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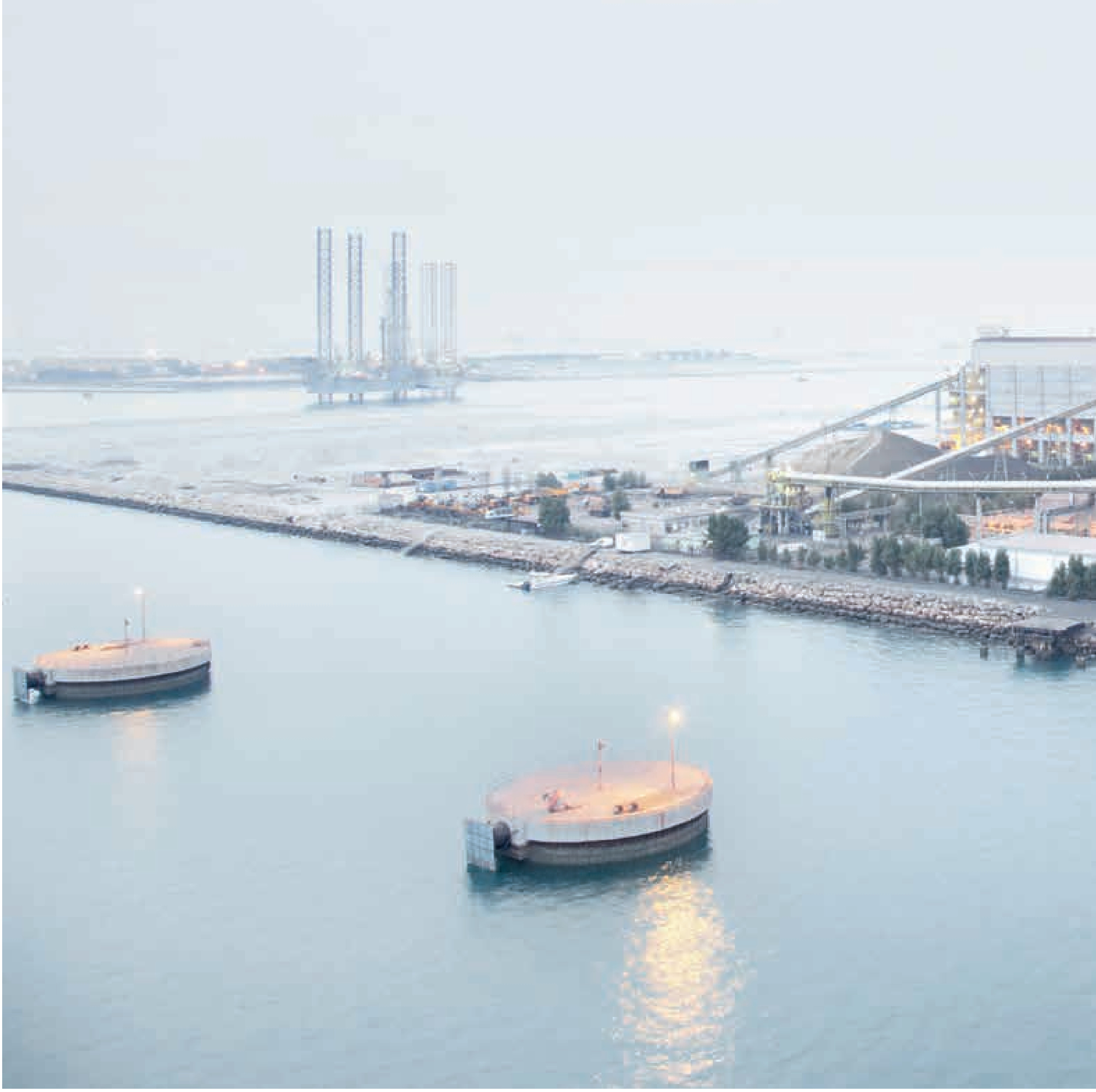
The corporate technical journal

Mining

The challenges facing mines and miners are numerous. Many mines operate in remote locations and under extreme climatic conditions. Equipment must fulfill high reliability criteria despite the rugged and harsh circumstances under which it operates. Adverse affects on communities and the environment must be minimized. Mining companies must keep track of their data and optimize processes to minimize waste and maximize productivity. Read this edition of *ABB Review* to learn how ABB is supporting mining corporations in fulfilling these demands.

The cover picture of this issue of *ABB Review* depicts the Esperanza copper mine in Chile. The photograph on the present page (and continued on page 5) shows Gulf Industrial Investment Co.'s iron ore pelletizing plant in Bahrain.



Mining

Overcoming barriers

Perpetual pioneering

Focus on mining

Claes Rytoft

Dear Reader,

This journal regularly looks at industrial processes and at the way in which ABB helps support, control and power them. Being an engineering journal, it is to be expected that it considers mostly their technical aspects. But in looking at these we should not forget that such processes would have no real purpose were there not a refined product coming out at one end – which in turn means raw products must be fed in at the other.

Not all of these raw materials are mined of course, but the importance of mining becomes clear when we consider that there is hardly a man-made object that does not contain some mined materials or was not produced using equipment containing them.

One of the reasons mining is so easily overlooked and underestimated is that it occurs mostly in distant locations, be they underground or in sparsely populated deserts or mountains regions. The remoteness of these locations often presents challenges to equipment: It must perform under extreme conditions (both climatic and operational) while maintaining the highest levels of reliability with minimal intervention. One domain in which ABB is making an important contribution is in large drive systems, for example for mine hoists, crushers and ventilation.

A central component in avoiding wastage and increasing profitability lies in operators making decisions based on accurate and actionable information. ABB is bringing its rich background in industrial control and system design as well as wireless communications into the field of mining, enabling for example, the convergence of information in the control room.

These aspects are discussed in 12 dedicated articles in this issue of *ABB Review*.

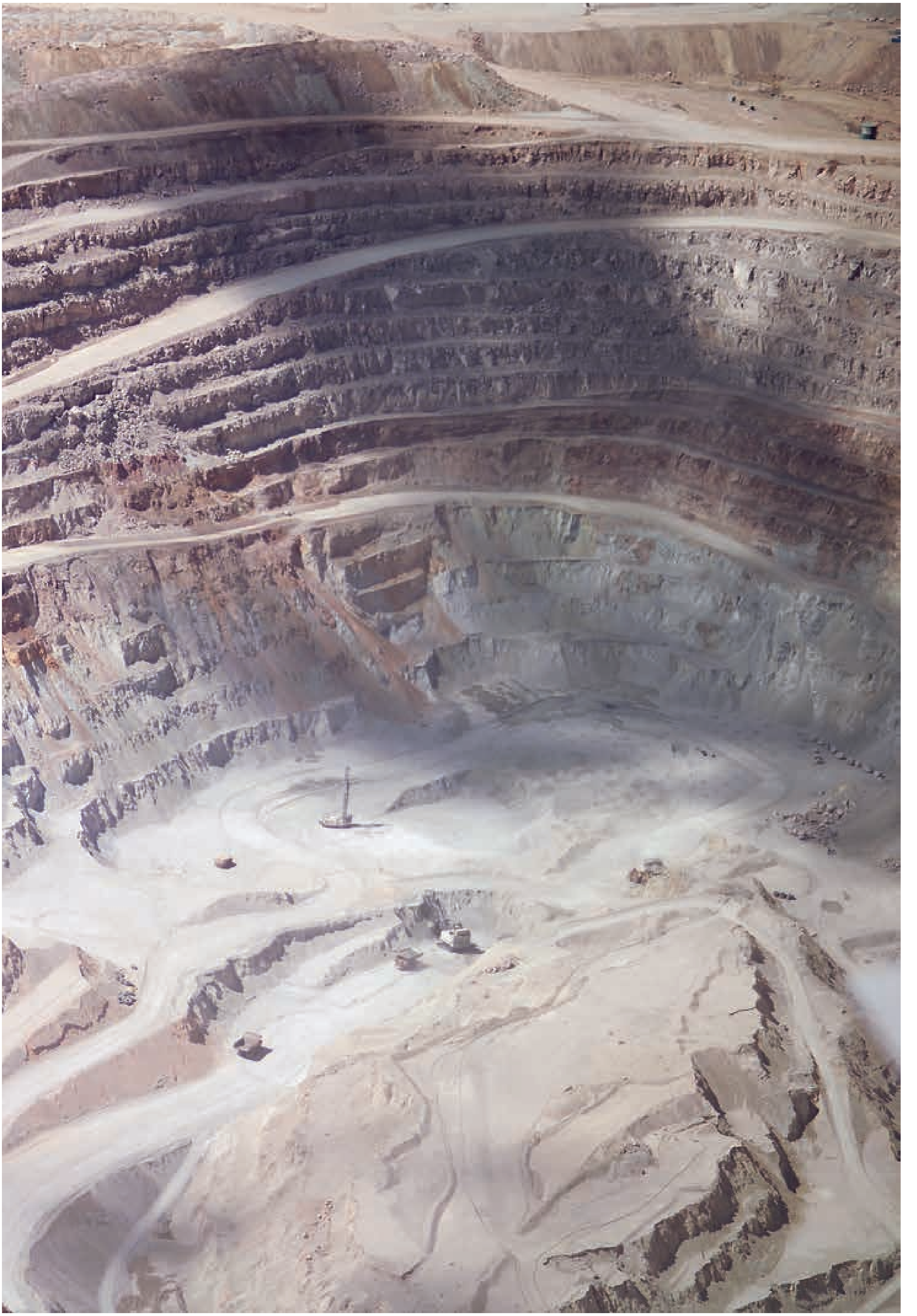
Looking beyond the scope of mining, the journal also features articles on trends in wearable computing, improving air quality in docks, and a new current measurement system. Continuing with this year's anniversary theme, we also look back on the company's 60 years in semiconductor manufacturing (both ASEA and BBC launched their first power semiconductor activities in 1954).

Did you know that besides this print edition, *ABB Review* is also available electronically? Both a classic pdf and interactive versions for tablets and smartphones are available for download. Details on this are provided on the inside back cover of the journal.

I trust that this issue of *ABB Review* will provide you with a deeper understanding of some of the issues facing mines and miners, and show how ABB is helping advance and support the industry.

Enjoy your reading!

Claes Rytoft
Chief Technology Officer and
Group Senior Vice President
ABB Group



Mine of the future

Technology convergence advances mining efficiency and productivity

EDUARDO GALLESTEY, CLIVE COLBERT – "Out of sight, out of mind" is an adage that could have been made for the mining industry. Mines are often in remote areas, can be underground and are seen only by a few. Yet everyone touches the metals and minerals they produce on a daily basis – from humble cutlery to high-tech phones there is very little that does not contain mined product. And that is not to mention the mined fuel that powers the world. Despite this pervasiveness – and a millennia-long history – mining has lagged other industrial sectors, like oil and gas, in terms of technology. But the industry is now at the start of a radical technological transformation that will be brought about by the integration of information and equipment – from rockface to factory – into one coherent extended automation platform.

Title picture
Total integration of all data and equipment will be the hallmark of the mine of the future. Already, systems are being put in place to facilitate this sea change in the industry. Among the many benefits will be the ability to remotely control mines, which are often in far-off locations.

Although demand for commodities is growing in the long term, the mining industry currently faces a unique set of challenges: Competitive pressure is driving miners to find ways to increase the production rate of their operations, reduce the cost per ton produced and extend the life span of mine sites or establish new ones. People and asset productivity has to rise too as flat underlying commodity prices, rising production costs and high price volatility (caused, in part, by supply disruptions, tight markets and new pricing systems) are currently forcing miners to reduce capital expenditure ➔ 1–2. Indeed, productivity improvement is now fast becoming a key competitive differentiator and is being built in to financial projection models.

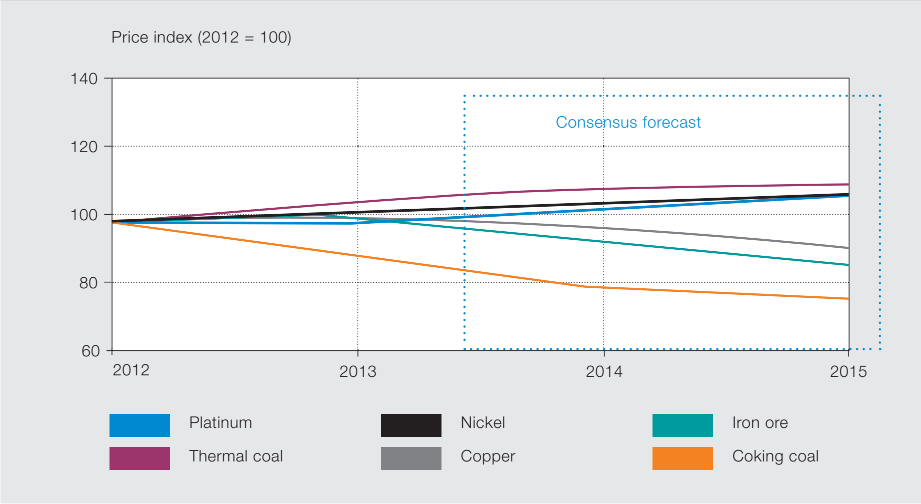
Rising energy costs mean this all has to be accompanied by reduced energy consumption and reduced carbon dioxide emissions. Mine operators are also having to look to ever more remote and inaccessible orebodies, and dwindling high-quality deposits. At the same time, miners must strive for higher workforce safety and fewer accidents – mining has, over the years, become much safer, but the number of accidents and fatalities is still at an unacceptable level.

Although demand for commodities is growing in the long term, the mining industry currently faces a unique set of challenges. The solution to these, and the future of mining, lies in automation and integration.

Added to all this is an aging workforce. In common with other industries, the age profile in mining is slowly creeping up and retiring workers are leaving with valuable know-how and experience. The situation is exacerbated by the remote and inhospitable location of many mines, which makes it difficult to bring in experts and recruit and retain competent staff.

The key to the future of mining lies in total integration. For example, with a modern automation platform such as ABB's Extended Automation System 800xA, an entire mining operation can be controlled.

1 Commodity prices have not performed well in recent years, making productivity improvements all the more urgent.



The solution to all these challenges, and the future of mining, lies in automation and integration of information and the use of that knowledge for real-time optimization of the mining processes.

An integrated view

Automation is not new to mining, but the automation employed in mines is generally more basic than in other industries and is often limited to simple control of motors, equipment or certain parts of processes.

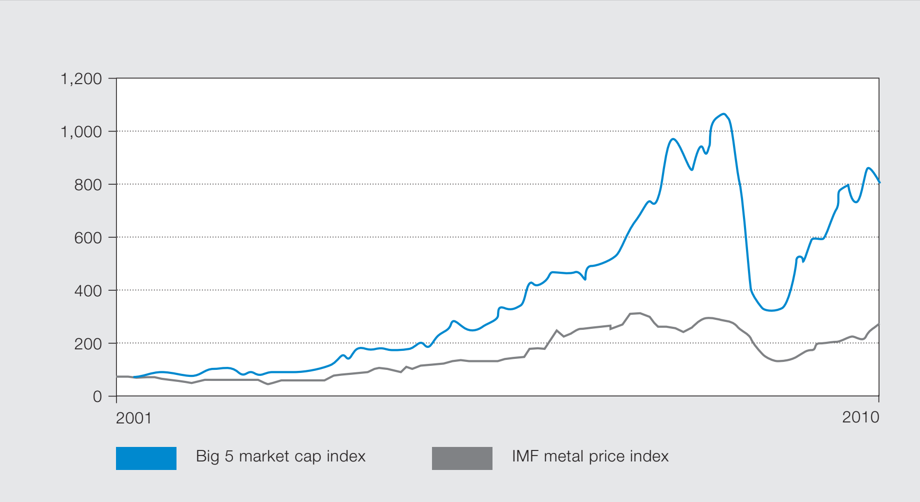
Further, mines tend to have a large number of independent pieces of equipment and systems from different suppliers. Each of these "islands of automation" can have its own data, data format and interfaces, and operators and control-room staff must scrutinize a multitude of conceptually disconnected screens in order to coordinate different parts of the process.

Integration of underground communications also improves production efficiency: Once a communication infrastructure has been established underground entirely new worlds of data exchange possibilities open up.

The key to the future of mining, then, lies in total integration of data and work processes. For example, with a modern automation platform such as ABB's Extended Automation System 800xA, an entire mining operation can be controlled: The System 800xA automation platform can handle traditional process-control systems, distributed control systems (DCSs), safety systems and electrical equipment such as drives and motors, as well as production planning, power management, maintenance, asset management, enterprise resource planning and documentation systems. These can be integrated into one single control environment. The system can integrate different users, live video, voice and public-address systems, plus Web applications and devices. Besides ABB products, third-party products can also be integrated in the process workflow.

This convergence channels more and more information from real-time systems into software, enriching four key areas that will enhance efficiency, responsiveness and profitability across the mining value chain:
- Intelligent production, and higher people and asset productivity
- Intelligent response to critical asset condition

2 High price volatility makes it all the more important to have a detailed view of the entire mining process – from rockface to end customer.



In ore-processing plants, the biggest uncertainty is the ore properties. Plants can react faster to variability if the ore properties are quantified ahead of time.

– Demand-driven planning
– Reduced energy consumption and waste

Intelligent production

Data integration can dramatically improve production efficiency and productivity ➔ 3. Some examples are:

Process optimized according to ore properties

In ore-processing plants, ore properties are the source of the biggest uncertainties. Plants can react faster to variability if the ore properties are quantified ahead of time. Extended automation makes this possible, as material movements and ore grades are tracked all the way from the mine to the processing plant.

This information can also be used by process optimization controllers that use these forecasts to make predictive adjustments to the grinding and flotation circuit according to the exact now known properties of the ore. The result is higher equipment utilization, increased recovery and lower energy consumption.

Production targets optimized according to market conditions

While some miners already have advanced process control (APC) solutions for real-time beneficiation (grinding and/or flotation) process management, most are unable to easily align this with the real-time conditions in the market. For instance, miners are unable to contextualize information on relative product pricing, data on ore and information from sales contracts, because this information is stored in disparate systems, often in a completely different unit from the control room operators.

Convergence of business IT systems and process control systems will allow the APC systems to refine the process set points to maximize financial returns for the current feed material and product pricing based on information from the sales and global pricing index.

Wireless communications enable just-in-time optimal process management

Integration of underground communications also improves production efficiency: Once a communication infrastructure has been established underground and the mobile and fixed equipment fleet has been computerized, entirely new worlds of data exchange possibilities open up. For example:
– The results reported by mobile equipment, such as online production status and production reports, analyses and statistics, can be retrieved. Further, the location and status of mobile equipment, including their local environmental data, can be monitored online.
– With this information, new drill plans and loading sequences for the production machines can be calculated and supplied in a timely manner to the operational teams underground for execution.

ABB and Atlas Copco Underground Rock Excavation, Sweden, have developed an innovative mobile integration system involving the System 800xA auto-

A modern asset optimization system can help mines to go from reactive to predictive maintenance strategies, avoiding unnecessary maintenance and reducing operating costs.

3 Effective integration of data from across the enterprise is essential to improve efficiency and productivity.

mation platform and Atlas Copco mining machines. The solution is currently installed in a mine in Kvarntorp, Sweden. This technology will offer mine operators unrivalled process control opportunities and information.

The communications infrastructure is invaluable for asset tracking too.

Intelligent response to asset condition in real time

Failure of a critical production asset can have a catastrophic impact on production targets. The loss resulting from a main conveyer failure, for example, can run into hundreds of thousands of dollars per hour.

A modern asset optimization system can help mines to go from reactive to predictive maintenance strategies, avoiding unnecessary maintenance and reducing operating costs. Extended automation solutions such as System 800xA can integrate modern maintenance systems from suppliers such as IBM, SAP or Ventyx. Real-time data on asset conditions can then be used to streamline maintenance effectiveness and enable condition-based monitoring.

In the case of the conveyer system above, if an asset monitor was to detect an abnormal condition, an alarm would be generated and the control system could slow the drive to reduce failure risk. Once integrated, these systems would connect directly into the IT systems and automatically raise a work order with the site maintenance crew. Once the crew completes the work, the completion could be instantly reported, allowing the control system to return systems to their normal state in the shortest possible time.

Demand-driven planning improves profitability

The mining supply chain extends from the extraction of raw materials through the transport of products to the end customer. To achieve production and productivity targets, mining companies need to achieve high operational performance and efficiency across supply-chain processes.

Better integration and automation across processing plant operations, mine planning and asset maintenance/management will guarantee the right product is available at the right time. It will also make sure that customer orders are accepted only when the supply chain can deliver them, thus improving negotiating power and risk management. In addition, this unified view ensures that equipment maintenance can be scheduled to minimize impact on production schedules while maintaining the required level of availability.

Reduced energy consumption

Improvements in energy efficiency can be driven not only by improvements in mining processes and technologies, but also by greater visibility and process

4 Visualizing System 800xA in a mobile environment to improve supervision, control and maintenance at the Boliden Aitik copper mine in northern Sweden

control across the value chain through information integration and process optimization.

For example, ventilation can consume as much as 50 percent of the total energy expended in underground activities, so ABB has now developed a new unique method for mine-wide coordinated control of fans and air regulators to achieve an energy-optimized and reliable solution that automatically feeds air to where it is needed.

Better integration and automation across processing plant operations, mine planning and asset maintenance/management will guarantee the right product is available at the right time.

Information convergence can reduce mining energy demands in a number of other ways too – for example, by forecasting energy requirements to exploit off-peak energy, modeling "what-if" scenarios for energy-intensive production steps and giving insight into the energy profile of a site.

Remote operation centers enable the vision

Mines of the future will be run from remote operation centers. Data from all parts of the operation will flow together to allow precise management of mining – from rockface to end customer – and resources and production to be optimized across multiple sites. A relatively simple example of mine/factory confluence can already be seen in an integrated power generation and coal mining company in Europe: When stock levels at the plant get low, an automatic message is sent to the fully automated mine, which digs, blends and mixes the coal automatically for delivery to the power station. Completely automated and optimized through one central control room, it represents the ultimate goal of future mining projects.

Future mining

ABB is committed to the mining industry and has a research program that covers all relevant topics – from sensors to modeling, visualization and optimization.

A holistic approach to the entire mining operation will feature smart devices and equipment – enabled for autonomous configuration, efficient operation and self-diagnostics – as well as software that delivers total, real-time transparency for the operators ➔ 4. This provides visibility of resources across the mine; intelligent production based on near real-time demand, market conditions and available ore types; and an optimal response to critical asset conditions.

By harnessing the full potential of extended automation and by bringing people, equipment and systems together in a fully integrated environment, ABB firmly believes that mining companies can vastly improve productivity, workforce satisfaction and safety. The automation journey for the mining industry has just begun.

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Conveying progress

ABB delivers reliable and almost maintenance-free gearless conveyor drives for high-power and high-torque applications

MARCELO PERRUCCI – With mining activities advancing into ever-remoter regions in which infrastructure is sparser, processing plants are often located further from the mine. Ore must be transported over longer distances (and sometimes underground) raising fresh challenges for conveyors. Conveyors may have to cover distances in the tens of kilometers and ascend steep gradients. At the same time, higher transport capacity is being required. To increase overall reliability, mining companies also want fewer transfer stations between conveyors, wherever possible. These requirements translate into wider and longer belts and thus higher torques being transmitted to the pulley shafts. Conventional solutions are limited by the power and torque restriction imposed by the gearbox. Partnering with the market-leading OEM, TAKRAF GmbH, ABB introduced conveyor systems meeting these increased demands while at the same time delivering radically higher reliability. Such an installation is being delivered to the mining company Codelco for the project El Teniente in Chile.

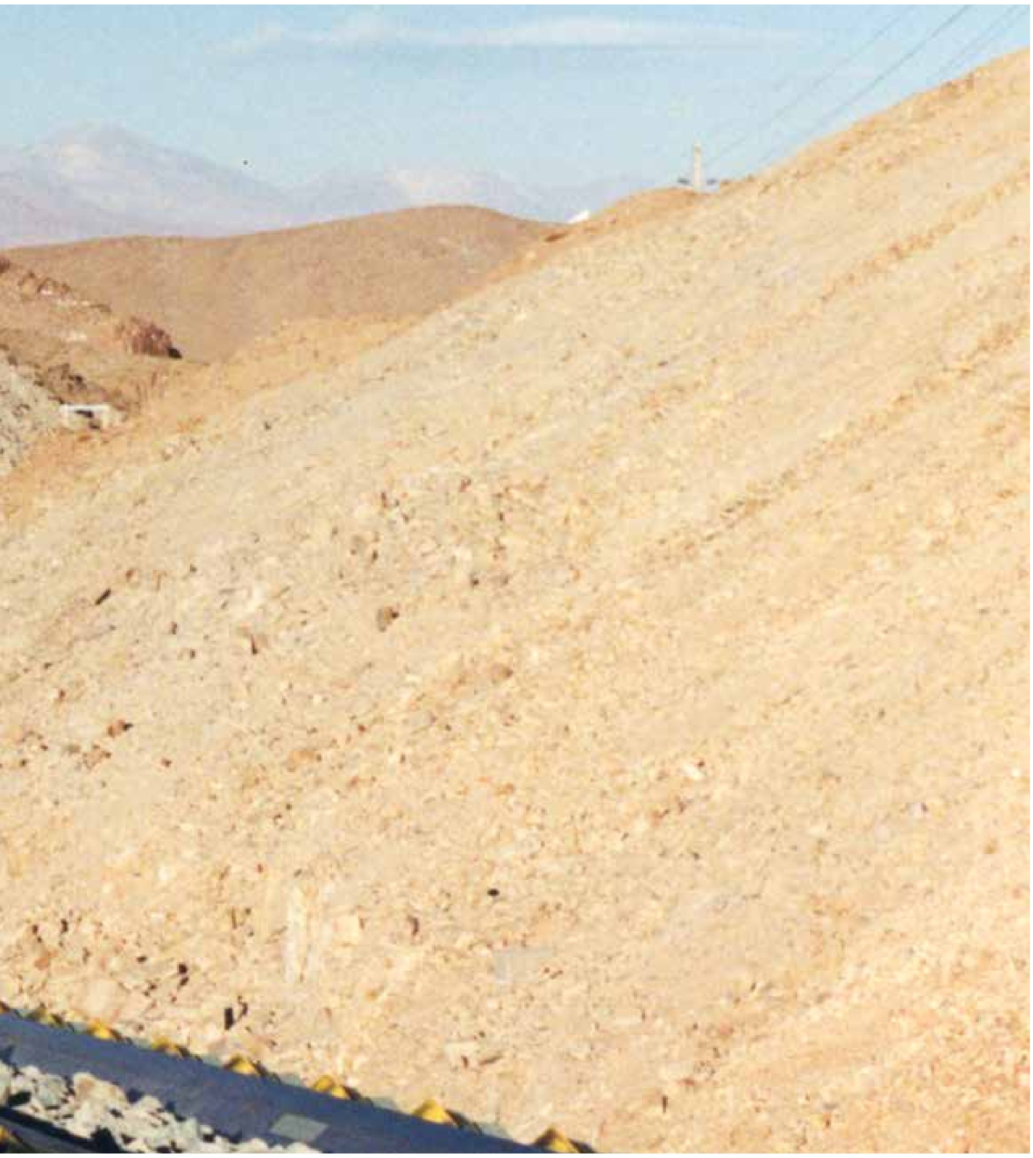


ABB and TAKRAF GmbH set about developing a low-speed drive technology addressing the main issues facing gear reducers.

Conventional conveyor transmissions face several limitations. First, the feasibility of a gear reducer with a power rating above 3.5 MW is very limited. Second, at high powers gear reducers are maintenance-intensive. The bearings of the gear reducer, together with the lubrication pump of the sealing, oil re-cooling devices, etc., can have an MTBF[1] of as little as three or four years. Changing bearings is linked to a major overhaul (failures on input bearings are most common).

Footnote

1 MTBF: mean time between failures

Title picture

Ores are being transported over longer and longer distances, raising fresh challenges for conveyors. This picture was taken at the El Abra copper mine in Chile.

Third, the operating life of the gear reducer is comparatively short (about 10 years on average). For example, a mine operation that is expected to last 20 years will require that the gearboxes be exchanged at least once during the life of the plant.

Studying the drive train of a 6 MW conveyor belt with the conventional solution reveals a count of more than 22 parts liable to wear and tear ➔ 1.

To achieve a power rating of 6 MW, the conventional geared solution requires two drive systems, each comprising a squirrel cage induction motor, a disc brake, couplings, and a gear reducer equipped with numerous parts such as motor and gear bearings, seals, tooth wheels and an oil lubrication with re-cooling unit.

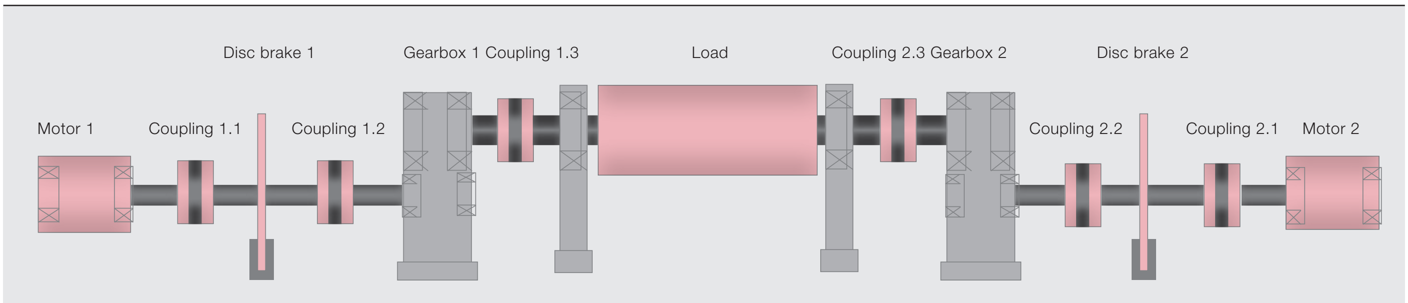
Recognizing the need for a more efficient and reliable solution, ABB signed a worldwide agreement with market-leading OEM, TAKRAF GmbH, in 2011. The partners set about developing a low-speed drive technology addressing the main issues related to gear reducers.

Go gearless!

The solution developed eliminates maintenance-intensive gearboxes and creates a gearless conveyor drive (GCD) for high-power applications. It uses a synchronous motor attached to an adapted pulley shaft specifically designed to support the high forces produced by the electrical machine.

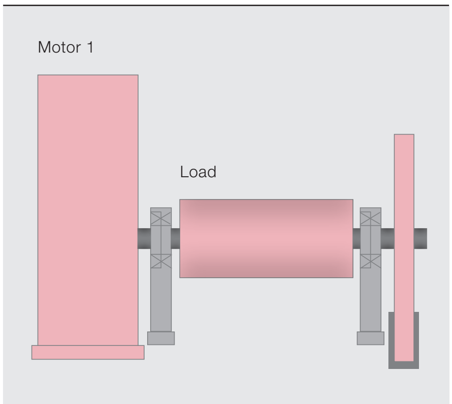
The synchronous motors run at very low speed and are driven by a frequency converter modulating the frequency and amplitude of the sine wave for full control of the application. This approach features all advantages inherent to such a

1 Geared drive with induction motors and gear reducers (eg, 2 × 3 MW)



Wear and tear (parts): > 22; MTBF: 3 – 4 years

2 Gearless single drive with synchronous motor (eg, 1 × 6 MW)



Main wear and tear (parts): 2
Motor MTBF: > 30 years

converter, including smooth control, controlled starting torque at very low frequencies, high power factor (which can be also be controlled to be 1, leading or lagging), and variable-speed control.

The frequency converters used in the GCD can be single drives, if only one motor is to be operated, or multidrive, where several inverter sections can be connected to the common DC bus with motors controlled individually. The latter approach can reduce cabling and installation costs as well as eliminate items such as individual transformers and circuit breakers. The converters can also operate in regenerative mode for downhill conveyors.

In contrast to the conventional solution, the drive train of the GCD system is simple and impressively long-lasting. The 6 MW power rating mentioned in the example above can be achieved with just one drive system, comprising a single 6 MW synchronous motor. The count of parts exposed to high levels of wear and tear is no more than two, with an MTBF of up to 30 years.

The configuration of the GCD solution → 2 clearly contrasts that of the conventional solution → 1.

The entire drive train is dimensioned to withstand the bending forces on the shaft, even during abnormal operating conditions such as earthquakes or short circuits.

Bearing or bearingless?

ABB and TAKRAF jointly developed a concept that can eliminate bearings on the motor side, dramatically increasing the availability of the system compared with the conventional geared solution, reducing acquisition and operating costs.

The entire drive train is dimensioned to withstand the bending forces on the shaft, even during abnormal operating conditions such as earthquakes or short circuits. This solution has a number of advantages for customers, such as the reduction of weight and length of the entire drive train, reduction of spare parts and ease of maintenance.

On the other hand, the equivalent installation with bearings also brings great flexibility for customers who have limitations in the installation, eg, when the conveyor's drive pulley is suspended several meters above the ground and concrete bases become unfeasible. Bearings are used as a good support to ensure a frictionless rotation of the conveyor pulley shaft, and can also help make the drive train more stable, reducing the requirement for reinforced foundations. ABB and TAKRAF are thus offering both solutions. The optimal choice depends on the particular customer and project → 3.

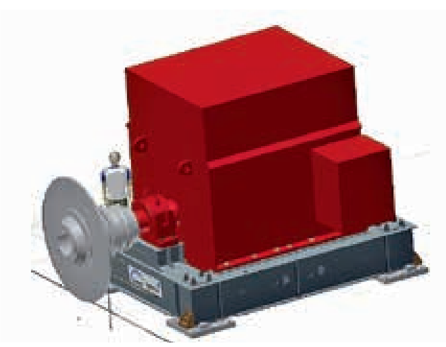
Teniente project

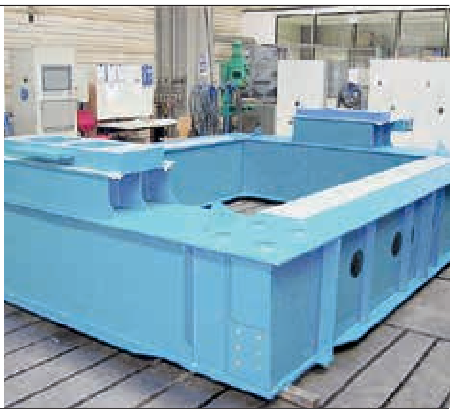
ABB has won an order to provide electrical equipment, including its new GCD, for Codelco's largest operation in Chile. The contract was awarded by Tenova

3 Comparison of bearing and bearingless solutions

Parameter	Solution with bearings	Solution without bearings
MTBF	Limited lifetime of bearings	Higher
Reliability	Reduced due to bearings and couplings	Higher
Requires additional supervision	Yes (for the bearings and coupling)	Yes (for air gap)
Lubrication system for bearings	Yes	No
Weight for transportation	45 t (higher and lower payloads exist)	30 t (higher and lower exist)
Crane capacity	Higher (only 1 piece)	Lower (can be divided in rotor and stator)
Coupling	Yes (Flexible)	No
Additional spare parts	Yes (bearings, coupling)	No
Drive train	Longer	Shorter
Capex and opex costs	Higher	Lower
ABB/TAKRAF solution available	Yes	Yes

4 Motor base frame made by TAKRAF





TAKRAF from Leipzig, Germany (as the main contracting party for the conveyor system) in December 2012.

The electrification of the new gearless overland conveyor is part of an overall $550 million expansion at the El Teniente mine, located approximately 70 km southeast of Santiago de Chile.

Project scope

The total scope of the El Teniente project is not limited to the GCD's drive train. ABB was able to contract the full scope of electrical equipment beginning at the end terminals of the feeding medium-voltage trail cable down to the motor shaft including all main and auxiliary power distribution equipment, sensors, customized E-houses, field instrumentation, cooling equipment as well as the control and automation system.

Main motors

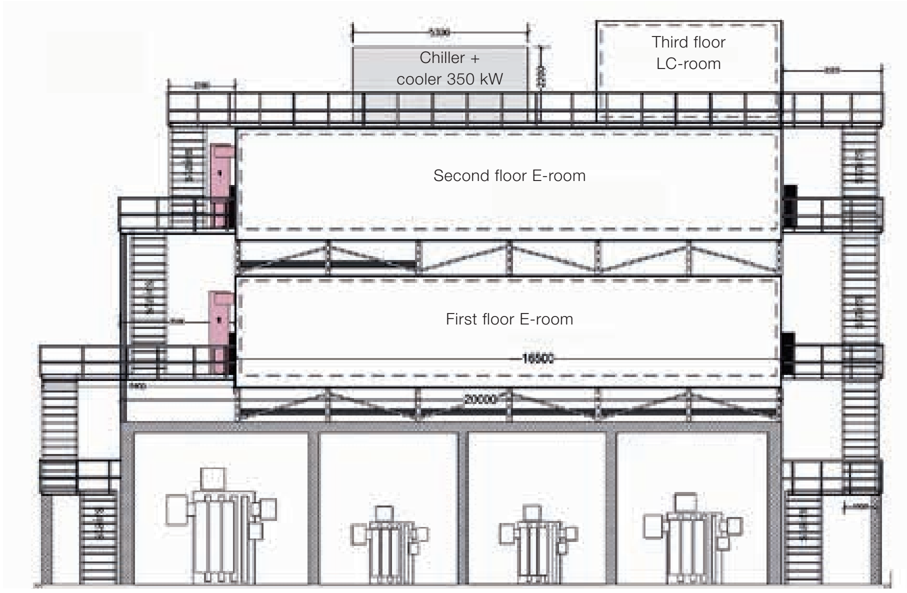
In total 12 motors of 2.5 MW, 56 rpm are to be supplied. Low-speed synchronous motors, as typically used in gearless mine hoists, serve as a basis for the motor concept. In addition, the motor had to be adapted for the conveyor application. For example, a means of easily realigning the motor after aligning the conveyor's drive pulley was needed. For this purpose, the motor is mounted on a special base frame constructed by TAKRAF → 4. The creation of this frame required a close collaboration between TAKRAF and ABB.

E-houses

The four E-houses are fully sealed and seismically proofed containers. Each E-house contains gas-insulated medium-voltage switchgear (SX2) with two incoming feeders. Furthermore the containers house motor controllers, low-

The electrification of the new gearless overland conveyor is part of an overall $ 550 million expansion at the El Teniente mine.

5 Space restrictions required the E-houses for CV-01 to be positioned above the transformers.



voltage switchgear (from ABB), UPS[2] with batteries as well as air conditioning, PLCs[3], communication panels, fire detectors and extinguishers. In addition space is reserved for the customer's own interfacing cabinets.

The containers are specifically designed for the demanding site conditions such as limited space and accessibility on rock ledges; heavy snow loads; and seismic requirements. The conveyor CV-01, for example, is designed as a three-story construction resting on top of the transformer boxes ➔ 5. Other E-houses have to be split in up to six sections for transportation.

The 6 MW power rating can be achieved with just one drive system.

Control equipment

Each E-house is equipped with redundant ABB PLC AC800M PM864 controllers. The controllers serve as the processing units for the main drives of the belt conveyor, auxiliary drives and field devices.

Communication is based on the redundant Ethernet MMS, redundant Ethernet Modbus TCP and redundant PROFIBUS DP fieldbus network to link, for example, to:
- S800 remote I/Os
- Dupline channel generators
- Belt monitoring devices
- CCM smart starter and VFDs (variable-frequency drives)
- Cooling unit for VFDs and motors ➔ 6
- Belt scales
- SOBO brake controllers
- Pt100 modules for temperature monitoring
- Counter modules for speed and slip monitoring (driven pulleys and non-driven pulleys)

Software

The controller applications are structured in a standardized and easy-to-read way according to ABB standards. The application is based on ABB's System 800xA Minerals Library. A set of purpose-built ABB software modules were developed to support the conveyor application.

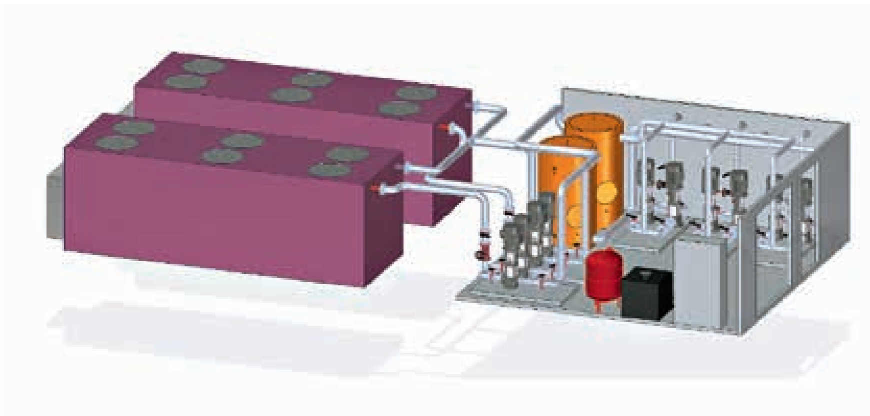
Central control station

Operators will obtain all necessary process information through five operator workplaces in the form of graphical

Footnotes

2 UPS: uninterruptible power supply
3 PLC: programmable logic controller

6 Cooling circuit for drives



The total scope of the El Teniente project is not limited to the GCD's drive train. ABB was able to contract the full scope of electrical equipment.

MCCP ensures that all connected frequency converters apply the same torque to the conveyor.

screens, alarm and event lists, and trending displays to monitor and control the equipment. Operators can control and monitor the process but cannot change parameters or configuration settings.

Main drives control

ABB VFDs are integrated with a high-speed drive bus interface (DDCS) for controlling the main drives control and with PROFIBUS DP to read diagnostic information.

ABB's Mining Conveyor Control Program (MCCP) provides the main control for the conveyor. The sophisticated control loop is superior to traditional control methods (such as basic master-follower) in control accuracy and flexibility. Special attention is given to the starting of the shared load and to shared operation between the motors in order to mitigate high torque peaks and longitudinal oscillation in the belt.

MCCP ensures that all connected frequency converters apply the same torque to the conveyor, whereas defined load sharing between different pulleys can be adjusted. In addition all necessary limitations, supervision and protection functions are included in MCCP.

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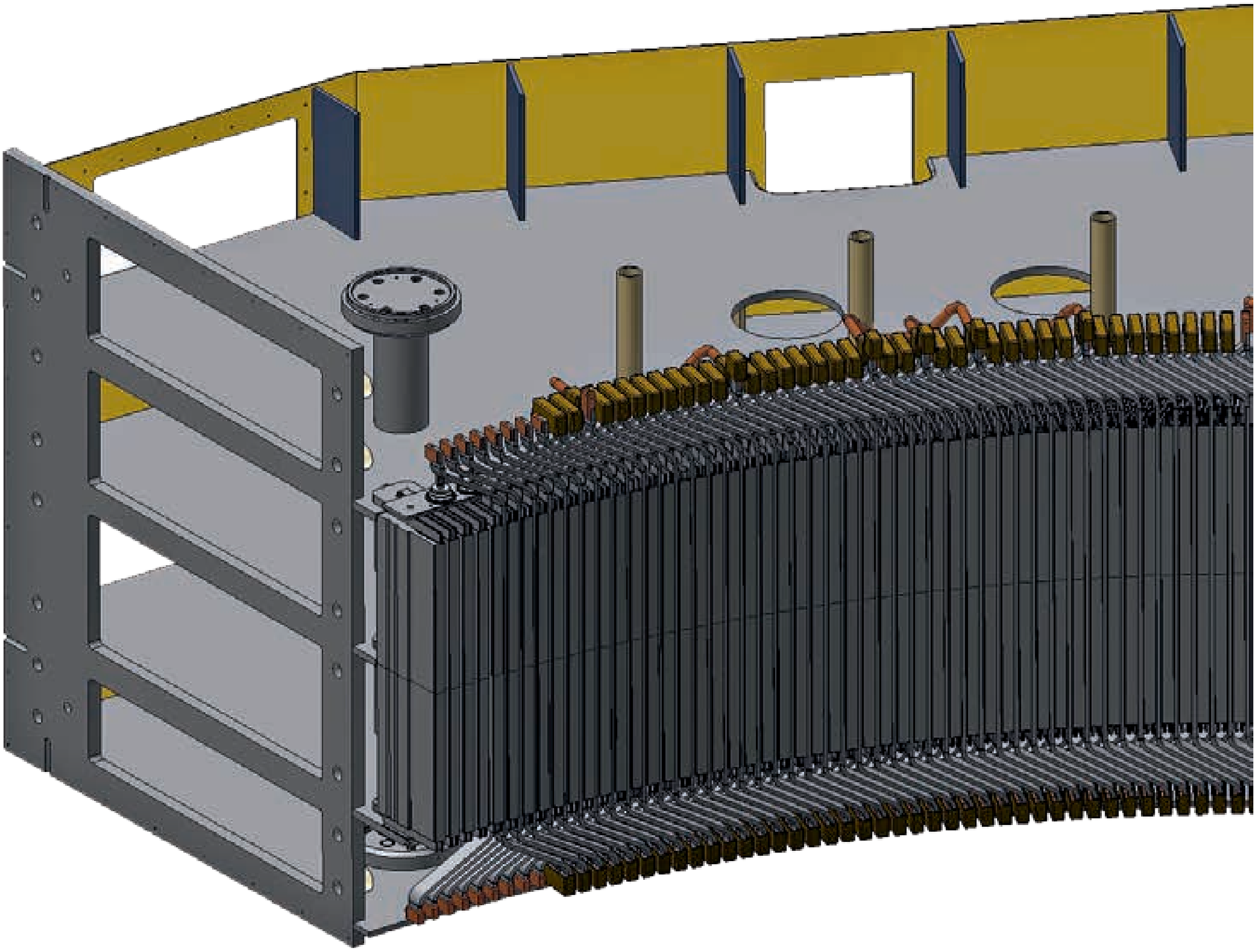


Advanced 3-D windings

GMD 3-D windings with just a few clicks

MACARENA MONTENEGRO-URTASUN, GIOVANNI CANAL, JAN POLAND, AXEL FUERST – Gearless mill drives (GMDs) are produced individually according to customer specifications and so are not available as an off-the-shelf product. According to IEEE, 33 percent of all failures, and the consequent exorbitant downtime costs, detected on large motors such as these during normal operation are related to the stator winding. ABB has introduced a 3-D winding design philosophy that allows different winding layouts to be evaluated and compared, offering a solid base for analysis and solution choice. This translates into reduced manufacturing costs, faster site installation, shorter repair times and a lower risk of winding failures due to poor design.

1 Flow diagram for the 3-D winding design process

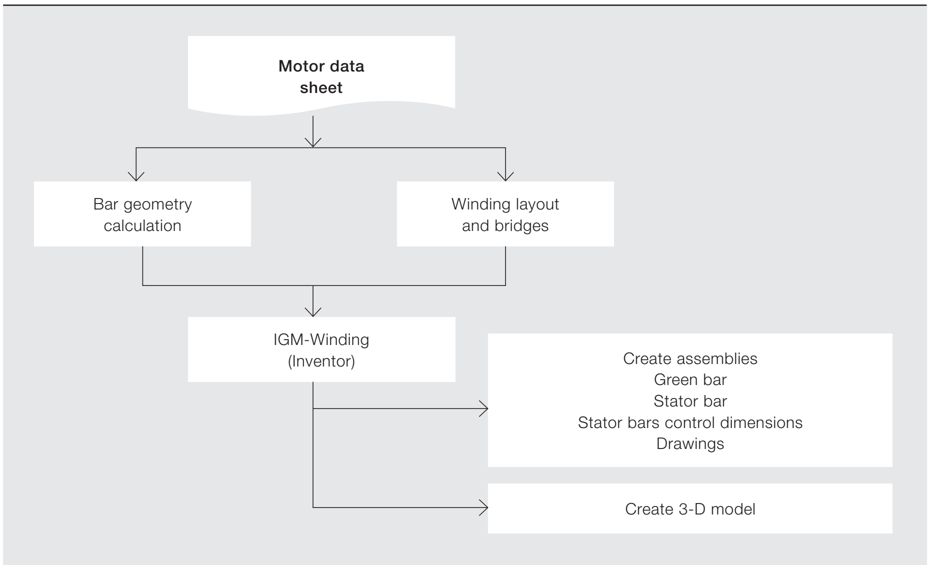


ABB delivered the world's first GMD, an 8,600 horsepower (6.4 MW) motor for a ball mill, to Lafarge Cement in France in 1969. Since then, GMD systems have become larger, more powerful, and are now operating at higher altitudes – even above 4,000 m – where the extreme environmental and boundary conditions challenge the lifetime of a GMD. Under these demanding conditions, only the very best winding design will perform.

Optimal design with IGM-Winding

The current design approach for GMDs is to develop 3-D GMD models based on parameterization and to generate 2-D manufacturing drawings. Today, the parameters are calculated from the motor specification data and a 3-D model is then created automatically. This model is the basis for further detailed engineering and numeric simulations. The most complex part of this is the motor winding design.

Title picture

ABB's sophisticated IGM-Winding design tool provides electrical machine engineers with a powerful means of optimizing windings. The resultant higher-quality product saves cost, speeds installation and lowers failure risk – especially welcome in remote locations.

Without the proper tools, winding design and optimization is almost impossibly demanding, requiring a huge amount of time just to evaluate possible winding layouts and minimize the risk of winding failures due to insufficient air clearances. The objective, then, was to develop a tool that would create a parametric 3-D model – from the single bar to the complete winding assembly – that allows evaluations and optimizations of different winding layouts before the best option for manufacturing is chosen. The output of the tool is the complete set of optimized and reviewed construction drawings necessary for the winding manufacture, and later, quality control. The tool ABB developed to do this is called IGM-Winding.

The design tool was implemented in three stages: the bar geometry calculation, the winding layout calculations and the 3-D parametric model of the winding.

Three stages, one project

Over the last two years, the design tool has been implemented in three stages, encompassing: the bar geometry calculation, the winding layout calculations and the 3-D parametric model of the winding. The tool output is the construction drawings of each piece required to build the winding → 1.

The bar geometry calculation consists of a short routine that allows the geometrical calculation of the stator bars, using as inputs the values of the motor data sheet.

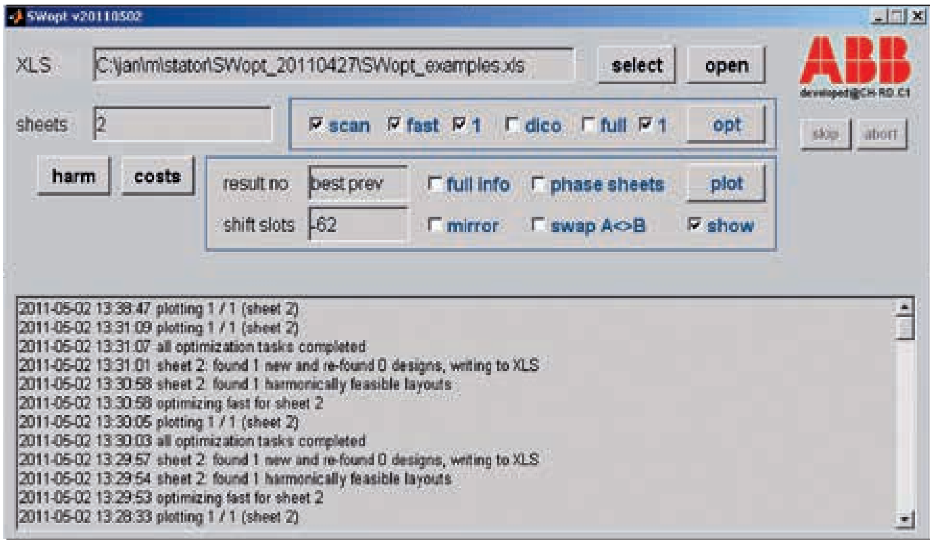
The winding layouts and bridges are calculated with a tool developed by ABB → 2a. The jumpers can be arranged in different ways without influencing the electrical layout of the design → 2b. When the final layout is chosen, it is necessary to create a list to define which type of bar is located in which slot → 2a.

The 3-D winding tool, IGM-Winding, implemented in Autodesk Inventor, builds and draws the 3-D parametric model of the winding and its components, using as inputs the values obtained from the bar calculation geometry and the winding layout calculation.

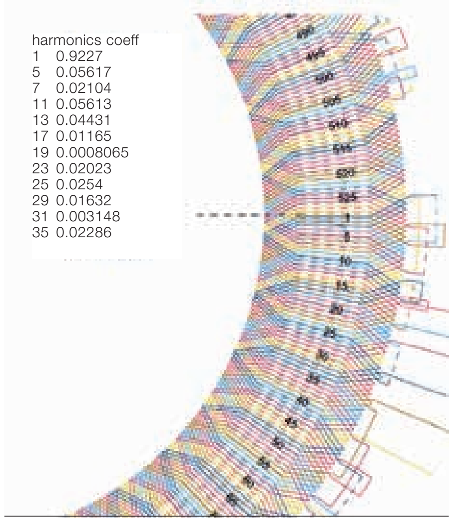
Choosing the best winding layout

Deciding on the best winding layout is a challenging optimization problem. Since fractional windings (layouts where the

2 Winding design tool



2a Typical display



2b Winding layout obtained with the tool

number of slots is not an integer multiple of the number of poles times the number of phases) are typically preferred for their favorable harmonics properties, each coil cannot just be connected directly to a neighboring coil. A valid winding layout must contain jumpers, which bridge gaps between coil ends that are some slots apart. These jumpers may be placed in more or less favorable ways, where the main criterion is the minimization of material (copper) and manufacturing costs. In fact, the layout problem for one single phase is an example of the famous traveling salesperson problem (TSP), which is one of the most widely studied problems in mathematical optimization. The goal is to find a route going through all coils (in TSP terms: cities) exactly once, such that the cost of the route (which is the cost of the connectors) is minimal. The TSP problem is known to belong to a class of problems that are hard to solve at present and it is widely believed that these problems will remain hard in the future.

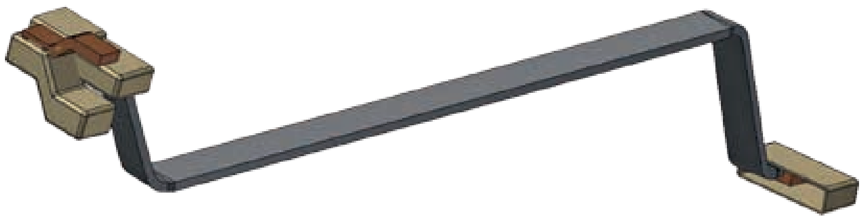
For the winding layout itself, a problem even tougher than the TSP problem has to be solved: There is one TSP problem for each phase and they interact because all the jumpers selected for the optimized layouts must not conflict with each other. Moreover, the electric fields induced around the jumpers interact if the jumpers are adjacent, so favorable interactions of fields that cancel each other out, rather than reinforce each other, are sought. In addition to the placement of the jumpers, the assignment of the bars to the three phases has to be decided and this decision influences the harmonics properties of the winding.

The task of optimizing the winding layout is translated into commonly used mathematical optimization frameworks: mixed integer programming (MIP) and constraint programming (CP). The MIP formulation offers the advantage that (piecewise linearized versions of) all design criteria can be accommodated in the framework. On the downside, MIP solvers typically employ a branch-and-bound strategy over a search tree, which may take large amounts of computational time to complete to proven optimality. CP, on the other hand, is a different approach that executes a search for good winding layouts guided by the constraints of the problem (the geometrical conflicts of the jumpers). It has the advantage that it can often produce very good solutions very quickly, but without the guarantee of global optimality.

3-D winding design

The first step in the 3-D winding design process is the creation of the 3-D winding assembly – a complete stator where the total number of slots is filled with the corresponding top bar (TB) and bottom bar (BB). For this first step, it is necessary to create a 3-D bar assembly that includes the bar plus all associated elements – ie, different lugs, z-connections and insulation caps. This is done for the top and bottom bar, because they are geometrically different → 3.

3 Bottom bar assembly with all elements (lugs, Z-connection and insulation caps)



The biggest innovation of IGM-Winding is its ability to parameterize, in 3-D, any winding layout, thus aiding comparison between variants and facilitating automatic drawing creation.

Once the TB and BB assemblies are built, the tool starts to automatically fill each slot of the 3-D winding assembly with the corresponding TB and BB type. After finishing, the 3-D winding assembly corresponds to a 3-D parametric representation of the winding layout.

Normally, it is possible to obtain several electrical winding layouts with different jumper combinations for one design.

The TSP problem is known to belong to a class of problems that are hard to solve at present and it is widely believed that these problems will remain hard in future.

The biggest innovation of IGM-Winding is the ability to parameterize, in 3-D, any winding layout, thus aiding comparison between variants and allowing the automatic creation of all construction drawings.

Once the winding layout is chosen, the 3-D design process continues with the integration of the winding into the frame ➔ 4. This step is crucial for the validation of the design, especially for GMDs located at high altitudes, and to corroborate by accurate measurement all the distances needed to install or adjust critical elements in the machine.

The layout of the terminal bars is embedded into the frame ➔ 5. This is the only part of the design that is done manually and it takes into consideration the best possible routing – based on bending angles, length of terminal bars and position of the terminal box.

IGM-Winding user interface

The IGM-Winding user interface determines the general software settings. The program generates the protocols of the steps and drawings during the process. These are stored in “Info” and “Log” and can be exported to a CSV file. The function called Green Bar creates two drawings: one for the green bar and one for the consolidated bar. These drawings are required at the beginning of the design process and they are sent to the copper supplier to produce the Roebel bars.

The function “Create Assemblies” needs to be executed before additional drawings are produced. It creates all the 3-D models of the different TB and BB assembly types (M01, M02, etc.) and their different elements.

The functions “Stator Bar” and “Stator Bar Control Dimensions” produce the drawings of the different bar types in a winding layout and their respective control dimensions for bar manufacturing. These drawings are very important for the bending tool manufacturing, for the bar production and for quality control.

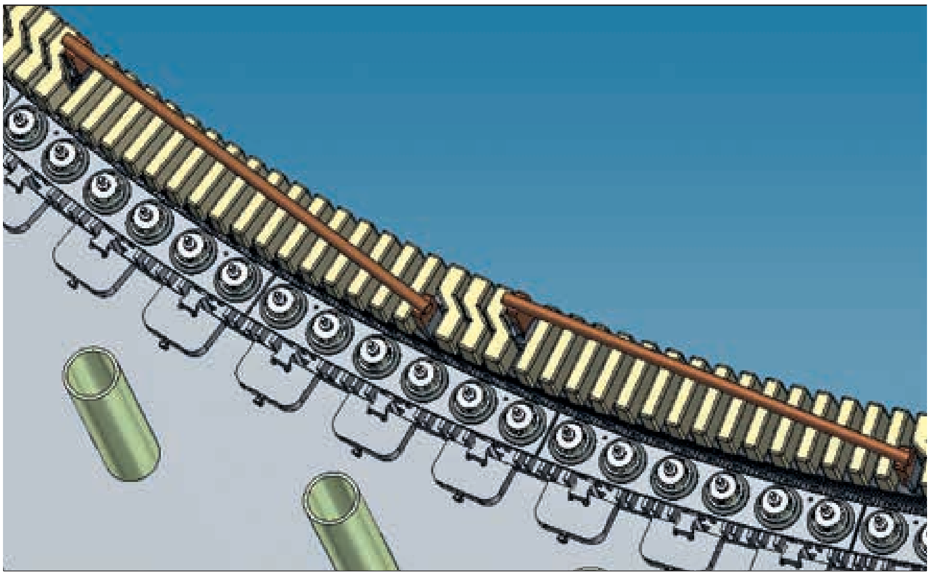
The function “Create 3-D Model” produces the 3-D winding assembly.

Optimization potential

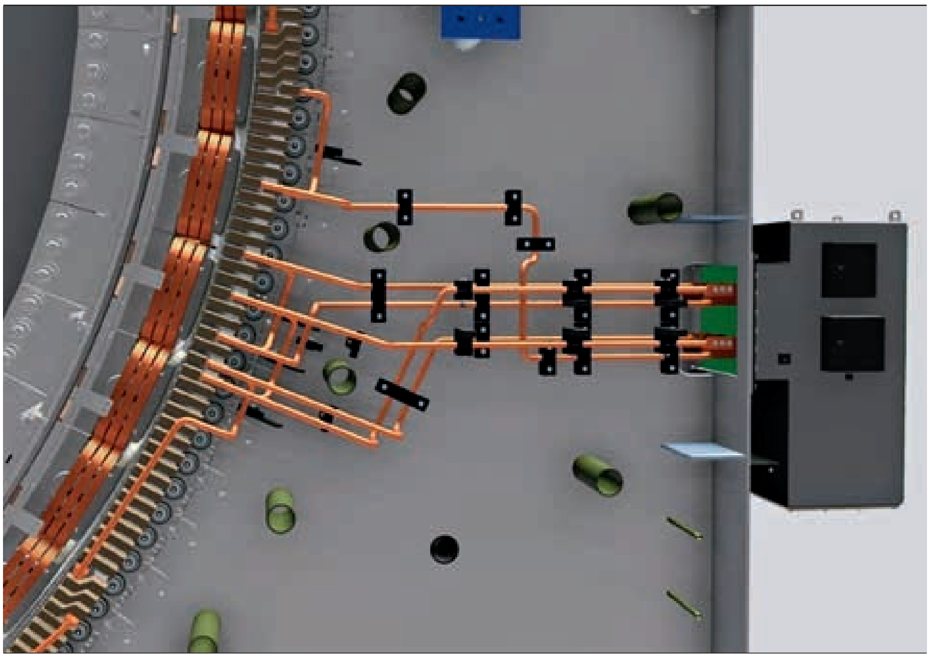
Once all the information is collected and the different possible winding layouts are defined, the optimization can take place.

The task of optimizing the winding layout is translated into commonly used mathematical optimization frameworks.

4 Integration of the winding into the frame



5 Terminal bar and phase bars connected to the terminal box. They must be designed with caution as space is limited.

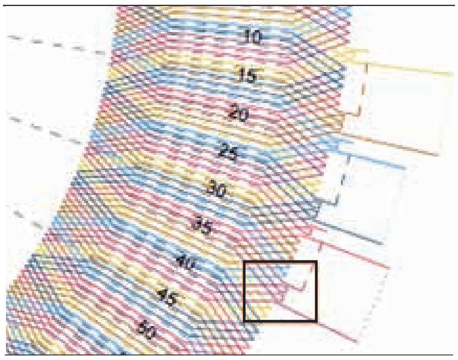


An example of a machine with 540 slots and 36 pole pairs serves to illustrate the capabilities of IGM-Winding.

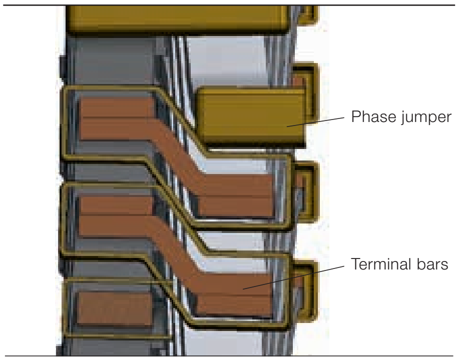
At first sight, the winding layout looks quite simple, with no jumpers in the stator winding, only the phase jumpers in the area of the terminal bars. A detailed view shows the phase jumpers, terminal bars and z-connections → 6. A 3-D winding assembly is marked in the black square, with a top view of the area in → 7. Thanks to the 3-D view it is possible to predict two regions where conflicts will appear when building the insulation caps over the bar connections on the winding. The space between the terminal bar insulation cap and the z-connection next to it does not permit construction. It is the same situation between the phase jumper insulation cap and the neighboring z-connection. Due to a lack of space it is not possible to build this winding using z-connections. For an alternative solution it is necessary to consider the minimum distance between the connections, and the feasibility of construction and insulation of the new connection geometry.

The optimization process can take place at any stage of the design and in this specific case includes mainly the construction feasibility of the alternative piece, preserving the minimum tolerances and air clear-

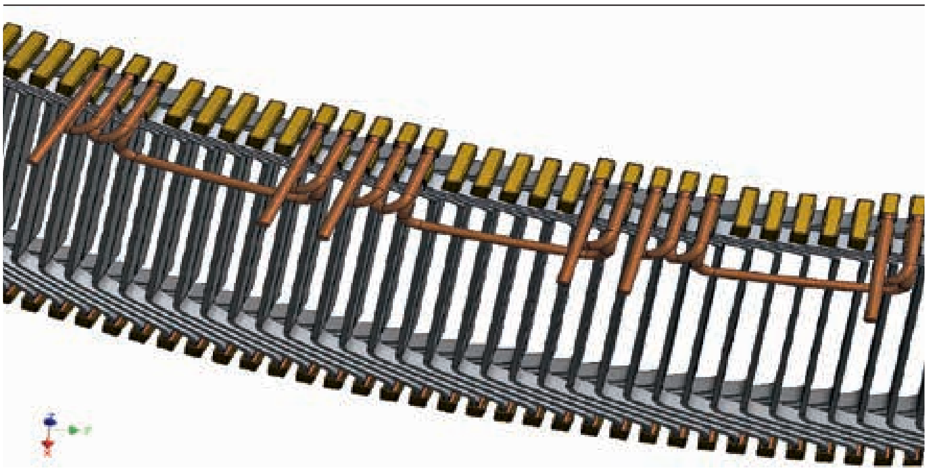
6 3-D winding assembly layout. The detail of the area in the red square is shown in the next figure.



7 3-D view of winding layout



8 3-D winding assembly



ances. The 3-D view of a winding layout shows a completely different scenario than the 2-D winding layout → 8.

The cost optimization, without any effect on quality or performance, is not only related to the number of bridges present in a winding layout. It can also be related to the price of a z-connection compared with the price of a small, bent bridge. The cost of the additional inductor required for a z-connection brazing, as well as brazing time, location of terminals, length, etc., disappears when the small bridge is applied (same inductor as terminal bars). All of these aspects should be considered in order to obtain the best feasible solution.

Optimized design, minimized risks

ABB's unique IGM-Winding tool optimizes the winding layout of an electrical machine, helping the design and construction teams to make the best decisions based on accurate, parameterized 3-D models. The automated process and foresight delivered in the early stages of critical design problems allow the minimization of design and drawing creation time.

The accurate prediction of critical distances minimizes the risk of manufacturing problems and, later on, of premature failure of the windings due to poor design, especially for GMDs located at high altitudes. IGM-Winding can be used to design any motor or generator and is already in use for ABB's GMD designs.

ABB's unique IGM-Winding tool optimizes the winding layout of an electrical machine, helping the design and construction teams to make the best decisions based on accurate, parameterized 3-D models.

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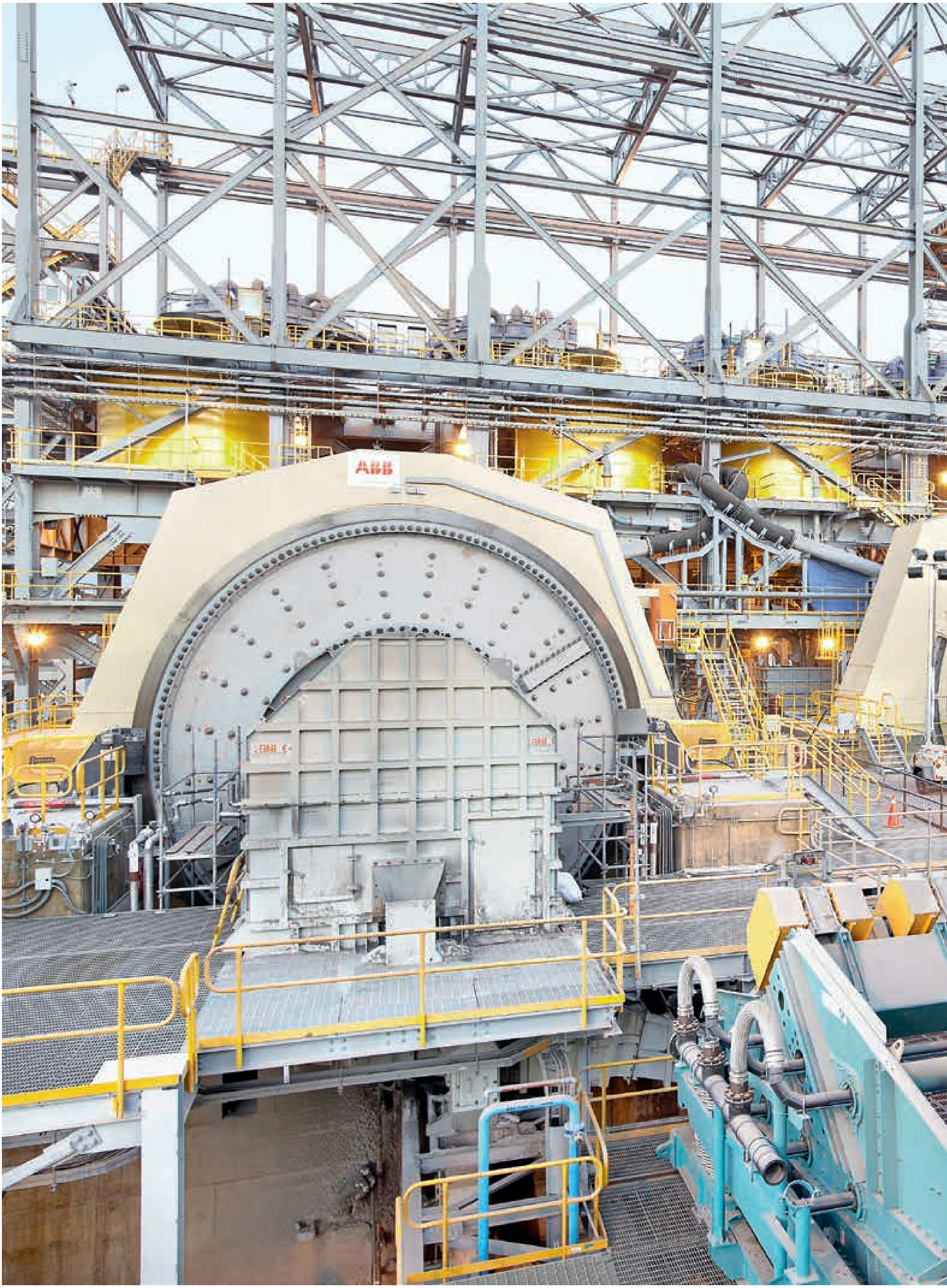


ABB

Bigger is better

ABB drive systems enable the mining industry to employ bigger mills

VENKAT NADIPURAM – One of the key challenges in the mining industry today is maintaining throughput in the face of ore grade quality that has declined by 40 percent in the last decade. Returns must be attractive even with energy costs and environmental regulations increasing. Industry analysts expect the mining industry to register modest growth in the coming decades, thereby making higher productivity essential. As an industry leader in mill drives, ABB combines its extensive industry knowledge with its application experience to provide a diverse portfolio of drive solutions for the mining industry.

Title picture
ABB drive solutions help operate the enormous mills being used in the mining industry today. This is the GMD at Esperanza Copper mine in Chile.

Throughout the comminution process, different mills are driven by different types of electrical drives.

1 Different processes used in comminution

Process	Size range (mm)
Explosion	∞ – 1000
Gryatory crusher	200 – 1000
Cone crusher	20 – 200
AG / SAG mill	2 – 200
Rod mill	5 – 20
Ball mill	0.2 – 5
HPGR	1 – 20
Stirred mills	0.001 – 0.2

Explosion | Crushing | Grinding

2 Ball mill at Boliden Aitik copper mine

At the most basic level, mining is about freeing trapped valuable metal from its ore. However, there is nothing basic about the comminution of raw ore. Complex processes using a variety of different mills are carried out in order to reduce the size of the raw ore pieces to a more usable form ➔ 1. Comminution circuits are typically connected by conveyor belts. Crushing and grinding are the two main and critical processes in a comminution setup, with each requiring reliable and energy-efficient equipment that also includes drive systems.

Comminution circuits are generally classified as either autogenous-ball milling-crushing (ABC) or semi-autogenous-ball milling-crushing (SABC) circuits. An ABC circuit consists of an autogenous grinding (AG) mill, ball mill and crusher. An SABC circuit consists of a semi-autogenous grinding (SAG) mill, ball mill, and crusher. A ball mill is a slightly inclined, horizontal rotating cylinder, partially filled with ceramic balls, flint pebbles or stainless steel balls, that grinds material to the necessary fineness by friction and impact with tumbling balls ➔ 2.

An example of an industry-standard comminution circuit providing high throughputs can be seen in ➔ 3. This circuit, however, has a high specific energy consumption per ton of ore processed, driven primarily by the low efficiency of the ball mills and the need to use steel media for grinding.

Ring-geared mill drive

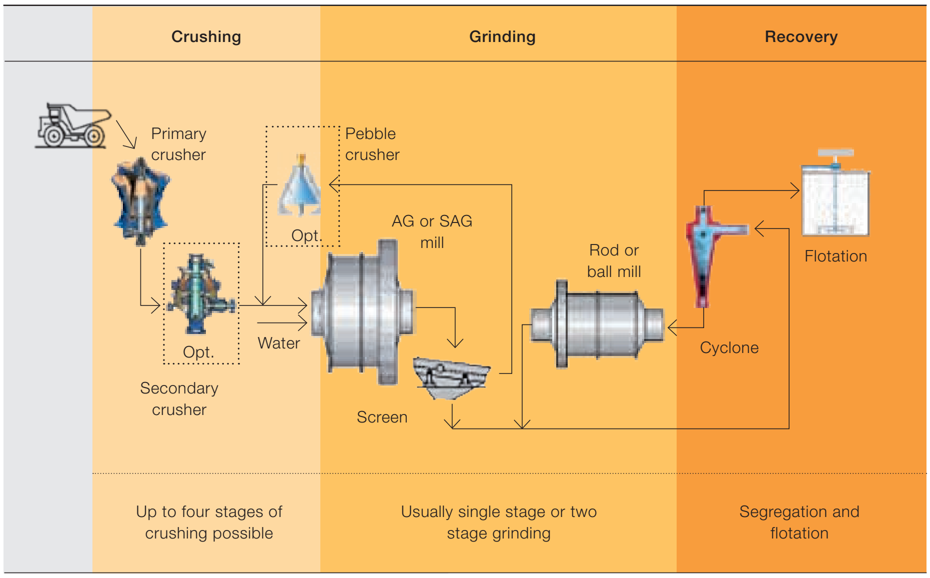
Throughout the comminution process, different mills are driven by different types of electrical drives. ABB provides a variety of different types of drive solutions for the mining industry.

For example, ring-geared mill drive (RMD) systems are good solutions when the power required to drive the mill is under 18 MW, ie, a maximum of 9 MW per pinion ➔ 4. Yet as tube mills grow in size in order to meet the demand for larger throughputs, the power required to drive them increases. Although ABB can manufacture drive systems for very large power ratings, the physical limitation of a mechanical gear limits its application for driving tube mills where the power required is over 18 MW.

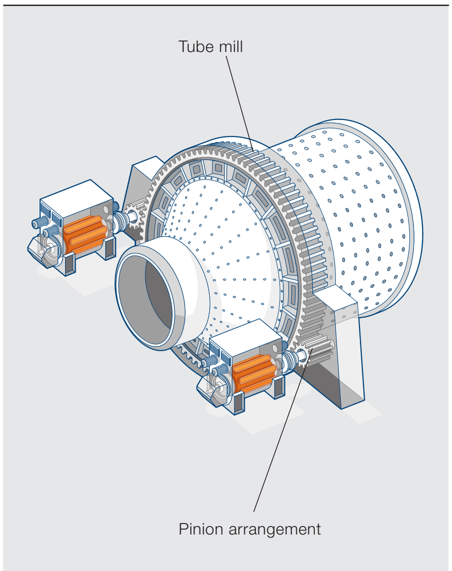
Gearless mill drive

The limitation of an RMD system was overcome by ABB when it introduced the first gearless mill drive (GMD) in 1969 for the cement industry. ABB introduced the first GMD into the minerals industry in 1985 and since then it has become the de facto standard equipment for mines with larger throughput requirements. ABB has sold and installed over 120 GMD units worldwide.

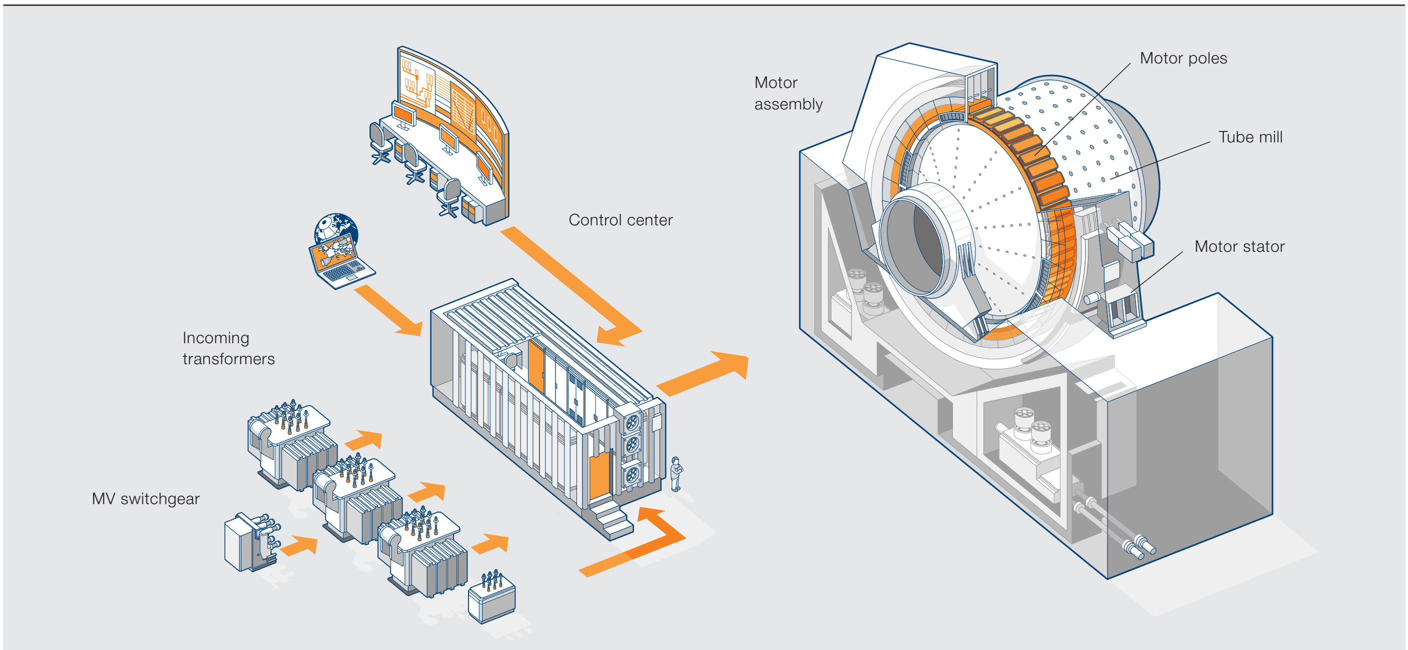
3 SABC flow sheet



4 Ring-geared mill drive solutions



5 Gearless mill drive solution



The advantages of a GMD application in the minerals grinding process have been well established over the past 40 years, with the benefits increasing exponentially as the mills get bigger.

In the GMD solution the drum of the mill forms the rotor of the motor, with the motor poles mounted along the external circumference of the drum → 5. The stator is mounted around the pole assembly. The operation is carried out with high precision so that the final gap between the poles and the stator is no more than 14–16 mm, depending on the mill size.

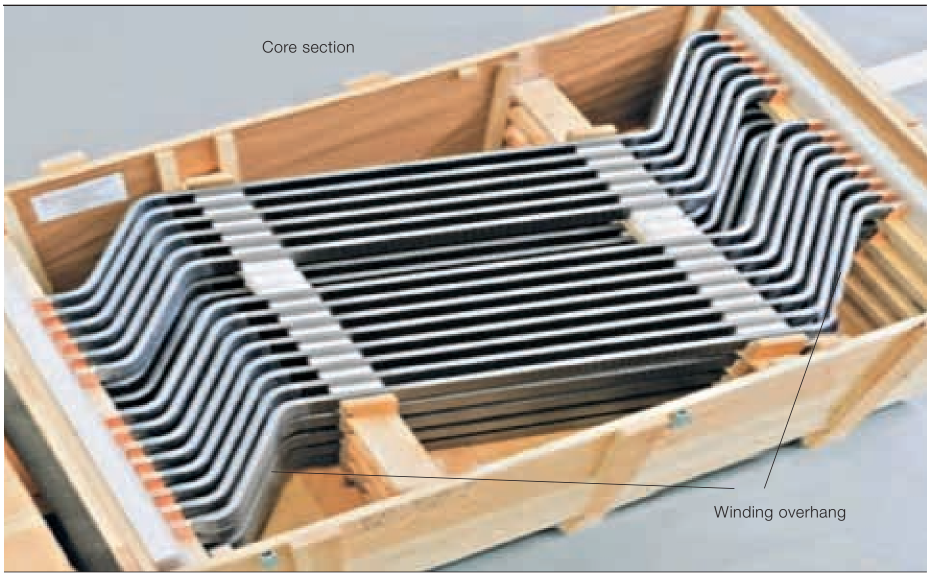
By not having a gearbox (gear and pinion), the mechanical limitation associated with gears is eliminated. This allows mill diameters to increase as required. The world's largest GMD, with a diameter of 12.8 meters, will be delivered by ABB to the Conga mine in Peru.

Eliminating gears improves the efficiency and availability of the mills and reduces maintenance work. The intrinsic ability of GMDs to provide variable speed improves the overall efficiency of the grinding process in terms of energy used and grinding result. Variable speed also reduces network sags during mill startup and allows features like frozen

Eliminating gears improves the efficiency and availability of the mills and less maintenance work is needed.

ABB provides optimized, state-of-the-art drive solutions for HPGR mills and currently has the largest installed base for the over 2 MW power range.

6 Full vacuum pressure impregnation for windings



charge protection, controlled roll back and positioning for mill maintenance needs.

Design improvements

Since the introduction of GMDs, ABB has delivered customized solutions for every individual mine and process requirement, from power ratings and size to site altitude. ABB's most recent achievement in this area was commissioning a 28 MW system at 4,600 m above sea level.

ABB continues to develop new features and designs to guarantee higher availability and reduced maintenance, particularly for high-altitude and remotely located mines.

The grinding process with HPGRs is a dry process, thus saving water, which is a scarce resource in many mining sites.

For example, particular attention has been given to the stator winding insulation. The stator winding consists of a bar winding with individually insulated strands that are intertwined to use the entire copper cross section almost evenly while reducing losses and lowering eddy currents → 6. These strands are packed in a Mica-based VPI insulation. The whole stator bar is "VPIed," including the slot section and the winding overhang area, which is important for high-altitude applications. The stator core sheets are pressed together to increase the overall stiffness, which minimizes the retightening work required during the ring-motor lifetime.

GMD condition monitoring

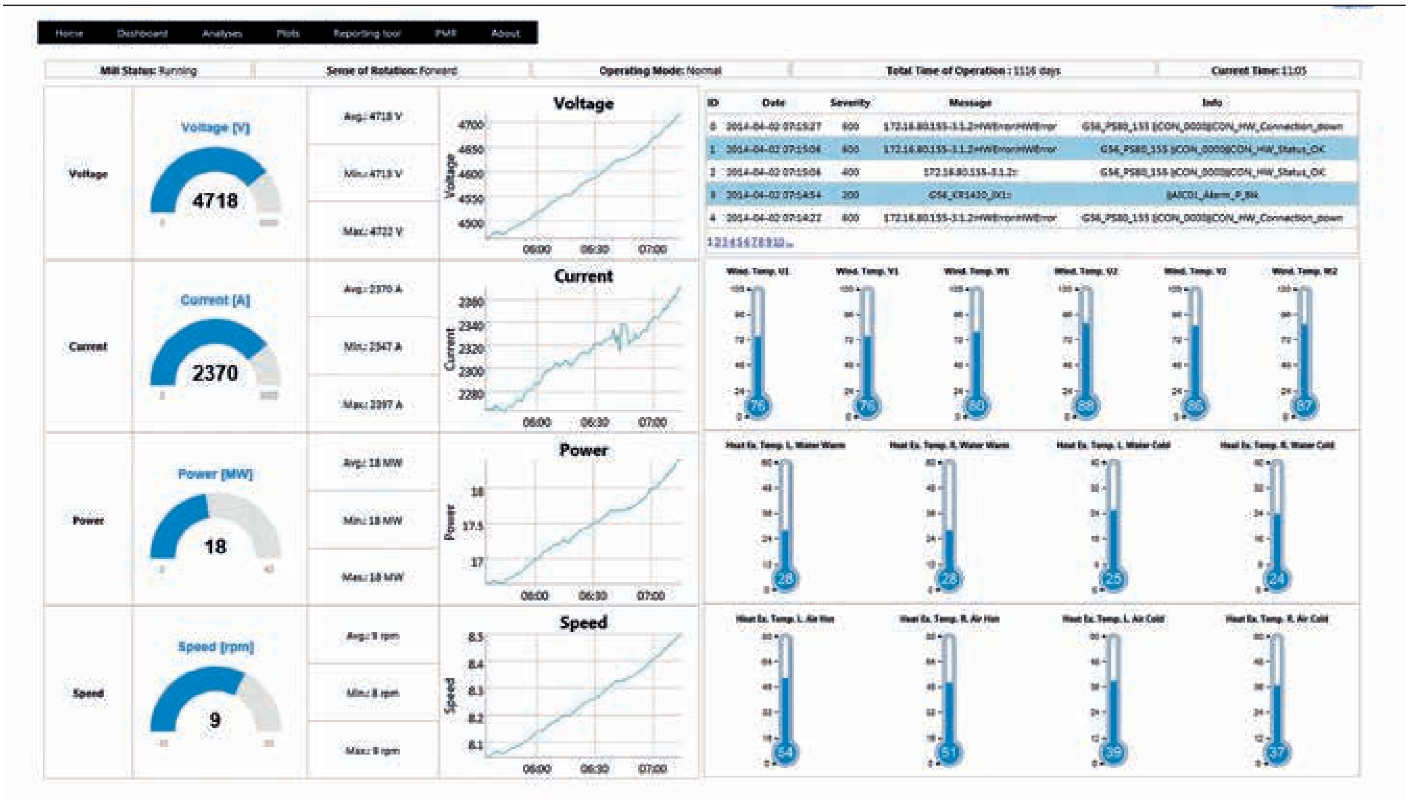
ABB has developed advanced remote diagnostic tools for troubleshooting as well as predictive maintenance. For example, with up-to-date operation information from the system, operators are notified of any potential problem long before an automatic alarm or trip is activated. Notifications are sent by e-mail or text messages to the mine operators as well as ABB remote diagnostic engineers → 7.

The diagnostic tools monitor a wide range of signals from all the key components of the GMD system including transformers, cycloconvertors and the ring motor. This allows for continuous analysis of the system status and the ability to inform the customer in a reliable and timely manner of any potential problems that may arise during operation.

A maturing grinding technology

Today's mining industry is increasingly facing a new challenge: how to develop bigger grinding machines to sustain

7 Screen shot of an ABB remote GMD condition monitoring console



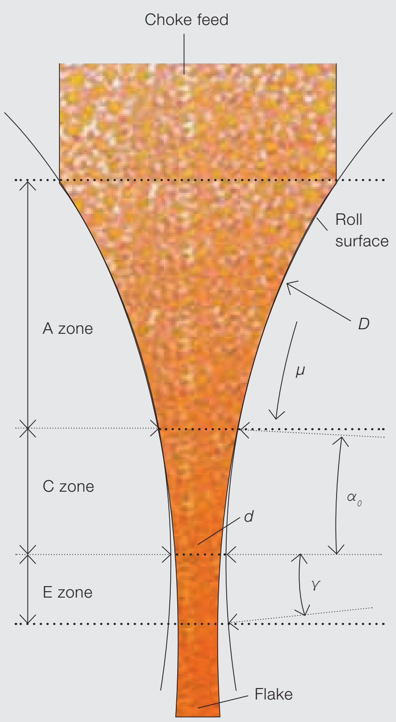
8 Operating principle for a HPGR

High-pressure grinding is achieved by using an advanced type of grinding roll. The machine consists of two counter-rotating rolls. One of the rollers is fixed and the other is movable in a horizontal direction.
A constant pressure is applied to the moving roller via hydraulic cylinders to impart pressure to the material.

Contrary to conventional crushing rolls, the particles are broken by compression in a packed particle bed, and not by direct nipping of the particles between the two rolls. This particle bed is created between two choke-fed, counter-rotating rolls. Between these rolls, a particle bed is pressed to a density of up to roughly 85 percent of the actual material density.

This compression is achieved by using high pressure of up to nearly 300 Mpa, exceeding the compression strength of the feed ore. During this compacting process the material is ground to a wide particle size distribution with a large proportion of fines, compacted into flakes.

The figure shown here indicates the flow of the material between the two rollers. The figure also depicts different zones, namely the "A zone" in which the material is pushed or accelerated toward the compaction zone; the "C zone," where the material is pressed; and then discharged into the "E zone."



A zone = Acceleration zone
C zone = Compaction zone
E zone = Expansion zone
D = Diameter of rolls
d = Flake thickness
α_0 = Angle of compaction zone
γ = Angle of expansion zone
μ = Circumferential speed

throughput with steadily declining grades, while at the same time minimizing energy consumption.

One way of meeting the challenge is to use high-pressure grinding rolls (HPGRs). HPGRs have proven to be extremely effective for grinding mineral raw materials, especially since manufacturers have developed roll-wear protection systems to better deal with hard and abrasive ores → 8.

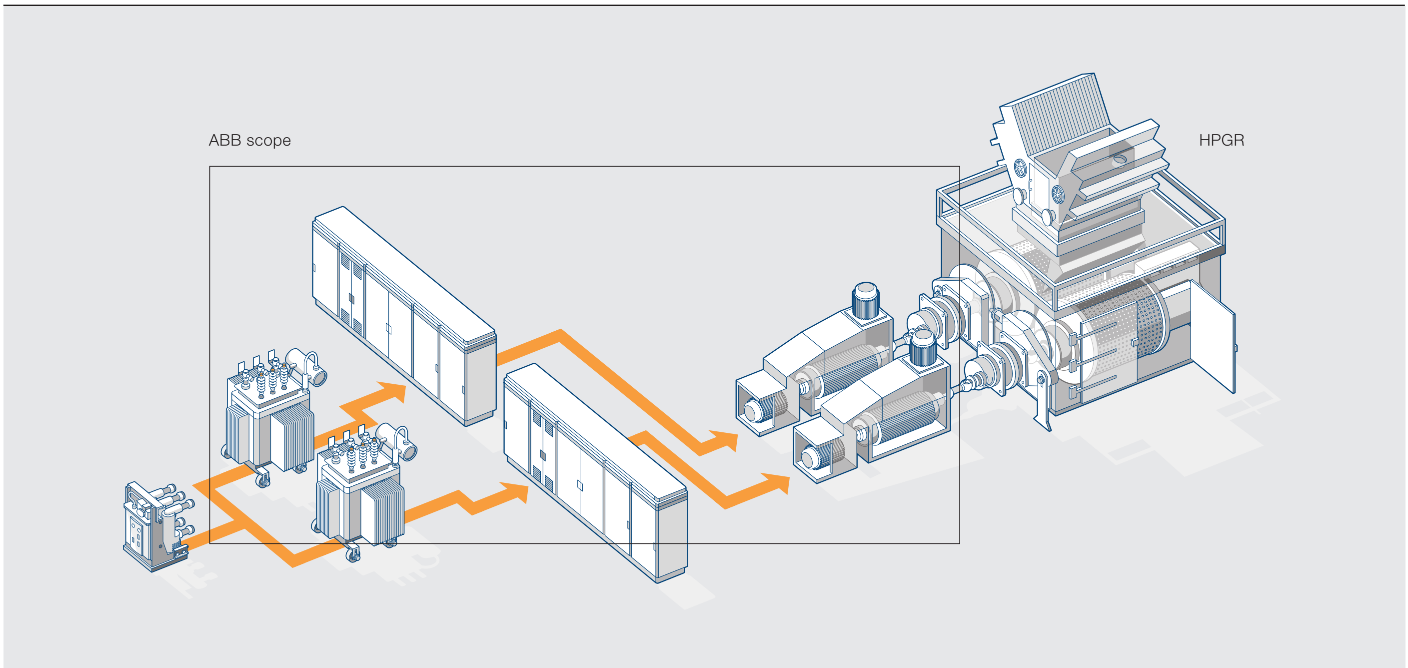
Additionally, the grinding process with HPGRs is a dry process, thus saving water, which is a scarce resource in many mining sites, eg, Chile.

Comminution circuits with HPGRs

The multiple benefits of including an HPGR mill in communition circuits has operators looking to combine them with other types of mills in order to optimize the total specific energy consumption of a comminution setup.

There are numerous benefits of using HPGRs in communition circuits in comparison with conventional grinding processes using SAG mills. The most significant benefit is an up to 20 percent increase in energy savings. Also, metal liberation is improved, a reduced grind-

9 ABB HPGR (high-pressure grinding roll) drive system



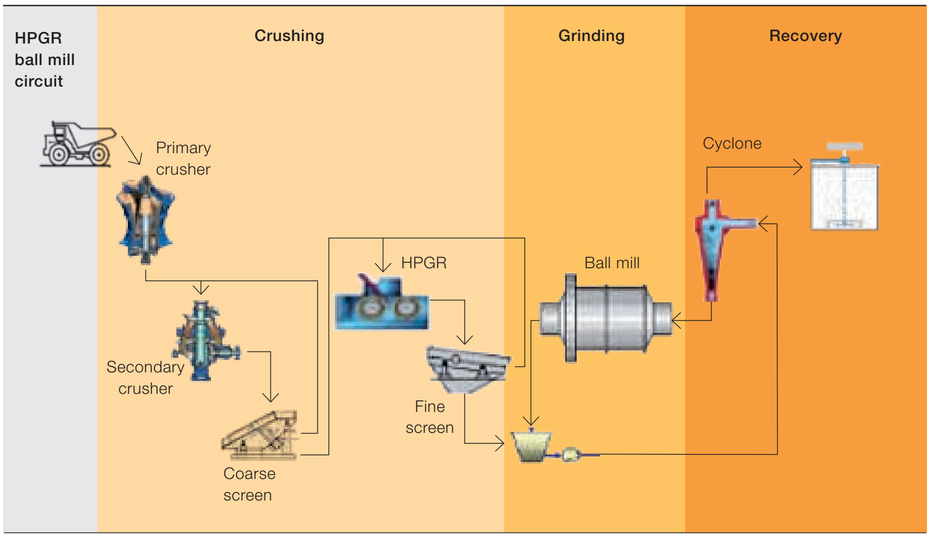
ability index is reached, commissioning times are shortened and designs are more compact.

HPGRs have been used successfully in mining operations over the years, indicating an increasing maturity of the product. As units become larger with higher throughput and deliver better reduction ratios than tertiary crushers, the combining of secondary crushers with HPGRs to replace SAG mills is occurring more often → 10.

ABB offerings

ABB provides optimized, state-of-the-art drive solutions for HPGR mills and currently has the largest installed base for the over 2 MW power range → 9. The ABB HPGR drive solution provides identical load sharing between both rolls at the desired speed. Being able to adjust the speed to fit actual ore properties decreases mechanical stress on the grinding application. The drive system is capable of compensating the reduction of circumferential speed caused through roll wear by increasing the motor speed (rpm). In this manner, the throughput can be maintained at optimized values over the rolls' lifetime. The direct torque control (DTC) feature provides the fastest torque/speed response on the market, enabling quick and accurate adjustment to the frequent load transients typical in HPGR applications as different sizes of material enter.

10 A comminution setup using HPGRs replacing SAG in primary grinding process.



HPGRs are poised to play an important role in the comminution circuits to help reduce energy costs, water requirements and footprint compared with the traditional SABC circuits. While being a standard solution in mineral processing, HPGR technology continues to undergo constant development. ABB is at the forefront of this development with many new features being added to further optimize drive system performance.

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Industrial evolution

Electrical integration using ABB's Extended Automation System 800xA with IEC 61850

ALAN FERNANDES TEIXEIRA, LEANDRO HENRIQUE MONACO – Industrial automation systems have evolved significantly over the past few decades, but they now face new challenges, especially concerning integration. In particular this concern focuses on how different locations and systems can be integrated in a way that reduces costs and increases overall efficiency and safety for the operation. ABB offers a complete integrated platform with Extended Automation System 800xA, which uses electrical integration based on the IEC 61850 standard for substation automation systems. This solution manages the production rates of complete industrial plants – by combining the benefits of different systems and locations into a single platform – as well as the energy consumption for each part of each process. In other words, ABB provides a high-tech solution that helps customers optimize production while increasing energy efficiency.

1 Combining ABB's Extended Automation System 800xA with IEC 61850 integrates different systems and locations into a single platform.

In an industrial environment the demand for higher profitability and process efficiency requires solutions that increase productivity using fewer resources. Included under the umbrella of resources is the need to reduce energy costs while, at the same time, optimizing production rates. To achieve this, industrial automation system solutions need to focus on four main challenges:
- Providing safety for personnel
- Reducing capital expenditure (CAPEX) for new plants
- Connecting in remote and harsh locations
- Dealing with the lack of integration between several systems

To address these challenges, ABB has combined its Extended Automation System 800xA with the IEC 61850 standard for substation automation systems so that the benefits of different systems and locations are integrated into a single platform ➔ 1. This platform not only decreases installation and maintenance costs but also increases plant availability by reducing downtime. Moreover, it provides added intelligence based on the smart combination of process and electrical data, thus allowing energy efficiency schemes.

Providing safety for personnel

Life is the most important asset. One way to preserve this statement is by reducing the exposure of a maintenance team to electrical danger to ensure a safer working environment. The communication protocols usually applied in electrical installations (eg, PROFIBUS and Modbus) already allow remote supervision and operation of a substation inside industrial plants. However, some activities, such as configuration and parameterization as well as access to disturbance record files (needed for analyzing electrical occurrences, such as voltage drops and overcurrent protection trips) require the physical presence of the maintenance team. For a majority of the protocols currently used, these two procedures can only be executed by connecting laptops locally to the intelligent electronic devices (IEDs).[1] One of the main benefits of using IEC-61850-compliant devices and systems is that the protocols proposed by the standard enable these two procedures to be carried out remotely once the IEDs are connected to an Ethernet network and all files can be transmitted using this infrastructure ➔ 2. The presence of a maintenance team is therefore only required in cases where there is a mechanical problem.

Reducing CAPEX for new plants

One of the main concerns for a greenfield implementation is CAPEX (capital expenditure). The amount of hardwired connections inside switchgear is one of the factors that make installation expensive. But it is possible to identify a pattern of how the cubicles (ie, IEDs) are connected to each other, and this pattern usually repeats several times inside a substation

In an industrial environment the demand for higher profitability and process efficiency requires solutions that increase productivity using fewer resources.

Title picture
As a complete integrated platform, ABB's System 800xA solution fulfills the requirements of a true energy management system and increases safety by enabling remote intervention and risk mitigation.

Footnote
1 An IED describes a microprocessor-based controller and is a term used in the protection and power system automation industry. It performs electrical protection functions, advanced local control intelligence and can communicate directly to a SCADA system. Examples include a protective relay, circuit breaker controllers and voltage regulators.

IEC 61850
IEC 61850 provides a standardized framework for substation integration that specifies the communication requirements, the functional characteristics, the structure of data in devices, the naming conventions for the data, how applications interact and control the devices, and how conformity to the standard should be tested.

For more application information on this standard, please refer to *ABB Review* Special Report: IEC 61850, pp. 1–64, August 2010.

Extended Automation System 800xA
System 800xA is an integrated process automation system that can engineer, commission, control and operate automation strategies for process, power, electrical and safety in the same system. Its integration architecture, based on Aspect Object (AO) technology, relates all plant data (ie, Aspects) to the specific plant assets (ie, Objects). One-click navigation allows the efficient engineering and presentation of the right information in the right context to the right user.

A common platform decreases installation and maintenance costs, increases plant availability and provides added intelligence based on the smart combination of process and electrical data.

(or in several substations of a plant). If the connections between cubicles of the same type could somehow be made by creating a communication protocol between the cubicles, installation costs would be reduced considerably. To achieve this, the IEC 61850 standard proposes the generic object-oriented substation event (GOOSE)[2] protocol. Therefore, for each typical cubicle there is a typical IED configuration that can be reused throughout the whole plant-optimizing engineering effort. Moreover, due to the digital protocol used by the IEDs, optical fibers take over from communication cables, and because they are immune to electromagnetic interferences, they can be placed closer to the busbars.

Another advantage is that given a common (software-based) configuration, only one IED needs to be tested, and any configuration adjustment required in the IED is easily replicated in all the other IEDs. Testing and commissioning are also made easier if a prefabricated E-house solution is used. Prefabrication allows for the cubicles to be tested while they are still in the E-house factory.

Remote connection

Many mines are being established far from economical centers, they are getting deeper and ore bodies are becoming more complex. These factors, combined with a shortage of skilled workers, mean the plants need to become more automated. Regarding substation systems, different substations situated in various locations need to be connected to the same supervision system so that remote control and maintenance is carried out from a central location. Applying the IEC 61850 standard to ABB's System 800xA establishes a digital communication link between the IEDs and the servers in the system to create such a connection → 2–3. This in turn provides maintenance personnel with the information needed to quickly identify the problem and the solution remotely. This means that hardware problems are fixed in the shortest possible time, which has the advantage of increasing plant availability and consequently productivity.

One platform, many systems

With the evolution of digital computing in industrial applications, several information systems were developed to provide a more complete database for the layers inside plants. Nowadays it is almost common to find many different systems in a plant for different applications (supervision, maintenance and production schedule systems), all of which rely on the same information (eg, a circuit breaker position). However, if all applications rely on the same information, one of two scenarios could be playing out, neither of which will lead to good plant management:

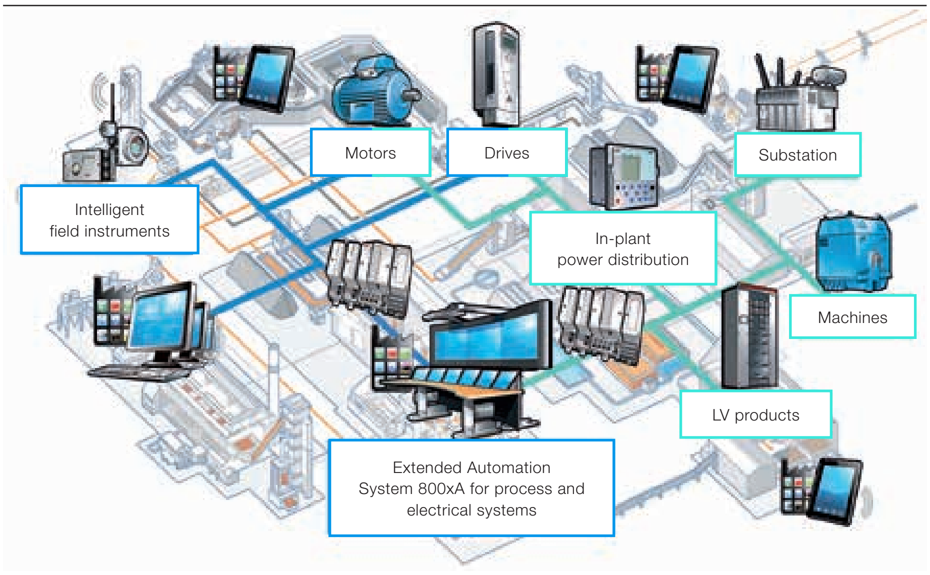
– The same information is input several times into these different systems.
– The "communication" between the systems is actually communication between the people operating those systems.

System 800xA's integrated platform completely eliminates this problem.

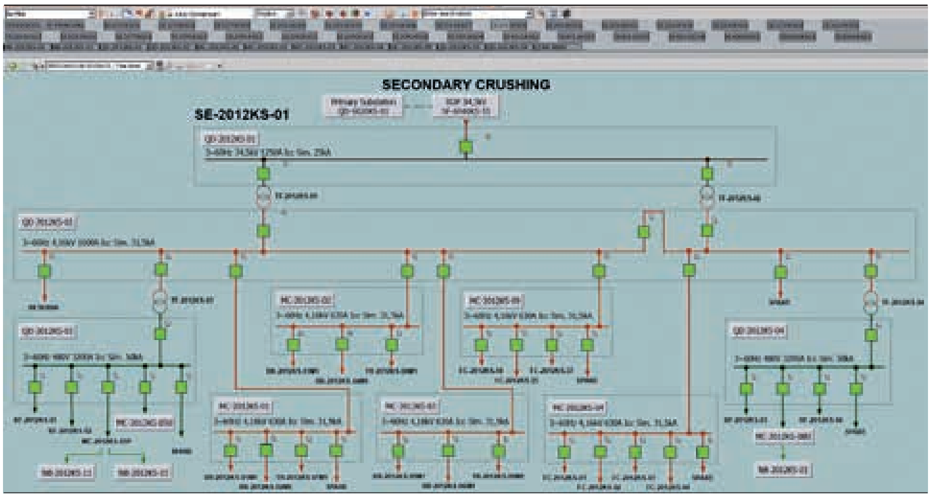
Footnote

2 GOOSE is the communication protocol defined by the IEC 61850 standard. It allows one IED to send fast messages to other IEDs independent of any supervisory system or controller. This is done to transmit important trip and interlocking information within 3 ms among IEDs.

3 System 800xA allows plants to integrate their own process control system so that a combined database for process and electrical parts exists.



4 Integrating all voltage levels simplifies the operation and communication between components.



Usually in industrial plants, management of high- and medium-voltage substations is handled by two completely different systems and teams. By applying IEC 61850 to both levels, it is possible to integrate all the substations into the same System 800xA system, thereby simplifying the operation and the communication between high- and medium-voltage switchgear, for example.

Besides integrating different voltage-level substations into the same system, System 800xA also allows the plants to integrate its process control system → 4. Therefore, using IEC 61850 compliant devices inside the same 800xA system that oversees process control, it is possible to have a combined database for both process and electrical parts, enabling the identification of relevant key performance indicators (KPIs) for the operation.

One of the most important KPIs is process efficiency, ie, the relationship between energy consumption and production rates. This indicator enables comparisons to be made between different process lines and even different equipment in the same process step. This helps to identify problems or discrepancies more quickly.

Overcoming challenges

While the evolution of automation systems has been advantageous for operations, it has also introduced some challenges for the future. For example, scarcity of natural resources is pushing companies to explore in extremely remote and harsh places, increasing operational expenditures (opex) during the lifetime. Therefore maintenance has become crucial to increase the predictability of the devices' behavior and reduce unproductive time during repair.

In a completely integrated system, information from different perspectives of the plant has a positive influence on decision-making and inevitably on the process itself. However, new systems have created different databases and a lack of integration between these has become critical in an industrial plant management environment. Information published in different systems at the same time can hinder efficient reporting and decision-making during faults or inefficient communication between teams in different sectors can cause an increase in production stops.

As well as providing a completely integrated platform, ABB's System 800xA solution fulfills the requirements of a true energy management system. Most importantly, this solution increases safety because it reduces the exposure of maintenance personnel to potentially dangerous situations by providing complete diagnostics to the control room, enabling remote intervention and risk mitigation before the maintenance team initiates its service.

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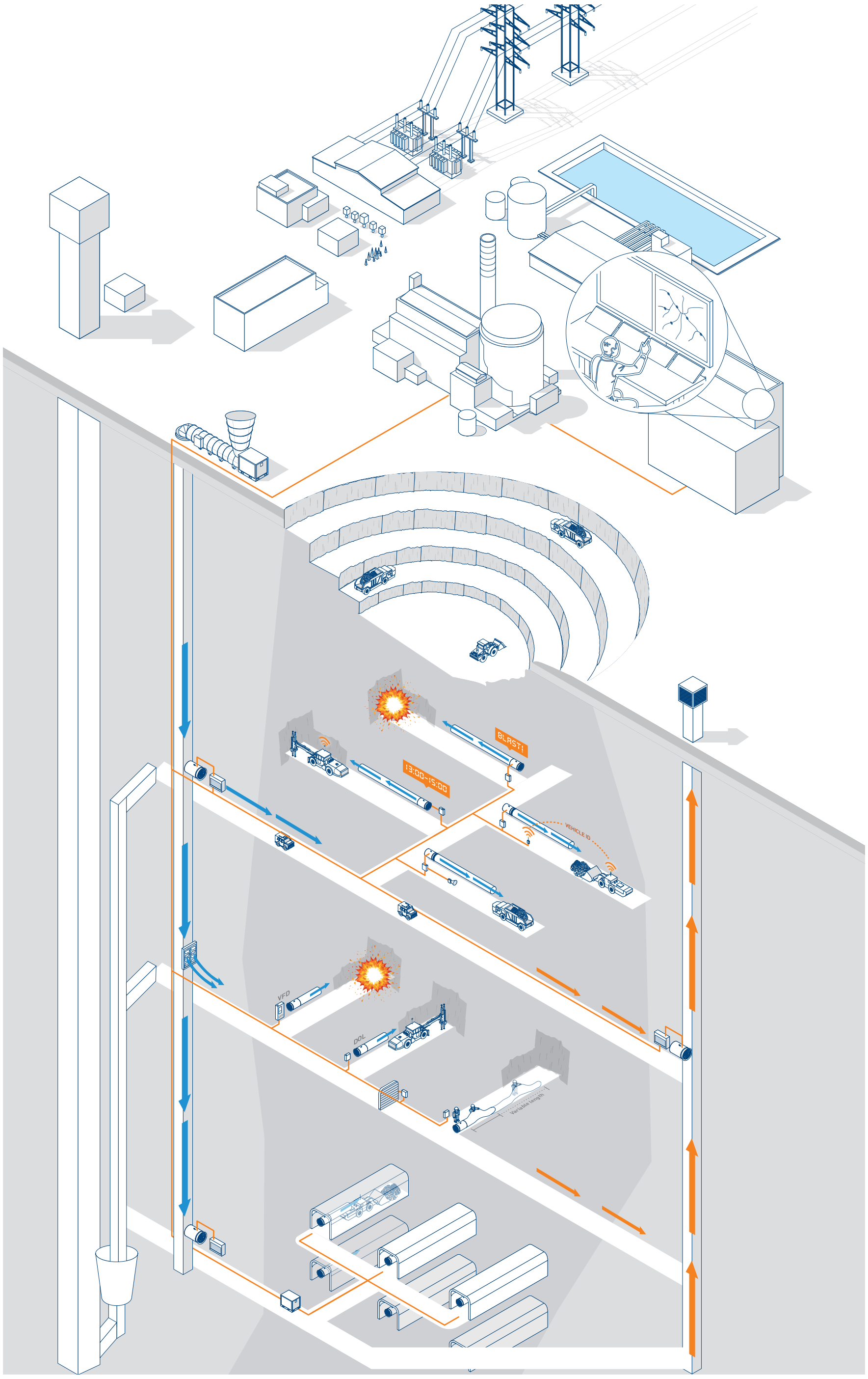
More efficient operations

Extended Automation System 800xA enables collaboration in mining operations



JOHAN BJORKLUND, ANDERS BOMAN, MIKAEL STEINER – The many challenges faced by the mining industry can be overcome by the effective implementation of automation. ABB's Extended Automation System 800xA has been a market leader among automation platforms for over a decade and is known for delivering productivity by consolidating the many subsystems of any operation (IT, electrical, safety, telecoms, logistics, process data, etc.) into one integrated system. It also provides high-performance operator environments – ideal for centralized control room solutions. System 800xA and mines are a perfect fit, proven in many installations around the world.

Programmable logic controllers (PLCs) have been in place for many years in the mining industry. But their use has tended to be in "islands of automation" and automation in mines has anyway tended to be more basic than in other industries – often limited to simple control of motors, equipment or limited parts of the processes. To overcome the challenges currently faced by the industry, what is needed is an automation solution that can encompass the entire mining process, from rockface to delivery of the mined product to the final customer.

ABB's System 800xA is an automation platform with the capacity to do this. It can integrate all kinds of products and solutions into a single control environment: Traditional process control systems such as PLCs and distributed control systems (DCSs); safety systems; electrical equipment such as drives and motors; and production planning, power management, maintenance, asset management, enterprise resource planning (ERP) and documentation systems.

In a mine, all process equipment – from mobile machines, transport vehicles, crushers, conveyors, mine hoists, gearless mill drives, ventilation fans, pumps to sensors and instruments – can be integrated with System 800xA. This means that the whole operation can be controlled and optimized under one single system. This allows, for example, blasting and crushing to be

Title picture
Automation is providing the key to reducing costs, and increasing productivity and safety for the mining industry.

optimized together with the grinding process in the concentrator, thus closing any gap in the value chain.

A new System 800xA generation

With close to 10,000 systems in operation in more than 100 countries, System 800xA has proven to be a world-class, market-leading DCS. System 800xA can monitor and control over 50 million tags and its sheer capability has helped ABB to be the top global DCS supplier for over a decade.

This sixth-generation release of System 800xA, commonly called v6, is not only aimed at new projects but also at upgrades of older DCSs running on unsupported operating systems such as Microsoft XP. System 800xA v6 provides customers with a more secure automation environment that lowers the total cost of ownership, while providing opportunities to improve operational productivity.

Protection against cyber threats

System 800xA v6 will add to an already-extensive list of leading security features such as advanced access control, white listing and a means to monitor and manage the control system's security integrity. For example:
- It is based on the latest Microsoft operating system, with its higher inherent security.
- Digital code signing of applications ensures software legitimacy.
- There is faster, more immediate access to approved antivirus files.

Lower cost of ownership

System 800xA v6 provides the ability to lower costs for new projects, retrofits and upgrades:
- In addition to virtualization, performance improvements and multiple-core technology can reduce the automation system's footprint significantly, leading to lower capital and life-cycle expenditures.
- A new intrinsically safe Foundation Fieldbus high-speed Ethernet (HSE) linking device is available that can further reduce engineering and installation costs because it can be installed directly in Zone 2, Class 1, Division 2 hazardous locations.

Productivity

System 800xA v6's collaboration platform and its built-in functionality allow the user to tackle money-saving initiatives and implement productivity-enhancing solutions for a fraction of the cost of adding third-party software and hardware. In addition to alarm management, advanced control, video systems, safety, electrical integration, power management and a host of other embedded capabilities, System 800xA v6 adds:
- Wireless mesh routers, enabling the safe and secure deployment of mobile operator clients, maintenance workplaces and process controllers.
- A new information management platform that provides secure connectivity to System 800xA so that data can be safely collected, viewed, historized and reported above the control system layer.
- An embedded public address system that allows text-to-speech announcements to be broadcast in multiple languages from System 800xA.
- Trends have been enhanced in System 800xA with the addition of alarm indication, autoscaling and adjustable sloped gridlines.
- New ways to visualize data are available with the addition of the System 800xA collaboration table providing a 3-D view of plant key performance indicators (KPIs).
- Batch management performance has been improved through the use of a new multithreaded batch-procedure executing environment.
- New packaged services are available from ABB and CGM (a leading operator desk producer) to make it easier to design and build a state-of-the-art, ergonomic, productivity-enhancing control room that includes the System 800xA Extended Operator Workplace.

> System 800xA v6 provides the ability to lower costs for new projects, retrofits and upgrades.

Removing the barriers

Special consideration has been given to a significantly improved upgrade experience, supported by an enhanced Sentinel customer care program, in System 800xA v6. This includes:
- More intelligent "role-based" installation and a configuration tool that reduces manual steps by over 80 percent. This installation and configuration tool can also be used to centrally extend and update the system over its life cycle.
- Additional tools, such as the start value analyzer, are available to ensure that the upgrade goes smoothly, without any surprises when it comes to initial values settings.

System 800xA and mining

The new generation of ABB's System 800xA further enhances the capabilities of this leading automation platform, making it an even more suitable automation solution for the mining industry. It will enable miners to increase productivity, reduce operational costs, improve safety and meet the plethora of other challenges facing the industry today.

To learn more about ABB's Extended Automation System 800xA, please visit: www.abb.com/800xA or You Tube: www.youtube.com/watch?v=POqw0rIJe78

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Seamless communication

ABB's private wireless field automation networks advance open-pit mining fleet management

ROMAN ARUTYUNOV – Modern open-pit mining is a high-tech undertaking in decidedly hostile environments. Safe and efficient operation requires precise coordination of some of the world's largest and most expensive machines in settings characterized by punishing heat and cold as well as extreme shock and vibration. Managing equipment and tracking data and materials are top priorities for open-pit mining operators, making fleet management a crucial part of their daily job. Luckily, it doesn't have to be a time-consuming and tedious affair. The ABB Tropos patented private wireless communication networks enhance open-pit mines' productivity and profitability by enabling advanced fleet management, thereby allowing for real-time data to be captured and analyzed at the mine's operations center.

Safe and efficient operation in open-pit mining requires the precise coordination of some of the world's largest and most expensive machines in a very hostile environment.

Mining is a capital intensive business requiring expensive heavy equipment operating in some of the world's most hostile environments → 1. The challenge is maximizing capital utilization by focusing the invested capital on revenue generating activities, ie, getting more of the best quality material from ground to port in the shortest time possible.

Fleet management applications enable mine operators to achieve their capital utilization targets by orchestrating the dependencies between different pieces of equipment around the mine through real-time work order assignments to equipment operators. Combined with precision guidance systems, fleet management applications ensure that power shovels are getting the best quality material out of the ground and haul trucks know exactly where to take the material, minimizing wait times between operations. In addition, fleet management systems can also include real-time health monitoring of the equipment in order to improve equipment life-cycle costs and minimize downtime.

Security attacks can create costly downtime, which in some mining operations is measured in millions of dollars per hour.

The importance of wireless networks in improving capital utilization cannot be emphasized enough. However, open-pit mines have some of the most challenging functional requirements for wireless networks. To begin with, for successful fleet management implementation, wireless networks must support mobility across the entire footprint of the open-pit mine and be reliable, scalable, flexible, secure and have multi-application capabilities. Mine fleets can vary in size from tens to hundreds of vehicles including haul trucks, power shovels, excavators, bulldozers, and draglines. Mobile coverage must be flexible enough to adapt to changing conditions and the topology of the open-pit mine.

Pits can shift in size and form requiring mobile coverage to adapt quickly and cost-effectively without extensive planning and implementation timelines.

The real-time nature of mission-critical fleet management applications requires low latency network support with less than 50 ms latency from the control room to the vehicle. In addition, open-pit mining requires reliable communications with minimal packet loss to ensure successful and real-time delivery of work orders to equipment across the mine. Multi-megabit broadband speeds are required for continuous equipment health, status and position monitoring, work order assignments, and operational safety video monitoring.

Title picture
Managing equipment and tracking data and materials are top priorities for open-pit mining operators. The ABB Tropos patented private wireless communication networks allow real-time data to be captured and analyzed at the mine's operations center, thus enabling advanced fleet management.

1 An open-pit mining excavator

Security is another major concern for open-pit fleet management implementations especially when it comes to Denial-of-Service (DoS), eavesdropping, and man-in-the-middle attacks. These types of attacks, if executed successfully on the network, can disrupt information flow between the control room and field equipment creating costly downtime, which in some mining operations is measured in millions of dollars per hour.

ABB Tropos wireless mesh networks support fleet management applications in some of the most hostile open-pit mining environments. An advantage of ABB Tropos technology is its ability to uniquely support the requirements of open-pit-mine wireless networking.

An open-pit mining environment

Mobile coverage is one of the major issues in open-pit mines. The implementation of tower-based wireless technologies, such as point-to-multipoint and cellular architectures, is challenging in terms of planning and cost. Towers are built away from pit edges on permanent ground and these edges can shadow RF signals, making coverage difficult at the bottom of the pit. The solution is to construct multiple towers around the circumference of the pit. However, when the pit form shifts, additional towers must be deployed to cover new areas. This is a costly and very time consuming solution.

The ABB Tropos wireless mesh technology greatly reduces the need for large towers and in some cases eliminates it altogether. Routers, deployed on trailers around the pit, "discover" each other automatically and provide ubiquitous coverage for the entire pit. When the pit topology changes due to new mine sites, the trailers are simply moved to new edges, creating coverage for mission-critical applications within minutes instead of the months needed for a tower-based design → 2–3.

High network availability, ie, available for five nines (99.999 percent), is required to support mission-critical fleet management implementations. To meet this requirement, wireless networks must have a built-in redundancy mechanism to minimize the probability of transmission fail-

For successful fleet management implementation in open-pit mines, wireless networks must be reliable, scalable, flexible, and secure across the entire footprint of the mine.

A mine is a dynamic mobile environment with vehicles and people requiring seamless mobility as they roam between access points in the network.

2 ABB's solar-powered Tropos router

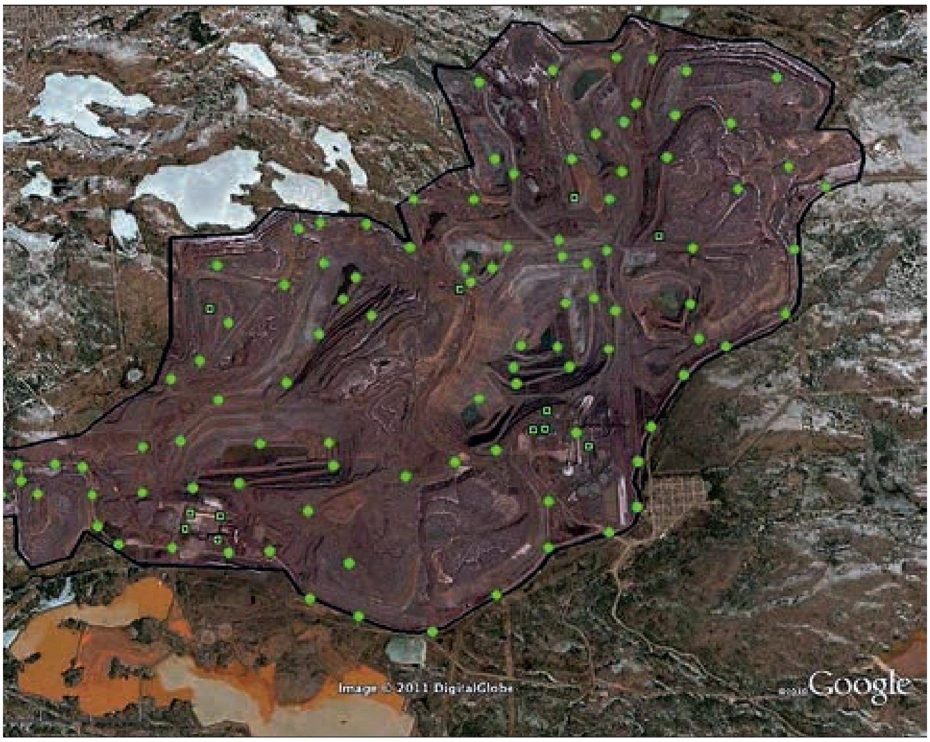
ures. With ABB's solution, high availability and reliability are achieved as Tropos routers operate in a mesh topology with multiple paths through the network, dynamic operating frequencies, multiple radios, and multiple retransmissions on every packet.

A mine is a dynamic mobile environment with vehicles and people requiring seamless mobility as they roam between access points in the network. Delays and packet loss due to roaming events are not well tolerated in this environment due to its mission-critical nature. Lost work orders can significantly delay operations and in some cases interrupt the flow, creating cascading delays across the mine. Most of the packet loss and delay typically occur prior to a handoff. To overcome this problem, predictive wireless routing algorithms such as the Tropos Predictive Wireless Routing Protocol (PWRP) significantly improve handoffs by identifying new paths through the network before current paths degrade. In addition, seamless mobility in the Tropos wireless network is achieved through make-before-break connectivity, which is available when Tropos mobile routers are used in vehicles. This soft-handoff capability creates a new path through the network while existing paths are still functional.

Securing communication networks

Cyber security attacks are a real concern for open-pit mines as mine operators increasingly use communication networks to monitor and control hundreds of automation devices in the field and large outdoor facilities. These field automation networks support a diverse set of mission-critical applications such as fleet management. In a typical mine network deployment architecture, the field equipment is connected to the local or remote control rooms using TCP/IP or serial communications. This setup creates the potential for cyber security attacks from the field to the control room or vice versa. Where security is implemented in a field area network is just as important as what is secured and how it is secured, and for maximum protection, security must be enabled at the edge of the network as well as at locations closer to the network's core.

3 A sample mesh router placement for an open-pit mine



With the ABB Tropos wireless mesh networks, routers deployed on trailers around the pit “discover” each other automatically and provide ubiquitous coverage for the entire pit.

In mining security, this can be achieved by bringing enterprise-class security to field area networks and by extending that security all the way to the edge. Enterprise security is a multilayer, multi-application security model, which provides in-depth-defense using a number of overlapping standards-based security mechanisms. These security mechanisms are layered one on top of the other and are intentionally overlapped to minimize the impact of failure in any one mechanism and reduce the probability of a security breach.

Enterprise security is a multilayer, multi-application security model, which uses a number of overlapping standards-based security mechanisms to provide in-depth-defense and minimize the impact of failure.

The key security functional requirements and corresponding mechanisms are:

- Network access control using 802.1x, MAC ACLs and 802.11i/WPA2 with central RADIUS server authentication to ensure that people and devices accessing the network are explicitly authorized before sending data through the network.
- Network resource and end-point protection using firewalls that block unwanted and malicious traffic, restricting its propagation across the network.
- Secure end-to-end data traffic transmission with AES encryption using Virtual Private Networks (VPNs) to protect against eavesdropping and man-in-the-middle attacks.
- Traffic segmentation and prioritization to effectively run multiple applications over common infrastructure while ensuring high levels of priority for mission-critical applications and protecting against DoS attacks.
- Secure network configuration and management for flexible security policy management and enforcement across the network.

Tropos mesh router’s unique distributed architecture makes it possible for such functionality to be implemented in each network element. When Tropos routers are deployed, the integrated security mechanisms are rolled out all the way to the edge and to each vehicle and device in the field, giving the network an active role in protecting field devices against cyber security attacks.

Thinking ahead

ABB Tropos wireless mesh networks not only solve today’s operational challenges in open-pit mines, but also create long-term strategic value for customers. Today’s fleet management applications form the foundation for autonomous operation in the future where driverless vehicles in the mine are orchestrated and controlled from a central control room. The highly reliable, scalable, multi-application mesh architecture enables mining customers to move from fleet management to fully autonomous operations with minimal incremental capital investment.

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Raising the issue of mines

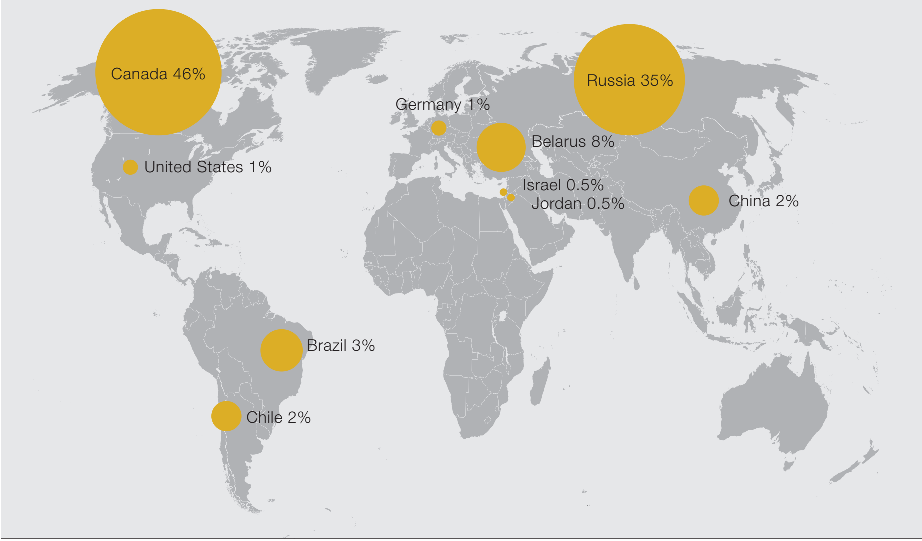
ABB hoists for mines

TIM GARTNER – A land area larger than the United States but a population about one-tenth the size endows Canada with huge acreages of pristine landscape. In this setting, industry has learned to minimize disturbance to the natural world. In mining, for example, great efforts are made by those who seek to develop natural resources to do so sustainably, with maximum energy efficiency and with minimal environmental impact. Raising mined product to the surface is one area in particular where technology can go a long way to accommodate Mother Nature. ABB has long supplied hoists to the mining industry and these can be not only installed in new mines, but also retrofitted to existing operations to equip them with the latest in hoist technology. Potash mining is one area where the benefits of ABB hoists are exploited.

Title picture
Energy efficiency, environmental impact and sustainability are important factors for mining operations when they come to choose a hoisting system for retrieving their produce to the surface. ABB's years of technology development in this area have resulted in a comprehensive range of hoisting products, including advanced friction hoists.


machinery

1 World potash reserves as reported by the United States Geological Survey. (Other countries make up 1 percent.)



> While four-rope and six-rope friction hoists are the most common, ABB has designed friction hoists using up to 10 ropes.

As the world's population passes the 7 billion mark and as more of that population become more prosperous, the demand for food rises inexorably. Agriculture would have lost the ability to keep up with this demand long ago if it were not for the magical powers of fertilizer. The three primary crop nutrients are potash, nitrogen and phosphate, and, of these, potash is the one of most interest to miners. Dug from natural mineral deposits deep in the earth left by the evaporation of ancient oceans, bringing potash to the surface efficiently and safely, while minimizing environmental impact, requires the most advanced hoist technology available.

Potash is produced in only 12 countries, whereby Canada, Russia and Belarus together account for just over two-thirds of global capacity and, according to the United States Geological Service, almost 90 percent of estimated reserves → 1. The Canadian province of Saskatchewan is home to almost half of world reserves and 35 percent of global capacity.

Friction hoists and drum hoists

While there are two main types of mine hoist systems – drum hoists and friction hoists – recent ABB hoist projects in the Canadian potash arena have involved friction hoists.

The main purpose of any type of hoist (friction or drum) is to raise or lower a load within the mine shaft using steel wire rope attached to a load. The load can be a skip (large metal container carrying mine ore), a cage (conveyance used to carry people, tools and mining machinery or supplies) or counterweights (used for certain types of hoists). One side of the rope is directly attached to the conveyance (skip, cage or counterweight). On a friction hoist, the other side of the rope is attached to another suspended conveyance on the other side of the friction hoist, while for a drum hoist, the other side of the rope is directly attached to the hoist drum. When the mine hoist drum rotates, it raises or lowers this steel wire rope, thereby raising or lowering the attached conveyance → 2.

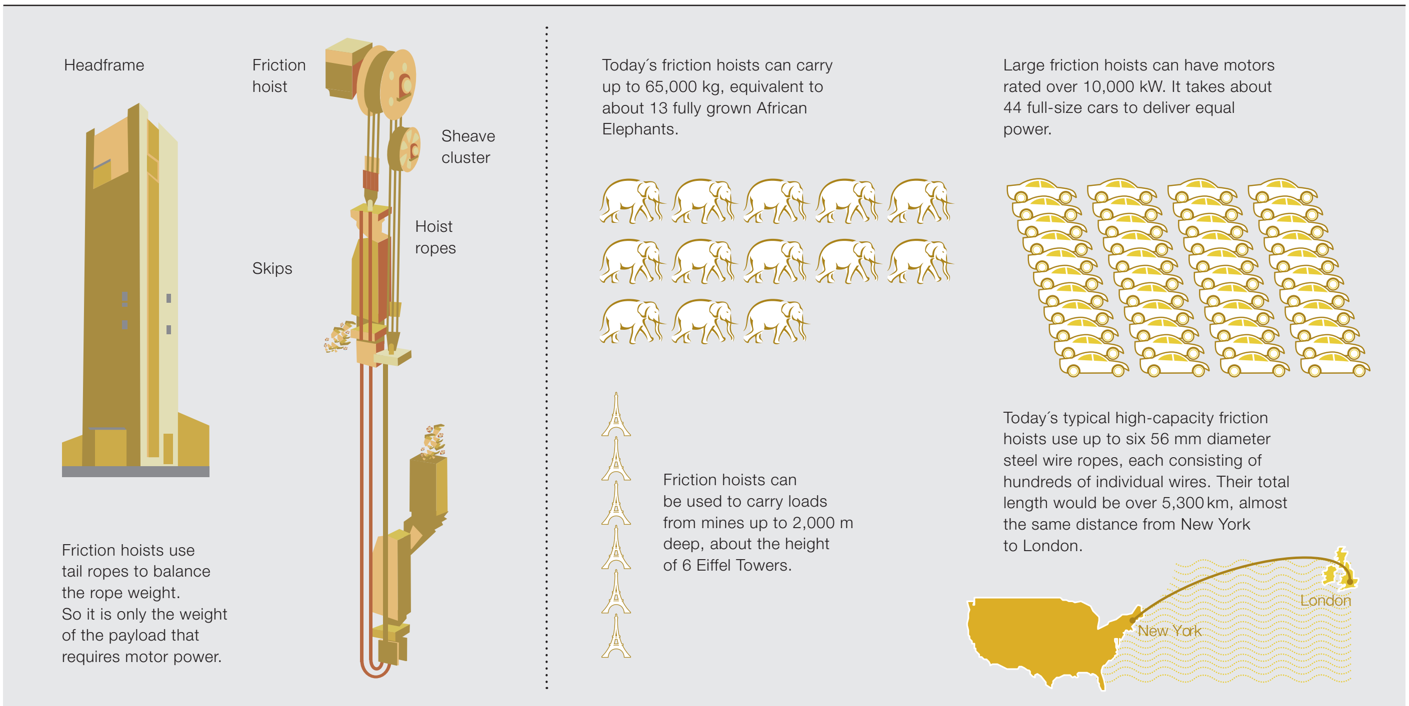
Unlike a drum hoist, the steel wire rope does not directly wind onto the friction hoist drum. Instead, it only passes over the friction hoist drum as the drum is rotated. The principle is the same as any pulley/belt driving mechanism and is used on most building elevators. Motor power/torque is transmitted from the hoist motor/drum assembly to the steel wire rope via the principle of mechanical friction between the rope and hoist drum. Since the rope is not wound onto the friction hoist drum, a friction hoist can use multiple ropes to support the mine payload. While four-rope and six-rope friction hoists are the most common, ABB has designed friction hoists using up to 10 ropes → 3. Drum hoists normally have only one rope for each drum and occasionally two ropes per drum in very deep mines or special circumstances.

ABB designs and supplies friction hoists, drum hoists, sheaves (wheels or pulleys), skips and other equipment used with mine hoist systems.

Friction hoists have proven to be the ideal solution for the Canadian potash mining industry due to their high energy efficiency and high payload capacity.

Mine hoist upgrades

Miners often upgrade hoisting capacity at their production shafts, especially if production rates increase. Sometimes this involves replacing the original hoist. Obviously, since the hoist enables the product to be removed from the mine, any interruption for upgrading work will stop production, so upgrades have to be performed in the shortest time possible. In some cases, this is no trivial task as extensive structural modifications may be required to the existing headframe



infrastructure in order to accommodate new, larger capacity hoists.

Two in one

In one case, in Saskatchewan, the production shaft contained two production hoists within the same shaft. ABB was contracted to upgrade both of the existing production hoists, but to do so within the same headframe and hoist foundations. This meant that the electrical and mechanical components of the upgraded production hoists had to fit precisely within the same hoist foundations. Since the new mine hoist could only be installed when the old mine hoist was removed, a tightly coordinated installation schedule was worked out between ABB and the customer.

ABB designs and supplies friction hoists, drum hoists, sheaves and skips.

The upgrade project occurred over two consecutive summer shutdown periods. In the first, one of the existing production hoists was upgraded with a new friction hoist and AC synchronous motor and drive, as well as a new hoist control and operator system. While this upgrade was underway, ABB provided upgrades to the other production hoist, including a digital front-end upgrade to a competitor's DC thyristor drive system as well as a new hoist control and operator system. The second production hoist was mechanically upgraded in the next summer shutdown and later a new AC synchronous motor and drive system replaced the DC motor and thyristor drive system.

Over the top

In a second case, the customer asked ABB to repeat an earlier project at a different mine where a completely new hoist house was designed and fabricated on top of the existing headframe. Executing this required significant construction activity, but delivered advantages including:

- The size and capacity of the new hoist was not limited by the existing hoist foundations, allowing the customer to select the hoist most suitable for the shaft infrastructure.
- Construction of the new hoist house as well as installation of the new hoist would occur without interrupting mine production. During normal mine production with the old hoist, the new hoist could be installed and commissioned without ropes – ensuring a short changeover.

Friction hoists have proven to be the ideal solution for the Canadian potash mining industry due to their high energy efficiency and high payload capacity.

Electrical and mechanical components of the upgraded production hoists had to fit precisely within the same hoist foundations. Since the new mine hoist could only be installed when the old mine hoist was removed, a tightly coordinated installation schedule was required.

The hoist selected was a four-rope by 5.95 m friction hoist outfitted with two AC synchronous motors and an ABB ACS 6000 AC drive system. A new hoist control and operator system was also installed and commissioned at the same time.

Surface-mounted hoists

Upgrades need not involve building a new hoist house on top of the existing production hoist headframe: ground-mounted hoists are also possible. In one recent case, a new ground-mounted hoist house was fabricated on the surface, near the existing headframe and production shaft. An extension was added to the top of the existing headframe where two sheave cluster assemblies (with four sheaves in each cluster) were installed. A completely enclosed rope travelway connected the new ground-mounted hoist house with the headframe extension. A new hoist control and operator system was also installed and commissioned at the same time.

Again, construction of the upgraded hoisting facilities did not interrupt production from the existing hoisting system.

3 Characteristics of friction hoists versus drum hoists

	Friction hoist	Drum hoist
Load-carrying ropes	Normally 4 or 6	Normally 1 but occasionally 2
Suitability for multilevel mines	Good with use of counterweight	Very good
Maximum hoisting depth	2,000 m (limited by hoist rope fatigue life)	3,000 m is deepest using two ropes
Motor power	Lower than equivalent-rated drum hoist	Higher than equivalent-rated friction hoist
Typical payload (potash industry)	45 t (higher and lower payloads exist)	30 t (higher and lower exist)
Relative cost	Lower than equivalent-rated drum hoist	Higher than equivalent-rated friction hoist
Hoist location	Can be mounted on ground or tower	Almost always surface-mounted
Headframe	Heavier structure than drum hoist	Lighter structure than equivalent friction hoist

Greenfield projects

Greenfield projects are generally the least complex as the new hoisting systems do not need to interface with any existing production or service infrastructure. In one recent project, slip-form concrete headframes were constructed over the newly-completed shafts, after which ABB installed and commissioned complete new mine hoisting systems including mechanical equipment, AC synchronous motors and ACS 6000 drive systems as well as hoist control and operator systems.

The hoists were four-rope (5 m diameter) hoists, each powered by a single 7 MW AC synchronous motor and ACS 6000 drive system. The service hoist was commissioned in late 2013 and is in commercial operation. The production hoist will be put into commercial operation in 2015.

ABB as hoist supplier

ABB works closely with potash customers to select, plan and install production and service hoist upgrades in the fastest and most economical manner possible using the most modern and energy-efficient mine hoist equipment. In doing so, the customer can:

– Significantly improve potash ore hoisting capacity.
– Rationalize spares and capital spare parts inventory since major mine hoist components are, in most cases, identical (drives, motors, transformers, bearings, etc.).
– Gain operational benefits: For example, functionally identical hoists support common maintenance practices and procedures.

ABB hoists are, of course, used in many more operations that those that mine potash – coal, various ores, etc. ABB will continue to further advance its mine hoisting technology over the coming years and work together with customers to improve their hoisting operations in the most sustainable manner possible.

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Transforming mining maintenance

Advanced service solutions for mining and mineral processing

EDUARDO LIMA, JESSICA ZÖHNER, ALIREZA OLADZADEH – Like many other industries, mining has to continuously improve profitability in the face of challenging and rapidly evolving production and market environments. One way to accomplish this is to reduce costs and improve productivity by making long-term efficiency improvements in production assets through the use of advanced maintenance and service strategies. This is an approach that ABB has long valued. ABB offers a broad portfolio of services from preventive-based and predictive-based long-term service agreements to reactive responses like emergency spare part provision. The portfolio embraces the very latest maintenance technologies, many of which ABB has itself developed.

A service and maintenance strategy that delivers state-of-the-art services is critical for the long-term profitability of any mining company – a fact that ABB has long recognized.

1 Conveyor maintenance is cost-intensive. ABB is currently working on a solution to monitor conveyors remotely.

Productivity in a mining enterprise can be very effectively maximized by the efficient utilization of production assets. This can be achieved through the use of automation, remote operations, diagnostics and production visibility tools, as well as by technologies that provide continuous, real-time information on the condition of mine equipment. A service and maintenance strategy that delivers this is critical for the long-term profitability of any mining company – a fact that ABB has long recognized.

A history in mining

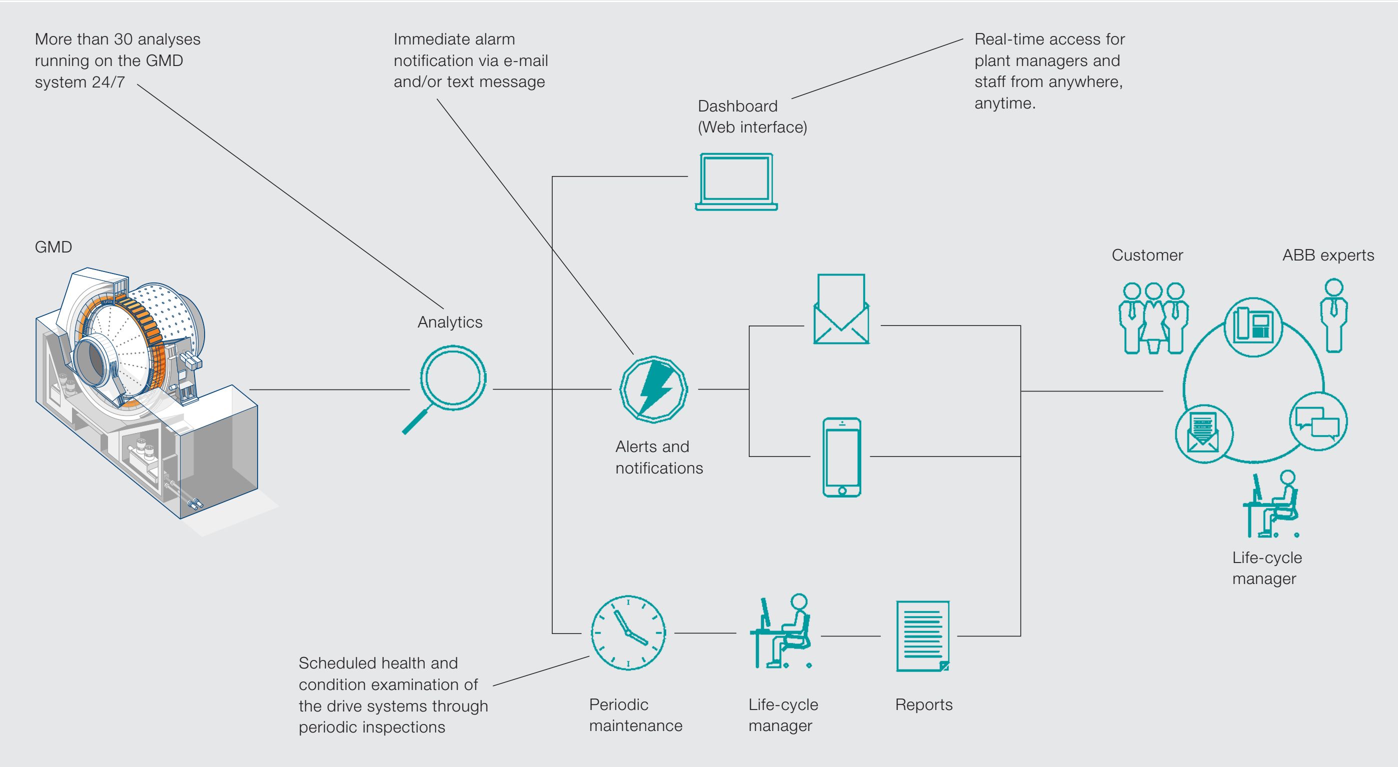
ABB's expertise in service and maintenance has evolved over the many years that the company has supplied advanced products and systems to mining operations. ABB products here include:

- Mine hoist systems that transport ore, miners and equipment between the surface and the mine quickly, safely and reliably.
- Variable-speed grinding solutions like gearless mill drives that drive the huge ore crushing mills and meet the highest levels of availability and energy efficiency.
- Variable-speed drive systems that enable conveyor systems, draglines and shovel excavators to operate more cost-effectively and be more energy efficient.
- Complete and fully integrated electrical, control and instrumentation solutions that power, automate and control the entire mine or production site.
- Software products that integrate the automation, electrical and enterprise systems to create a collaborative working environment across the whole value chain from mine to market.

ABB has a huge installed base at mines all over the world: More than 600 mine hoists, 125 gearless mill drive systems, more than 300 conveyor belt solutions, and over 80 complete electrical, control and instrumentation installations → 1. To help its customers maintain these assets in prime working order, ABB offers a broad portfolio of services, from preventive-based and predictive-based long-term service agreements to reactive responses like emergency spare part provision.

Title picture
Advanced maintenance and service strategies are essential for modern mining equipment like the sheave pictured.

2 The real-time analyses and diagnostics of the drive system utilize data collected from the control system and drive controller.



The portfolio embraces the very latest maintenance technologies, many of which ABB has itself developed. These include remote monitoring and remote diagnostics; "fingerprints" of plant and equipment that pinpoint underperforming assets; and asset optimization services that minimize the cost of assets over their life cycle. By elaborating on some of these service technology areas, a broad understanding of how service and maintenance technology can contribute to profitability can be obtained.

ABB SupportLine gives customers access to what is probably the most comprehensive and advanced support program in mining.

ServicePort™

ABB has developed a secure, remote-enabled service delivery platform – ServicePort™ – that allows customers and ABB experts to view, scan and track key performance indicators (KPIs) to ensure maximum performance of equipment and processes. By automatically collecting, analyzing and monitoring the KPIs, users are able to make informed decisions about specific assets and the production process. The objective is to improve availability, process efficiency and product quality, while reducing risk and energy costs.

ServicePort can host multiple applications, called performance service channels, that automatically gather and analyze specific equipment or process data to produce relevant KPIs. Performance service channels fall into three categories:
– Equipment performance services monitor utilization and performance of ABB-made products, such as control systems and drives.
– Process performance services diagnose and improve production or business processes, such as loop performance and cyber security.
– Industry performance services diagnose and improve equipment or processes specific to certain industries, including mine hoist systems in mining.

Uniquely, ServicePort is an all-in-one solution – all channels work together and allow ABB to configure service strategies that align with the customer's needs.

Another product that ABB has developed specifically for the mining and mineral processing industries is RDS (remote diagnostics services) for maintaining, assessing and analyzing drives in grinding systems (gearless mill drives, ring-geared mill drives, and high-pressure grinding rolls).

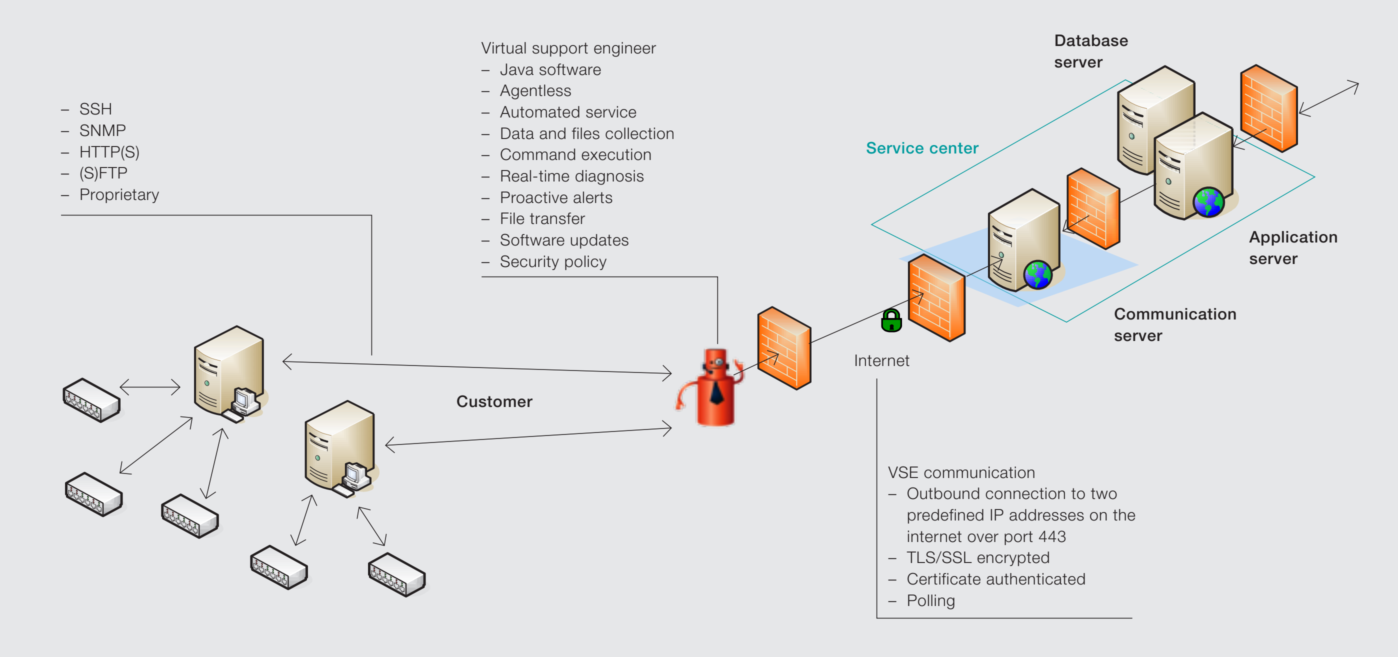
RDS consists of three components.

Remote troubleshooting

ABB has long offered its customers around-the-clock support from experts (via ABB SupportLine) and remote troubleshooting. These two services are available for most ABB power and automation products in the mining industry including grinding systems, mine hoist systems, plant automation systems, variable-speed drives, and many others.

ABB SupportLine gives customers access to what is probably the most comprehensive and advanced support program in mining. The service provides customers with immediate access to ABB technical support engineers who have the

3 The architecture of RDS is developed to ensure the highest security standards for the customer system.



Remote troubleshooting enables ABB experts to access ABB products through a secure remote connection and troubleshoot the problem at hand.

knowledge, experience and resources to handle the support request immediately.

Remote troubleshooting adds a further dimension to remote support. It enables ABB experts to access ABB products, such as a grinding system or mine hoist, through a secure remote connection and troubleshoot the problem at hand. This speeds support, eliminates travel and allows specialists from different fields to work on a problem simultaneously.

Periodic maintenance report
This is a scheduled health and condition examination of the drive systems through periodic inspections. The results are presented in a periodic report identifying the condition of the system.

Condition monitoring
A condition monitoring dashboard is presented that allows customers and ABB experts to access all drive-system operating data in real time ➔ 2.

RDS also has an analytics tool that continuously and automatically assesses the overall operating condition. More than 30 analyses continuously run on the drive system in order to optimize the asset performance and reduce planned and unplanned maintenance. Trends and forecasts are generated around-the-clock by state-of-the-art predictive methods.

RDS is based on a remote access platform that enables a secure connection to the mine site. The platform architecture includes a service center, a local application called visual support engineer (VSE), and field devices. The service center is a Web-application server that functions as the core of the system, acting as knowledge repository, control center and communication hub. The local application (VSE) is a software application located at the customer facility that monitors supported devices and systems. The field devices include any physical device located in the customer network ➔ 3.

All RAP users are managed by strict permissions, data is encrypted and support scenarios are reported. Remote access sessions are controlled by the customer.

Asset management and optimization

According to technology and industry analysts, ARC Advisory, reactive maintenance is five times more expensive than preventive maintenance and 10 times more costly than predictive asset management. Predictive asset maintenance is triggered by asset condition, rather than a fixed period of time or a number of equipment cycles elapsing. This makes it far more cost-effective [1] .

ARC Advisory defines two types of plant asset management (PAM) systems: one for production assets and one for automation assets. PAM systems are defined

4 Optimizing an entire plant is possible with an ABB long-term service agreement.

as a combination of hardware, software and services that monitor asset conditions to identify potential problems before they escalate.

Reactive maintenance is five times more expensive than preventive maintenance and 10 times more costly than predictive asset management.

ABB covers both types of assets (production and automation) in a single product developed specifically for mining. This proven solution provides real-time monitoring, notification and maintenance-workflow optimization of the automation and plant equipment, as well as of field devices, IT assets and the production process. It brings together in one interface and in the proper context for each category of user – operations, maintenance, engineering and management – all information in the various automation and monitoring systems, thereby providing a composite view of the health and performance of each asset.

ABB's asset monitor application analyzes the data in real time. This analysis is performed through a customized monitoring logic for each family of devices. The logic takes into account process variables or software, nominal manufacturer data, parameters and other technical standards. It is developed using failure analysis tools such as fault tree analysis (FTA) and a hierarchical diagram of the equipment. The FTA shows chains of different events associated with a particular failure or "top event," ie, an abnormal system state. It is split into a logical tree showing the causes of subsequent events through the use of logic gates and branches.

Criticality analysis – a systematic methodology that classifies equipment criticality – can further improve matters by showing which equipment needs to be focused on.

ABB has a large portfolio of power and automation products as well as systems, and this helps deliver a unique capability in asset management and optimization that extends across the full range of mine assets: instrumentation, electrical equipment, control loop monitoring, plant equipment monitoring, computerized maintenance management systems (CMMSs) integration, mechanical and vibration monitoring, and custom asset monitoring.

Fingerprints

A "Fingerprint" survey can quickly assess equipment performance, maintenance effectiveness, process control optimization, and plant overall equipment effectiveness (OEE). It is typically completed in just a couple of days on-site, in contrast to traditional plant audits that can take weeks or months to complete.

The Fingerprint provides an assessment of how efficiently the site's process automation and electrification assets are performing and how well production processes are controlled. This information is analyzed off-site; recommendations for improvement are provided; and the business impact of implementing the changes is calculated.

An in-depth equipment-specific fingerprint, such as an electrical and mechanical assessment of mine hoist systems, can also be performed if a wider review is not required.

Making a difference

ABB has a long and deep expertise in the technologies that power and automate mines and mineral processing sites ➔ 4. Via service agreements, this expertise can assist customers in the mining industry to improve productivity by efficiently utilizing production assets. ABB continually develops new service technologies and products that improve asset performance and mine profitability. By bundling these services and technologies into a tailored long-term service agreement with the customer, ABB is able to offer its entire expertise and act as a strategic maintenance partner.

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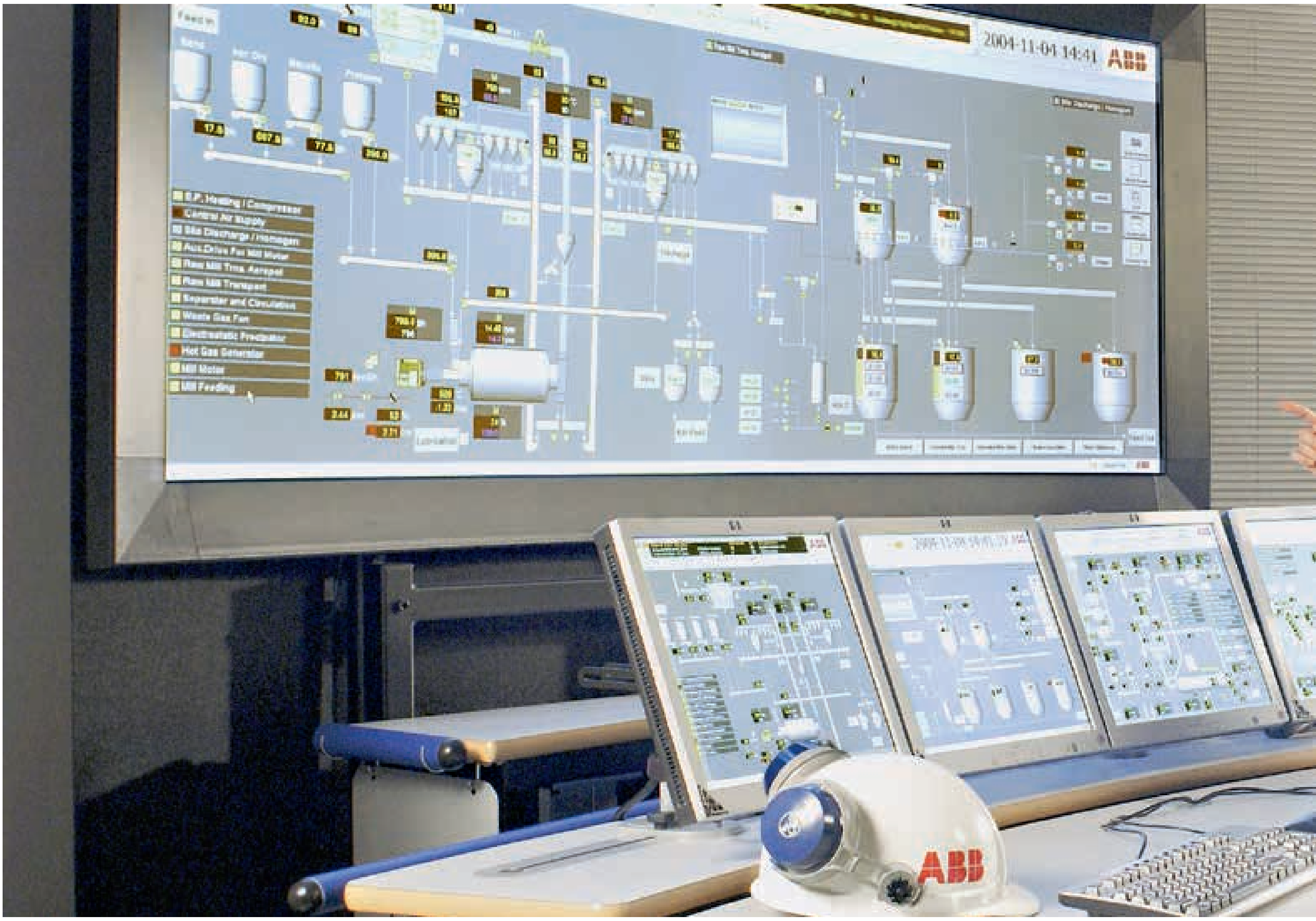


Advancing System 800xA

Demystifying MPC and how to deploy it with ABB's Extended Automation System 800xA

EDUARDO GALLESTEY, MICHAEL LUNDH, TOM ALLOWAY, RICCARDO MARTINI, MICHAEL STALDER, RAMESH SATINI – Model predictive control (MPC) is a well-established technology for advanced process control (APC). Its roots can be traced back to the 1970s [1, 2]. This technology has the proven ability to provide control solutions using constraints, feed-forward, and feedback to handle multivariable processes with delays and processes with strong interactive loops → 1. These types of control problems have successfully been handled in many industrial applications [3].

Optimization is an inherent capability in an MPC controller.

Using MPC brings many benefits. For example, there is less variation in process variables (PVs), which allows set points to be chosen that are closer to performance boundaries, which in turn leads to an increased throughput and a higher profit. MPC brings a structured approach to solutions that would otherwise consist of combinations of feed-forward and feedback with PID (proportional integral derivative) controllers, possibly with override functions.

Additional benefits of MPC are:
– Increases in process knowledge (estimation of hidden variables)
– Higher levels of automation, freeing operators to focus on more important tasks
– Extended scope of control strategy for optimization of, for example, specific energy consumption

Title picture
MPC automates many control room functions, freeing operators to focus on more important tasks.

Optimization is an inherent capability in an MPC controller → 2. Examples are often found in blending, mills, kilns, boilers and distillation columns.

MPC technology

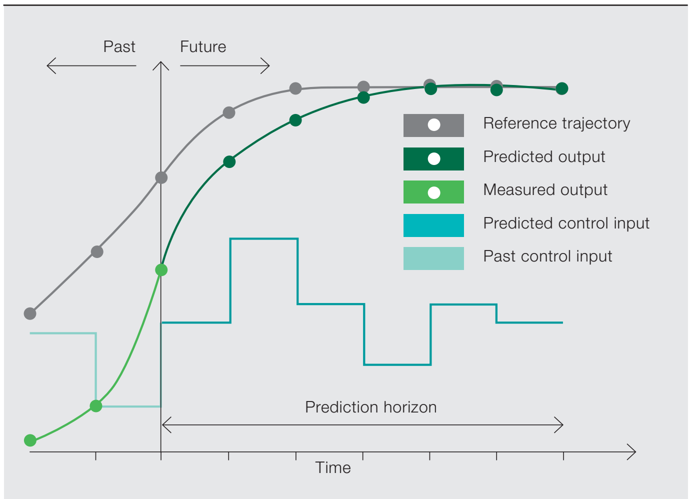
From a user perspective, the main components in an MPC are:

– The plant model
– An objective function
– A state estimator
– An algorithm for solving constrained optimization problems

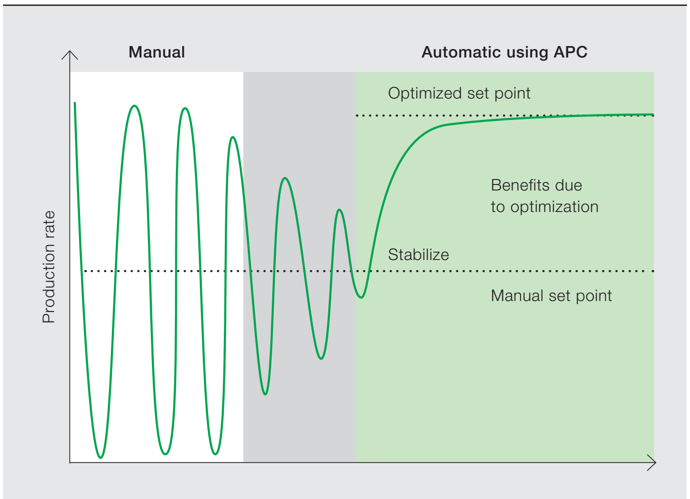
MPC reduces variation in process variables in many industrial applications, which in turn leads to an increased throughput and higher profit.

The following actions take place on a cyclic basis and are repeated with equidistant intervals, of which the sampling time is chosen with respect to the time scale of the controlled process:
– The actual state of the process is estimated from current and past measurements and from the state at previous sample(s) using a state estimator. Kalman filters and moving horizon estimators are well established methods for this. The estimated state $\check{x}(k)$ is assumed to be an accurate approximation of the sometimes unmeasurable state in the true process. It is used as the starting point for the optimization in the next step.
– The plant model can be used to predict the future trajectories of the plant outputs for a given sequence/

1 Past and future trajectories in an MPC

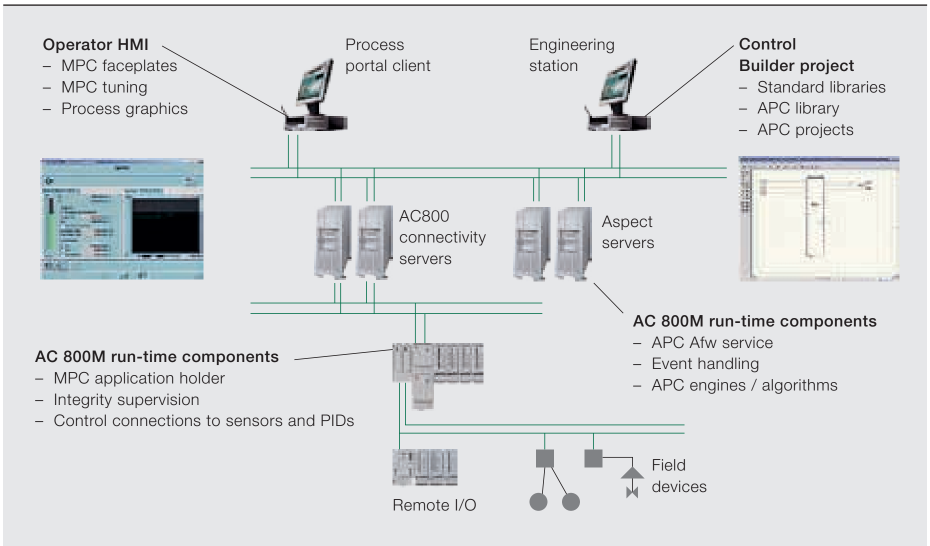


2 APC enabling optimization



Using the square form in the objective function serves to make the control problem “well behaved.”

3 System 800xA APC overview



trajectory of future control signals. Optimization determines the future control signal such that the objective function is minimized. The optimization may also account for constraints on the process inputs and the process outputs.

– Finally, the first instance for each calculated future control signal is applied to the process.

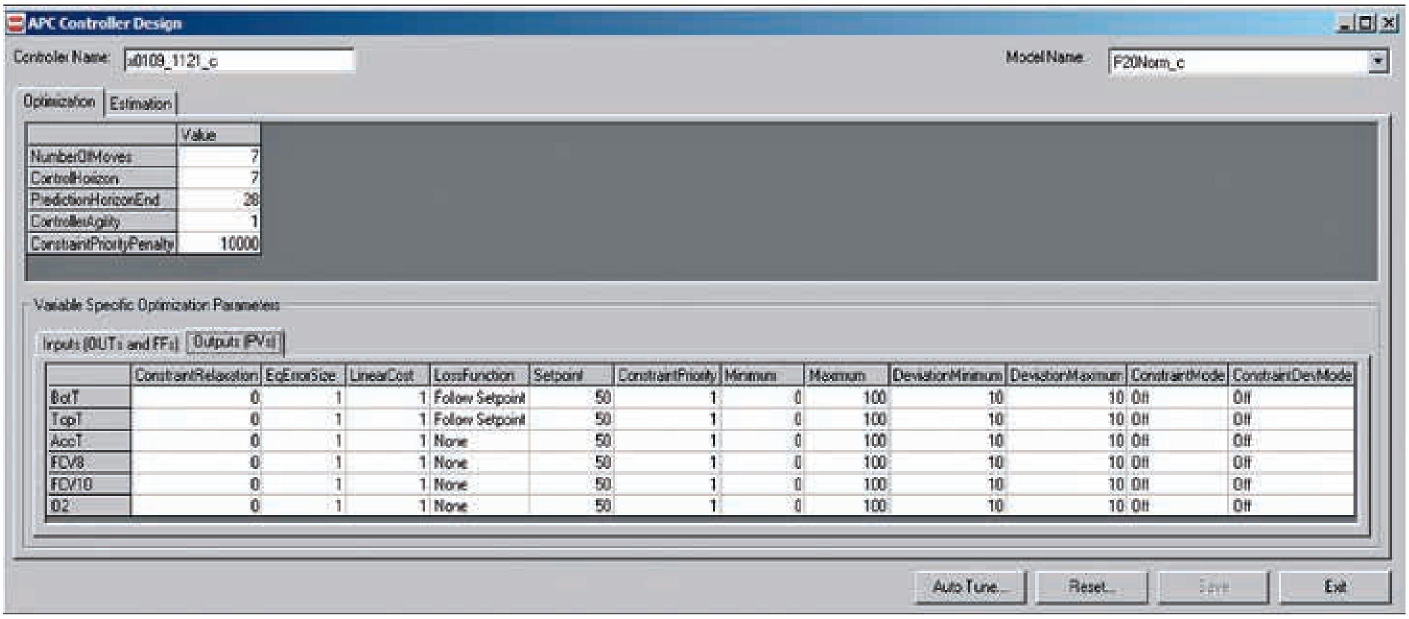
It is worth noting that normally the objective function is a weighted sum of deviations in the plant outputs and in the control signal increments. There may also be linear terms for minimization or maximization of certain variables. Using the square form in the objective function serves to make the control problem “well behaved” .

Traditional implementation of MPC

MPC has been utilized for process control within ABB for a long time, initially using third-party solutions from other vendors. Later, solutions were implemented using the ABB products Predict & Control, and Expert Optimizer. Typically MPC provides set points for the underlying cascaded PID controllers. Common for these approaches has been that the MPC has been running on a separate server, which is not part of the DCS (distributed control system). Signal data is then normally exchanged with the DCS using OPC; measurements, consisting of PV and feed-forward (FF) variables, are sent to the MPC, and the MPC outputs, also called manipulated variables (MVs), are then sent to the DCS.

However, for these solutions to work, a number of additional signals need to be exchanged between the DCS and the

4 GUI for entering tuning parameters



MPC on the external server. These carry information, eg, about which level-1 PID controllers will accept a set point from the MPC and whether the output from the PID is saturated. It is also necessary to move data between the MPC and the operator displays. Further information that needs to be exchanged is the status of the MPC, where often a "heartbeat" signal is used to indicate that the external MPC is alive. All of this communication needs to be configured before the engineer has even started to deal with the control problem. This must also occur before deciding to add or remove signals from the MPC. There is no question that the threshold to use MPC has been substantial.

Advanced process control in 800xA

The new product, System 800xA APC, is am MPC controller fully integrated in Extended Automation System 800xA ➔ 3. It is available as a system extension. In addition there is a tool, the Model Builder, for modeling, controller tuning, and simulations.

In System 800xA APC there is a control module for an MPC controller in the AC 800M controller. Using this control module the MPC controller is easily connected to measured signals and to downstream PID controllers. Once this is done, and the application is downloaded to the AC 800M controller, the MPC can be operated manually using preconfigured operator displays and faceplates. The connections between the MPC and the other objects are established using "control connections." These are bidirectional multi-signal connections where not only signal values are transported but also the Boolean information about operational modes for the downstream PID.

System 800xA APC utilizes the 800xA infrastructure fully. Since an MPC controller can be computationally demanding the execution of the APC service for the MPC engine can be distributed to any server in the 800xA system. If desired, eg, for additional reliability, a redundant service can also be configured. Further, the System 800xA infrastructure provides all the necessary supervision, and all events and anomalies are recorded in the 800xA alarm and event functionality.

Other benefits of the System 800xA APC are:

- Built on already established ABB products
- Migration path for Predict & Control (P&C) and Expert Optimizer controllers
- A structure for the MPC application is enforced, which simplifies maintenance since all related artifacts are stored in one location

With this new product the control engineer can now concentrate on the control problem, leaving all other issues to the platform.

Configuring System 800xA APC

The MPC controller is packaged as an 800xA system extension with a library and a service. Configuration of an instance of the MPC controller in the 800xA APC starts in the 800M Control Builder. After connecting the PVs (measurements), MVs (controller outputs), and FF variables (measurable disturbances), the application can be downloaded to an 800xA controller. Normally the MPC MVs are connected to external set points for cascaded level-1 PID controllers.

The following has then been accomplished:

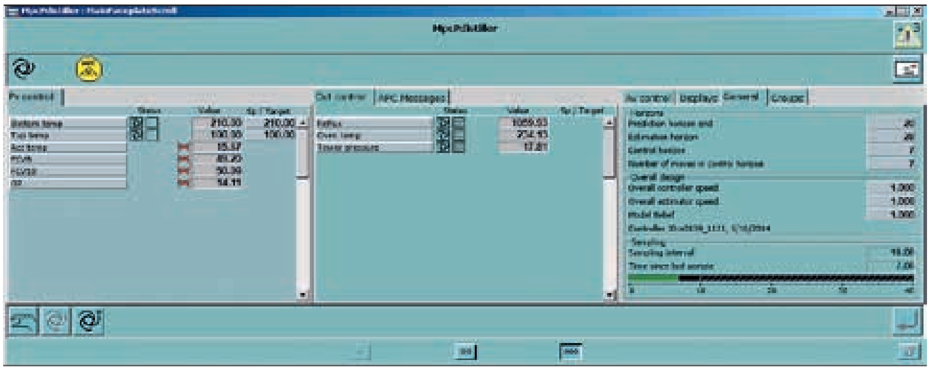
- The MPC can be operated in manual mode from faceplates. All signals can be visualized in faceplates. This is useful, for example, for plant testing to obtain data for empirical modeling.
- Supervision is automatically established for the data transfer between the control module and the 800xA service with the MPC engine.
- By using control connections between the MPC and the cascaded PID controllers the MPC will notice when a PID is not operating in auto mode with an external set point, and the MPC will also notice when signals in the PID saturate. The MPC is then able to take the correct actions when such situations occur.

Modeling and controller design

The Model Builder is intended for, as the name indicates, creating the model that will be used in the MPC. The model can be created in three different ways.

The System 800xA infrastructure provides all the necessary supervision, and all events and anomalies are recorded in the event and alarm functionality.

5 Main operator faceplate



One way is that a model can be obtained using empirical modeling, where a discrete time-state space model is calculated from logged data. Data should preferably be obtained from an identification experiment where the MVs are changed up and down. There are different ways to do this; the simplest is to make step changes in each of the MVs sequentially.

Alternatively a model can be defined by a set of low-order transfer function models, one for each input-output relation in the multivariable model. A typical low-order transfer function is defined by the parameters in:

$$G(s) = \frac{K}{sT + 1} e^{-Ls}$$

but more complicated transfer functions can also be defined.

A third possibility is to graphically build a first-principles model using predefined blocks. This is the most generic method that is supported in the Model Builder.

Control engineers can concetrate on the control problem leaving all other issues to the platform.

Although these are completely different approaches, a model can be merged together by using smaller models of any of the three types.

The Model Builder provides functions to analyze models. There are functions for step responses and also for model validation where the model is fed with logged inputs and the simulated model outputs are compared with logged outputs.

Once a model is considered to be of sufficient quality for use in the controller, an MPC can be designed. This is also done in the Model Builder. Design parameters are entered in a table → 4. An auto-tuning feature is available to provide initial parameters for less experienced users.

The influence of the chosen tuning parameters can be evaluated by simulations with different inputs. There are possibilities for simulation with steps in set points, in feed-forward, and in output disturbances. Robustness can easily be evaluated when using a different model for simulation than the one that is used in the MPC controller.

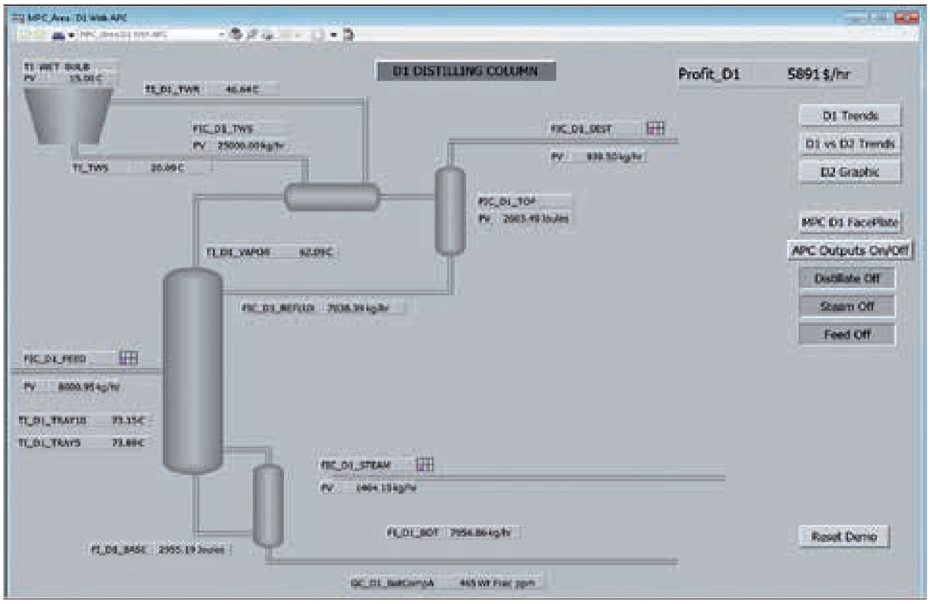
The controller parameters are stored together with the model as an xml file.

MPC commissioning in System 800xA

The final step is to deploy the designed MPC in the 800xA system. In System 800xA Plant Explorer an xml file, with tuning parameters and model, can be selected to configure the online MPC algorithm with one of the MPC controllers that was defined in the Model Builder. Now the MPC controller is fully operational in the 800xA system and can be switched to auto mode to fulfill its task.

Once the basic configuration is finished a number of tailor-made faceplates are generated by the system → 5. These faceplates contain complete information

6 Distillation column



Once a model is considered to be of sufficient quality for use in the controller, an MPC can be designed.

for both the operator and the APC engineer. In other words, not only set points and limits are available, but also the internal parameterization of the controller is accessible to authorized 800xA users.

Most of the tuning parameters are available in the faceplates provided or operator displays. This is useful if further online tuning is needed.

In cases where several APC controllers are deployed in the same server, it might be necessary to spread the CPU load. This is achieved using the scheduling tool provided by 800xA APC, where each controller is assigned a time slot for its optimal starting point.

Additional functionality is available due to the integration with System 800xA. For example, 800xA offers integrated alarm handling, National Language Support and APC key performance indicator (KPI) tables.

Typical use cases

There are five typical use cases for APC controllers.

Distillation columns in oil and gas

Distillation columns are widely deployed in the process industry. Their use is recommended when there is a need to separate components that have different boiling points. The main idea is to introduce the raw mix of components, usually in liquid form, into the middle section of the distillation column. Through successive vaporization and condensation steps the low boiling point components are concentrated at the top of the column and the high boiling point components are concentrated at the bottom. A typical example is the separation of crude oil into components such as gasoline, kerosene and diesel.

Since each step influences the others, the problem is naturally multivariable. However the process is highly repeatable and thus well suited to modeling via empirical or data-driven modeling. Typical process variables are temperatures, pressures and compositions at the different levels of the column, while the main actuators are feed, firing, reboilers for the column bottom, pump-around flows, cooling rates and overhead pressure control bypass → 6.

MPC projects in this field deliver better process stability, more homogenous quality of the components extracted at each step, and, depending on the customer business objectives, yield maximization, throughput increase, reduction of quality "giveaways," or minimization of energy consumption [4].

Grinding and flotation in the minerals industry

In a typical grinding circuit at, for example, a copper mine, the ore is introduced in the mills where abrasion, attrition and impact reduce its size. Usually, the grinding circuit contains at least two interconnected mills with material classifiers (eg, cyclones) separating the fine material from the coarse (that then goes for re-grinding).

The process is very energy intensive with power consumption of roughly 20 to 30 MW and feed throughputs of 2,500 to 3,000 t/hr. Process variables are mill loads, motor torque and power, plus pressures and flow rates. The ground product is specified in terms of fineness range. The typical results of an APC controller → 7 are increased throughput, homogeneous product quality and lower maintenance costs.

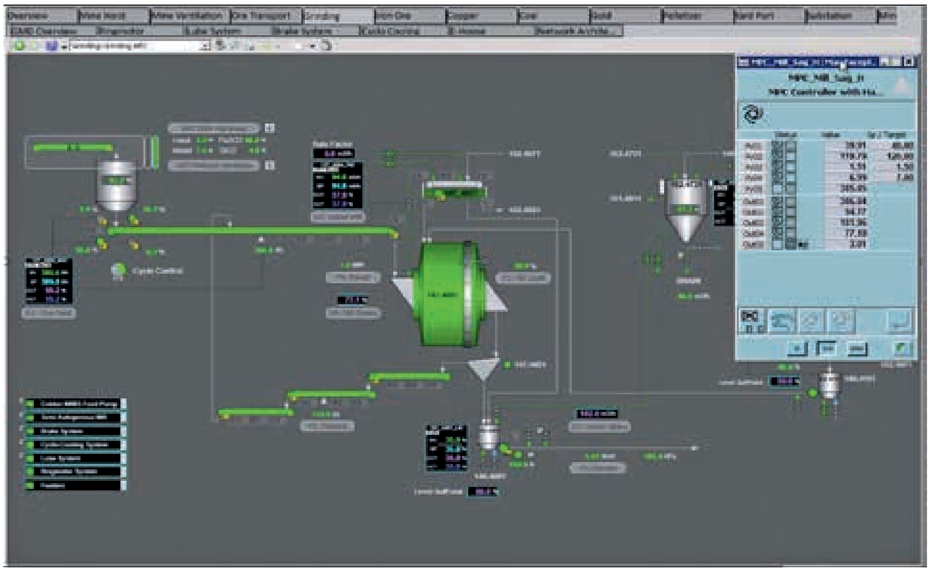
Further, APC can be advantageously deployed in the flotation plant, where the ground ore, now in slurry form, is "washed" to separate valuable minerals from waste. The goal being maximum production or maximum yield at a given concentrate quality, APC performs timely adjustments to froth levels, air flows and reagents leading to process stabilization and increased recovery [5].

Kilns in the cement industry

The rotary cement kiln process is intrinsically unstable, there are long time delays and large perturbations acting on it. The control problem consists of maintaining a given temperature profile along the kiln plus obtaining good burning conditions. Further, the control strategy needs to achieve that at the lowest energy consumption possible, which means riding along constraints such as amount of air in the exhaust gasses. The problem ex-

An auto-tuning feature is available to provide initial parameters for less experienced users.

7 Minerals grinding application



hibits relatively long time delays related to the slow transport of the raw meal along a series of heat exchangers, cyclones and then the kiln.

Actuators are kiln speed, energy input (fuels), air and feed, while the process parameters to be controlled are temperature in the kiln front (or specially built soft sensor thereof), temperature at the kiln inlet, and oxygen in the gasses traveling through the system. Additional complexity might also come from the usage of alternative fuels, where the control strategy needs to calculate the optimal fuel mix for the given conditions.

The typical benefits a user can expect to achieve from using System 800xA APC for cement kiln optimization (branded as "Expert Optimizer") are increased output, lower fuel consumption, longer refractory life and better and more consistent quality [6, 7].

Continuous pulp digester

The Kamyr continuous pulp digester is a complex tubular reactor where wood chips react with an aqueous solution of sodium hydroxide and sodium sulfide (referred as white liquor) to remove the lignin from the cellulose fibers. The product output from the digester is cellulose fibers or pulp. Most continuous digesters consists of three basic zones: an impregnation zone, one or more cooking zones and a wash zone. The white liquor penetrates and diffuses the wood chips as it flows down through impregnation zone. The mix is heated to a target cooking temperature where bulk delignification starts, and the majority of lignin is removed. The cooking process is stopped at the beginning of the wash zone by reducing the temperatures and cooked pulp is washed in a counter-current washing zone, using wash liquor injected at the bottom of the digester.

Producing an even quality pulp at a consistently high production rate is a challenging task for digester operators where the raw material quality, such as chip size and chip moisture, tends to change with the seasons, natural geographic factors, and the wood source. The schedule also swings from hardwood to softwood making the process control task more complex.

At the core, advanced control package for the digester (known as OPT800 Cook/C, an application built on the System 800xA APC platform) stabilizes pulp production, reduces chemical usage and coordinates the numerous loops to incur optimum, on-specification, pulp quality at minimum variance. This optimum pulp quality production assures the minimization of bleaching chemical use where bleached grades are produced. In addition, these controls maximize production, yield, and paper stock drainage on the paper machine in both bleached and brown product mills. The process variables includes blow kappa number, digester level, residual alkali concentration and the production rate. The product quality is specified in terms of Kappa target, and level range.

The exemplary results from recent installation indicates a 51% reduction in blow kappa number, a pulp quality indicator with a stable blow flow rate, and a 60% reduction in chip level variation in the digester. Stabilized chip movement leads to stable residence time in the different zones of the digester [8].

Industrial steam power plant

In several process industries (oil and gas, pulp and paper, minerals, etc.) production requires both steam and electrical power. In these cases, plant operators often build in an in-situ utility unit to satisfy these needs. These are not mainstream power plants like those normally built for power generation. Indeed, not only is the steam needed at different, very specific pressures and temperatures, but its consumption rate is also highly variable due to the variability of the process conditions, trips and/or starts of steam consumers, etc. It follows that steam network stability and reliable power output are difficult to attain. In some cases, steam is generated also via energy recovery from other units eg, furnaces in a steam cracker or from byproduct gas usage eg, blast furnace gas for a steel manufacturing plant. This introduces further disturbances to the steam network as energy and fuel recovery is subject to upstream unit's availability and cycles.

Typically the foremost important goal is delivering enough steam, at the required parameters, to the process while producing as much power as economically optimal at a given market conditions. In

8 Steam temperature stability with and without APC

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other configurations, the problem might also comprise delivering heat to a district heating system.

Further complexity is added by energy market variables, prices, and local rules for energy markets. In addition to that, internal incremental production price depend on variable fuel block prices. It follows that in many cases the optimal power output is very different between peak and low energy prices and thus re-positioning of the power production is needed. For instance, when the real time energy price is below the internal production price the tie line import is maximized. But when the real time market price is higher than the internal price, the tie line is minimized.

From an APC point of view, typical actuators are boiler rates, steam turbine inlet/extraction rates, gas turbine MW targets, attemperators, pressure control valves, steam flows to users and vent valves. There are multiple constraints and couplings, delivering a text book case where APC can outperform classical control schemes, typically based on cascades of PIDs and separate PIDs operating with staggered set-points.

Projects of this sort have been executed by ABB quite often in recent years and have delivered a more stable and reliable steam supply to the process with, reduced operating costs, higher energy efficiency ➔ 8, higher average profit (eg, by selling more at higher price and less at lower price) and lower disturbances to the power plant and energy users [9].

Advanced outputs

This is a new extension to System 800xA, leading to straightforward design and deployment of APC in ABB's 800xA DCS: 800xA APC.

800xA APC cleanly splits the work related to modeling and control design from the more usual tasks of connectivity, safety locks, and HMI settings, which effectively happen in a configuration-free manner. The system also facilitates remote commissioning and application support.

The typical use cases in the cement, minerals, pulp and paper, and oil and gas industries cover the vertical industries where ABB has a strong footprint.

ABB continues to invest in this technology with the aim of increasing the value that the company's control system delivers to its customers, across the entire ABB global footprint. The optimization that is inherent to MPC brings not only financial benefits to ABB's customers, but contributes to an ongoing drive to reduce emissions, and resource use, which delivers benefits beyond the scope of the process under consideration.

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Bounding ahead

IT maturity takes the mining industry from laggard to leader

JAY JENKINS – Up until recently, almost every other industry surpassed mining when it came to using information technology to support and enhance their business. Surveys by market research companies consistently report that industry as a whole generally spent 3 to 5 percent of revenue on IT while miners spent less than 1 percent. That has all changed over the last five years. The exploitation of IT in mining is enabling companies to increase productivity despite the many challenges faced by the industry.

1 To compete in today's environment, mining companies have to create an integrated operating environment.

The increased level of complexity in the mining industry has been a tremendous driver in getting mining companies to look toward IT to help them stay competitive, especially in cost containment. The shift toward IT in the mining industry has been helped by an influx of high-level executives from outside the mining sector. These executives have come from consumer-product companies, high-tech businesses and financial institutions, and are driving IT investment philosophy. This has raised the bar for the whole industry. Finally, large industrials have recently acquired their way into the mining equipment, technology and services (METS) industry – a segment worth $90 billion per annum and representing 6.5 percent of Australia's GDP, for example – and are applying their mature approaches to IT enterprise-wide when creating solutions for mining companies.

These factors have created an opportunity in the mining sector to learn from the pioneering efforts in other industries when it comes to deploying technology. Other manufacturing sectors, both discrete and process manufacturing, learned early on that islands of automation and islands of information led to performance issues that created both production volume and quality problems → 1.

> The increased level of complexity in the mining industry has been a tremendous driver in getting mining companies to look toward IT to help them stay competitive, especially in cost containment.

IT/OT convergence – an integrated enterprise

One of the most promising results of cross-pollination from other industries is the introduction of integrated remote and autonomous operations. The convergence of IT (information technology such as enterprise asset management and enterprise resource planning, logistics and operational systems) and OT (operational technology such as process logic controllers on machinery) in this area has led to more efficient processes.

Of course, mining companies have been investing in their own research and development – work that finds synergy with the technology adopted from other industries and allows technology advances on an enterprise scale.

It is possible to bring autonomous equipment into mining on an industrial scale. This autonomy and ability to control equipment with highly standardized, mature and integrated IT systems means that mines can be run effectively from remote operation centers many hundreds of kilometers away → 2.

The key drivers for pursuing the integrated mining enterprise, as identified by Gartner [1], include:
- Critical skills shortage all the way from the mine face to the corporate level.
- The ability to effectively optimize the entire value chain, not just certain parts of it.
- Increased public visibility and accountability, including in areas of sustainability as well as financial performance.

Title picture
Information technology is transforming the mining industry by connecting its many disparate parts into an integrated operating environment.

A research study concluded that one of the biggest opportunities miners had was to learn from other industries and move toward an integrated mining enterprise through the adoption of standardized architectures.

2 Integrated IT systems will enable mining operations to be run remotely.

– Consistency of output from both a quality perspective as well as from a predictability of performance perspective.
– Ability to operate in a highly volatile economic atmosphere.

These align very closely with the results of the Ventyx 2012 Global Mining Survey [2] as well as recent published executive interviews [3]. Recognizing these benefits, a number of leading mining companies are now pursuing integration – but they are achieving less-than-optimal results as the lack of industry-accepted enterprise architecture (EA) standards in mining is slowing the integration effort. Other industries, from automotive to semiconductors, have all faced this issue in the past and over the course of the last 15 to 20 years have adopted numerous industry standards that have facilitated speedier implementation of integrated operations. Mining can and should follow a similar approach and leading companies are already adopting OAGIS, S95, B2MML and standards like PAS55, for example. Ventyx, by learning from the lessons of others and applying detailed mining expertise to these standards, acts as a catalyst for customers who are on the road to quicker maturity.

No one single industry standard will serve the complete breadth and depth of the mining industry, but there are several EA activities that deserve the industry's attention and support. Key among these is the Exploration, Mining, Metals and Minerals (EMMM) forum of The Open Group (a vendor and technology-neutral industry consortium), which has developed an EA reference model for the industry. Being a reference model it is sufficiently generic to serve as the foundation for any mining enterprise's specific architecture but with ambitions and capability to automate more of the complexity required for an efficient autonomous mining enterprise.

There is a huge opportunity in the mining sector to learn from the pioneering efforts in other industries when it comes to deploying technology.

The first step then for any mining company in moving toward an integrated operating environment is to ensure that it:

3 The location, quality and quantity of product in transit can easily be tracked in an integrated operating environment.

One of the most promising results of cross-pollination from other industries is the introduction of integrated remote and autonomous operations.

- Understands the benefits of integration
- Has a strategy and approach to how it intends to achieve integration
- Selects vendors and products that are compatible with that integration strategy and intended blueprints that make this practical

Buying technology that is isolated and stands alone might solve a point problem but it ultimately creates an insurmountable barrier to achieving the competitiveness that an integrated enterprise can deliver. Therefore, Ventyx is investing in more seamless integration within its own products as well as working with relevant players who are also aiming for the outcomes of an open platform.

The Ventyx integrated mining model

Ventyx has significant intellectual property (IP) that almost any mining organization should be able to leverage when crafting their integration strategy. The Open Group has convened a global forum, the Exploration, Mining, Metals and Minerals Vertical (EMMMv), to create enterprise architecture standards and reference models for the exploration, mining, metals and minerals industries. Ventyx methodologies and process models generally align with the EMMMv model. Ventyx's unique IP can cut through the complexity of integrated mining models and help mining companies focus on the critical processes that make them excellent when performed well.

Bottom line

The mining industry has advantages that other industries did not have. It can leverage the 15 to 20 years most other industries spent in trying to understand and then move toward an integrated enterprise. By adopting an integration model, communication and data standards that facilitate integration, and then selecting and deploying solutions that fit within the parameters of their plans and the standards they choose, they can achieve in a few years what other industries took decades to accomplish.

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One and done

A unified platform approach helps miners overcome the complexities of today's business processes

DAVID WESTLAKE – Managing the mine-to-market process is a complex challenge for any company. Manual methods and point software solutions cannot start to address the intricacies and the need for real-time visibility that characterize today's closely interrelated commercial and outbound logistics processes. The Agnico Eagle company experienced this firsthand as it grew from a single operation to seven operations spanning three countries and from providing a handful of products to more than 20 different products – all in the course of a few years. A unified platform approach to automation has helped Agnico Eagle overcome the complexities of today's market business processes and has empowered the company to reduce costs and improve commercial outcomes.

The primary benefit of automating via software is that data can be entered once and the business rules in the system take it from there.

Agnico Eagle is a leading international gold producer, with mines and exploration properties in Canada, Finland, Mexico and the United States ➔ 1. Not so long ago and in common with many other enterprises, its market business processes were managed almost entirely with Excel spreadsheets and Word documents. But, as the operations expanded across multiple mines, countries and languages, a more robust means of managing these processes was required. Today, Agnico relies on a unified software platform to manage and streamline its mine-to-market processes. The resulting real-time visibility and elevated levels of coordination have led to lower administrative costs, tighter inventory management and quality controls, and improved commercial outcomes.

This platform approach to automation was used to improve processes across five of the most complex areas of commercial and logistics operations today: contracts, compliance, logistics, invoicing and risk management.

Title picture
After raw produce is mined, it is only at the beginning of a long and complex path to its ultimate use. Keeping track of all the business processes involved in that journey is best done with one unified software platform. Shown are trucks hauling at Agnico's open-pit gold mine in Canada.

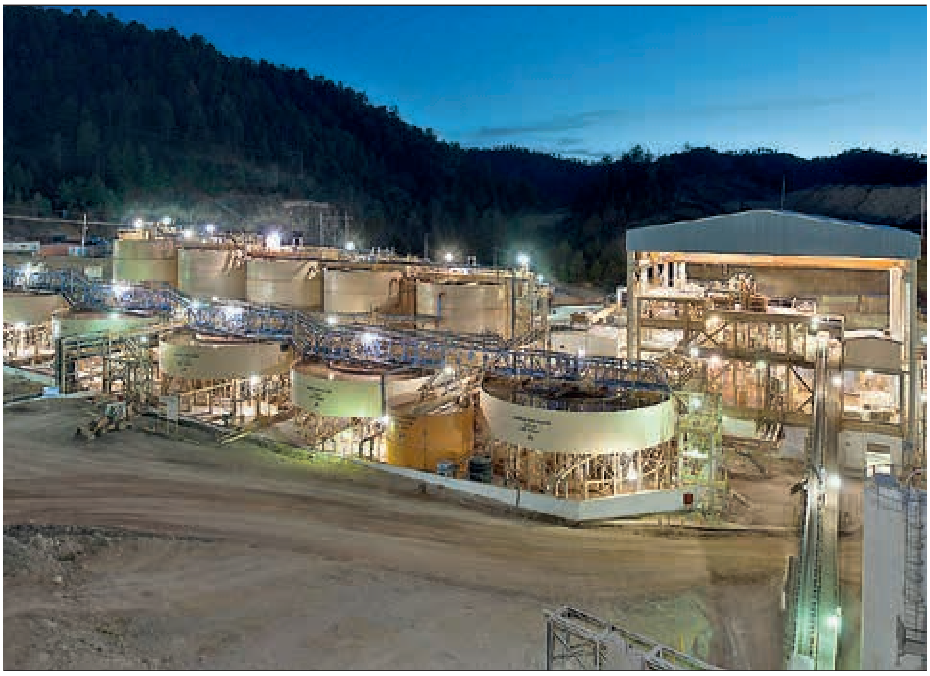
Streamlining management of complex contracts

Commercial contracts have become very complex and challenging to manage. At Agnico, the sheer number of different types of contracts across multiple products (gold, silver, copper, zinc and lead) was starting to weigh heavily as administrators wrestled with issues such as multiple contracts within a single product, specific quality specifications and complicated payment terms and delivery schedules. As operations continued to expand, it was clear this would soon become too onerous a process to manage manually, as well as too costly in terms of personnel.

In moving to a software platform, contract administration was one of the fundamental areas that Agnico sought to improve. The primary benefit of automating via software is that data can be entered once and the business rules in the system take it from there. Essentially, the contract data goes into the system where it is checked automatically for accuracy and completeness – ensuring the contract is calculated correctly. With the administrative paper chase eliminated, company personnel can spend more time on more constructive tasks. Equally important, accurate invoices can now be generated immediately after month close instead of weeks later.

The unified software platform manages and streamlines mine-to-market processes. The resulting real-time visibility and elevated levels of coordination have led to lower administrative costs, tighter inventory management and quality controls.

1 Agnico's Pinos Altos processing plant on the Santo Niño fault in northern Mexico



Meeting complex compliance, auditing and reporting requirements

In mining, compliance is an absolute → 2. A company that does not comply with regulations does not operate. Robust auditing capabilities are fundamental to ensuring and proving compliance with Sarbanes-Oxley and other mandates, as well as to reconciling what has shipped to a customer compared with what a company believes it has produced.

Agnico can create a month-end invoice for any outstanding invoice utilizing an accurate month-end valuation of inventories. This allows an instantaneous total calculation for mark-to-market accounting purposes.

Software enables a company to achieve full control over its information. With a software platform, data is checked and audited to ensure contracts have been entered into the system correctly, and access to commercial data and invoicing is tightly controlled (access privileges, change history, etc.) and continuously monitored. This information lockdown not only saves a company time and effort, and streamlines the audit process, but it also enforces the segregation of duties that is frequently required for compliance. As a publicly traded company, Agnico has benefited greatly from these capabilities.

Software also enables easier reconciliation of output and customer delivery. At Agnico, software is leveraged to achieve visibility into the actual assays of truck shipments and to track individual truck units right through to the end customer.

Additionally, visibility into outturn weights and assays can also help a company adjust its mining plants and plans (eg, tracing quality issues to their source to facilitate fixes) and operate more profitably through improved mine grade understanding. At Agnico, this vital visibility is part of a feedback loop to drive continuous process improvement.

2 In all kinds of mining, like the open-pit mine shown, compliance is an absolute must.

Software has given Agnico visibility into, and control over, logistics operations. Logistics personnel can visualize what is in each truck in terms of contained metal and its value, and are able to see which truckloads are allocated to which railcar.

Another important lesson has been to get all of the key people actively engaged – and keep them engaged – throughout the implementation cycle.

Taming complex logistics

Another challenge common to all mining companies is to manage complex shipping environments and shipment scheduling. This includes managing multiple forms of transportation as well as rapidly changing capacities, contractual quotas and variable delivery schedules. This is more than just a matter of moving minerals and metals to market. It is also a matter of visibility – understanding what materials went into which trucks and railcars and where the materials ultimately ended up.

As with contracts and compliance, software has also given Agnico visibility into, and control over, logistics operations. Logistics personnel can visualize what is in each truck in terms of contained metal and its value, and are able to see which truckloads are allocated to which railcar. And they can use the software to "move" the truckloads around between railcars to drive optimal logistics, just as if each truckload was a building block imprinted with information. For example, certain blocks can be held back should it be discovered that a rail line has a problem, while other blocks can be substituted as required to fulfill the order to the customer.

There is a significant ancillary benefit of this visibility, one that flows across several complex processes. Through the software platform, Agnico is able to visualize and value at any given moment (especially month and quarter ends) its entire inventory and precisely what is in transit and/or still a receivable. This is a major leap forward from merely "seeing" a mass of inventory with no clear handle on its composition and value until a formal reconciliation can be done.

Accelerating complex invoicing processes

As with contracts, invoices increase in number and become more complex as a mining company grows. As mentioned above, software enables contractual data, charges, weights and assays, and so on to be entered and checked just once. Consequently, rather than worrying

3 A unified software platform integrates all required business information, like data from the grinding mill control room shown here.

whether terms and conditions are correctly reflected, personnel can instead focus on ensuring that the underlying data is correct and on timely invoicing.

No longer must employees repetitively agonize over whether a penalty or a specific commercial term has been included in an invoice, because its inclusion has been verified by the software. Similarly, business rules in the software can automatically put in current Metals Bulletin or Metals Week pricing, so personnel are relieved of this repetitive task as well.

At Agnico, this has dramatically accelerated the invoicing process.

Simplifying complex risk management

It is endemic in the mining industry that companies are subject to price fluctuations at every accounting period close. Hence, it is critical to have a full and accurate picture of month-end inventories in stockpiles, in transit and in warehouses, and of their valuations so that there are no surprises. At Agnico, this ability is enabled by the same software platform that is streamlining contracts, driving compliance, taming logistics and accelerating invoicing.

Consequently, Agnico is able to create a month-end invoice for any outstanding invoice, strictly for internal use, utilizing an accurate month-end valuation of inventories. This allows the creation of an instantaneous total calculation for mark-to-market accounting purposes – so the total current value of what the company has in transit, in inventory and in unpaid invoices is known.

> Software enables contractual data to be entered and checked just once, so personnel can focus on ensuring that the underlying data is correct and on timely invoicing.

As an important ancillary benefit, this same capacity powers Agnico's ability to issue provisional invoices, which are subsequently followed by a final invoice. Again, this helps avoid surprises, such as customer bill-backs, while also improving cash flow.

Requirements for a successful software solution

Point software solutions are as incapable as manual methods of addressing the complexities and needs for real-time visibility of today's closely interrelated commercial and outbound logistics processes. As can be seen from the five complexities outlined above, the key word is "interrelated." Point software solutions do not "do" interrelated processes nearly as well as a software platform that shares data, visibility, business rules and other functionality across multiple processes. For this and other reasons, an end-to-end platform solution figured large in Agnico's push to automate its market business processes.

Other key considerations included support for complex operations with ample headroom for growth, along with the functionality to enforce standardized business practices across the company's multinational, multi-time zone and multi-language operations (eg, issuing standard formatted invoices and centralizing the rollup of month-end commercial results/numbers/projections across all operations). Equally important was the ability to provide end-to-end market business process visibility, giving real-time product quantity and quality information at all points in the commercial and logistics chain.

Agnico Eagle's results to date

The platform solution that Agnico implemented, Ventyx MineMarket, was built expressly to manage the complete mine-

Data is checked and audited to ensure correct entry. Access to data is tightly controlled and monitored. This not only saves effort and streamlines the audit process, but it also enforces the duty segregation frequently required for compliance.

to-market process. A high-level view of the business advantages realized thus far include:
- Faster order-to-bill and time-to-payment cycles, leading to improved cash positions.
- Reduced risk and incident of errors, contributing to customer satisfaction and improved commercial results.
- More controlled data into accounting, enabling improved compliance processes and reduced financial risk.
- Streamlined and less paper-intensive financial auditing, reducing third-party auditing costs.
- Reduced administrative workloads, allowing personnel to be refocused on more strategic tasks.
- Consistency across business processes such as invoicing, alleviating workloads for accounts receivable and other departments touching various market business processes.
- Accelerated financial reporting, including faster mark-to-market reports.
- Improved analytics and forecasting, powering improved business intelligence and planning, ensured product quality, and closer alignment of production and demand.

Lessons learned

Automating mine-to-market operations end-to-end is a significant move and companies can expect to learn many things along the way. At Agnico, the most important lessons included the need to not simply ask what the software can do for the company, but also to focus on what the company needs to do with the software. In other words, decide what the software should accomplish and then adapt it to the specifics (eg, if the software should support the processes already in place or be used to completely revamp and improve current processes). To enable this, the platform has to be flexible – that is a priority. But the company has to be flexible too.

Another important lesson is to get all of the key people actively engaged – and keep them engaged – throughout the implementation cycle. A sea change of this import cannot be implemented solely by fiat – it requires buy-in and collaboration across multiple process participants, data owners and day-to-day users. For example, stakeholders should determine in advance what reports, types of contracts, etc., are needed to allow appropriate software configuration. That way, the stakeholders have ownership.

Equally important is to select a vendor with deep domain expertise in mining as well as process automation – and a vendor who will be around for the long term.

Finally, business expansion should be pre-empted: A limited number of processes and operations can be supported on a software platform, with expansion to more as required. This way, expertise in using the software can be built up and the company is ready to act quickly when growth projections become reality. It is easier to build from the ground up than to remodel at a later date.

One for all

The five areas of complexity described above are just some of the ways that Agnico Eagle has benefited from moving the management of its market business processes from spreadsheets to a unified software platform → 3. Other uses include running “what-if” scenarios to stay ahead of changing business conditions and engaging in more accurate demand planning. The beauty of a platform approach is that the same platform can automate (and link) multiple business processes, eliminate silos of information and ensure that complete and up-to-date information is available across all mine-to-market operations.

It is not just precious metal miners like Agnico that can benefit from automation and access to real-time information across the commercial and outbound logistics chain. Base metals, coal, iron ore – practically any type of mining operation – stands to benefit as well. Mine-to-market operations are going to become even more complex and subject to auditing over time. Piles of spreadsheets, point solutions and disjointed processes only add to the complexity, but a platform approach enables miners to tame it.

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Modern cyborgs

Going where only science fiction dared to venture

MARKUS ALEKSY, ELINA VARTIAINEN, MARTIN NAEDELE – Humans exhibiting enhanced capabilities through the use of implanted computers and electronics – otherwise known as cyborgs – have long been standard fare in popular science fiction movies and stories. This idea is no longer confined to creative Hollywood minds but is gradually finding its way into industries where it is proving to be very effective in terms of plant maintenance and personnel safety. Building on recent advances in mobile computing and sensor technology, the concept of wearable computing combines these technologies to produce invisible sensing devices that are capable of providing accurate information about the very often complex environment in which they operate. ABB has looked at how industrial environments, and in particular the service industry, can benefit from wearable computing solutions, and solutions combined with augmented reality. The science fiction of yesterday has become the technology of today.

Title picture
Industrial environments are benefiting from wearable computing and augmented reality solutions to improve plant maintenance and ensure personnel safety.


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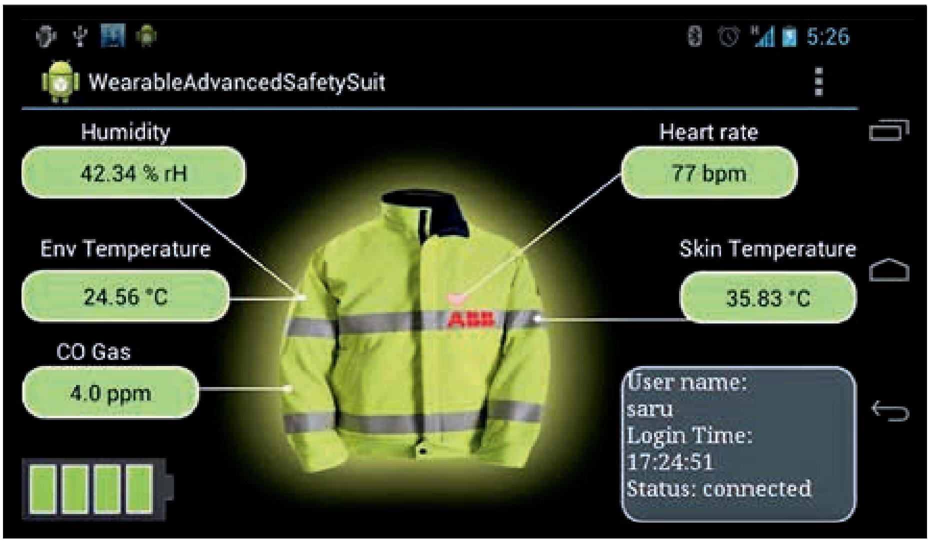
1 The mobile app for displaying the values of the sensors embedded in safety clothing



Recent advances in mobile computing and sensor technologies have enabled innovative solutions in the form of mobile apps and wearable computing. Mobile devices, such as smartphones and tablets, allow information to be quickly and cheaply accessed, processed and communicated without being confined to a single location. Sensor technologies can measure information in a particular environment and transmit the data to a mobile device for closer inspection. Modern and rugged mobile devices, equipped with different types of sensors (eg, light sensor, gyro, GPS, WiFi and accelerometer) and extended functionality are proving very useful in industrial environments.

Wearable computing takes the combination of mobile devices and sensors to a higher level by making the computer invisible (it is embedded into clothing or everyday items) and always on [1]. Though not an entirely new concept, costs and technical reliability were serious obstacles to the widespread practical implementation of wearable computing in the past [2]. A full-scale wearable computing solution consisting of a head-mounted-display (HMD)-based augmented reality (AR) and hand-gesture-based interaction was expensive. However, the popularity of mobile apps and the availability of advanced mobile technologies have now enabled the development of more affordable applications that provide field personnel with timely, accurate and detailed information on the move.

Supporting service efficiency

Proper service is vital in ensuring that industrial plants are safe to work in and operate without unexpected shutdowns. While the servicing of a particular device or system area may be routine to experienced service engineers, complex cases often mean additional and up-to-date information, such as customer products, application domains, the history of the installed equipment, and service procedures and processes, is required to support problem solving and reduce the impact on the rest of the plant. The quicker this information can be accessed, the faster the problem can be solved. Therefore the instant availability of up-to-date information is a vital prerequisite in any business environment today.

> The instant availability of up-to-date information is a vital prerequisite in every business environment to support problem solving and reduce the impact on the rest of the plant.

In global operating enterprises, this information is stored in many databases of the enterprise information technology infrastructure. ServIS, ABB's installed base information system, is an example of such an enterprise information system that keeps track of all ABB products and systems at a customer site, including technical and project details. It is integrated with other ABB information systems, such as ABB Product, ABB People and the global customer identification system.

> Utilizing mobile and wearable systems, such as HMDs, eyeglasses or contact lenses, to access installed base information provides an opportunity for more efficient service delivery and execution.

These systems could be used to:

- Locate industrial equipment in large plants: AR can be used to overlay a real-world view of the plant with information related to the location of the equipment. The current location of the worker can be obtained via a GPS sensor built into a mobile device while the GPS position of the equipment can be loaded from an installed base management system such as ServIS.
- Identify industrial equipment: Advanced identification and labeling techniques, such as bar codes and NFC- or RFID-based tags (near-field communication

The popularity of mobile apps and the availability of advanced mobile technologies have enabled the development of applications that provide field personnel with timely, accurate and detailed information on the move.

or radio-frequency identification) can be used to identify equipment. The data read from the bar code or tag can be used to request further information from backend systems, such as ServIS.
- Access different types of information: As well as being able to access information such as previous service reports, technical drawings, manuals and checklists, field service workers could access the process control system of a plant to view real-time values of different process devices without being confined to a single location. Moreover, AR features could be used to overlay real-world images with work instructions or equipment or safety-related information [3].
- Situational awareness: Recent environmental changes or updates affecting service execution can be directly pushed to the service worker via wearable devices (eg, wristwatch displays and smart watches) in a nonintrusive way.
- Monitor work quality and documentation: Cameras and microphones could be used to continuously collect information (eg, sound recordings or movies) for plant analysis and auditing. Video recordings of work demonstrations can help to improve the quality of the work [4, 5].
- Seamlessly integrate the worker: Mobile and wearable solutions would enable the seamless integration of field service workers into service processes, allowing asset information to be retrieved and updated instantly. Moreover, they could enable service workers to connect to remote diagnostics and optimization applications, or expert systems hosted by either backend systems or in a cloud environment.

Using off-the-shelf components, new support tools for field service tasks have been developed by ABB that instantly provide important environmental, health and process information.

Increasing safety

In industrial working environments, field service engineers face different types of hazards. A wearable system that can sense, collect information and issue warnings about the environment around it – such as temperature, humidity, oxygen level, poisonous gases, noise or radiation, as well as the vital signs of the wearer, such as heart or pulse rate, tiredness, consciousness and cognitive load or stress level – would increase the safety of maintenance and service staff [6]. Existing wrist-worn devices, such as Basis B1, can already measure skin resistance, pulse rate, temperature and even the worker's stress level.

Wearable systems can support rescue and self-rescue operations. They can warn personnel of impending dangers, such as fire, water or lack of breathable atmosphere, and direct them to safe escape routes, even if exit signs are not available, broken, or invisible because of the smoke

Wearable computing combines mobile computing and sensor technology to produce invisible sensing devices that provide accurate information about the complex environment in which they operate.

2 The prototype for showing tank values in a camera view of a mobile device

and fire. Additionally, rescue teams can utilize the location functionality of such devices to locate personnel still in the plant.

ABB solutions

ABB provides various solutions that can be utilized on mobile devices:

ABB's ServIS is an enterprise information system that is integrated with other ABB information systems, such as ABB Product, ABB People and the global customer identification system.

- The Ventyx Service Suite enables field operators to maintain assets and reduce costs.
- The Ventyx Shift Operations Management System (eSOMS) ensures the safe, efficient and reliable operation and maintenance of facility assets.
- The Ventyx Advanced Work Management (AWM) Mobile Inspector collects and manages data relating to all physical assets.

In addition to these, several prototypes have been successfully developed in the search for new ways to implement mobile and wearable computing. In one prototype, sensors were sewn into a high-visibility vest, which was then operated via a smartphone. The sensors collected environmental conditions (carbon monoxide level, temperature and humidity) as well as the vital signs of the worker (heart rate and skin temperature) → 1. They were complemented with feedback devices, such as a vibrator and speaker as well as an emergency/panic button. All the components were connected via a body area network (BAN) to a microcontroller.[1] The wearable safety suit could be connected via Bluetooth to the smartphone, which runs a control app to collect sensor data, display alerts and send notifications to a remote con-

Footnotes

1 The researchers used e-textile technology for the integration of the sensors and micro-controller inside the safety suit.

3 The prototype for demonstrating how devices can be localized within a plant or factory to provide more information

trol center and/or a supervisor when abnormal conditions are detected. The corresponding messages contained GPS coordinates of the last location of the field service worker, allowing him to be quickly located.

Another project investigated the possibility of utilizing AR for control systems in industrial environments. In AR, live images are shown on the camera display of, for example, a mobile device and this view is then augmented by computer-generated content (eg, graphics). Several prototypes have been produced including one where a maintenance engineer points a mobile device at a water tank. After identifying the tank, the camera display is then augmented with live status values ➔ 2.

In another prototype, AR and sensor technologies were combined by adding a sensor to measure the temperature of an object. When the camera view of the mobile device is directed toward the object, the display shows the object's temperature trend over time. The ability to view historical data enables engineers to perform fault tracing and testing during maintenance work.

A third prototype demonstrated how equipment can be found and identified within plants and factories. Mobile devices with sensors can determine the location of a field technician and from this immediately identify and provide information about devices in the vicinity ➔ 3.

The availability of a variety of personal and mobile computing technologies has enabled the creation of new support tools for field service tasks. Using off-the-shelf components, important environmental, health and process information can be instantly obtained and shared with others while the engineer is on the move.

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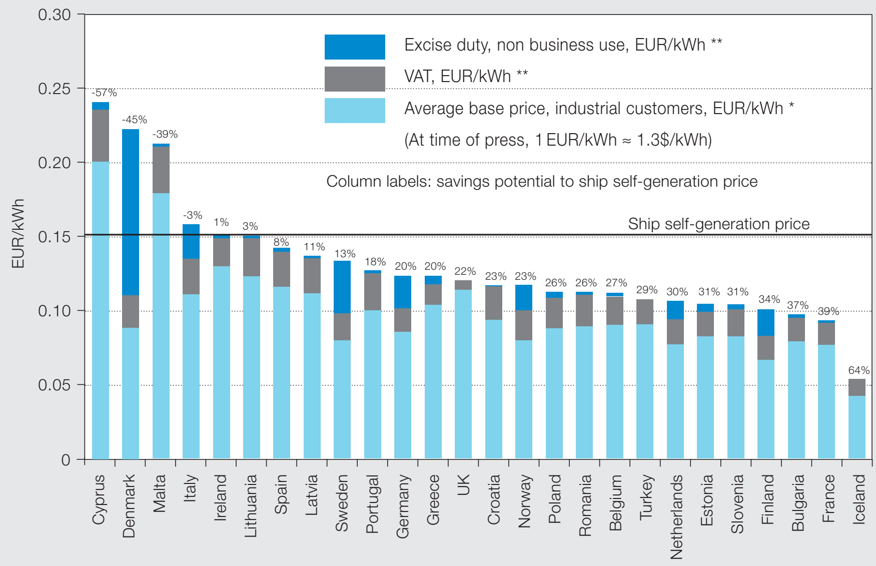
Clean air in the docks

Taxation incentives can improve air quality in ports

PETR GURYEV – Maritime shipping is the backbone of global trade, and the ports in which goods are loaded and unloaded are vital assets in assuring the economic viability of regional economies. However, the numbers of large and heavy ships docking in ports can lead to unacceptable levels of local pollution. Even though a moored ship does not need to power its propellers, the diesel engines are typically left running to meet the ship's auxiliary power requirements. These can range from the accommodation of the crew to cooling and other needs of the cargo handling. One alternative to using the ship's own diesel engines is to connect the ship's onboard electricity network to a dockside power supply. The technology behind such connections has been discussed in past issues of *ABB Review*.[1] Although there are several technologies available on the market for emissions reduction, ie, scrubbers, purified fuel and LNG,[2] only shore-to-ship power provides absolute emissions reduction from ships at port. The rate of adoption of this solution, however, does not depend on technical and environmental arguments alone, but also on regulative and fiscal incentives.

1 Electricity price structure in 2013 before exemptions on excise duties



* Average half-yearly electricity prices for industrial end-users without taxes and levies (first semester of 2013). Band Ic with annual consumption between 500 and 2,000 MWh. Eurostat. Accessed February 2014, base nrg_pc_205.

** a) Excise Duties Tables (2013) REF 1038 rev 1. European Commission, Brussels. Accessed February 2014.
b) Electricity taxes and duties tables for the Netherlands. Belastungdienst. Accessed February 2014.
c) Taxes and Levies on Electricity in 2012 (for Norway and Turkey). Union of the Electricity Industry – EURELECTRIC. Accessed February 2014.

Stricter local, national and regional legislation on port emissions has caused the market for shore-to-ship power to grow from a handful of projects to dozens per year over the last five years. The two main drivers of this market are:

- The environmental benefits of emissions reduction
- The operation expense reduction by saving on the difference between the self-generation price and the electricity price from the grid

To provide an incentive for this development, governments usually provide either subsidies for capital investments or exemptions on excise duties for shore-power electricity. Although North America and Asia presently prefer support in the form of subsidies, Europe has used both options. Several countries in Europe have already adopted or applied for excise duty exemption for shore-power electricity. Although news on this has been reported in the media, a clear picture of the real economic benefits has so far been lacking. The electricity price structure in Europe and the excise duty exemption has had a marked impact on the payback period of shore-to-ship power in different European countries.

Several countries in Europe have already adopted or applied for excise duty exemption for shore-power electricity.

In mid-2011 Germany and Sweden received approvals from the European Commission to reduce excise duties for electricity used for shore-to-ship power. The exemptions allowed reductions in excise duties of 97 to 99 percent for three years with the right to extend this further. In 2014 approvals for exemption were prolonged by the EU council implementing decisions for another 6 years for both countries (directive documents COM/2014/0538 and COM/2014/0497). In 2013, the Finnish Port Association and Danish Energy Association also proposed excise duty reductions to their governments. The Danish parliament voted for the exemption of the excise duties to more than 99 percent on May 27, 2014 (Law L 171), whereas for Finland a final decision has yet to be made.

The existing electricity price structure with tariffs, VAT (value-added tax) and excise duties (including environmental taxes) but without exemptions for shore power are compared in → 1 together with the savings potential relative to ship self-generation using MDO/MGO[3] fuel.

Title picture
The title picture view shows the port of Ystad in Sweden. Sweden is one of the countries that has taken the lead in providing tax incentives to encourage use of dockside power supplies.

Footnotes

1 See: K. Marquart, "Power from shore: ABB shore-to-ship power solutions are cutting noise and greenhouse gas emissions by providing docked ships with shoreside electricity," *ABB Review* 2/2010, pp. 82–83, K. Marquart *et al.*, "Shore-to-ship power: ABB's turnkey solution is effectively reducing portside emissions," *ABB Review* 2/2010, pp. 82–83, *ABB Review* 4/2010, p. 56–60, and L. Thurm *et al.*, "Onshore and onboard: Looking at the shoreside and shipside technologies and the case for standardization in shore-to-ship power" *ABB Review* 1/2011, pp. 36–40.

2 LNG: liquefied natural gas

3 MDO and MGO are typical marine fuels used by ships at port. MDO is marine diesel oil, and MGO is marine gasoline oil. The self-generation price is calculated in ABB's shore-to-ship power business case tool using an MDO/MGO fuel price of $950/MT and fuel consumption of 210 g/kWh, euros/$ = 1.2982.

The highest share of excise duties in the electricity price is found in Denmark and Sweden. It is also high for Finland, Germany, Italy and Norway.

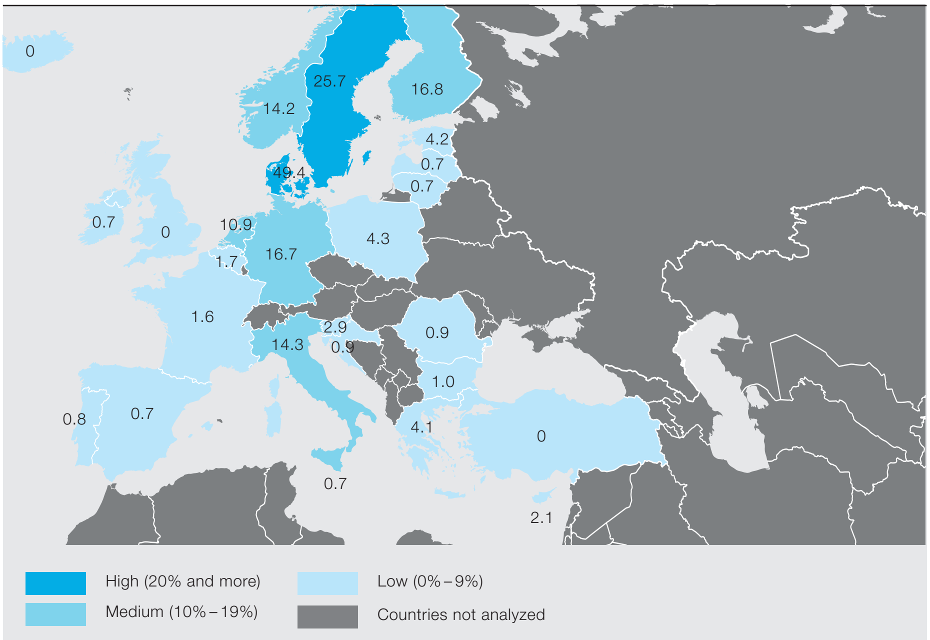
The countries considered can be classified into two main groups: those whose total electricity price is higher than that of ship self-generation and those whose total electricity price is lower than that of ship self-generation. Although countries in which the total electricity price is higher than the self-generation price are not likely to have commercially attractive business cases (unless a special lower base tariff is provided, eg, the Venice cruise project), it does not mean that these countries are principally unsuitable for shore-to-ship power projects. The main benefit of shore-to-ship power remains emissions reduction, and such projects will continue as long as notable subsidies are provided for capital infrastructure (eg, the Livorno cruise project in Italy). Cyprus, Denmark, Malta and Italy fall into this group of countries.

The highest share of excise duties in the electricity price is found in Denmark and Sweden. It is also high for Finland, Germany, Italy and Norway; moderate for the Netherlands; and small for Poland, Estonia and Greece. In the remaining countries analyzed it is between 0 and 2.9 percent. Denmark, Sweden, Finland and Germany already have excise duty exemption or have applied for it. The 10 countries with the highest share of excise duties are shown in → 2 along with the influence of excise duty exemption on savings potential compared with ship self-generation costs.[4]

Footnote

4 In addition to the excise duty reduction for shore power in Sweden and Germany, the law approved by the Danish parliament implies a reduction to 0.004 DKK/kWh (circa 0.0007$/kWh), which is also 99 percent, while the Finnish Port Association did not specify an exact amount in its proposal.

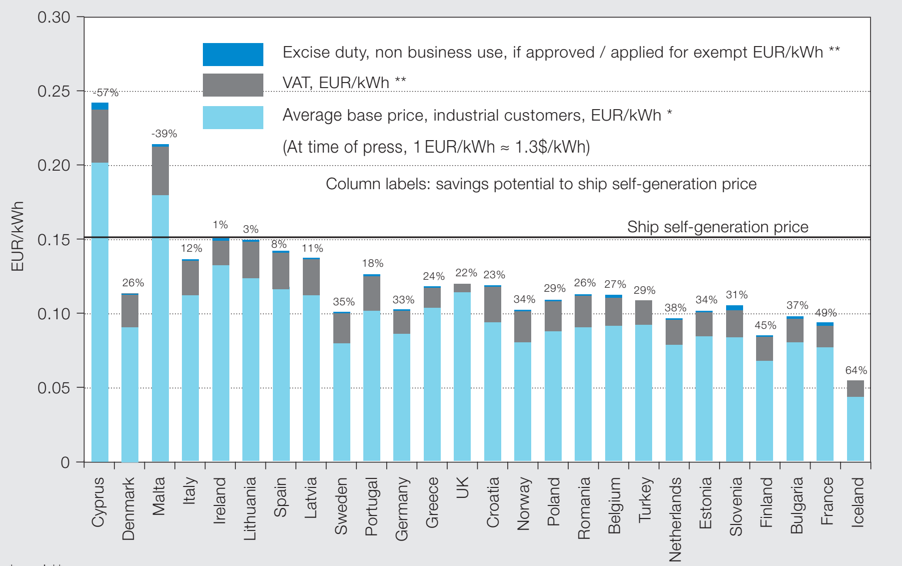
2 Excise duty share in total electricity price and its exemption effect on savings potential



Country	Share of excise duties in electricity price (%)	Excise duties exemption status	Saving potential			
			Before exemption (%)	After exemption* (%)	Delta (%)	Relative growth of saving potential* (%)
Denmark	49.4	Approved by parliament	-45	26	71	273
Sweden	25.7	Approved and prolonged	13	35	22	63
Finland	16.8	Proposal prepared	34	45	11	24
Germany	16.7	Approved and prolonged	20	33	13	39
Italy	14.3		-3	12	15	125
Norway	14.2		23	34	11	32
Netherlands	10.9	No information	30	38	8	21
Poland	4.3		26	29	3	10
Estonia	4.2		31	34	3	9
Greece	4.1		20	24	4	17

* Considering either already approved/proposed in application or 99 percent exemption

3 Electricity price structure in 2013 with approved, proposed or potential exemption on excise duties for shore power in selected countries



* and **, see → 1

4 Formulas expressing savings potential

4a Improvement of payback period

$$\text{P.b.period improvement} = \frac{\text{P.b.period 1} - \text{P.b.period 2}}{\text{P.b.period 1}} \cdot 100\%$$

4b Model for expressing simplified – not discounted – payback period used in ➔ 4a.

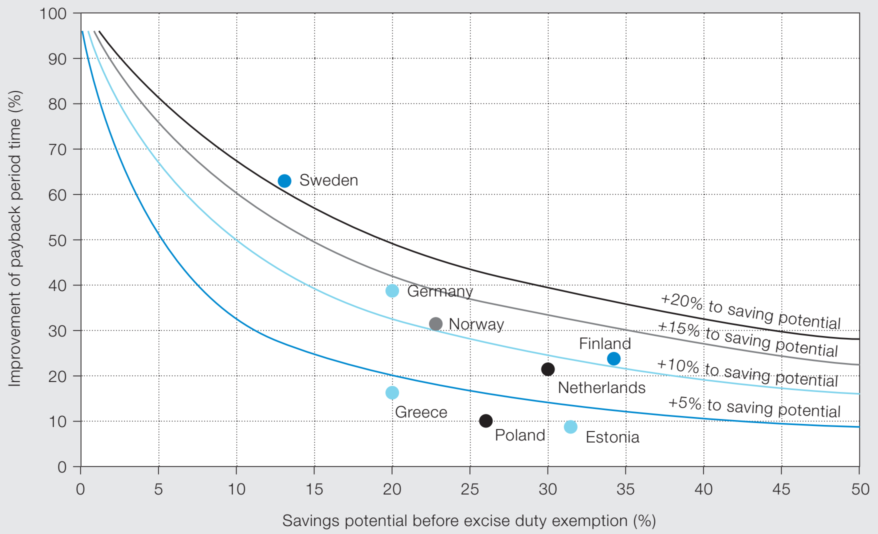
$$\text{P.b.period years} = \frac{\text{CAPEX [EUR]}}{\left(\text{El.selfgen price}\left[\frac{\text{EUR}}{\text{kWh}}\right] - \text{El.grid price}\left[\frac{\text{EUR}}{\text{kWh}}\right]\right) \cdot \text{Annual consumpt.kWh}}$$

4c Payback period improvement for shore-to-ship power after excise duties exemption

$$\text{P.b.period improvement} = \frac{\text{Sav.pot.2} - \text{Sav.pot.1}}{\text{Sav.pot.2}} \cdot 100\% = \text{Relative growth of sav.pot } \%$$

where Sav.pot.1 is savings potential without exemptions in place and Sav.pot.2 is savings potential with exemptions in place.

5 The improvement of the payback period for shore-to-ship power projects depending on initial savings potential and its change after excise duties exemption



The effect of 99 percent excise duty exemptions on savings potential compared with the ship self-generation cost applied for the seven countries listed above, in addition to those already approved by Sweden, Germany and Denmark, is shown in ➔ 3.

To measure the effect of excise duty exemption on business case, the payback period was analyzed. The improvement of the payback period can be assessed by formula ➔ 4a where payback period is estimated by the simplified – not discounted – model expressed in ➔ 4b.

The final formula of payback period improvement for shore-to-ship power after excise duties exemption is shown in ➔ 4c.

The improvement of the payback period is shown in ➔ 5 (Denmark and Italy are not shown here because savings potential before excise duty exemption was negative.)

This graph can furthermore be used to measure the influence on the payback period of other electricity price elements (base tariff and VAT).

Most European countries have attractive electricity prices that permit savings compared with ship self-generation in the range of 1 to 30 percent.

Incentives can reduce emissions

Most European countries have attractive electricity prices that permit savings compared with ship self-generation in the range of 1 to 30 percent. Exemption of excise duties for shore-side electricity is an attractive instrument for countries where excise duties constitute a high percentage of the total price. The lower the initial savings potential with respect to the self-generation price, the higher the effect of excise duty exemption on the payback period. Sweden and Germany have already adopted such measures and in a recent parliament vote Denmark decided to follow suit. Finland is presently developing a proposal for exemptions of excise duties on electricity used for shore power.

By implementing such exemptions in the 10 European countries with the greatest share of excise duties in total electricity price, the business case would improve by 10 to 60 percent depending on the total initial electricity price and share of excise duties. Denmark should thus get the EU council approval for excise duty exemption, while Finland, Italy, Norway, the Netherlands, Poland, Greece and Estonia should adopt such measures at a national level first.

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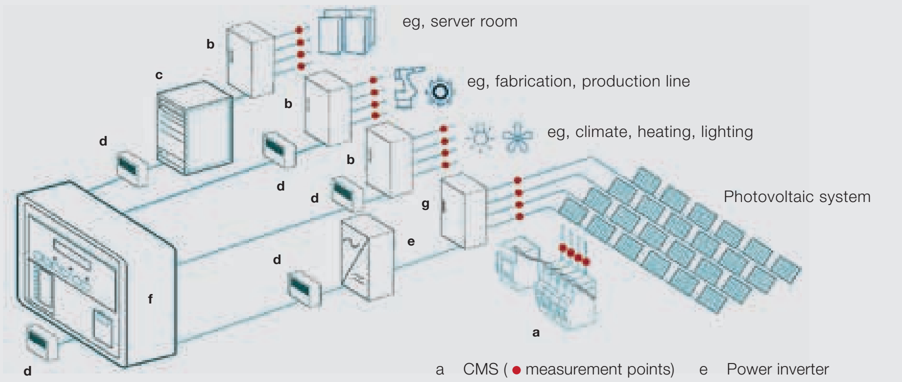
Current account

How Modbus enables a new current measurement system

PAWEŁ LUDOWSKI, HARM DEROO, FILIPPO APUZZO, ROLAND PRÜGEL – Commercial and industrial enterprises are very dependent on the reliable operation of their electrical systems. Furthermore, there is a clear trend across the board toward more efficient use of energy – a trend driven by both environmental and financial considerations. While top-level energy or current usage is a quantity relatively easily monitored, transparency closer to the devices is more difficult to achieve and commercially available systems that target this fail to meet ABB requirements in several areas. What is needed is a completely new approach to monitoring current close to the load. This new approach is called the ABB Current Measurement System and its Modbus-based communication protocol is a core element of its functionality.

1 A sample electrical installation monitored by CMS



a CMS (● measurement points)
b Subdistribution
c UPS system
d Energy meters
e Power inverter
f Main distribution
g Combiner box

ABB began development of the Current Measurement System (CMS) in 2009. The CMS consists of several current sensors connected by a serial bus to a control unit. The control unit and the current measurement modules were developed in close cooperation with external partners. The communication protocol, which is an important part of the functionality of the CMS, is based on a protocol developed by ABB in a previous project.

The CMS opens up completely new possibilities for monitoring the status of power distribution units (PDUs) and their single branches →1. The CMS makes it possible not only to detect potential failures but also to predict overloads and the subsequent risk of tripping circuit breakers.

Communication protocol

As stated above, an important part of the CMS functionality is the communication protocol, which defines the user communication, address assignment and sensor management. This protocol regiments communication between the control unit and external devices, as well as the internal communication between the control unit and the sensors, and is based on a well-known Modbus serial line protocol. Experience garnered during a previous project helped ABB and its external partners prepare a detailed protocol specification (hardware interface, data format and so on).

A four-wire flat cable connects the control unit to the sensors. Two of the wires supply power to the sensors and the other two are used for data transmission. The physical interface RS-485 was selected for external device connection → 2.

The CMS opens up completely new possibilities for monitoring the status of power distribution units (PDUs) and their single branches.

Modbus uses a master-slave protocol. In this, only one master will be connected to the serial bus, but up to 247 slaves can be connected. In the case of the CMS, the control unit is the master device and current sensors are slave devices.

Modbus communication is always initiated by the master and only one transaction at a time is possible. Modbus has two request modes: unicast and broadcast. In the unicast mode the master device addresses an individual slave device, which returns a response message after processing the request. In the broadcast mode the master sends a request to all slaves and no response is returned by them.

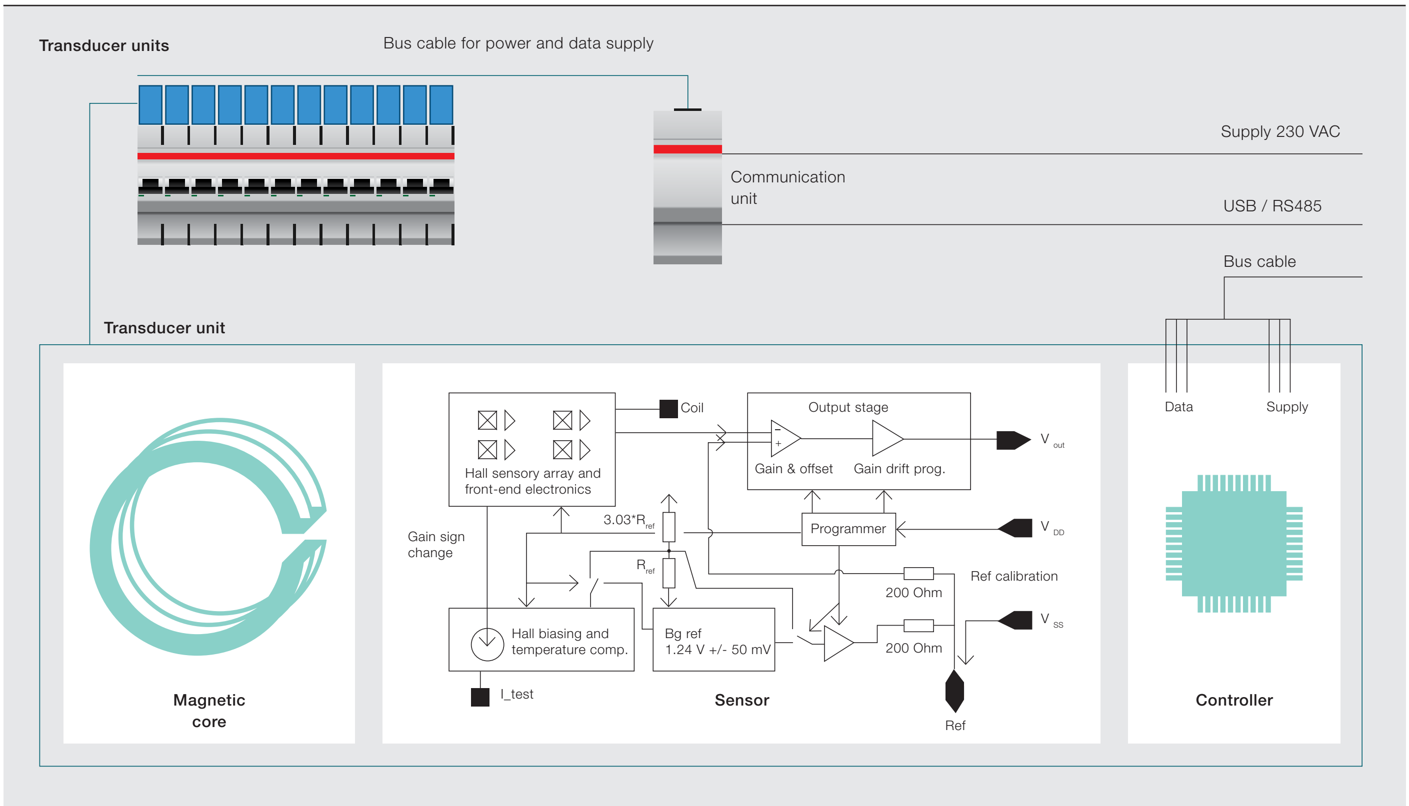
The maximum size of a Modbus/RTU (remote terminal unit) frame is 256 bytes and it must be transmitted as a continuous stream of characters. If a silent interval of more than 1.5 character periods occurs between two characters then the message frame is declared incomplete and is discarded by the receiver. Messages have to be separated by a silent interval of at least 3.5 character periods.

Modbus uses a "big-endian" representation for addresses and data items. That means when a numerical quantity larger than a single byte is transmitted, the most significant byte is sent first. For example, the 16-bit (ie, two-byte) hex value 1A3B is sent as two 8-bit (ie, one-byte) hex values 1A then 3B.

The data model in Modbus is based on a series of tables, where the four primary tables are: read-only discrete input, read-write coils, read-only input registers and read-write holding registers. A coil is a boolean (bit) variable and a register is an integer (word) variable. There are also three categories of Modbus function codes: public function codes (validated by the MODBUS-IDA.org community),

Title picture
How does ABB's Modbus-based communication protocol in the CMS enable visibility of current consumption in industrial devices?

2 CMS overview



The CMS makes it possible not only to detect potential failures but also to predict overloads and the subsequent risk of tripping circuit breakers.

user-defined function codes and reserved function codes. Registers in the CMS are always two-byte (16-bit). While the Modbus application protocol defines memory area for read-only registers (input registers) and read-write registers (holding registers), the CMS current sensor module supports only holding registers.

In the CMS, the Modbus protocol has been extended by a few additional features. These initialize the network by assigning Modbus ID addresses to sensors and linking them to appropriate registers in the control unit. By default, all sensors have the same address (247), so it is necessary to assign a new individual ID address to each sensor during the installation phase. Because a CMS sensor does not have a hardware switch to set the ID it was necessary to develop a software ID assignment procedure. This procedure is based on Modbus custom functions for broadcast addressing. Depending on installation requirements, several configuration procedures are available: In the most general form, the master module broadcasts a message with a custom code containing a unique sensor serial ID (SID) and new Modbus ID. When this frame is broadcast, all devices on the bus are informed about the ID assigned to any other device. To prevent conflicts, every device that received a broadcast ID assignment frame has to compare its own SID with the SID of the destination sensor in the broadcast frame and, if they agree, it changes its ID to the ID in the assignment message. Otherwise, the request is ignored.

An important part of the CMS functionality is the communication protocol, which defines the user communication, address assignment and sensor management.

This protocol fulfills a global standard, which allows the CMS to be used in a wide spectrum of customer applications.

3 The CMS is compact and easy to install.

4 Typical applications

Data center
Data centers consume significant amounts of energy, so there exists the potential for large cost savings if energy consumption can be reduced, even by a small percentage.

The power consumption in a data center is known at a high level, but is tricky to ascertain at the device level – and it is at this level that energy-efficiency measures can be very effectively implemented.

This is where the CMS comes in. In combination with an AC500 PLC (programmable logic controller) and an energy meter, the CMS can provide energy usage transparency. Several such CMS projects are underway and there is growing interest from the market.

Hospital
Life-support systems in hospitals are, literally, vital. These systems must work without any interruption.

The CMS is being used in combination with SMISSLINE TP to ensure this by offering electrical current monitoring in each branch of the power system and giving operators the chance to detect abnormal system parameters before they evolve into problems.

ABB has helped many hospitals increase the reliability of their equipment in this way.

The system is very flexible and can be customized and extended with new devices regardless of manufacturer.

The communication protocol was fully documented by 2010. In 2011, the CMS was transferred into the product development phase and at the end of that year the first prototypes of the control unit and sensors were available, at which point intensive work on the device firmware started.

Tests and production

Special test software was written in the Perl programming language for the CMS. A new Perl module was created to support the Modbus/RTU protocol that had been extended by the Modbus custom functions specially for the CMS. Included in this module is a set of functions that can be used for quick and easy creation of any test scenario for both the control unit and the current sensors. These functions allow testing of all device registers and operation of the Modbus custom functions.

A set of configuration functions was also written that allows the CMS to be easily set up and prepared for testing. A log file records information about all operations performed by the software as well as Modbus frames that were sent to and from the CMS. To facilitate software setup, system configuration data is stored in XML format.

CMS advantages

The first production version of the CMS was released in mid-2012. The product launch took place at the "Light + Building" fair in Frankfurt in July 2012, where the compact size, technology, measurement results, user-friendliness and flexibility of the CMS was exhibited.

The CMS opens up a multitude of monitoring possibilities in many industrial applications → 3–4. However, the capabilities of the system need not be confined to current measurement alone and further innovative applications are already being investigated.

Communication is based on a well-known Modbus serial line protocol.

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Semiconductor generations

ABB looks back on 60 years of progress in semiconductors

CHRISTOPH HOLTMANN, SVEN KLAKA, MUNAF RAHIMO ANDREAS MOGLESTUE – Many of the great transformational periods in human history were driven by technological breakthroughs, but had consequences reaching far beyond technology. Progress in maritime navigation in the 15th century opened up trade routes between continents. Refinement in mechanical engineering enabled industrialization in the 18th and 19th centuries. Recent decades have been marked by changes of similar dimensions, attributed to progress in computing and communications – and thus ultimately by progress in semiconductors. But semiconductors have at the same time also driven another revolution – one that is maybe less visible but equally significant: From the humble charging of mobile phones to the transmission of power over thousands of kilometers, power electronics has become a vital enabler of the modern lifestyle. ABB has over the past 60 years played a pivotal part in the development of power semiconductors and their applications.

ABB's predecessor companies, ASEA and BBC, both commenced semiconductor development in the early 1950s.

Just as there were large ships before Henry the Navigator and steam engines before James Watt, the basics of today's semiconductor applications predate the semiconductors they use. Early computers used relays, radios used tubes and power converters used mercury-arc valves[1] or mechanical switches. The basic circuit topologies at the heart of these examples were not too different to those still in use today. But because semiconductors led to more compact designs, greater reliability, lower losses, lower costs and greater ease of use, they opened the technology to new applications while developing it to levels of performance and sophistication orders of magnitude beyond what would otherwise have been possible.

Title picture
300 V / 800 A thyristors manufactured by BBC in the early 1970s

Semiconductor basics

A semiconductor is called as such because it displays an intermediate level of conductivity between a conductor and a nonconductor. Its electrical behavior can furthermore be influenced by factors including the presence of impurities, electric fields, light and temperature. Many of these phenomena had already been recognized in the 19th century ➔ 1 but it was not until the early 1930s that a workable explanation emerged in the form of the band theory of conduction, drawing on insights from quantum physics.

In power electronics, semiconductor properties are used to create devices that can alternate between being "on," ie, conducting large electrical currents with as low an on-state voltage as feasible, and "off," ie, blocking as high a voltage as required with minimum leakage current. The transition phase between the two states should be kept as short as possible. The simultaneous presence of nonzero voltage and current leads to device-level losses, representing not only wasted energy but also threatening thermal damage of the device.

The diode

The diode is the simplest of all power semiconductor devices. It simply conducts current in one direction and blocks it in the other. It is thus well suited for simple rectifier (AC to DC conversion) applications.

ABB's predecessor companies, ASEA and BBC, both commenced semiconductor development in the early 1950s. BBC's activities were based in Baden, Switzerland, and ASEA's in Ludvika, Sweden. BBC created its first semiconductor diode in 1954 ➔ 2. The first commercially available diode (100 V / 100 A), targeted at rectification for electrolysis followed in 1956. BBC's early diode designs used germanium, but because

Footnote

1 See also A. Moglestue, "From mercury arc to hybrid breaker: 100 years in power electronics," *ABB Review* 2/2013, pp. 70–78.

In rectifier applications, thyristors present the advantage over diodes that the phase angle can be controlled and hence the flow of power regulated.

1 Early milestones of semiconductor history

1787	Antoine Lavoisier proposes the existence of the chemical element silicon
1824	Jöns Jacob Berzelius isolates pure silicon
1833	Michael Faraday observes a temperature dependency in the resistivity of silver sulfide, not conforming to that of a metal
1839	Alexandre-Edmond Becquerel observes the photovoltaic effect
1874	Karl Ferdinand Braun observes rectification in metal sulfides
1886	Clemens Winkler discovers the element germanium
1897	Joseph John Thomson discovers the electron
1906	Jagadish Chandra Bose, Greenleaf Whittier Pickard and others develop the “cat’s whisker detector,” a primitive semiconductor rectifier for radio receivers
1907	Henry Joseph Round invents the light-emitting diode
1920s	First commercial diode-based rectifiers appear for low-power applications
1926	Julius Edgar Lilienfeld proposes the principle of the field-effect transistor
1932	Alan Herries Wilson explains energy bands
1939	Russell Ohl discovers the p-n junction
1947	William Shockley, John Bardeen, Walter Brattain and others produce the first transistor at Bell Labs
1950	William Shockley describes the principle of the thyristor (the first thyristor is produced by General Electric in 1956 and commercialized in 1958; BBC launches its first thyristor in 1960)
1954	BBC and ASEA independently commence development of power semiconductors

2 BBC’s first semiconductor diode (germanium, 1954)

of the material’s thermal and blocking-voltage limitations, this was soon replaced by silicon.

The thyristor

Moving beyond simple rectifier applications, a device was required that could be switched on at an arbitrary point in time. The design best suited to this was the thyristor – a device whose principle had been proposed by William Shockley in 1950. A thyristor has two main contacts rather like a diode (the anode and cathode) but also has an auxiliary contact (the gate). A current applied at the gate causes the thyristor to start conducting (if a positive voltage is present between anode and cathode). Once conduction has begun, the trigger current can be removed, with conduction not ceasing until the main current falls below a threshold value (usually at the zero-crossing of the current). A turn-off cannot be arbitrarily triggered unless auxiliary circuits are used to artificially force such a zero crossing.

Thyristors are thus well suited for inverter (DC to AC conversion) applications in which the receiving network is strong enough (eg, through support of local generation) to enable forced commutation of the inverter. They are also well suited for rectifiers where they present the advantage over diodes that the phase angle can be controlled and hence the flow of power is regulated. BBC produced its first thyristor in 1961 → 3.

Successful traction applications

An early successful traction application for diodes was the type Re4/4 locomotive (4,980 kW) built for the BLS railway (Switzerland) from 1964 → 4. These locomotives, still featuring their original rectifier circuits, remain in use today.

Having no means to directly control a diode rectifier, traction was controlled by a tap changer on the transformer. Such was the rate of progress, however, that in 1967, ASEA began producing a locomotive controlled by thyristors. This was the 3,600 kW type Rc for SJ (Swedish Railways) → 5. Again, many of this type remain in use today.

Improvements in semiconductors

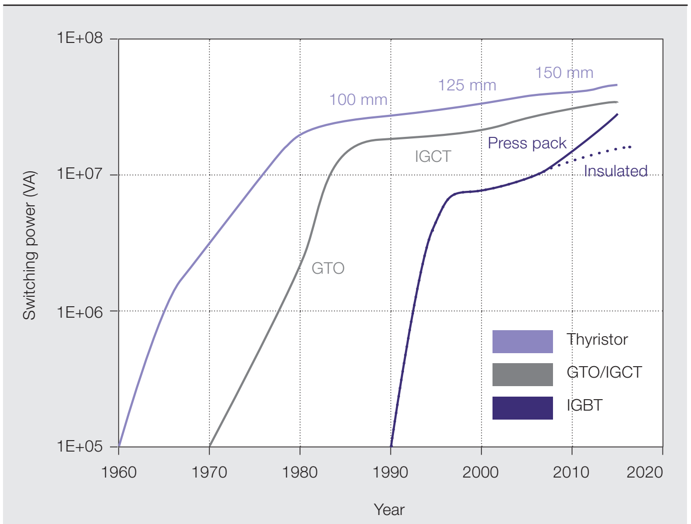
From 1960 to 1980, blocking voltages and the power that could be handled per de-

3 In 1961, BBC launched its first thyristor (1,200 V / 100 A). The diode range reached 650 V / 200 A.

4 The Re 4/4 locomotive (1964) of BLS (Switzerland) uses BBC diodes.

5 The Rc locomotive (1967) of SJ (Sweden) uses ASEA thyristors.

6 Evolution of switching power



An early successful traction application for diodes was the type Re4/4 locomotive built for the BLS railway (Switzerland) from 1964.

vice grew in a roughly linear fashion ➔ 6–7. In 1976, BBC became the first European manufacturer to introduce neutron transmutation doping (as an alternative to doping with phosphorous atoms, neutrons would be irradiated into the silicon, converting some silicon atoms to phosphorous). This led to a very homogenous dopant concentration and permitted blocking voltages to advance to 4 kV.

In 1969, BBC acquired Sécheron and sought to consolidate this company's semiconductor activities with its own. Plans to build a joint manufacturing plant on Sécheron-owned land in Gland, Switzerland, fell through. However, a well-equipped and modern facility was opened at Lampertheim, Germany, in 1969. The following year the decision was made to concentrate all manufacturing activities there. Despite this, some of the Ennetbaden activities were transferred to Birr, Switzerland. Activities there were mostly focused on development and pilot production but small volumes of commercial manufacturing also occurred.

HVDC

During the mercury-arc era, ASEA had maintained a position as undisputed leader in HVDC technology due to the high blocking voltages of its valves. Nevertheless, the company recognized that semiconductors were the way forward. The world's first commercial HVDC link, which dated to 1954, between the Swedish island of Gotland and the mainland was supplemented by an experimental semiconductor valve in 1967. The first commercial application of semiconductors for HVDC followed at the same location in 1970.[2]

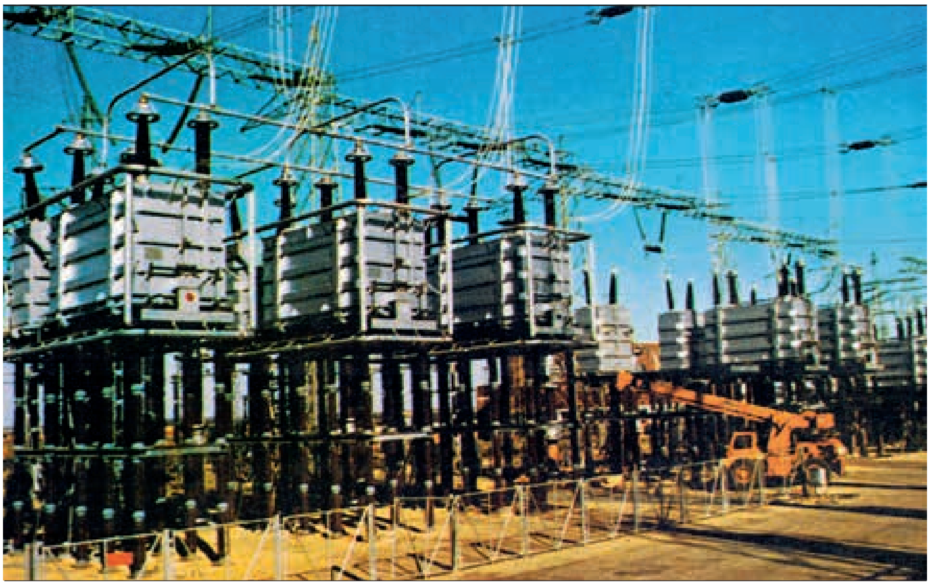
Footnote

2 See also A. Moglestue, "60 years of HVDC: ABB's road from pioneer to market leader," *ABB Review* 2/2014, pp 33–41.

7 Milestones from ABB's 60 years in semiconductors

1954	Semiconductor development commences in Ludvika (ASEA) and Baden (BBC)
1956	BBC launches its first diode (100 V / 100 A)
1961	First BBC thyristor introduced (1,200 V / 100 A)
	Diodes reach 650 V / 200 A
1969	New plant opened in Lampertheim (BBC)
1970	Thyristors reach 3,000 V / 800 A
1976	Neutron transmutation doping introduced (BBC)
1977	New plant opened in Lenzburg (BBC)
1980	Thyristors reach 5 kV / 2 kA
1988	ASEA and BBC merge to form ABB
1990	Lampertheim plant is sold to IXYS
1991	ABB's semiconductor activities are concentrated in Lenzburg
1992	4.5 kV / 600 A IGBT sample is presented
1995	First samples of 4.5 kV / 3 kA IGCT are presented
1996	GTO and diode offering reaches 4.5 kV / 4 kA
	3.3 kV / 1.2 kA IGBT module for traction is introduced
	Bidirectional controlled thyristor (BCT) technology is introduced
1997	ABB launches a complete line of IGCTs from 500 kW to 9 MW
	4.5 kV / 1.2 kA IGBT module for traction with integrated heat sink is introduced
	2.5 kV / 700 A IGBT for HVDC Light® is introduced
1998	5 inch IGBT wafer fab opens in Lenzburg
2000	2.5 kV StakPak modules for HVDC light are introduced
2001	1.2 kV – 1.7 kV thin wafer soft punch-through platform (SPT) IGBT is launched
2003	High-voltage SPT IGBT/diode platform is launched (with record-breaking safe operating area)
	2.5kV – 3.3kV SPT-IGBT HiPak module platform is launched
2005	Lenzburg upgrades to 6 inch IGBT wafer fab
	3.3kV-6.5kV SPT IGBT HV-HiPak module platform is launched
2006	1.2 kV – 6.5 kV low loss SPT+ IGBT platform is launched
2007	High-power technology (HPT) IGCT platform is introduced
2009	8.5 kV / 8 kA thyristor is introduced
	High-voltage BIGT technology is introduced
2010	Capacity extension is added at Lenzburg and Polovodice is acquired
	4.5 kV StakPak modules for HVDC Light are introduced
	10 kV IGCT technology is demonstrated
2011	BIGT is demonstrated for HVDC breaker
2013	Ground is broken for WBG lab in Baden-Dättwil Improved HiPak 2013 is introduced
	BGCT technology (IGCT with reverse-conduction diode on the same wafer) is introduced
2014	Enhanced-trench IGBT technology is introduced
	60 years of semiconductors at ABB

8 The Cahora Bassa (Mozambique) HVDC project of 1970



The disruptive innovation caused by the adoption of semiconductors for HVDC opened up the market to competition from other players. A consortium consisting of AEG, Siemens and BBC supplied the Cahora Bassa project in Mozambique in 1977 (1,920 MW, 1,450 km) → 8 and the Nelson River project in Canada in 1978 (900 MW, 940 km in 1985). Thyristor manufacturing for these projects was split equally among the three partners, with BBC's share being manufactured in Birr (Lampertheim was not set up for the processes required). This activity was transferred to a new plant in Lenzburg, Switzerland in 1979.

In response to the new competition, ASEA sought to consolidate its leadership by intensifying its thyristor development activities. In 1984, the company supplied the record-breaking Itaipu link in Brazil (780 km, 500 kV / 6,300 MW).

The GTO

The major drawback of the thyristor is its need for auxiliary circuitry to support commutation when the receiving AC network is weak, or in a DC to DC conversion. This challenge was met by the gate turn-off thyristor (GTO). A GTO is similar to a thyristor, but can be turned off using a negative current at the gate. GTOs became especially popular in motor drive applications. Although GTOs were available from as early as 1960, both BBC and ASEA were late in entering this market. BBC introduced its first GTOs in 1980 (1,400 V). However, it was a technology transfer agreement with Toshiba in 1985 that finally permitted the company to catch up.

Despite this delayed start, ABB was in later years to become a world leader in GTO manufacturing, not least because many competitors had erroneously assumed the technology was heading for obsolescence (due to IGBT developments) and had prematurely ramped down their activities.

The merger

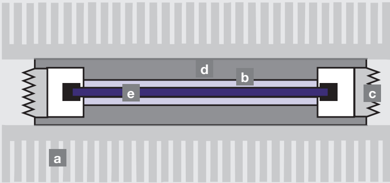
Following the merger of ASEA and BBC to form ABB in 1988, it was decided to concentrate all activities in Lenzburg. The Lampertheim facility was sold to IXYS in 1990 and that at Västerås was closed in 1991.

ABB's semiconductor manufacturing activities were vested in a subsidiary company, ABB Semiconductors Ltd. Previously, ABB had considered semiconductors a largely internal activity, with devices being developed and manufactured first and foremost to meet the requirements of other parts of the company. ABB Semiconductors broke with this paradigm and grew ABB's semiconductor market by actively selling semiconductors to external system manufacturers.

ABB Semiconductors' CEO, Anders Nilarp, soon earned himself a reputation as a charismatic manager, constantly seeking to motivate and empower employees. His continuous striving for higher quality

9 Cross-section of a pressure contact device

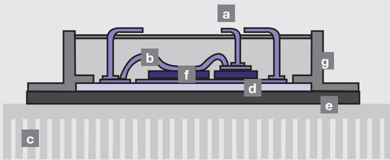
In pressure contact modules, the load current enters through one surface (d) and leaves through the opposing surface. Low electrical and thermal resitances of the contacts are assured through high mechanical pressure on those surfaces.



- a Heat sink
- b CTE compensation (Mo)
- c Housing (ceramic)
- d Copper
- e Semiconductor

10 Cross-section of a HiPak IGBT module

In insulated housing modules, the semiconductor (f) is galvanically isolated from the heat sink (c). Electrical contacts within the module are provided by bonding wires.



- a Power and control connections
- b Bonding wire
- c Heat sink
- d Ceramic (usually AlN)
- e Base plate (usually AlSiC)
- f Semiconductor
- g Housing

11 3.3 kV HiPak module launched in 2003

in both products and processes made ABB Semiconductors a finalist for the 1995 European Quality Award. In 1996 it was nominated “Supplier of the Year” by General Electric.

Nilarp also championed the semiconductor business within the ABB Group at a time that the Group saw its priorities elsewhere. His greatest achievement in this respect was gaining funds and approval for the new BiMOS (IGBT and diode) factory, which opened in Lenzburg in 1998.

IGBT

An IGBT (insulated-gate bipolar transistor) is a switching device that can be controlled by applying a voltage rather than a current to the gate, hence greatly simplifying the design of gate drives. Another advantageous property lies in the IGBT’s short-circuit capability. When the on-state voltage rises above a critical level, the device will intrinsically limit the current. An IGBT can thus survive exceptional operating conditions without requiring additional protective circuitry. All these factors allow for simpler converter designs.

A further advantage of IGBTs lies in their mechanical installation. GTOs and thyristors of higher ratings are pressure contact devices → 9, meaning the current flows “vertically” from one surface of the package to the other. To assure reliable electrical and thermal conductivity, devices are mounted in stacks at a specified pressure. Maintenance staff can thus not replace a failed device without dismantling an entire stack. In IGBT insulated modules, current flows through the module’s external terminals, which are all arranged on the same side of the module → 10. The internal electrical contact to the devices is assured by bonded wires, whereas thermal conductivity is assured through the nonconducting base plate → 11. Both mechanical and electrical connections use bolts. Individual devices can thus be replaced with far greater ease. There are, however, applications that require press-pack modules (for example, redundancy requirements may rely on failed modules going into and remaining in short circuit). ABB’s StakPak IGBT modules address these applications → 12.

As ABB’s manufacturing facilities were initially not set up for the complexity of the IGBT manufacturing process, the company’s early production relied on parts of the process being performed at external facilities. The 1998 completion

> A GTO is similar to a thyristor, but it can be turned off using a negative current at the gate.

> Following the merger of ASEA and BBC to form ABB in 1988, it was decided to concentrate all activities in Lenzburg.

12 2.5 kV StakPak Modules for HVDC light launched in 2000

13 IGCT modules for various power classes (1997)

of the BiMOS factory in Lenzburg finally enabled ABB to handle the entire IGBT production process in-house.

In the following years, with further technological improvements in terms of lower losses and higher robustness, IGBTs entered many markets previously dominated by GTOs, such as marine drives and railways, but also new applications such as converters for wind power, power-electronics-based transformers and the groundbreaking hybrid breaker for HVDC that ABB launched in 2013.[3]

Thyristors and GTOs hold their own

Although one might be forgiven for assuming that the rapid advance of the IGBT would spell an equally rapid end to the GTO era, demand for these devices is still strong today. Indeed, development is ongoing.

In 1997, ABB launched a new GTO-based device: the IGCT (integrated gate-commutated thyristor). An IGCT is essentially a GTO with an integrated gate unit. The doping profile assures lower losses while an intense but brief current pulse assures a rapid turn-off ➔ 13.

The thyristor market too continues to thrive, as the device remains the unchallenged semiconductor of choice for high-power HVDC links. In 2009, ABB introduced a 150 mm, 8.5 kV thyristor for such projects.

> An IGBT is a switching device that can be controlled by applying a voltage rather than a current to the gate, hence greatly simplifying the construction of gate drives.

Further strengthening its presence in the bipolar market, ABB acquired the Prague-based company, Polovodice, in 2010. Today, bipolar production occurs in both Prague and Lenzburg. In the same year, a further capacity enhancement was completed in Lenzburg for BiMOS and bipolar production. ABB thus has a strong position and manufacturing capability in both markets.

Silicon carbide

Looking toward the future, ground was broken at the ABB Corporate Research Center in Baden-Dättwil, Switzerland, in 2013 for a research lab dedicated to wide-bandgap power-electronics material. SiC (silicon carbide) semiconductors, eg, offer lower losses than silicon and better tolerance to heat. ABB's predecessor companies had already researched SiC in the 1960s and 1990s, but understanding of the manufacturing techniques has since advanced to the point that such devices are genuinely becoming feasible.

Ready for the future

The chain of the delivery of electrical power, spanning transmission, conversion and delivery, is embarking on an era of exciting changes. On the demand side this is being driven by the growth and integration of renewable energies and the greater emphasis on efficiency. But these demands would remain wishful thinking were it not for the progress at the semiconductor level that is making this revolution possible.

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Footnote

3 See also M. Callavik *et al*., "Breakthrough!: ABB's hybrid HVDC breaker, an innovation breakthrough enabling reliable HVDC grids." *ABB Review* 2/2013, pp. 7–13.

Further reading
H. Zeller, "The winning chips: History of power semiconductors at ABB." *ABB Review* 3/2008, pp. 72–78.

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