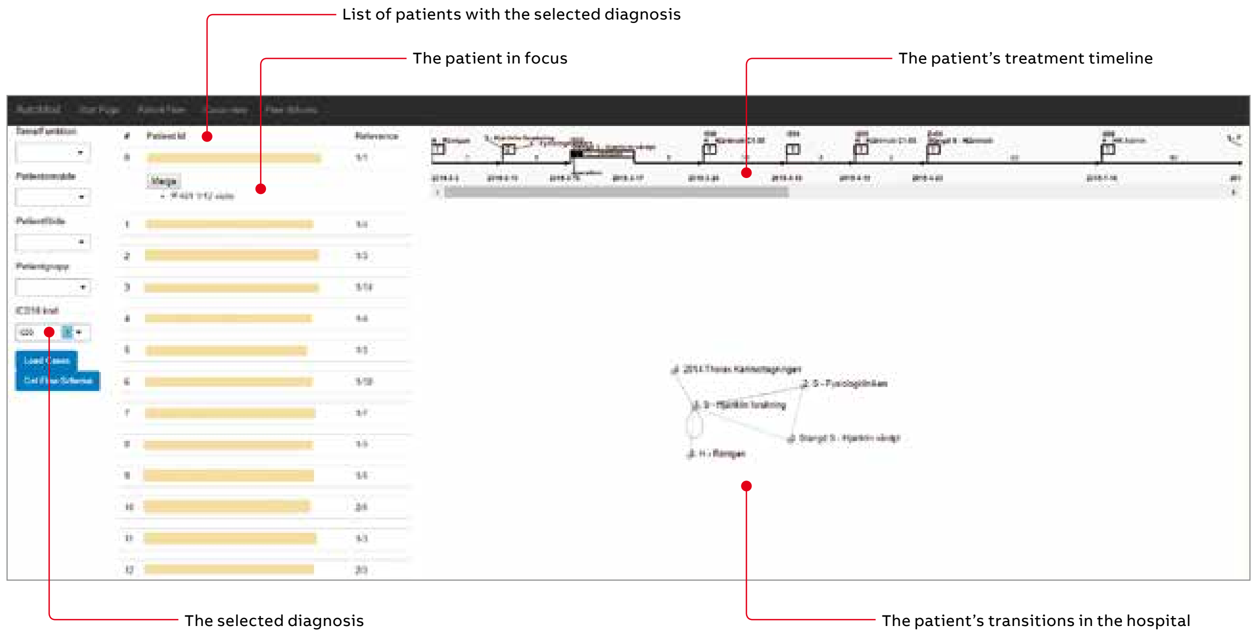
—
AutoMed is a web-based portal designed with several views to enable interactive medical data exploration.

The overview of patient cases depicts the disease history of patients. Filters and an identification number allow a particular, yet anonymous, patient to be located. The timeline visualization of a disease shows flow in time, including diagnoses, departments visited, services received and waiting times →5,6. To ascertain why waiting occurred, the waiting period is correlated with the availability of necessary resources, eg, number of free beds during that time.

The transition diagram emphasizes the patient's transitions between various departments during the treatment process. Insight is won by visually enlarging the departments and connections transited by many people. By hovering over the visual elements with the mouse, the user receives precise numerical information. The user can identify departments and transitions that are involved in a specific disease by applying filters →7.

Because the success of a visualization is measured by its usability, this web portal was demonstrated to medical personnel and tested by individuals hands-on. Preliminary feedback was positive: participants anticipated further system enhancements and were open to a continuation of the project.

Visualization challenges and future steps
Access to good quality data is essential for successful development of data-driven solutions, yet is challenging for many industries, including health care. Multiple data-related problems were faced in the scope of both projects; these included legal issues during data transfer, poor data quality, missing data, domain-specific jargon, etc. To amend these difficulties, extensive manual analysis and data processing was conducted in



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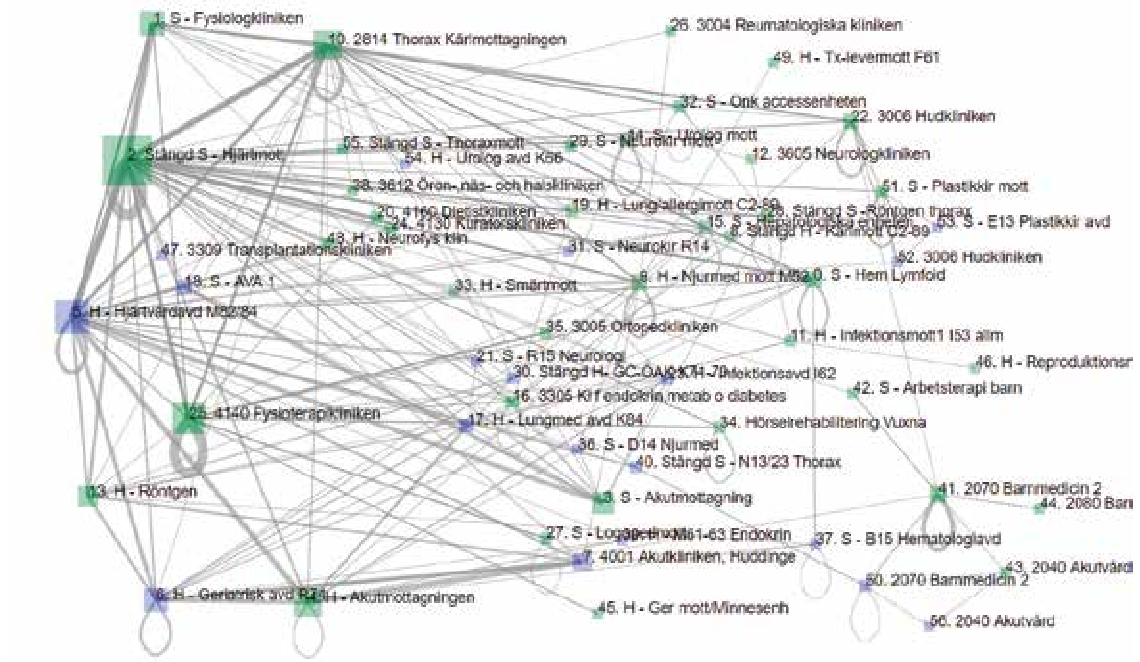

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06 The overview of patient's display visualizes the timeline of a disease flow in time.

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07 The patient transition overview visualizes how patients move between the departments: the size of the department symbol, as well as the thickness of the connecting lines, is based on the number of visits.

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tight collaboration with domain representatives before ABB experts could forge ahead with actual project goals.

Having a large number of diverse stakeholders onboard both projects opened up collaboration opportunities and permitted consideration of a large range of perspectives. Conversely, research processes were occasionally hampered because different stakeholders had widely variant agendas.

—
ABB will continue working on effective big data visualizations, thereby introducing machine learning and artificial intelligence.

During the course of field studies, ABB's experts witnessed entrenched legacy working practices that tended to curtail acceptance of new solutions and methods. Nonetheless, industrial operators and medical staff were interested in the advantages of new visualization solutions and anticipated the possibility of increasing production efficiency in the future.

Inspired by the success of both projects, ABB researchers will continue working on effective big data visualizations. The next logical step introduces machine learning and artificial intelligence to provide the user with hints for the next most appropriate action to take. •

MODULAR PROCESS PLANTS: PART 2

Plant orchestration and pilot application

Modularization of plants is seen as the way to solve challenges faced by the process industry. ABB, with others, has developed concepts and products for the automation of modular process plants. Complementing the article in the previous edition of ABB review, plant orchestration and pilot study experience are now discussed.

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For process plant owners, modularization is seen as a promising technology that will solve many of the challenges they face, such as improved flexibility and interoperability between plant assets. For that reason, ABB has been working with several groups (Bayer, the Technical University of Dresden, INVITE – a public-private partnership of TU Dortmund and Bayer Technology Services GmbH – and the Helmut Schmidt University of Hamburg) since 2014 on ways to effectively automate modular process plants.

Modularization is seen as a promising technology that will solve many of the challenges process owners face.

A modular automation system has two layers, connected by a network.

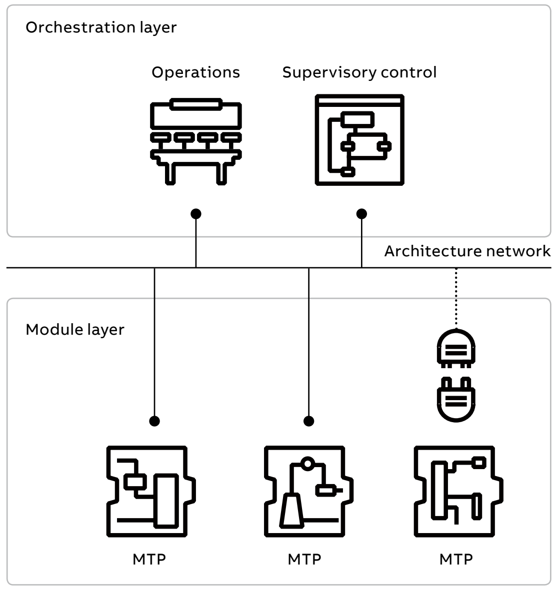
- The module layer: a small controller executing the logic of a single process module.
- The orchestration layer: here, process modules are integrated and combined to form one process plant.

Unlike a traditional plant that may be based on many thousands of tags, a modular plant is more like an object-oriented software environment, but with a function-oriented approach, based on modules. One achievement of the joint project is the definition of the process module interface, the so-called module type package (MTP), that allows seamless integration of process modules into an orchestration system [1] →1.

Within the MTP, the automation interfaces required for the communication between the module automation system and the overlying orchestration system are specified. The MTP is used to identify the functionality and communication interfaces of a modular automation system and is, therefore, the key to the low automation engineering effort promised by modular plant architectures.

The module layer is assembled from the needed module types, which can be chosen by the engineer. Every module provides a set of encapsulated process functions, called services, that can be orchestrated from a supervisory control system. These services describe process functions, such as mixing, tempering or heating. The modules work together to fulfill the requirements of the plant.

When building a new system, the module types are first engineered then integrated into the supervisory system. By re-using modules of the same type, the engineering effort for the plant can be dramatically reduced.



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The communication between the module layer and the orchestration layer is via OPC UA. The supervisory control system is an OPC UA client that connects to the modules' OPC UA servers and uses them to communicate the required commands to the module.

For the more modest requirements of the module layer, a smaller automation system, like a Freelance AC700F controller or the B&R X20 family, can be used, for instance. For the orchestration layer, ABB's Extended Automation System 800xA has been chosen.

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By re-using modules of the same type, the engineering effort for the plant can be dramatically reduced.

Orchestration layer
On top of the modules is the orchestration layer. The orchestration layer controls the modules and the services they contain – starting, stopping and visualizing them – and shows the module's HMI, according to the module specification as defined in the MTP. A typical orchestration layer does not use another controller but controls the modules using OPC UA via, for example, a normal PC. Since the modules are defined in a very convenient manner in the MTP, the engineering of an orchestration system is very simple and fast.

Orchestration layer engineering
Orchestration layer engineering has three parts: a module type library, the definition of the plant structure and the definition of the control philosophy.

An essential part of the concept is the extensible module type library. Every module type used is imported into the library and is accessible for the other parts. Import is done by simply selecting an MTP file. No further configuration is needed.

Once the required module types are added to the library, the engineer can use them to define the plant structure. Every module type exposes its boundaries within the MTP. The boundaries can be treated as being connection points of the module, either for the material connection (connecting a pipe) or an information flow connection (connecting a signal). This information can be used for engineering the plant topology. For each module, a symbol is dropped into the topology editor and thereby an instance of the module is created →2. The modules are interconnected using their inputs and outputs, as designed in the MTP. Every module has a unique tag name so it can be identified in the supervisory control system.

The last step is the definition of a control philosophy. For the engineering of the control philosophy, an approach based on a sequential function chart (SFC) is used. Within the SFC, it is possible to define steps, transitions, and parallel and alternative branches, as described in IEC 61131 Part 3. The major difference to standard SFCs is the definition of the control logic behind the steps and transitions. Instead of having IEC 61131 Part 3 code, a list of the modules, the module's services and the possible commands are used. The modules that are usable are automatically included in the tables based on the previously engineered plant structure.

With the quite simple engineering concept as described, a large portion of the runtime can be generated. The runtime consists of two major parts: visualization and orchestration of the modules.

From the engineering tool, the information required for the plant is imported into System 800xA. In System 800xA, all relevant information for the operators and plant engineers is automatically generated →2–4.

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01 Architecture of ABB's modular automation system.

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02 Plant modeling using process modules. For each module a display is generated.

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03 For every tag of every module, the faceplates and symbols immediately have access to the online values. Dynamization is done automatically.

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04 Module orchestration workplace within System 800xA. An overview display is automatically created, showing the topologies of the modular plant and the sequences for the orchestration.

With the described generation of the orchestration System 800xA, engineering of the modular plant and setting up the orchestration runtime is almost completely automated. The user gets a fully functional operation environment that is immediately able to orchestrate the modules, once an online connection has been established.

Pilot applications
To check the concepts work, a prototype has been applied to two situations: one in conjunction with NAMUR (the German user association for automation technology in process industries) and one – a real-life pilot case – together with the pharmaceutical company, Bayer AG.

NAMUR application
The NAMUR application consists of three different module types, each having a set of between two and four functions that can be used:
- Feeder (BPxx), used four times in the plant. Functions: inertization, dose, discharge and fill.
- Mixing reactor (RPxx), used once in the plant. Functions: inertization, run and tempering.
- Distillation (KWxx), used once in the plant. Functions: inertization and run.

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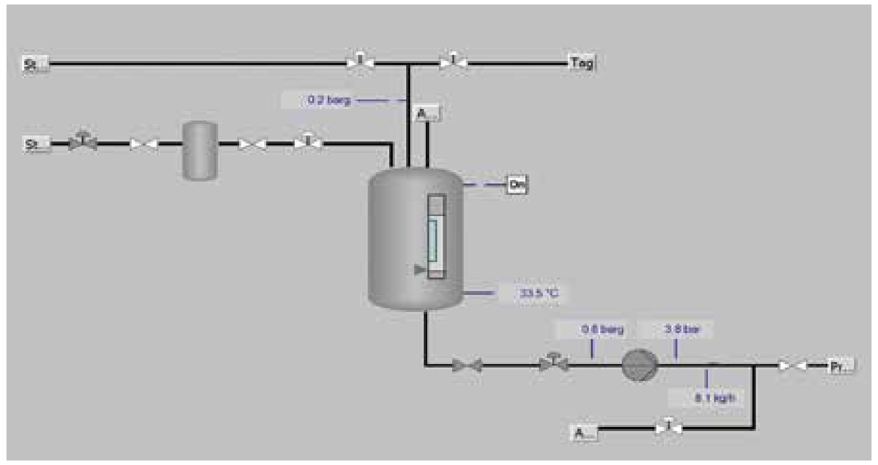
Engineering of the modular plant and setting up the orchestration runtime is almost completely automated.



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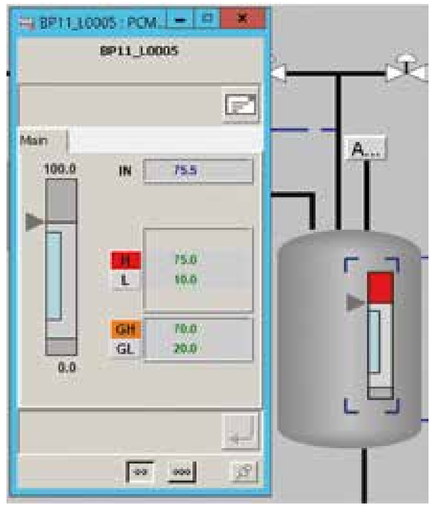

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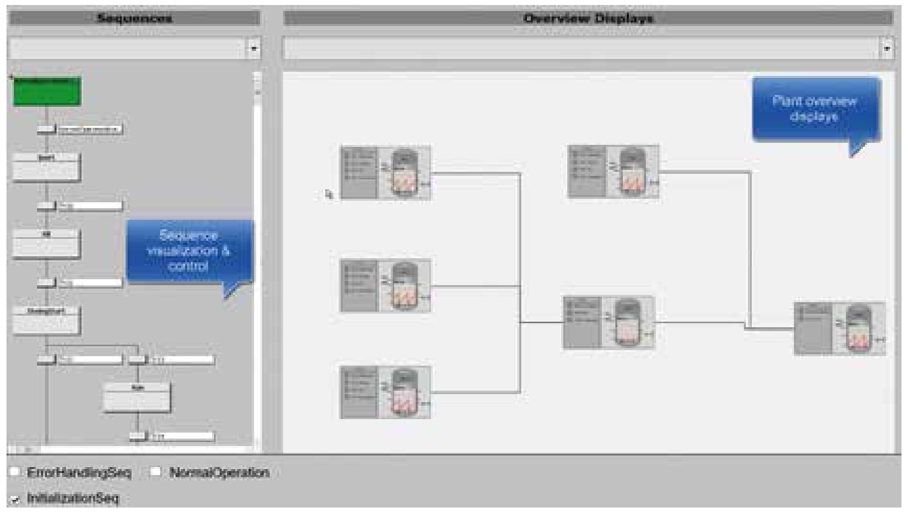

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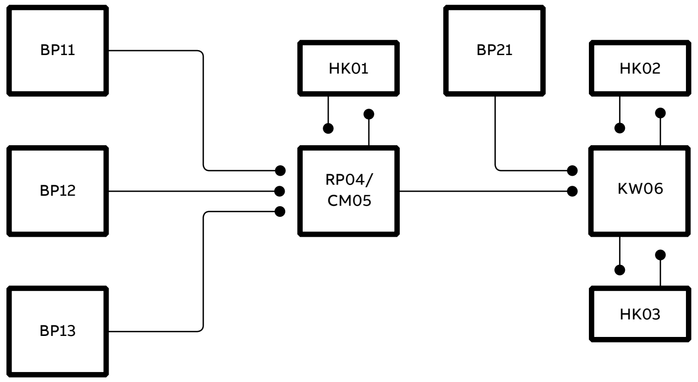

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The modules are connected as shown in →5. Three of the feeder modules represent a dosing system for the mixing reactor. The mixing reactor feeds its product into a distillation stage that is also connected to a feeder module.

Also, there are heaters connected (HKxx in →5). These were neglected in the pilot application. Furthermore, the reactor can be exchanged for a continuous reactor (CM05 in →5). This module is very similar to the RP reactor and has not been used within this pilot application.

The process has to be inerted, so that there are no unwanted contaminant reactions, before the other functions can be executed. Thus, these other functions of the module types have to be interlocked with the inert function.

For each module type, an HMI must be provided. The HMIs were derived from the piping and instrumentation diagrams delivered by NAMUR for the case study.

A description of the modules and the modular plant was also delivered. Based on this information, the modules of the case study have been implemented using ABB components and the prototype. For each module type, an MTP has been created.

These MTPs have been used to engineer the plant topology and a sequence has been developed that is used for startup of the plant. The sequence stops once the plant has reached steady state.

Bayer pilot application

The pilot application provided by Bayer is a filtration plant system that produces active pharmaceutical ingredients. For the pilot use case, two of the modules have been equipped with ABB Freelance controllers and one will be equipped with a B&R X20 Controller. The engineering was done using the prototype and Freelance engineering software.

The services for every module type have been derived based on the piping and instrumentation diagrams, functional descriptions, sequences, code examples and tag lists provided.
The conventional engineering documents were taken as input and converted into a service-based description.

Afterwards, the MTPs were created and added to the MTP library in the orchestration engineering tool. In this tool, the topology of the modular plant and the sequences to run the plant have been designed. One of the resulting modules can be seen in →6 [2].

—

The pilot applications show that the modular automation concepts for modular plants, including operation and supervisory control, work.

Both pilot applications show that the concepts are working and deliver the targets of reduced engineering effort, reduced commissioning time and fast time-to-market.

Modular automation makes for speedy engineering

The pilot applications show that the modular automation concepts for modular plants, including operation and supervisory control, work. The engineering effort required to set up the system using this new approach was seen to be substantially less than traditional methods. Additionally, once a module has been commissioned, it is then available for re-use, which speeds future engineering and commissioning of a modular plant. Overall, effort for plant engineering and commissioning is greatly reduced.

—

The final result is a software product that can be used for the automation of modular plants.

The project delivered valuable input to MTP standardization efforts. Results gained within the project have also been fed into the community from different perspectives (university, corporate research, product development and plant owner). Thereby, the standard, which will be further maintained by the project partners, could be driven forward significantly.

The final result is a software product that can be used for the automation of modular plants. This will be further developed by ABB and partners to meet the latest requirements, integrate missing features and be compliant to the newest parts of the standard. •

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05 Case example provided by NAMUR.

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06 Bayer filtration module equipped with ABB's modular automation system. Photo courtesy of Bayer AG.

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AUTONOMOUS SYSTEMS

Unravelling events and alarms with data analytics tools

ABB's new comprehensive, experience-tailored data analysis and diagnostic tools provide process industries with transparent ways to identify, compare and handle disturbances, alarm floods and time series data. Deployed onsite or in the cloud, this remarkable new system helps engineers make better decisions.

01

01 DIAS helps operators to diagnose disturbances and alarm floods in modern process industry control rooms.

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Nowadays, process automation systems continuously produce immense quantities of data. Considering an upstream oil and gas system for instance: ABB service engineers receive around 1.5 GB of compressed data monthly with more than 3900 tags and 250,000 alarms and events. For industrial use, this flood of information must be available and its veracity incontrovertible.

DIAS combines modern data analytics approaches with the rich experience of ABB's service engineers for a comprehensive analytical process solution.

Data analytics is the ultimate key to unlocking the wealth of information generated so that desirable and undesirable process states can be discerned, recommendations for improvements can be issued and operators can follow through with necessary actions. Nevertheless, the process of unearthing truly useful information from raw data requires deep domain knowledge, and the process is highly tedious.

Because safety, efficiency and profitability go hand in hand, ABB developed a new analytics solution for today's process industry automation needs: Data Analytics Tools for Industrial Automation (DIAS). Created in 2017 to boost analysis and diagnostic capabilities, DIAS combines modern data analytics approaches with the rich experience of ABB's service engineers to deliver customers a comprehensive yet experience-tailored analytical process solution →1. Customers obtain a holistic view of historical data, complete with interactive plots that allow engineers to zero in on important details and perform intelligent and efficient data analysis. In this way, context and insight into processes are won. The result is better decision-making and a safer and more profitable operation.

Alarm and event explorer

Alarms indicate disturbances in process plants. Once triggered, alarms can spread rapidly and these alarm floods can overload operators who might not be able to handle these events safely. Such alarm floods in the chemical sector cause most industrial incidents investigated by the US Chemical Safety Board [1]. Not only is the safe operation of a plant imperative for the human workforce, costs associated with these events can impair profitability.

For this reason, ABB explored ways to improve the data analysis process in an offshore gas and oil separation plant →2. These plants are designed to separate crude oil, gas and condensates at a location near the well before these materials are exported. ABB was entrusted with the operational data of a plant to evaluate the DIAS system; this data was recorded over a period of 382 days.

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ABB's system allows service engineers to find and investigate a suspicious event. AE Explorer rearranges the view to inspect the event rapidly and easily.

Relying on their experience, ABB service engineers began by investigating process alarms and trip events. The DIAS Alarm and Event Data Explorer (AE Explorer) was shown to help the engineers to quickly identify interesting events. The results can be presented in comprehensive, yet human-readable views →3. By diving into details, dragging, and many other actions, engineers can easily explore the data to gain clarity about the event or situation in question.

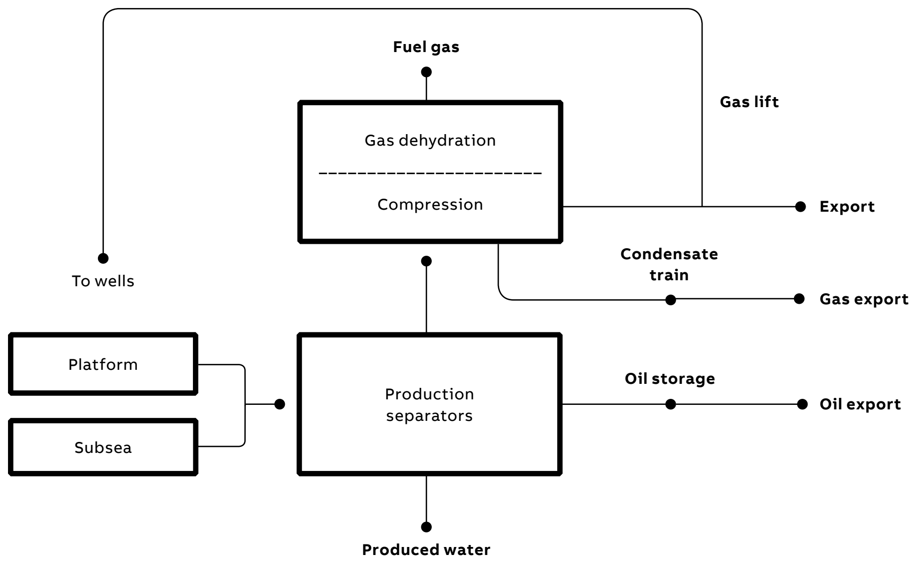
If service engineers find a suspicious event occurrence, they can click on this event occurrence and activate the "investigate" function. AE Explorer will then rearrange the view to allow the operators to inspect the event of interest rapidly and easily. And, based on the sorting result, a clear picture of the causal chain of events is presented to the user →4. Thus, DIAS allows engineers to be more responsive to their day-to-day situations, eg, disturbances.

Abnormal situation analysis

The use of distributed control systems and the interconnectivity of process plants has meant that alarm flooding is a real challenge for the alarm management of modern process plants [2]. The ability to quickly and accurately diagnose recurrent alarm floods can add substantial value to the operation of a plant. Therefore, DIAS offers an innovative machine learning-based tool to cluster and classify problematic alarm floods; thereby selectively identifying the recurrent alarm floods among the vast quantity of operational data.

ABB rigorously tested this useful function on an offshore gas-oil separation plant →2. In this case DIAS identified 1,473 unique alarm tags. Given an alarm flood threshold of eight alarms per 10 minutes, DIAS identified 926 alarm floods and grouped them, automatically, into five classes based on their similarity. In one abnormal situation, DIAS grouped 16 alarm floods into the same class. DIAS also accurately identified the location of the abnormal situation, ie, Produced Water Reinjection (PWRI) system →5.

Alarm flood sequences, in this aforementioned class, start with a low-flow alarm in the pump P11 (A FICA 130 L, the outlet flow) and are, shortly



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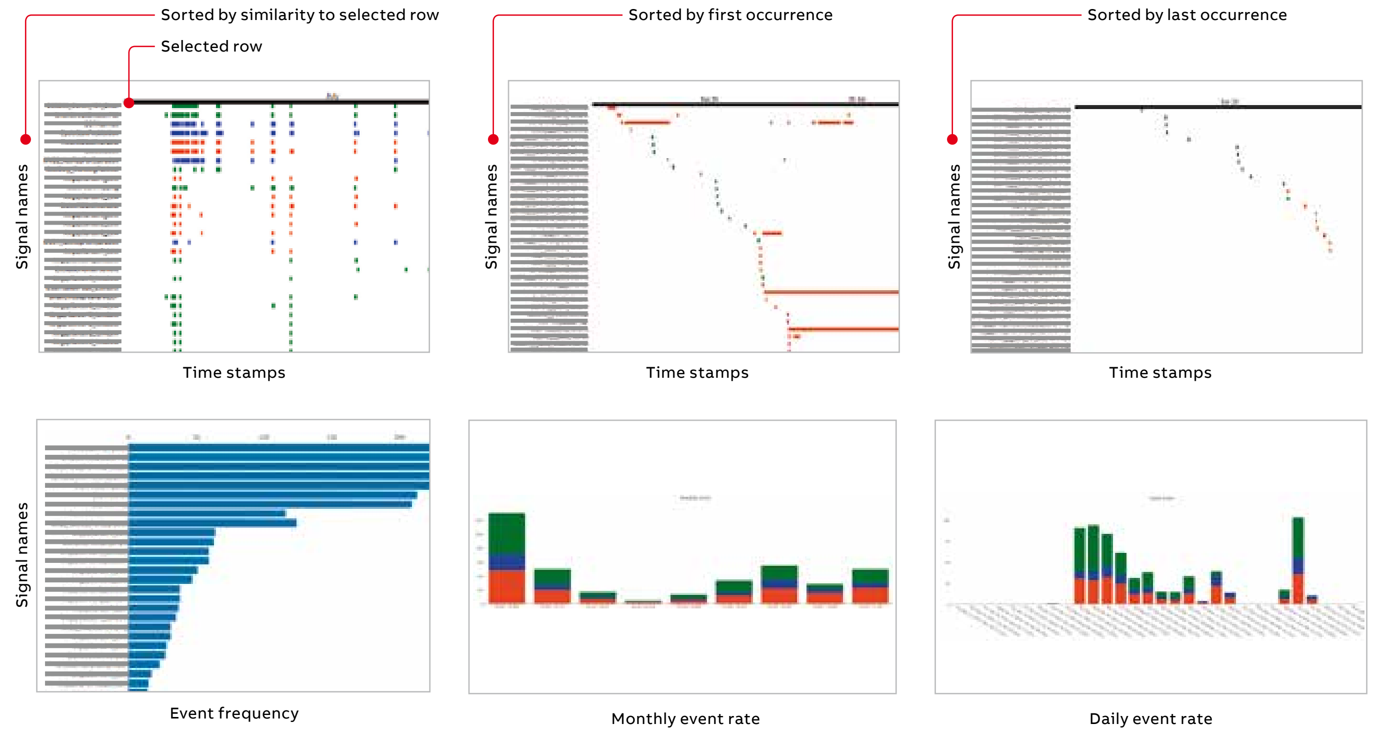


03b

—
02 Process overview of the separation plant.

—
03 DIAS Alarm and Event Data Explorer (AE Explorer) is shown.

03a A cheat sheet can be accessed.

03b The AE Explorer makes event identification and sorting easy.

thereafter, followed by a low-flow alarm in pump P21 (A FICA 116 L, the outlet flow); this leads to trips of both pumps. The level of the degassing drum increases quickly until high-level alarms for the water level (C LICA 128A H) and the oil level (C LT 118 H) are successively triggered.

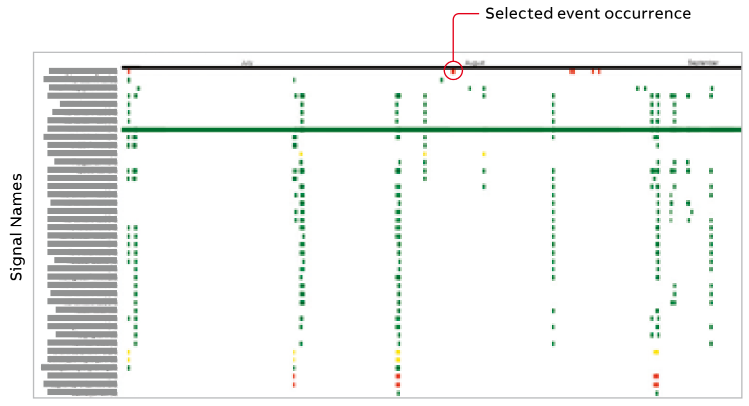
—

DIAS offers an innovative machine learning-based tool to cluster and classify problematic alarm floods.

This new approach of alarm co-activation was shown to be appropriate for the analysis of ongoing sequences and was superior to the established sequence alignment approach for the analysis of abnormal episodes in this oil and gas separation plant [2,3].

Because it is crucial for humans to understand and interpret the results of machine learning algorithms, DIAS adds invaluable capabilities: it provides engineers with transparency and allows them to improve the clustering results based on their process knowledge. This is accomplished with an intuitive Graphical User Interface (GUI). For instance, two of the 16 alarm floods that have been grouped together by the algorithm are presented within the same vertical box →6a. Consequently, engineers can inspect and validate the resultant classes by applying specific comparison tools or the AE Explorer.

To further support service engineers determine the all-important root causes of similar alarm floods, AE Explorer can tag similar alarm floods with vertical rulers, and then AE Explorer can search for events that occurred frequently, shortly before and, or, after these tagged alarm floods →6b.



04

The higher the frequency of an event, the greater is the possibility that this event has a cause common to that of the tagged alarm floods →6c. This ability to classify events and root out alarm flood causes contributes to safety, productivity and hence profitability.

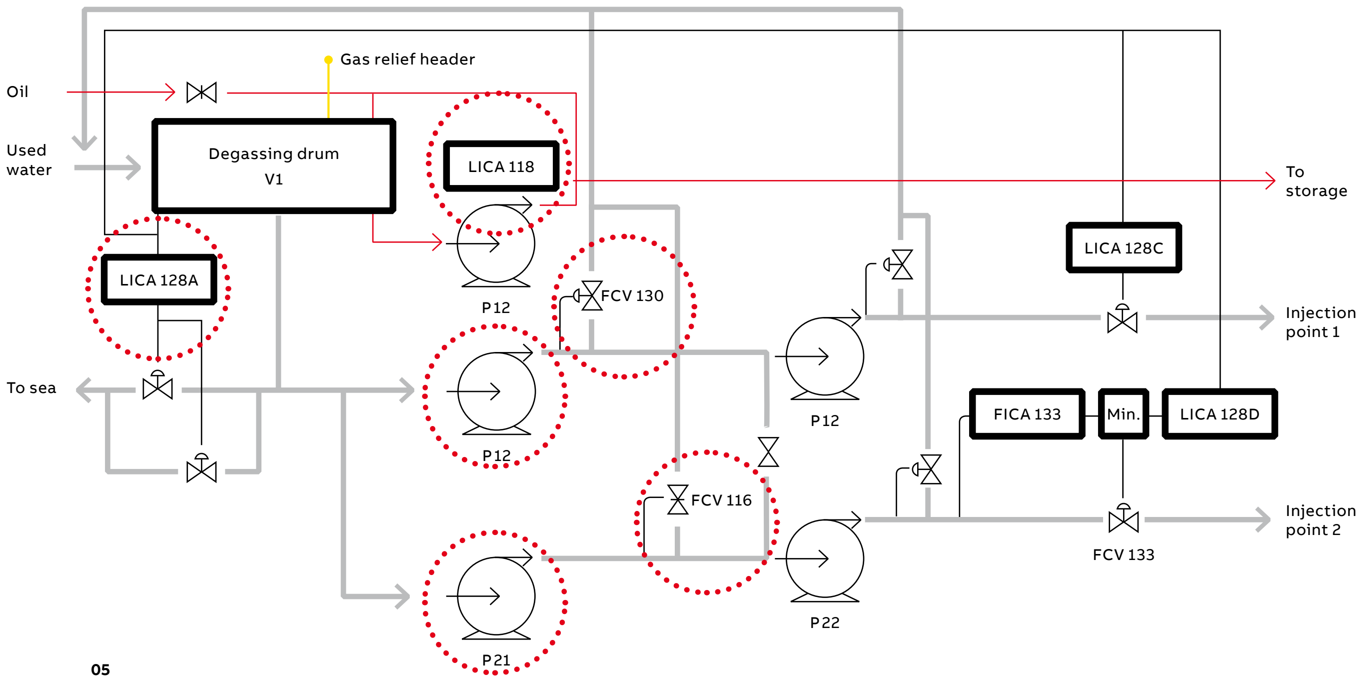
Exploring time series data
The minerals and cement industries rely on gearless mill drives to function free from impediments. To improve the analytics capability of these systems, ABB service engineers analyze operational data generated from these drives, but are particularly focused on time series signal values produced shortly before and after an event. To do this, they can initially use AE Explorer to identify the event of interest. Subsequently DIAS can redirect them to the transient view, where they can compare and analyze the time series data recorded shortly before and after the selected event →7a.

The transient recorder viewer allows service engineers to gain deep insights into the history of an event. For instance, they can identify a sensor failure by comparing the difference between current values measured for motor input and motor output →7b.

—

DIAS provides heat map views that highlight important features in time series data.

In addition to providing an overview of specific interesting situations across signals, DIAS provides heat map views that highlight important features in time series data, eg, a heat map that shows abrupt changes in signals →8a. Each observed heat map episode represents the abrupt change level of a signal at a specific moment. The darker the color, the greater is the change level. When engineers click on one episode, they are redirected to a high-resolution trend viewer for more detailed inspections. Another helpful tool is the DIAS high density trend viewer, which can provide engineers with an overview of the queried time series data →8b. To help engineers understand time variation



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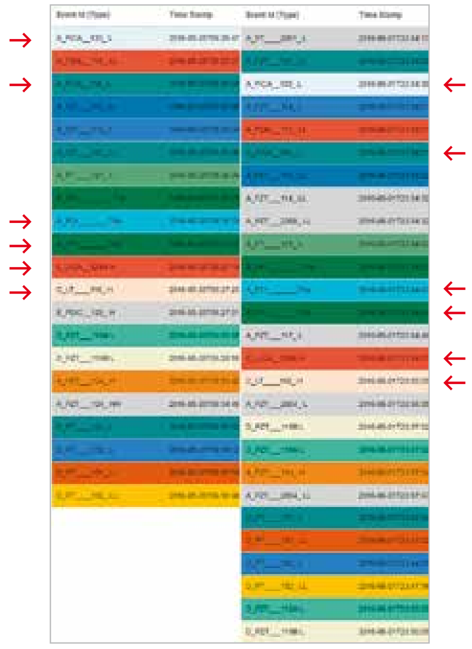

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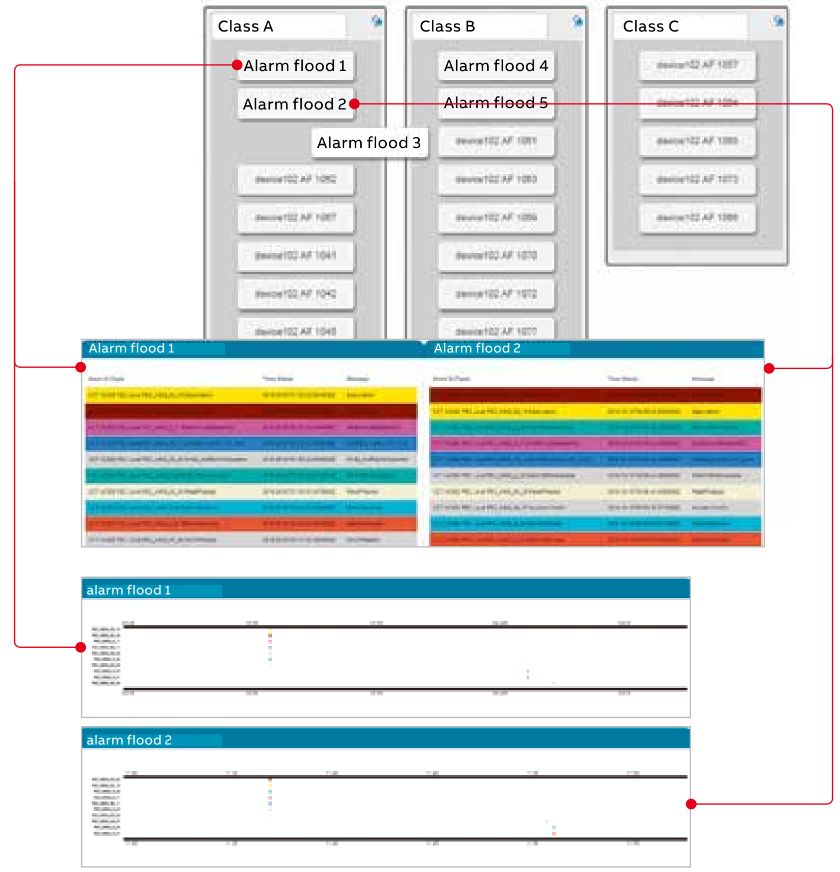

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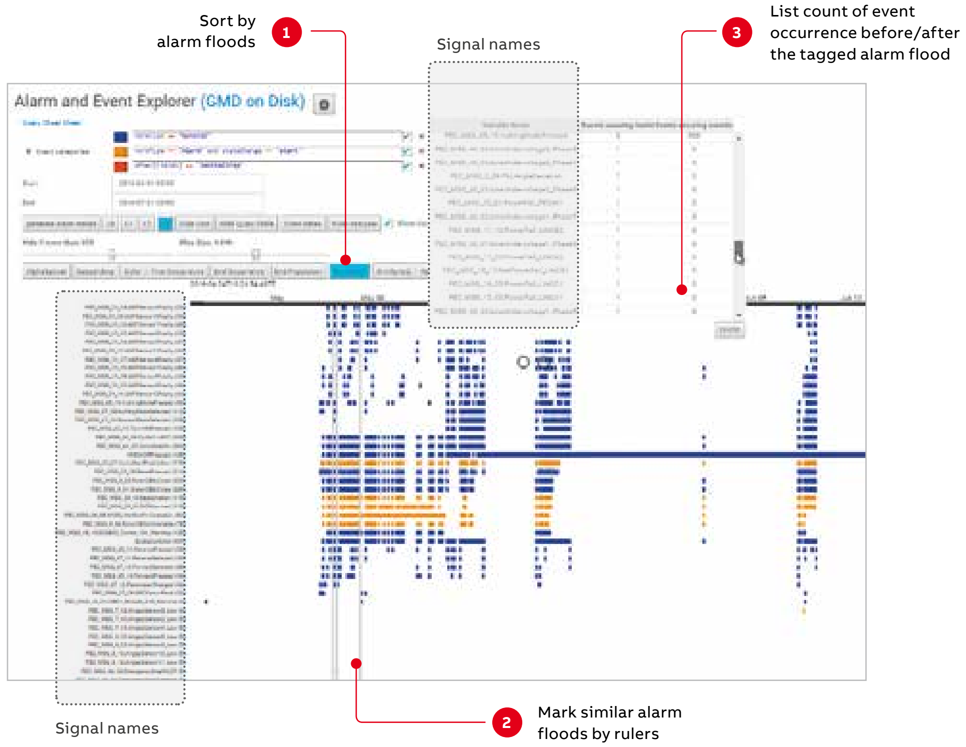


06c

—
04 Event causal chain is shown.

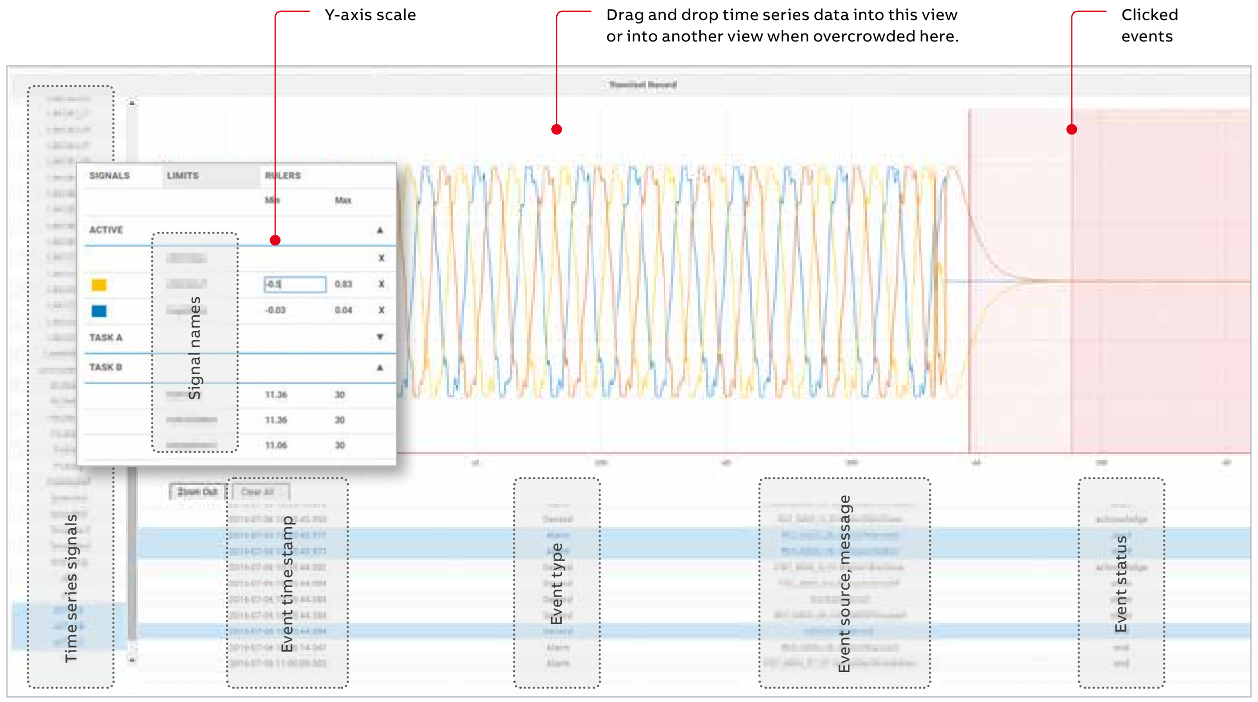
—
05 Process diagram of the PWRI section. Grey indicates the water system, black the oil system, and yellow the gas system. Diagnosed root cause: change of type of fuel in the pumps.

—
06 DIAS allows engineers to recognize alarm floods and event.

06a Two alarm floods grouped into the same class by DIAS.

06b Engineers can check and tune clustering or classification results

06c Identification of a common cause for several failure instances is possible.



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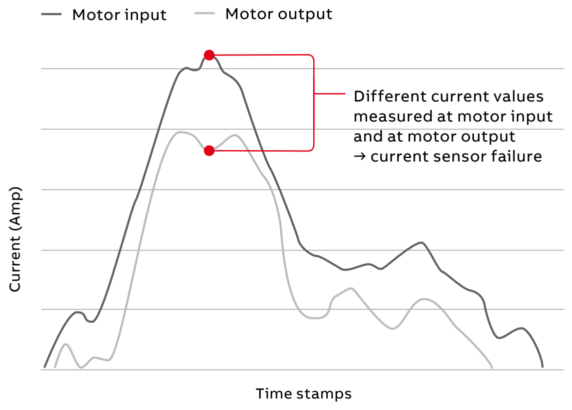

07b

patterns better, the trend viewer ranks signals based on trend shape similarity; the most similar shapes are ranked highest and listed at the top. All of these advanced tools provide the necessary capabilities that make DIAS an invaluable analytical system for process industries that rely on gearless mill drives.

DIAS evolution and future applications

Seizing on decades of experience providing exemplary service to process industries, ABB's service engineers have accumulated deep domain knowledge about operational data and developed best practices for ways to analyze data. DIAS has been iteratively developed with expert input from engineers to support their daily work in the best possible way. For ABB, this means providing the most reliable analysis results possible. Utilizing state-of-the-art technologies, DIAS has been developed as a web application. Each DIAS tool is modularized and can be deployed either on-site or in the cloud.

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Utilizing state-of-the-art technologies, ABB has developed DIAS as a web application. Each tool is modularized and can be deployed either on-site or in the cloud.

Due to the wide diversity of alarm management systems used currently by process industries, there are various popular alarm and event data storage paradigms. To shift the complexity of data connection away from the service engineer's work, DIAS offers configurable data connections. Additionally, different data connections can be switched seamlessly via the user interface, such as ABB Real Time Database (RTDB) file system, Microsoft SQL Server, Oracle database and Elastic search. Regardless of which data storage is connected, the service engineer can search for interesting alarms and events with a universal query interface →3b. Such queries embed a wealth of process knowledge. To share that knowledge and save query efforts, DIAS stores query templates and makes them accessible to different users. Thus, a comprehensive user-friendly and flexible system is available to serve customers.

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07 Transient recorder viewer is shown.

07a Switching to the transient view, operators can zero in on specific events.

07b Current sensor failure revealed by transient view.

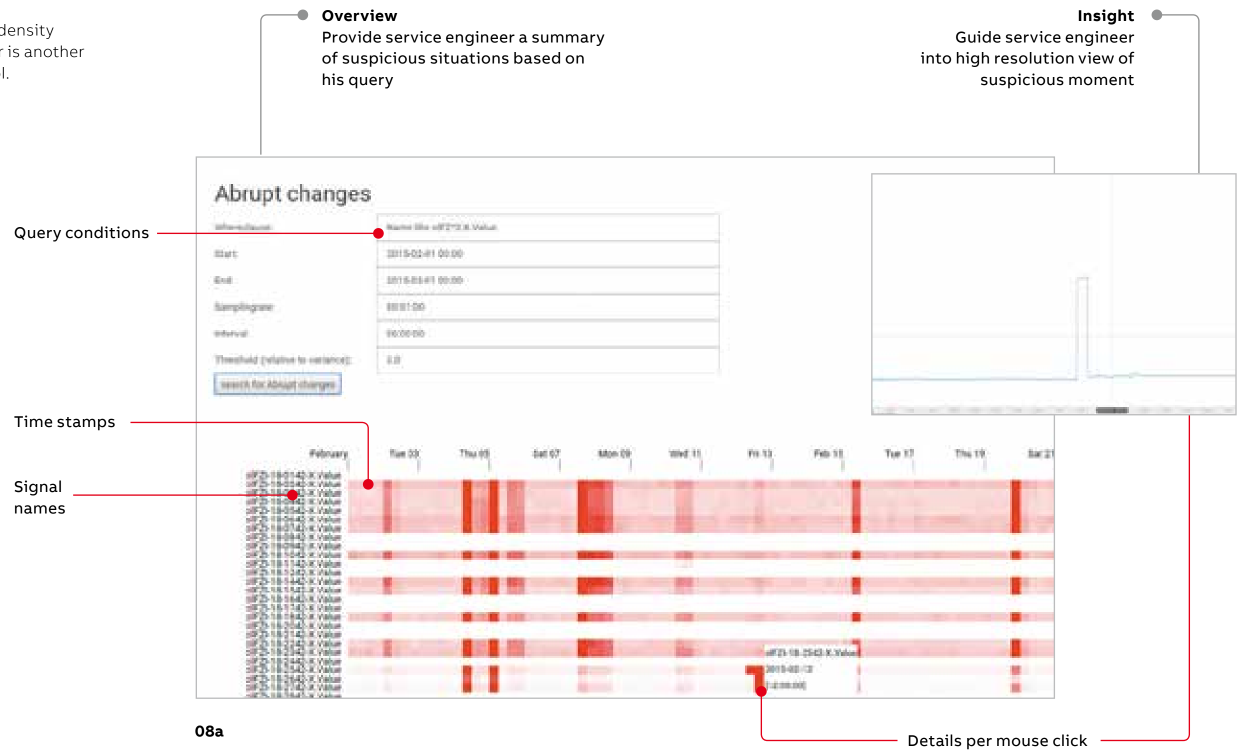
—

08 AB Explorer has extra tools to further help operators.

08a Operators can locate a heat map showing abrupt changes.

08b A high-density trend viewer is another valuable tool.

Currently, ABB service engineers from various business units use DIAS to address real-world customer cases. In addition to upstream oil and gas plants, and industries that rely on gearless mill drives, power generation plants have employed DIAS successfully. In the future, ABB will release individual tools within ABB products such as: ABB Ability™ Manufacturing Operations Management and ABB Ability™ Performance Optimization for Control Loops to enable better control and insight. •



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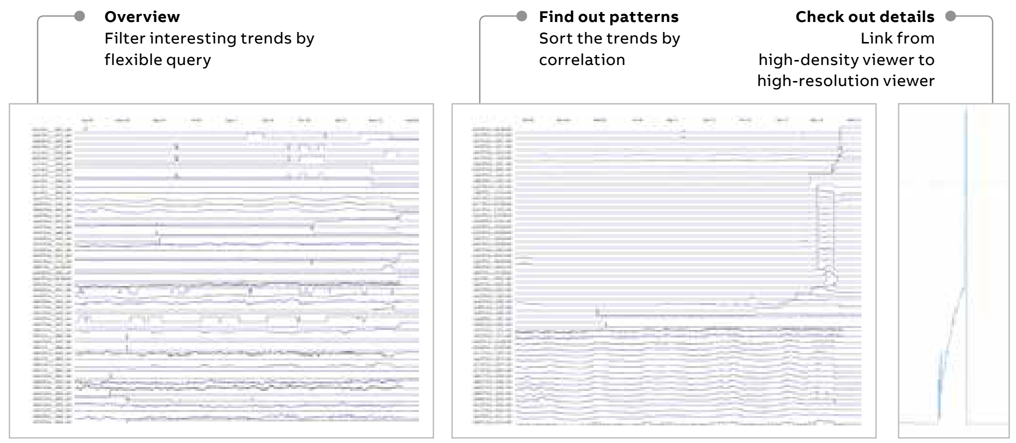

08b

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AUTONOMOUS SYSTEMS

New panel harvests a world of drive data

ABB’S new Drive Connectivity Panel taps the power of the latest Internet of Things (IoT) mobile technology to interact with drives in a spectrum of industrial environments. Thanks to the panel’s connectivity to ABB Ability cloud services, customers can remotely monitor the status of their ABB drives, operational KPIs and much more. This direct approach to the cloud is unique.

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ABB, the leader in the standard and premium drive market, has developed the Drive Connectivity Panel →1, a unique plug&play device that was awarded the “Innovation Product 2018” prize in China by Modern Manufacturing Magazine. The new panel offers an array of features designed to make an extremely broad range of information from inside the drive easily readable and visualizable. Customers can tap into data such as motor behavior settings, control macros, diagnostics, energy efficiency and energy savings, to name just a few key areas.

—

Data provided by this new platform can reveal the true potential of drives and help create new business models and customized services.

Thanks to the latest Internet of Things (IoT) mobile technology available anywhere – including both narrowband (NB) IoT and Bluetooth – the panel can interact with drives in a spectrum of industrial environments. And thanks to the panel’s connectivity to ABB Ability cloud services →2, data encryption and resulting high level of cybersecurity, customers can remotely monitor the status of their ABB drives, operational KPIs, events, and real time and historical parameter trends through continuous data uploads. Remote assistance provides easy access to ABB expertise on-site to track down problems.

01

All of this adds up to substantial customer value in areas such as device and asset management, remote condition monitoring, predictive maintenance, powertrain insights, product use analysis and process optimization and customization. Indeed, data provided by this new platform can reveal the true potential of drives and help create new business models and customized services.

02

—
01 ABB’s new drive connectivity panel allows customers to remotely monitor the status of their ABB drives and much more.

—
02 The Connectivity Panel transmits a drive’s data to the Ability Condition Monitoring for Drives cloud service. This in turn delivers accurate, real-time information about drive events, thus enhancing powertrain availability, reliability and maintenance.

—
03 Chinese manufacturing – a major business area for ABB – has been characterized by steady growth in the IIoT.

Close to the cloud
In many small to medium-sized companies, many of which are in remote locations in big countries such as China →3, application of drives can present a challenge because of the absence of an on-site Internet connection. Under such circumstances the customer typically needs to install and commission a gateway or edge device – a task that is not only time consuming but requires a connection to a fieldbus port, which may already be in use for programmable logic controller (PLC) signaling.

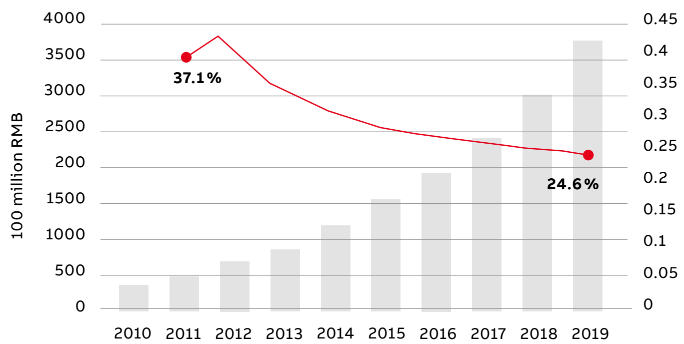
Even if this is possible, though, only a subset of drive data is communicated to the cloud gateway, meaning that data that is not accessed by a PLC will not be available. Furthermore, data communicated between a PLC and a drive is sometimes insuffiecient to support high level analytics such as deep learning, remote condition analysis and failure prediction.

Here, the Drive Connectivity Panel offers an answer: Installation and commissioning of the panel is a plug-and-play procedure that does not require the powertrain to be stopped. Data is collected through the drive’s panel bus via ABB’s internal protocol. As a result, operational data pertaining to the drive, together with logs and even black box data, can be sent to the cloud directly via cellular network using NB-IoT. A NB-IoT modem, SIM card and high-performance antenna are implemented together in the panel hardware as a complete offer. Even data traffic is covered. In addition, the Panel’s Bluetooth interface enables on-demand remote assistance services through its Drivetune Mobile App.

—

Installation and commissioning of the panel is a plug-and-play procedure that does not require the powertrain to be stopped.

The Drive Connectivity Panel’s direct connection to the cloud is suitable for a vast number of customers who require a low-cost cloud solution →3. Such companies can ill afford the cost of stopping machinery during production in order to determine how efficiently a drive and the entire drivetrain are operating, whether there are any indications of an impending failure, and what they can do to minimize the possibility of a failure during production. To date, ABB’s direct approach to the cloud continues to be unique, thus profoundly differentiating ABB Drives from all other competitors. •



03 Source: China’s Ministry of Industry and Information Technology

AUTONOMOUS SYSTEMS

Machine learning solves grinding mill liner monitoring

To prevent ore from wearing out grinding mill drums, replaceable liners are inserted. ABB and Bern University of Applied Science have developed a liner wear monitoring system based on accelerometers and machine learning that identifies the best time to change the liner and thus reduce downtime costs.

—
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In large mines, ore is milled onsite to extract valuable minerals. The grinding mills that perform this extraction consist of a large drum in which the ore itself, and sometimes added steel balls too, carry out the physical grinding process. As the drum rotates, the ore/balls are lifted up the side of the drum's interior by vanes to the cascading angle, where they fall off and crash to the bottom, reducing the ore.

As drum diameters can be as large as 10 m, the drum is an expensive piece of kit. To prevent damage to the drum, metal or rubber liners are inserted. The costs of liner replacement are high due to mill downtime and replacement parts so it is economical to change the liner as late as possible, but also at a time that minimizes productivity loss. To achieve this goal, it is important that the actual liner wear is known. The wear can be measured from inside the mill but this requires a costly production stop. A method to detect wear during operation is therefore desirable →1.

Vibration monitoring
As the ore hits the liner, vibrations arise. These vibrations and their transfer function have been shown to change with liner thickness and this effect underlies a promising method to measure wear. Accordingly, ABB and The Institute for Intelligent Industrial Systems (I3S) at Bern University of Applied Science, conducted harmonic response and transient simulations to investigate this behavior. The results showed clearly that the amplitude of the acceleration signal from a worn liner is higher than that from a new liner.

—
It is economical to change the liner as late as possible, but also at a time that minimizes productivity loss.

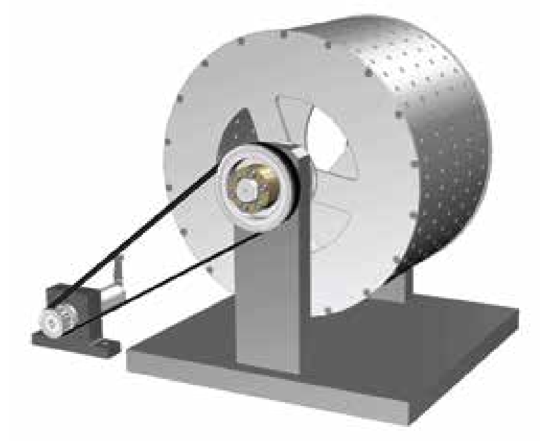
To verify these findings and because access to a real ore mill is difficult, a scale model of a mill was built →2. With this prototype, many experimental measurements with different liner thicknesses were performed by ABB and I3S. All measurement data was analyzed with deep neural networks and classified with a high accuracy in the correct wear classes.

To transfer this process from the lab to a real mill environment, measurements were made at a real ore mill. With this data, I3S and ABB developed a prototype that allowed the liner condition and

Photo: Boliden

—
01 Monitoring the liner wear in high-throughput grinding equipment is critical if process uptime is to be maximized. The image shows the mill at the Boliden mine at Garpenberg, Sweden – where mining has been carried out since at least 375 BC. This mill contributes to the mine's production figure of 2.5 million tonnes of ore per year.

01



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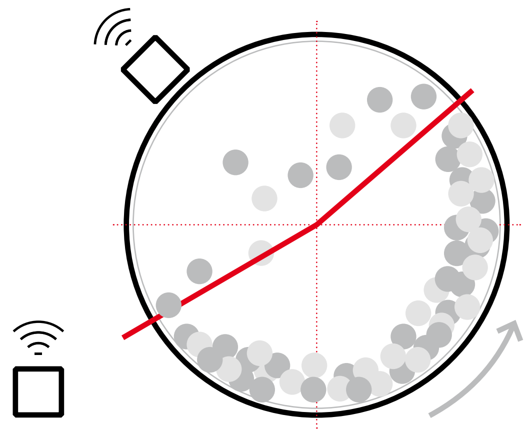


02b

process parameters of a mill to be measured during operation.

Simulations

Harmonic response and transient finite element method (FEM) simulation in ANSYS [1] of new and worn-out liner models reinforced the idea that there is a measurable difference in the liner acceleration signal caused by ore impact at the drum wall between a new and a worn-out liner. For example, the frequencies from a worn liner are higher than those from a new liner. In effect, as the rubber wears, the damping properties decline. The main measurable differences in the simulations are in the amplitudes →3. This correlates to the theory that a thin rubber layer gives rise to a stronger impact, resulting in higher excitation forces.

Liner wear

The measurement of the liner thickness was made indirectly by acceleration sensors at the outer surface of the scale model drum.

The raw signal from these sensors was processed to extract features that can be used by a deep neural network to recognize patterns. The ”patternnet” (ie, pattern recognition network) used includes one input layer, three hidden layers each with 500 neurons and an output layer to classify the liner thickness.

—

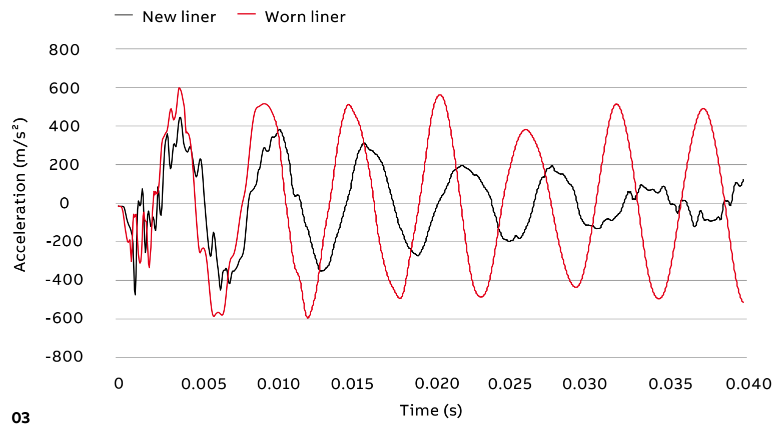
The results showed a very high accuracy (close to 98 percent) for the scale model measurements – ie, only 2 percent of the measurement datasets were classified falsely.

This configuration was used to classify the data from the scale model as well as from the field tests. In the laboratory, seven different liner conditions on the scale model were simulated. Liner thicknesses from 2 up to 17 mm and different loads reflect these conditions. The goal was to classify the preprocessed raw signal in one of the corresponding seven classes. The results showed a very high accuracy (close to 98 percent) for the scale model measurements. This means that only 2 percent of all the measurement datasets were classified falsely. This reflects the results from the training (70 percent) and the test (30 percent) dataset. →4 shows the confusion matrix of classification. Furthermore, data that is not correctly classified appears near to the matrix diagonal, which means the classification error is small.

The results from the field test measurements also showed a good accuracy. It was to be expected that the accuracy would be significantly lower here because of environmental effects but with an adapted deep neural network based on Tensorflow [2] a relatively high accuracy of 82.9 percent was achieved. The goal is to improve accuracy further with more data.

Toe and shoulder angles

To determine the cascading angle in the ore mill, the acceleration signal data from one turn of the real mill was used. In →5, the acceleration signal from one rotation is visible. In the impact zone, where stones hit the liner, high amplitudes are visible. Also, in the region of the shoulder angle, where the stones leave the liner, signal changes are visible. These arise because, in the area of the shoulder angle, the ore pieces lie loosely on top of each other. The gravity vector is shifting in relation to the position of the ore and the ore starts to leave the ore bed by sliding towards the center of the ore bed, creating vibrations at the mill shell.



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02 Scale model

02a Scale model of an autogenous mill for experimental measurements in the lab. The model consists of a steel drum, driven by a toothed belt connected to a small electrical motor. The drum interior is covered with an interchangeable rubber layer to simulate the liner.

2b Function sketch of scale model with toe and shoulder angle and WLAN acceleration sensor. The sensor is placed on the outer surface of the drum to measure the vibration. The acceleration signal is the dependent variable; liner thickness and mill load are independent variables; and revolution speed, temperature, stone size and stone quality are controlled variables. Different measurements with 2 to 17 mm liner thickness and from 1 to 4 kg mill load was made. For each condition, at least two acceleration measurements of 2 min with a sampling frequency at 970 Hz were made.

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03 Simulated acceleration signals from transient simulation of a new liner and a worn liner. The acceleration signal of the worn liner has higher amplitudes and frequencies from less damping.

—

04 Confusion matrix of liner thickness classification in seven classes (2, 5, 7, 10, 12, 15, 17 mm) from measurements on mill scale model.

To find the toe and shoulder angle, the information entropy of the signal is calculated. The entropy of the signal (over a certain moving window) represents the amount of information contained in the signal [3]. In other words, the more random and unpredictable the acceleration signal due to the impacts is, the greater its entropy will be. Thanks to this calculation, changes in the acceleration signal and thereby the toe and shoulder angle can be detected. An important parameter is the window length of the calculated index. For this data, a window length of 1,180 samples shows good results.

—

With an adapted deep neural network based on Tensorflow, the results from the field test measurements also showed a relatively high accuracy: 82.9 percent.

All confusion matrix

Output class \ Target class	1	2	3	4	5	6	7	
1	159 14.2 %	0 0.0 %	0 0.0 %	1 0.1 %	0 0.0 %	1 0.1 %	1 0.1 %	98.1 % 1.9 %
2	0 0.0 %	159 14.2 %	0 0.0 %	0 0.0 %	0 0.0 %	0 0.0 %	1 0.1 %	99.4 % 0.6 %
3	0 0.0 %	0 0.0 %	160 14.3 %	0 0.0 %	0 0.0 %	0 0.0 %	0 0.0 %	100 % 0.0 %
4	0 0.0 %	0 0.0 %	0 0.0 %	153 13.7 %	0 0.0 %	5 0.4 %	1 0.1 %	96.2 % 3.8 %
5	0 0.0 %	0 0.0 %	0 0.0 %	0 0.0 %	153 13.7 %	1 0.1 %	3 0.3 %	97.5 % 2.5 %
6	1 0.1 %	0 0.0 %	0 0.0 %	6 0.5 %	0 0.0 %	153 13.7 %	1 0.1 %	95.0 % 5.0 %
7	0 0.0 %	1 0.1 %	0 0.0 %	0 0.0 %	7 0.6 %	0 0.0 %	153 13.7 %	95.0 % 5.0 %
	99.4 % 0.6 %	99.4 % 0.6 %	100 % 0.0 %	95.6 % 4.4 %	95.6 % 4.4 %	95.6 % 4.4 %	95.6 % 4.4 %	97.3 % 2.7 %

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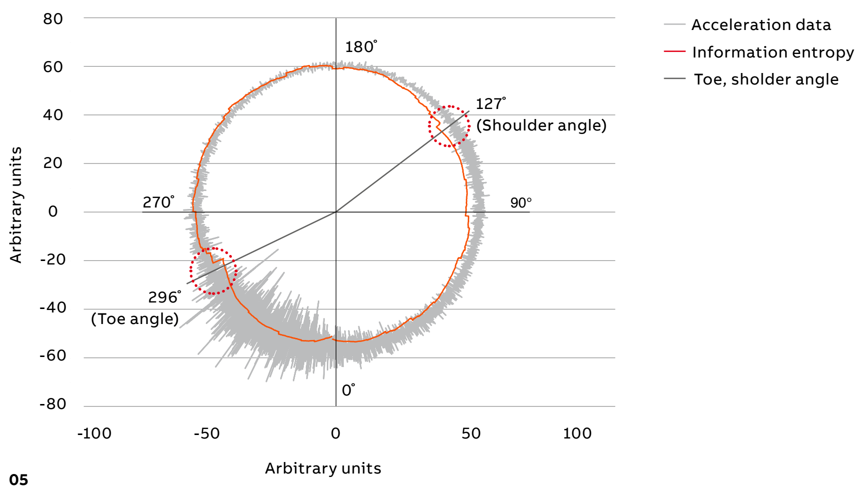

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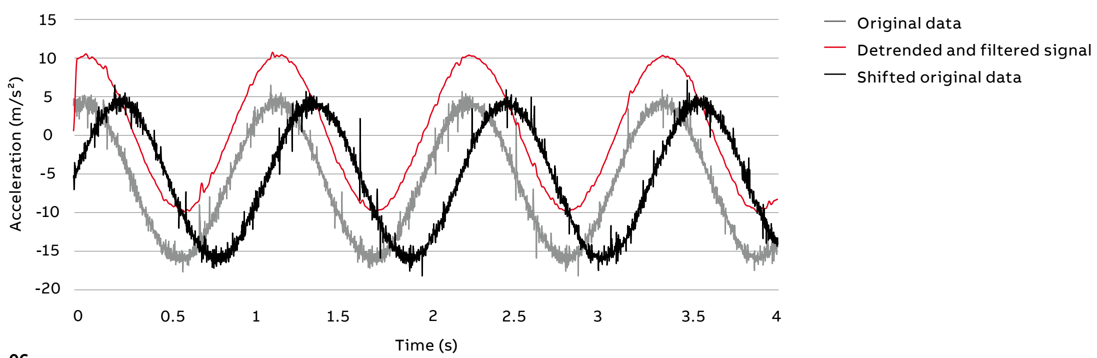
— 05 Polar plot of toe and shoulder angles from one turn at a real ore mill.



06

— 06 Preprocessing the acceleration data. The shifted signal is calculated by the original signal and the detrended and filtered signal.

Field tests
To verify the mathematical models, field tests were carried out. The sensitive sensor equipment was protected from the harsh and dirty mill environment by a robust metal enclosure. The equipment includes a battery, timer, several acceleration sensor drivers, an analogue-to-digital converter and a data acquisition device. The acceleration sensors themselves were mounted with magnets directly on the mill drum and their cables led back to the box. The enclosure was mounted on a fully operational mill and left to collect data for several weeks.

—

The raw vibration signal is very noisy due to the many impacts recorded when the mill is rotating, so raw data reprocessing is necessary.

Data analysis with machine-learning techniques
The raw vibration signal is very noisy due to the many impacts recorded when the mill is rotating and it is difficult to distinguish the various liner conditions. Therefore, raw data preprocessing is necessary. Only with a standardized data basis it is possible to apply machine learning algorithms. Over many iterations, the best classification model was sought.

Preprocessing the data
Because the measurement starting points are not the same every time, there are differences between the datasets. But for a proper evaluation it is necessary to have a uniform data basis. For this reason, a phase detector was included in the setup. The original signal was filtered through a low-pass filter (2 Hz cut-off frequency) and then a curve fitting and a detrending was applied. It was possible to determine the phase in the detrended and filtered data. This phase was then used to shift the original data so that all data sets have the same starting point →6.

After the phase shifter, the data from the 2 min measurements made was divided into slices representing one drum revolution. Additionally, the slices were resampled into 1,024 samples. This raw data preprocessing ensured a consistent data basis for the machine-learning algorithm.

Feature extraction
Machine-learning algorithms try to map a set of features to the correct target values. The right choice of these features is thus very important. Different features were tested, eg, wavelets, entropy and Fourier analysis. The best result was achieved with a combination of statistical values, the raw acceleration data and the FFT (fast Fourier transform) of each slice. All these features were combined into a table with the corresponding target value. This table is used as input matrix for the neural network.

Building a neural network for pattern recognition
To classify the data, different machine-learning methods such as support vector machines, decision trees or neural networks were tested. The best results were achieved with neural networks. A neural network should recognize patterns in each signal. These patterns help to classify the signal into a target class. Classes were built for all the measurements derived from the different mill load and liner thickness test runs.

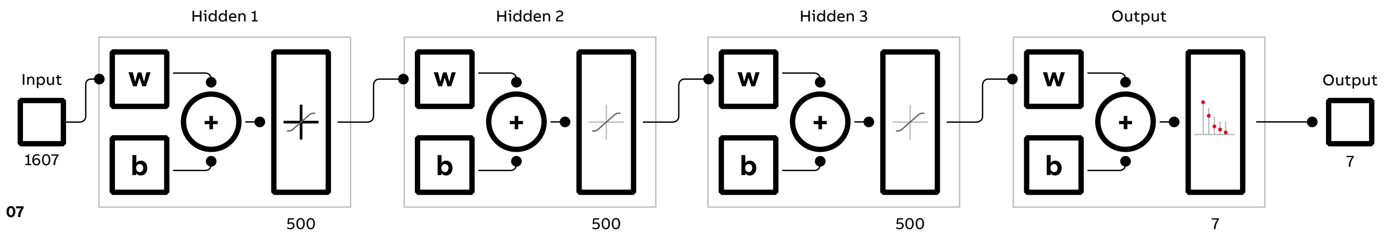
After the definition of the classes, the input and output matrices for the neural network were constructed. The input matrix includes the feature table described above and the output matrix defines the correct target class for each feature set. Then a neural net [4] with three hidden layers each with 500 neurons and an output layer, for classification, was created →7.

Of the data set, 70 percent was used for training the neural net, 15 percent for validation and 15 percent for testing the neural net. The network training employed a "scaled conjugate gradient backpropagation" – effectively a method that updates critical model parameters (neuron weights and bias) on the way through in an iterative fashion. Finally, a fine tuning of the network hyperparameters (ie, impactful parameters not tuned in the core model) that delivered an optimal neural network setting and enabled the liner condition to be determined reliably.

—

Thanks to the system, it will be possible to replace liners depending on their condition, which reduces downtime and costs while saving resources.

Liner monitoring for increased productivity and reduced costs
The hypothesis that the acceleration signal changes significantly with liner thickness was confirmed with simulations, and measurements on the scale model and on a real mill.
The monitoring system developed by I3S and ABB shows how acceleration sensors and machine learning techniques can then be used to measure the condition and process parameters of a mill during operation. Thanks to the system, it will be possible to replace liners depending on their condition, which reduces downtime and costs while saving resources. This new monitoring system will help mill operators increase productivity and plan maintenance. •



07

— 07 Neural network for liner thickness classification.

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Energy

The concept of “fail fast” is core principle of today’s technology innovators, yet it is unacceptable in such mission-critical industries as power generation and distribution. ABB has over a century of experience delivering reliable power, and uses it as a platform from which to innovate new technologies to make power lines sturdier, green fuels more usable, and transformer protection better.

ENERGY

ABB's rugged PowerLine DPA UPS handles harsh conditions

01

ABB's PowerLine DPA UPS is built to withstand the harsh conditions found in many industrial settings. Inovyn – Europe's largest PVC producer – opted for the PowerLine DPA due to its ability to survive the excessive dust, corrosion, humidity and heat in the Inovyn factory.

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For many industries, the consequences of electrical power loss can be disastrous – valuable production time is lost, costly and complex production line restarts may be necessary, product may be ruined, equipment can be damaged and safety issues may arise.

On top of total power outages, the voltage may sag or swell over short periods. It may also do so over longer periods – so-called brownouts or overvoltages. Moreover, there can be electrical noise on the line, or frequency variation or harmonics may appear in the voltage. Such events can result in data loss, production loss, nonavailability of essential services, risk to hardware, financial losses and safety concerns. For these reasons, many enterprises employ uninterruptible power supply (UPS) systems.

However, industrial settings are notoriously tough places in which to locate 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 UPS is specifically designed to withstand such harsh environments →1. 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 15 years' lifetime of the PowerLine DPA UPS.

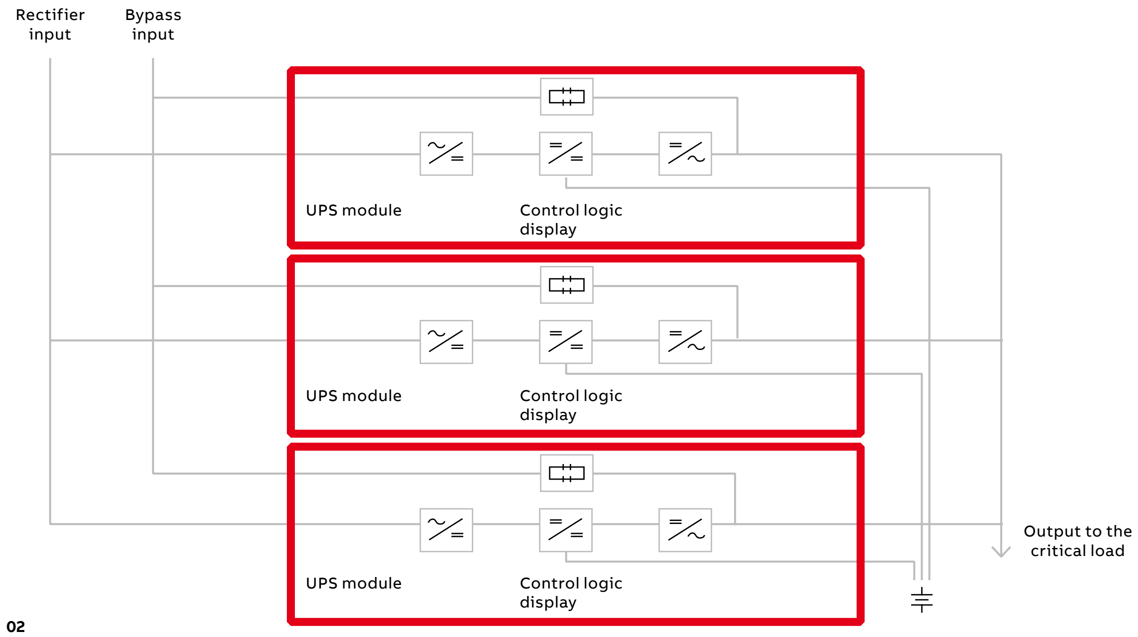
Decentralized parallel architecture

UPS systems with a centralized parallel architecture (CPA) have some degree of hierarchical, centralized control or hardware (eg, a static bypass). This makes CPA devices vulnerable should a failure arise on one of these centralized components; one fault can bring down the entire UPS. With DPA, on the other hand, the UPS is modularized and each module has all the hardware and software needed for autonomous operation: rectifier, inverter, battery converter, static bypass switch, backfeed protection, control logic, display, and mimic diagram for monitoring and control →2. A module's output is not affected by failures elsewhere in the UPS. If one module is lost, the others take up its load. In other words, a multimodule system is fault tolerant and there are no single points of failure. Availability is maximized.

—

DPA is a modular architecture that provides not only the best availability but also the best serviceability, scalability and flexibility.

The only UPS elements common to all modules are contained in the mechanical frame that accommodates the UPS modules – I/O connection, customer interface signaling, maintenance bypass and a system display. These elements are noncritical for UPS operation.



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01 Inovyn, the largest producer of PVC in Europe, settled on the ABB PowerLine DPA UPS as it can easily cope with the harsh conditions in Inovyn's Belgian factory.

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02 With DPA, each UPS module has all the hardware and software it needs for autonomous operation; there are no shared critical elements.

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03 Part of the Inovyn PowerLine UPS installation.

DPA – serviceability

One major advantage of DPA is that the modules can be online swapped, ie, removed or inserted, without risk to the critical load and without the need to power down or transfer to raw mains supply. This unique aspect of modularity directly addresses continuous uptime requirements, significantly reduces MTTR (mean time to repair), reduces inventory levels of specialist spare parts and simplifies system upgrades.

DPA – scalability

The modular nature of DPA enables modules to be added as UPS power requirements increase – if a new process line is opened, for example. This approach means the initial rated power does not have to be oversized to cater for future expansion – modules are simply added when needed.

PowerLine DPA

ABB already markets power protection products that are based on DPA and the ABB PowerLine DPA 20-120 kVA UPS is a recent addition to this product portfolio →3. The PowerLine DPA UPS is specifically designed to overcome the many environmental challenges faced when deploying such sophisticated electrical equipment in a harsh industrial setting.

Survivability is crucial, so particular attention has been paid to physical robustness. PowerLine's protection, rated up to IP42, can easily cope with dust, water condensation, excessive humidity (up to 95 percent), corrosive air contamination and rough manhandling. The UPS is designed to operate in a temperature range of -5 to +45 °C. High priority has been given to safety and PowerLine DPA features a high degree of protection for users and maintenance staff. The device's compliance with the relevant standards – IEC/EN 62040-1 for general and safety aspects, IEC/EN 62040-2 for EMC and IEC/EN 62040-3 for performance and test – has been verified.

Real estate for electrical equipment is often a limited or expensive commodity. The PowerLine DPA UPS has not only a small footprint but has cable access at the front (top and bottom), which eliminates the necessity for rear access and the associated extra space this entails. Also, because the power modules are stacked vertically, no extra floor space is taken up when expansion modules are added.

PowerLine DPA is an online double conversion UPS: The incoming AC is first converted to DC, from which the output AC is then synthesized – giving a clean sinusoid. These two conversion steps give rise to the term "double conversion" and isolate the output voltage waveform from any disturbances on the input AC side.

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The PowerLine DPA UPS is specifically designed to overcome the many environmental challenges of harsh industrial settings.

The device has a high overload capacity and robust short-circuit capability. In some industrial applications, the UPS AC input power is fed from switchgear or motor control centers and often shares bus connections with electrically noisy loads such as variable speed drives. Therefore, an input isolation transformer is sometimes installed to protect the UPS input from the effects of electrical noise. With rated powers of 20 to 120 kVA and an input power factor of 0.99, the UPS requires no onerous electrical installation considerations and is straightforward to service.

Installation brackets that support easy installation, vibration dampers, IP42 cabinet protection, halogen-free cables and a black start capability are some of PowerLine DPA's other features designed specifically for deployment in demanding industrial situations.

Remote monitoring

In a power-fail situation, it is important for all relevant personnel to be quickly and fully informed of the system status. For this reason, the PowerLine DPA UPS can be supplied with relay boards and a network management card that provide connection to the DCS (distributed control system) or SCADA (supervisory control and data acquisition) system via SNMP, Modbus TCP or Modbus RS 485. These interfaces allow environmental monitoring, extensive alarm handling and dispatching, redundant UPS monitoring, integration of PowerLine DPA into multivendor and multiplatform environments and the supply of UPS data to Web applications.

PowerLine DPA at Inovyn

The Inovyn site at Jemeppe-sur-Sambre produces 475,000 tons of PVC per year – the equivalent of 50 semitrailers per day (the PVC in every credit card in Europe comes from here) →1, 4–6. Around 500 people work round-the-clock shifts to maintain the company's position as the largest producer of PVC in Europe. Because their plant presents a challenging environment (excessive dust, corrosion, humidity, heat, etc.), Inovyn opted for the PowerLine DPA for their power protection needs.

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Because their plant presents a challenging environment, Inovyn opted for the PowerLine DPA for their power protection needs.

Such a high level of PVC production requires a precision system. "Our factory has very many DCS I/O operations," explains Pierre Henveaux, electrical engineer and Head of the HV and LV Sector. "The DCS – data control system – is a computer that controls the plant: it starts the motors, opens and closes the valves, etc. In short, it controls all the equipment. Jemeppe has the highest number of I/O operations of all our factories in Europe. It's just not an option for the system to go offline and for us not to know what's going on."

PVC is produced in batches and the DCS must be as efficient as possible, especially as the number of I/O operations will only increase as technology advances. "Our standards are very high. One of our top requirements is for uninterruptible electricity supplies. If we lose control for two milliseconds, all is lost: the data does not get through and the system goes into safe mode. If we lose a DCS for longer than 40 milliseconds, it's a catastrophe." Inovyn has its own electricity generation system, which produces one-eighth the power of an average nuclear reactor, but even this is not immune to micro-outages.

ABB-Inovyn partnership

Inovyn and ABB have been working together since 2000 and have built up a good relationship. Previous UPS systems were mainly developed for data centers, but the Inovyn application needed something much more robust and it was this requirement that led ABB's teams to come up with the PowerLine DPA UPS.

Inovyn has installed two PowerLine DPA units →6. On top of the equipment quality, Inovyn found the system to be very robust as each module is enclosed in a solid housing protected by powerful filters. This sturdy construction delivers a UPS that will last 10 to 15 years – considerably longer than any competitor's equivalent.

Inovyn is currently using an older-generation DCS, but plans to move to a more efficient system in coming years. The PowerLine DPA UPS will allow simple expansion when the time comes. The company will also install two new UPS systems in their new production line, which is to come on stream during 2019.

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04 Some of the process equipment at the Inovyn plant.

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05 Raw material for the manufacture of PVC at the Inovyn plant.

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06 Polymerization equipment at Inovyn's Jemeppe-sur-Sambre plant in Belgium.

A UPS for the future

The guarantee of a continuous supply of clean power has become a prerequisite for the success of many enterprises. The PowerLine DPA UPS, designed to withstand the rigors of harsh industrial environments, can provide this guarantee. PowerLine DPA's modular architecture makes it simple to service or expand and because its online swapping attributes mean it never has to be switched off, first-class availability is achieved.

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The PowerLine DPA UPS simplifies expansion when Inovyn upgrades its DCS in coming years.

With an efficiency of up to 96 percent and unity power factor, the PowerLine DPA UPS offers improved efficiency and optimization of investment as well as ease-of-use and enhanced safety in a wide variety of very tough industrial environments. As Inovyn are finding out, these characteristics, combined with ease of serviceability means PowerLine DPA delivers a very low TCO over its lifetime. •

ENERGY

The fuel cell – a green powerhouse

Fuel cells generate electricity by combining hydrogen and oxygen. The only byproducts of this reaction are water and heat →1. A greener energy source can hardly be imagined. How can fuel cells be used to help the world in its quest for carbon neutrality, and what challenges lie ahead?

01 By simply combining hydrogen and oxygen to produce electrical power, fuel cells represent an extremely environmentally way to generate power. Even the byproducts of the fuel cell reaction – water and heat – can be beneficial.

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Rising urbanization is increasing global demand for energy [1] – a demand that is often satisfied by fossil fuels like oil, gas and coal →2. In developing countries, for example, despite a growing use of renewable energy sources, around 70 percent is still supplied by nonrenewable fossil fuels.

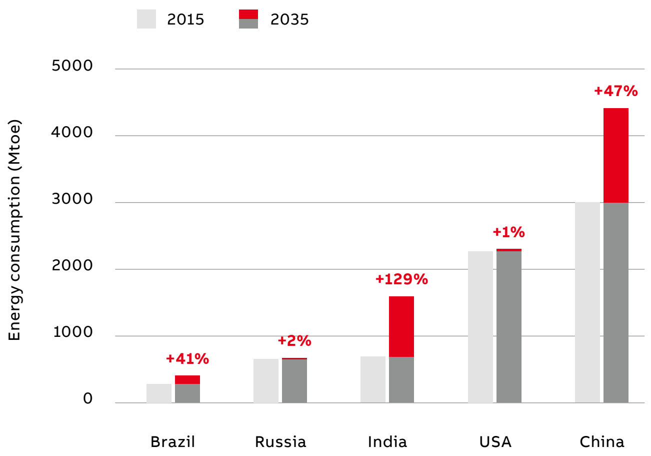
Fossil fuel sources are limited and are increaslingly difficult and expensive to extract. Not only that, but their use exacerbates greenhouse gas (GHG) levels, ozone layer depletion, acid rain damage, air pollution and climate change. Moreover, the fossil fuel supply chain itself can also have adverse effects, such as the air and water pollution and other dangers that can arise from fuel extraction, transportation and processing.

The fuel cell needs only one step to oxidize its hydrogen fuel to electrical energy.

One way to achieve power generation without CO, CO_2, SOx, NOx or particulate emissions is to use a fuel cell.

The fuel cell
A fuel cell is a flow reactor that directly converts the chemical energy of a fuel to electrical energy through electrochemical reactions. Whereas a combustion engine follows a multistep process (from chemical to thermal to mechanical to electrical) to convert the chemical energy of a fuel to electricity, the fuel cell needs only one step to oxidize its hydrogen fuel to electrical energy →3. The products of this conversion are electricity, water and heat. The water and heat are removed to improve fuel cell operation. Oxygen can be obtained from the ambient air and, if sustainably sourced hydrogen is used, no GHGs are produced. No pollutants are emitted and thus there is no risk of breaching environment and public health regulations.

Fuel cells were invented in 1839 by Sir William Robert Grove, a Welsh physicist, and were later



02

— 02 Total primary energy consumption in millions of tons of oil equivalent [1].

used by NASA to provide drinking water as well as electricity for space vehicles. Though early hydrogen misadventures (eg, the Hindenburg disaster) hindered fuel cell development for some time, recent technical advances have resulted in fuel cell technology that is reliable, safe and widely accepted by the public and private sectors. There are many types of fuel cell →4.

Because of the fuel cell's inherent modularity, they are predicted to have a bright future in stationary, portable and transport applications →5.

Stationary applications of fuel cells
Stationary fuel cell power plants provide clean, efficient and reliable distributed power. Continuous reductions in fuel cell costs and improvements in their efficiency present a favorable marriage of economy and sustainability, as evinced by the surge in the number of such plants in recent years →6.

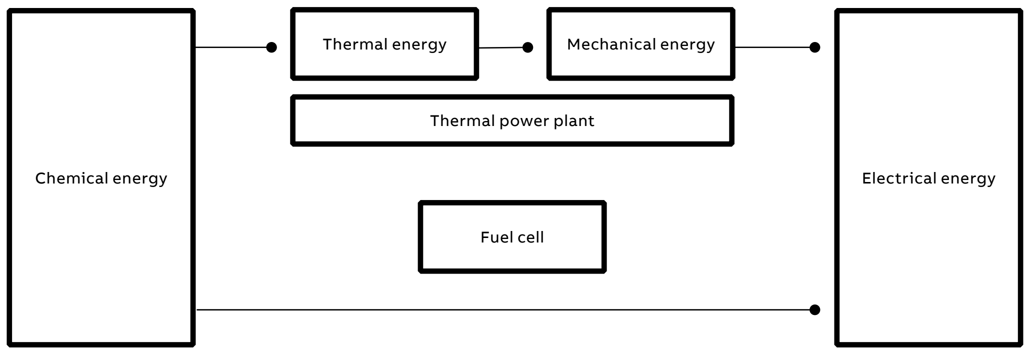
Currently, the world's largest fuel cell park – constructed by FuelCell Energy Inc. in 2014 – comes in at 59 MW and supports Hwasung city, South Korea [3]. This plant runs on hydrogen obtained from the natural gas supply to the local district heating system.

Another successful fuel cell deployment is a 300 kW system in Fenchurch Street, London [4]. The challenge here was the integration of the fuel cell system into an established building with limited space. The fuel cell was, therefore, integrated into the building's cooling, heating and power configuration. This installation achieves an emission reduction of 18,000 kg of pollutants and 1,800 tons of CO_2 when compared to an equivalent conventional combustion-based power generation scheme.

—

Because of the fuel cell's inherent modularity, they are predicted to have a bright future in stationary, portable and transport applications.

Fuel cells are now widely accepted as an alternative power source in rural regions where power supply is absent or unreliable. For example, the Poelano High School in Goedgevonden, Ventersdorp – a rural region in South Africa – has successfully implemented hydrogen fuel cell technology to deliver 2.5 kW for the school's information, communication and technology (ICT) and lighting needs. The solution is reliable, efficient, safe and quiet. Such mini-grid fuel cell configurations can relieve or augment national grids and deliver social, political and economic benefits for remote or ill-served regions the world over.



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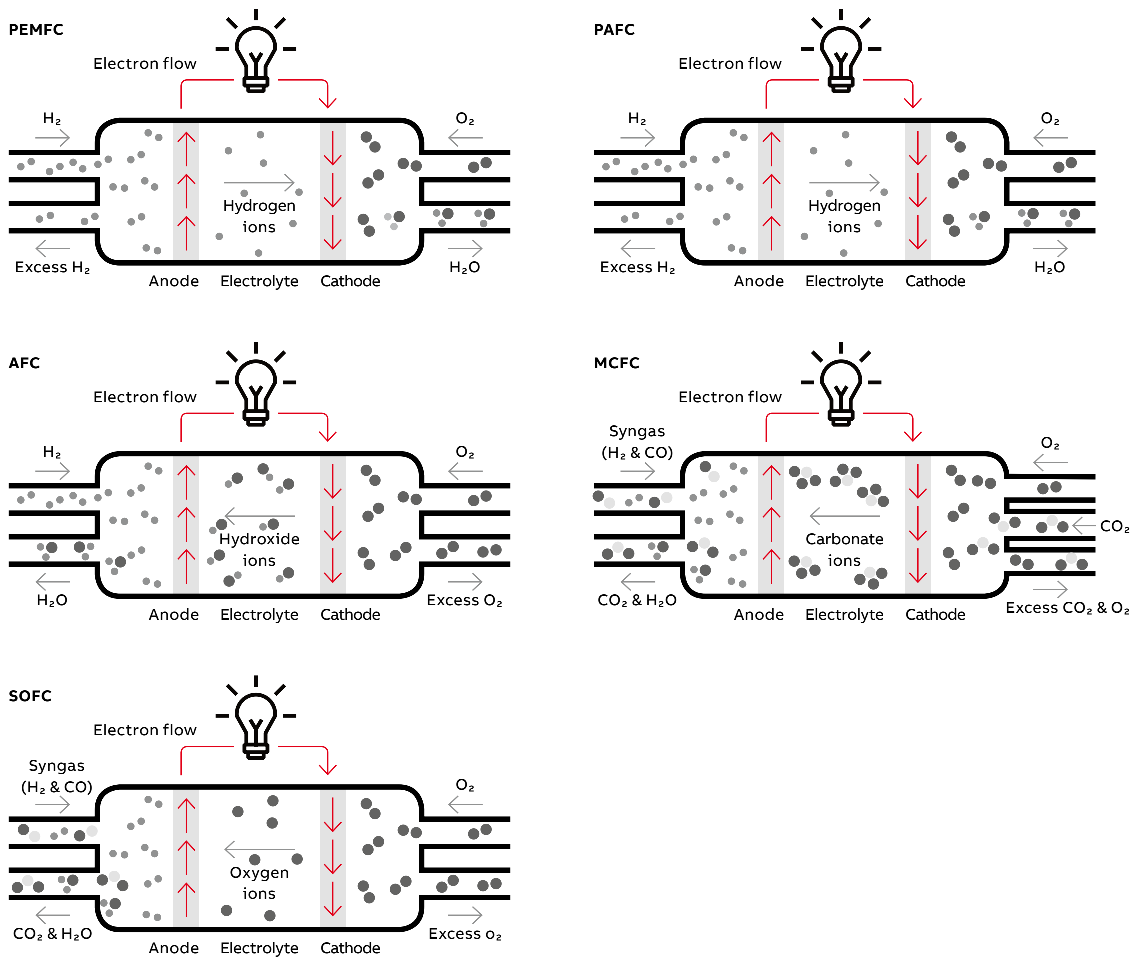
— 03 Energy production process in a fuel cell.



04

— 04 Types of fuel cell.

	PEMFC/PEFC Proton exchange or polymer electrolyte membrane fuel cell	PAFC Phosphoric acid fuel cell	AFC Alkaline fuel cell	MCFC Molten carbonate fuel cell	SOFC Solid oxide fuel cell
Applications	Stationary power, combined heat and power, transport	Stationary & cogeneration power generation (mostly in hospitals because exhaust temperature of water used for sterilization process)	Space and undersea, less used in automobile, drinking water	Stationary power generation, hybrid with gas turbine and combined heat power plants, industrial and military	Stationary power, auxiliary power in vehicles, combined heat and power
Fuel	H_2/reformate	H_2/reformate	H_2/reformate	H_2/CO/reformate	H_2/reformate
Oxidant	O_2/air	O_2/air	O_2/air	CO_2/O_2/air	O_2/air
Cost	Costly	Expensive	High	Low	Low
Efficiency (%)	50–60	40–55	50–60	55–65	55–65
Power density (kW/m³)	3.8–6.5	0.8–1.9	1	1.5–2.6	0.1–1.5
Power range (kW)	1–250	50–200	1–100	1000–2000	1–900
Operating temperature (°C)	60–200	175–200	65–200	600–650	650–1000
Risk	Sensitivity of platinum catalyst to CO poisoning – needs additional reactor to reduce CO in the fuel gas if the hydrogen is derived from hydrocarbon/alcohol fuel	Corrosion because of acids, CO poisoning and sulphur-rich compounds	Alkali electrolyte reacts with CO_2 present in impure O_2/H_2 – leads to CO_2 poisoning and affects the cell's lifetime	High operating temperatures and corrosive electrolyte accelerate component breakdown, corrosion and thus decrease cell life	High operating temperatures lead to decreased cell life

05

— 05 Fuel cell applications.

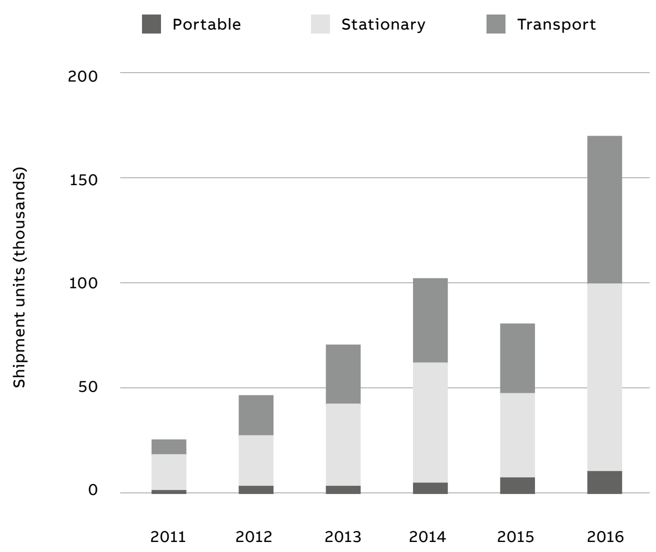
Portable applications of fuel cells
Portable fuel cells (PFCs) are often desirable replacements for traditional lithium-ion and lead-acid batteries due to their higher energy density →7. Moreover, PFCs have advantages such as off-grid operation, longer run times, rapid recharging, lower weight, convenience, reliability and low operating costs. Hence, PFCs are utilized for military applications, auxiliary power units and portable products like torches and electronics. PFCs can provide power in a range of 5 W to 500 kW.

For example, unmanned aerial vehicles (UAVs) use portable fuel cells for their primary propulsion system because of the fuel cell's efficacy and reliability, longer operational life and low thermal, acoustic and vibration signatures. One instance is Ion Tiger, a liquid-hydrogen-powered UAV developed by the United States Naval Research Laboratory, which weighs just 17 kg when equipped with 550 W of fuel cell power. Ion Tiger can stay aloft for over a day, more than six times longer than a battery-powered equivalent would. The use of cryogenic liquid hydrogen doubles this flight endurance.

Transport applications of fuel cells
To combat toxic air and declining fossil fuel reserves, many countries are rolling out hydrogen refueling infrastructure to accommodate vehicles powered by fuel cells →8. City authorities are reacting too. For example, Aberdeen City Council has introduced Europe's largest fleet of hydrogen fuel cell buses [6]. In the first year, the fleet had more than 1,600 refueling events. Refueling takes just 5 to 7 minutes. The hydrogen refueling station was extremely reliable and available (99.99 percent) and dispensed 35,000 kg of hydrogen. City planners are now considering the expansion of the fleet, not least because this successful exercise won them the 2016 Low Carbon Championship award for the transport initiative of the year. Similar fuel cell buses have been successfully deployed in other cities around the world.

—
Many countries are rolling out hydrogen refueling infrastructure to accommodate vehicles powered by fuel cells.

Maritime operators, who contribute 3 to 5 percent of global CO_2 and over 5 percent of global SOx emissions, are also keen to use fuel cells and have therefore executed a number of research projects in this area →9. ABB, too, has fuel cell activities related to the maritime industry: the MARANDA project [7], for instance, is a joint venture of several companies financed by the European Union.
The project will design and implement a 165 kW proton-exchange membrane fuel cell unit to be installed on board the research vessel Aranda. The main objective of the research project is to verify the fuel cell's ability to produce emission-free electrical power with low noise and vibration levels in the marine environment. ABB will deliver the electrical power conversion technology needed to attach the fuel cell system to the vessel's electrical power plant. Another fuel cell pilot project (100 kW capacity) was performed by ABB and Ballard in conjunction with Royal Caribbean Cruises [8].



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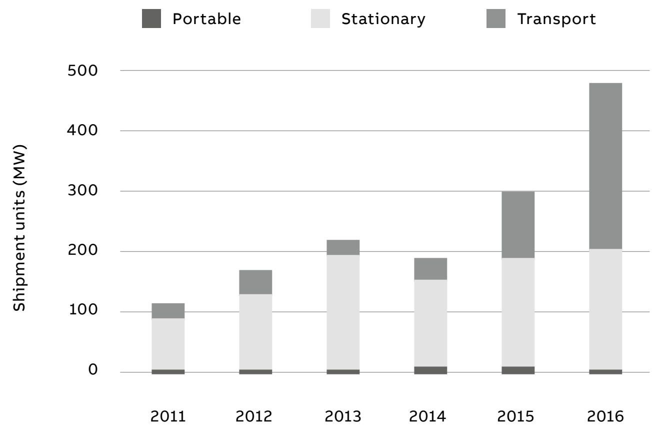

06b

Photo fig. 08: AdrianHancu, istockphoto.com

—
06 Fuel cell systems shipped [2].

06a Shipped units in thousands.

06b Shipped units per year in MW.

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07 Comparison of the energy density of compressed hydrogen (3,000 psi) versus lithium-ion and lead-acid batteries [5].

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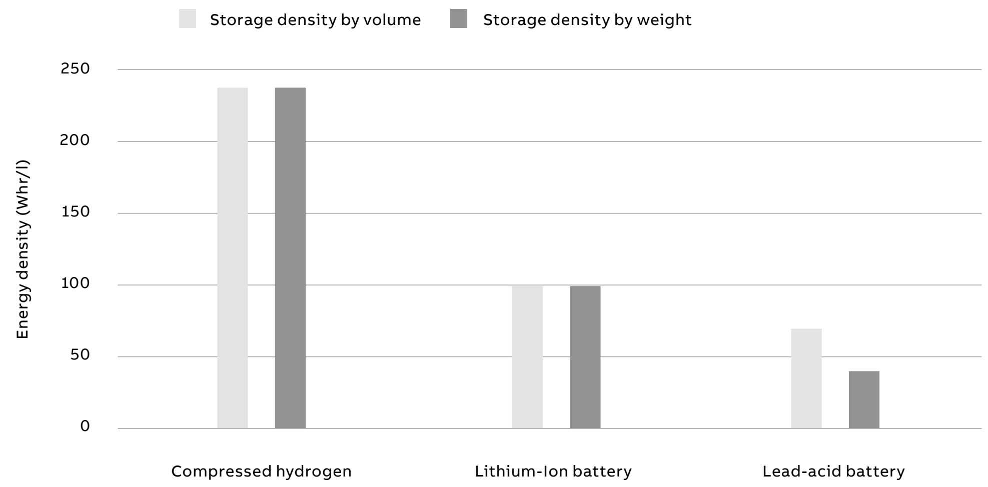
08 Clean, high-energy-density fuel cells are the ideal solution for powering transport in urban areas.



07

Challenges of hydrogen and fuel cells
Though hydrogen disperses very quickly in air, rapidly dropping below flammability level; does not have a lot of "bang-power" per volume compared to other common fuels; and its very rapid burn rate means that exposure to heat or flame will be extremely brief, care must be taken when handling it. Indeed, there are currently several standards governing fuel cell installation.

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ABB will deliver the electrical power conversion technology needed to attach the fuel cell system to the electrical power plant of the Aranda research ship.

08

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09 Energy Observer is the world's first hydrogen vessel. This former racer emits no GHGs or fine particles and produces on-board, carbon-free hydrogen from seawater.

Photo: Gaël Musquet, Wikimedia Commons

The fuel cell landscape has challenges in other areas, though:

- Safe and effective hydrogen production, storage and distribution.
- Cost, mostly due to expensive catalysts. Cost is the biggest hurdle for fuel cells today.
- Fuel cell stacks, built to generate higher voltage and power, need to be optimized for output, efficiency, cost and size. However, lifetime performance degradation, a key performance parameter, is not fully understood (kinetic loss, ohmic loss, loss of mass transport and loss of reformate are thought to be the sources of degradation). Moreover, the effects of freezing, thawing and stack impurities, as well as mitigation of stack water flooding or drying-out dangers, must be explored and accurately modeled. Multiphysics computational fluid dynamics (MCFD) and reduced order model (ROM) techniques can be exploited to model fuel cell electrochemistry, heat transfer and fluid mechanics to provide control and operational characteristic curves and to investigate fine-tuning and optimization. These operational characteristic curves are useful in designing the control and protection systems and power electronics needed to integrate fuel cells with the main grid.

Despite the challenges that remain, fuel cell technology has found wide acceptance with the public and with business. As a green powerhouse, the fuel cell is unrivaled – for what other power source can not only provide a clean source of electrical power but also deliver heat for the home or workplace and pure water that can be processed for drinking? •

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ENERGY

The TXpand™ rupture-resistant transformer solution

Internal arcing in oil-filled transformers can have catastrophic consequences. Designed using a numerical methodology, ABB's TXpand solution, which includes optimized tank design and safer component selection, can mitigate the effects of most internal arcing events.

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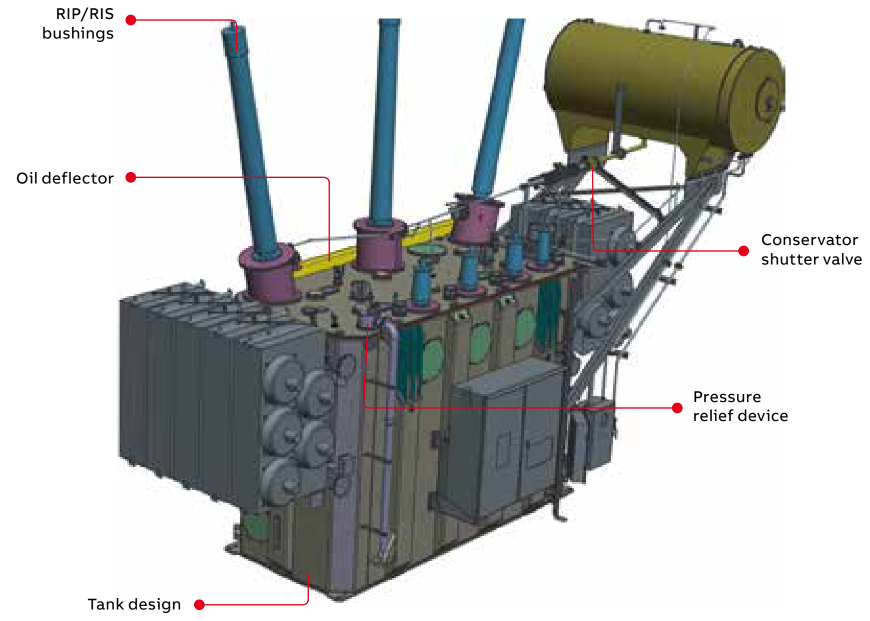

02

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01 Despite design precautions to prevent internal arcing in transformers, there is always a residual risk of such an event, with the possibility of a consequent tank rupture, leading to a fire. ABB's TXpand rupture-resistant transformer solution has been specifically developed and optimized for the power industry to mitigate the consequences of internal arcing.

—
02 TXpand features.

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Oil-filled transformers are critical power network components that operate continuously in harsh conditions. Although low – at around 1 percent per transformer service year [1] – the rate of major failures among these transformers is not insignificant, especially as the consequences of failure (major oil spills, fire and collateral damage) can be catastrophic.

A low-impedance internal arc in oil-filled electrical equipment heats and vaporizes the surrounding oil to create a gas bubble. This effect is not the same as a chemical explosion, which requires an explosive mixture of fuel and oxidizer. For this reason explosion prevention systems, such as the rupture discs commonly used in petrochemical applications, are rarely used in transformers.

ABB has specifically developed and optimized the TXpand solution to mitigate the effects of internal arcing in transformers →1.

TXpand

A fire-risk mitigation strategy should consider several electrical protection measures, the most important of which is the inclusion of a fast-acting circuit breaker to limit fault duration and, therefore, the amount of energy injected into the fault zone. Mitigation must also encompass a transformer design that complements the electrical countermeasures. TXpand has five such measures →2.

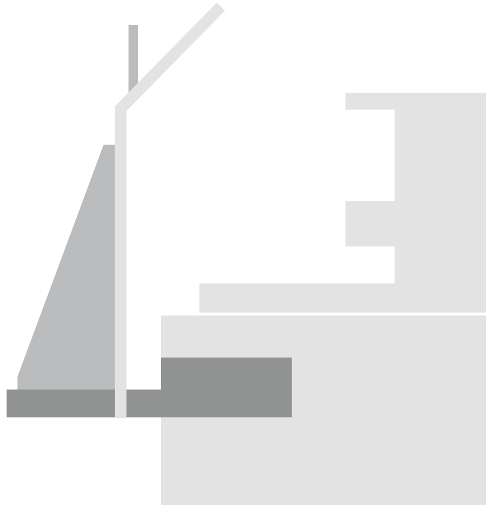
Tank design

A Hydro-Québec survey on their 735 kV network reported that in 50 out of 74 major failures, tank rupture was the main cause of oil spill and, thus, fire risk [2]. This type of hazard can be managed by the rupture-resistant tank design proposed here. The philosophy is to contain a specified arc energy by absorbing the fault energy in a plastic deformation of the tank. The corresponding tank design is the core of the TXpand solution. TXpand has been developed by careful analysis and modeling to make the most rigid areas flexible and the weakest points stronger. Strategic rupture points allow the most unpredictable failures to be controlled.

—
The philosophy is to contain a specified arc energy by absorbing the fault energy in a plastic deformation of the tank.

RIP/RIS bushings

Oil-impregnated paper (OIP) bushing failures cause the most fires following a transformer internal fault [1]. The Hydro-Québec survey mentioned above showed these bushing failures to be the second main cause of oil spill (18 cases out of the 74 failures) [2]. The use of resin-impregnated paper (RIP) or resin-impregnated



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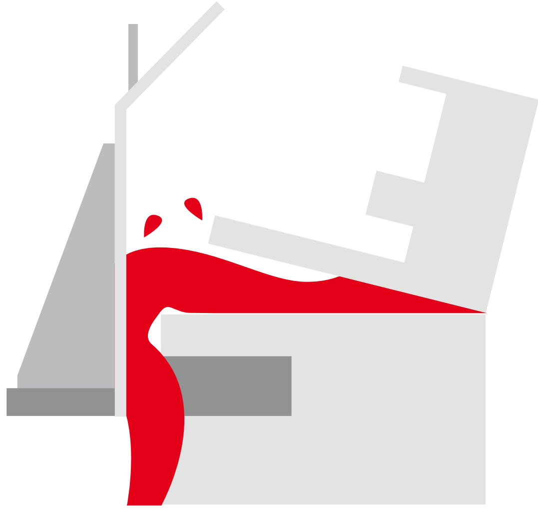

03b

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03 By directing it onto and down the tank external wall, the oil deflector prevents ejected oil endangering personnel.

03a Normal situation.

03b With ejected oil flow deflected.

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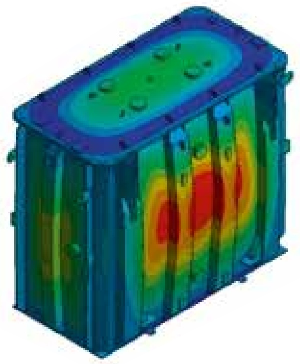
04 Tank numerical analysis process.

04a Displacement (tank flexibility.)

04b Strain (global strenth evaluation.)

04c Critical regions (tank rupture points.)



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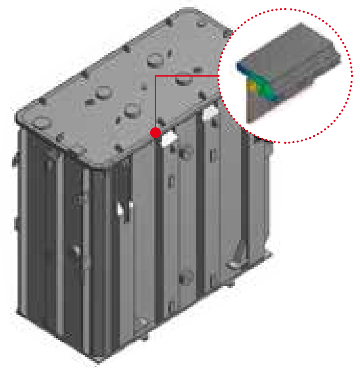

04c

synthetics (RIS) bushings can mitigate the risk of major oil spills, fire and porcelain shattering during internal arcing.

Conservator shutter valve

The conservator shutter valve is installed on the oil pipe connecting the conservator and the tank. The valve allows oil flow in both directions but it will close and initiate an alarm if the flow rate exceeds a certain limit. In the case of bushing failure or main tank rupture, the shutter valve should prevent oil spilling from the conservator and feeding a fire.

Pressure relief device (PRD)

A PRD is a spring-loaded valve used to vent the internal pressure after the arc energy has been consumed by the tank deformation. A pipe is installed at the outlet of PRD to guide the oil and gas away appropriately to the base containment system.

Oil deflector

The fifth of the transformer design mitigation measures concerns the strategic rupture point, which is designed to be at the transformer cover weld. Because a hot oil/gas mixture could be ejected for a short period, an oil deflector can be installed on the strategic rupture points to divert the stream and prevent spills impacting the safety of personnel →3.

What is behind the tank design?

Arcing in oil has been studied for many decades and much has been learned about the science of the phenomenon. For example, it is known that the arc energy depends on the maximum current available, the arc duration (which is short if the electrical protection is efficient) and the arc voltage. From a case recorded on the Hydro-Québec 735 kV system, a pressure effect of the surrounding gas bubble on voltage was observed [3] and a more accurate equation was proposed to calculate the arc voltage, the most evasive of the parameters to measure.

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A good understanding of the science of the tank itself is critical.

The chemical composition of the arc has been under investigation since 1953, mainly for circuit breaker applications. The authors of five published studies agree that the arc gas generation rate is linear and the temperature in the reaction zone is about 2,000 °K [1]. In an extensive experimental program on distribution-type transformers in conjunction with numerical simulations, it has been concluded that a gas-to-volume conversion factor of 85 cc/kJ at standard temperature and pressure matches reality well [4]. This arc gas generation is used in the following expression to characterize the pressure built up in a transformer tank [3]. The equation has a dynamic amplification factor that is a ratio of the localized dynamic pressure to the final steady pressure. This dynamic effect was observed in transformer experiments with chemical explosions in special vessels [5] and an extensive numerical experimental study with high-pressure injection [3].

$$P_s = F\left[100\sqrt{\frac{1}{4}+\frac{kE}{100C}}-50\right]$$

Ps: calculated tank pressure (kPa)
E: fault energy level to withstand (kJ)
k: arc energy conversion factor (5.8 x 10^{-4} m^3/kJ)
C: tank expansion coefficient (m^3/kPa)
F: dynamic amplification factor

A good understanding of the science of the tank itself is critical. The importance of the tank expansion coefficient on the internal tank pressure was first realized in 1959, during experiments on oil-filled rectangular transformer tanks subjected to sudden discharges of nitrogen, and was simultaneously confirmed by numerical studies [6,7]. However, tank resistance characteristics were virtually unknown so, in 2011, Hydro-Québec and ABB launched an extensive investigation into this topic. In over five years of research, a numerical methodology was developed to analyze transformer tank behavior in the plastic domain, up to the rupture point. These numerical results have been validated in around 40 destructive experiments. All numerical parameters, such as the geometry simplification, mesh size, element type, contact element, boundary conditions and results analysis were calibrated via this experimental process. These years of learning yielded numerical simulations that gave accurate displacement results and, therefore, the expansion coefficient of the tank – and, ultimately, tank strength characteristics →4.

Large power transformer test

A full-scale 330 kV, 210 MVA transformer equipped with a mock-up active part was designed and manufactured according to the TXpand design rules [8]. This water-filled tank was subject to an injection of pressurized air equivalent to the gas produced by a 20 MJ arc energy in oil. This high energy release is, to ABB's knowledge, the highest such ever reported. The tank expanded as predicted by ABB's numerical simulations and the tank absorbed all the energy injected without any rupture →5. The PRD took more than 5 s to release the tank internal pressure, which is rather slow in comparison to a three-cycle fault duration (50 ms).

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All numerical parameters were calibrated via an experimental process.

In a second test, a higher pressure was injected, with the intention of causing a tank rupture. Even if the gas bubble is created at the bottom of the tank, the tank ruptures at the strategic rupture point predicted by the numerical simulation – eg, the tank cover weld.

06

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05 330 kV transformer tank pressure test.

05a Before internal fault event.

05b After internal fault event.

06 SSVT internal fault test (40 kA for 300 ms).

SSVT transformer test
The TXpand simulation techniques – developed for power transformers – were applied to a 650 kV BIL (basic impulse level) station service voltage transformer (SSVT), which has an internal tank volume one-hundredth that of a power transformer. The analysis led to several design changes to improve tank resistance against internal arcing. In 2017, a full SSVT assembly was tested with an internal fault current of 40 kA for 300 ms according to standard IEC 61869-1 2007 for the highest protection level (stage 2 and class II) →6. The SSVT successfully passed all test requirements: the tank resisted the pressure, no ejecta or fragmentation was observed and oil was evacuated by the PRDs within about 5 s. This experiment demonstrated that the powerful numerical methodology developed for large power transformers can be scaled down for SSVTs.

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The TXpand solution is based on a numerical methodology, a deep knowledge of arcing gas generation and many years of research and development.

TXpand is simple, efficient and cost-effective
The TXpand solution is based on a numerical methodology, a deep knowledge of arcing gas generation and many years of research and development. Experiments on both large power transformers and SSVTs have demonstrated the efficacy of TXpand. From collaborations with customers, TXpand has been seen to be simple, efficient and cost-effective. ABB now has a proven technology that significantly mitigates the consequences of a transformer internal arc event. A safer transformer could also be used as a starting point from which a cost and risk review of the costly substation base oil containment system could be initiated. •

05a

05b

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01

BUZZWORD DEMYSTIFIER

Autonomous systems

How autonomous are today's industrial systems?

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Can a production facility's level of autonomy be compared to the levels of autonomy now generally accepted for vehicles? Far from being an apples-and-oranges comparison, these two application areas share a world of similarities – thus shedding light on the meaning of autonomy itself.

Everybody's talking about autonomous systems as they apply to cars. But what's the status of these systems in industry? While the US National Highway Traffic Safety Administration (NHTSA) has established very clear definitions of the five levels of autonomy [1], similar definitions in the field of industrial automation are yet to be set. Nevertheless, these two application areas can be readily compared.

But just to avoid confusion, it must be clear that automation and autonomous systems are two substantially different animals. Simply put, autonomous systems are characterized by the ability to act independently of direct human control →1, whereas automated systems are not [2,3].

When it comes to autonomous systems in industry, a fair and achievable objective is to target NHTSA's Level 3. In terms of engineering, when translated into an industrial control system, this can be defined as a system that can itself perform all aspects of a configuration task. Therefore, it identifies the most suitable configuration based on insights it gains from a global data pool of optimized device settings that consider an innumerable combination of connected devices, the industrial domain, and environmental data such as climate conditions.

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Simply put, autonomous systems are characterized by the ability to act independently of direct human control, whereas automated systems are not.

In terms of operations, Level 3's industrial counterpart can be described as follows: The human operator must be ready to take back control at any time when the autonomous system requests the human operator to do so.

Photo bottom of page 75: Franck-Boston, istockphoto.com

02

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01 In industrial engineering, the objective is to eliminate the need for human intervention through the increasing application of machine learning.

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02 An ABB FlexPicker robot. The algorithms driving such machines are helping to maximize flexible and hygienic processing of foods.

In both, engineering and operations cases, the objective is the same: to eliminate the need for human intervention through the increasing application of machine learning →2. Technically, this requires significant changes at the control layer of an autonomous system, because the control layer needs to have a holistic plant view.

In view of these circumstances, it can be expected that artificial intelligence will change today's control paradigm from signal marshalling to process data analytics, from feedback loops to prediction, and from process calibration to self-optimization.

Looking ahead, engineering, operation and control will merge in tomorrow's autonomous systems into a continuous cycle of self-learning algorithms that will enable process and plant optimizations we can hardly imagine today. •

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Electrification in transportation

Global transportation relies on a complex and nuanced array of technologies and processes, from power generation and distribution, to where and how that energy is converted, literally, into motion. The next issue of ABB Review will reveal ways that different industries are putting electrification to work to increase efficiency, lower costs and collectively help save the planet.