ABB review

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The corporate technical journal

Robust production

In modern society, production takes center stage in numerous ways. For the individual, it is a source of goods and commodities. For the economy, it is a source of wealth. ABB's involvement in production is manifold – from the delivery of the energy that makes it all possible, through control and automation systems, to sensors and motors that keep the shop floor moving.

The front cover shows a motor being installed at the Kappala wastewater plant in Lidingö, Sweden. Further ABB products on this site include switchgear, inverters and a control system. The inside front cover shows a refinery in Houston, United States.

Contents

Robust production

Claes Rytoft

Dear Reader,

Industrial production accounts for around 31 percent of global GDP and 34 percent of global employment. Whether making a process chemical or the latest smartphone, the logistics form a complex choreography involving the interaction of numerous disciplines. Production is also close to the heart of ABB, as not only are most of its customers part of this sector (or serving it), but as a manufacturing company itself, ABB understands and shares the challenges faced.

In a fast moving world, industry is in a constant state of change as new means of production create new opportunities. One example is in the field of robotics. Until recently, the typical industrial robot toiled away behind a strictly enforced safety enclosure whose necessity was dictated both by the nature of the work and the design of the equipment. Although robots continue to be the backbone of these heavy-duty tasks, their potential is no longer restricted to such environments. Many future production lines will feature robots and human colleagues working in the same space, side by side, while each doing what they can do best and exchanging workpieces as part of the workflow. The safety of such interactions will be assured by a combination of hardware design and robotic behavioral safeguards. The lead article of this edition of ABB Review looks at ABB's groundbreaking YuMi® robot.

Raising the efficiency and robustness of production involves optimization in many areas transcending the actual design of the equipment. Notably, software and services are increasingly taking center stage. Examples discussed in this journal include transformer health management and the dynamic scheduling of tasks to save energy costs.

Further production-related contributions presented include electromagnetic stirring in arc furnaces (leading to, eg, higher efficiency and consistency), a softstarter enabling new and valuable motor control options, a medium-voltage UPS (uninterruptable power supply) and a way to make installation work more efficient through prewiring.

A major challenge in designing and operating electrical systems lies in the oscillations and instabilities that can occur, and if not adequately mitigated, can damage equipment or lead to blackouts. Under the title "Taming the power," ABB Review is launching a series of articles centered on this theme. The first of these looks at medium-voltage power converters.

ABB's success is dependent on attracting bright minds to perform university research in our technology domain. In honor of Hubertus von Gruenberg, Chairman of ABB's Board of Directors from 2007 to 2015, the company has created an award for the best PhD thesis within the fields of power and automation. The award (with $300,000 for funding postdoctoral research activities) will be presented every third year. You can learn more about the award in this edition of ABB Review.

I would also like to invite you to take part in a survey seeking your feedback on this journal. Your opinions are highly valued and will be used to further improve the publication.

Enjoy your reading.

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

See more from ABB Review

Additional pictures and videos are available in the ABB Review tablet edition.

YuMi®

Introducing the world's first truly collaborative dual-arm robot that will radically change assembly lines

PHIL CROWTHER – In recent years, progress in robotics has made it much easier to deploy robots on production lines: Installation has become quicker; programming and reprogramming have become simpler; and robots have become more versatile, enabling them to turn their hand to many more tasks than before. What was missing, though, was a collaborative robot – one that could work beside a human, unconstrained by safety barriers, and be easily taught its task. That has now changed. After years of research and development, ABB has unveiled YuMi®. YuMi is the first industrial robot that can truly be called collaborative and that complies with the safety standards enabling it to work hand-in-hand with humans on assembly lines. This groundbreaking robot ushers in a new era in manufacturing.

Title picture
YuMi represents a breakthrough in the field of collaborative robots.

1 YuMi features padded arms that stop immediately if there is any unexpected contact.

Few production arenas are changing as quickly as that of small-parts assembly. The electronics industry, in particular, has seen demand in this arena skyrocket past the supply of skilled labor. As conventional assembly methods diminish in value, manufacturers are finding it strategically and economically imperative to invest in new solutions.

ABB's market introduction of YuMi – a play on words that means "you" and "me" – is a groundbreaking solution for human-robot collaboration in the small-parts assembly environment.

First, safety

YuMi literally removes the barriers to collaboration by making protective fencing and cages a thing of the past. Its design is based on a revolutionary integration of motion control software, speed-limited hardware, reduced weight, a compact frame and 14-axis agility. The lightweight, padded, magnesium arms can stop the robot's motion in milliseconds if necessary – in the event of an unexpected collision, for instance → 1.

Like the human arm, YuMi has no pinch points, so there can be no crushing between two opposing surfaces as the arm flexes. The padded arms enclose the cabling and air connections, which eliminates snagging, reduces maintenance requirements and makes it easy to keep the robot clean and dust-free.

YuMi is safe around people and is the first industrial robot to be independently certified to such a high level of safety.

The combined effect of these features is the ensured safety of human coworkers on production lines and in fabrication cells.

Productivity

In addition to its inherent safety, YuMi is a highly efficient and proficient robot – two qualities that accelerate its return on investment. ABB designed YuMi to become productive very quickly as an all-in-one solution, with integrated arms, hands, torso, control technology and a parts-feeding system.

2 To teach YuMi its new task, the operator manually takes it through the required motions, which are recorded.

The future of robotics and automation depends on humans and robots working together – and nowhere is that more true than on the assembly lines around the world that build the electronics upon which society has come to depend.

In designing YuMi, ABB's global presence brought the benefit of an overview of manufacturing trends in 53 countries, many – such as those in north Asia – with high-growth forecasts for electronics. Foremost among these trends is the rapid merging of consumer, computer and communication devices (3C convergence). This has led consumers to expect constant innovation at affordable prices, further straining production processes. For manufacturers, the consumer market has changed the rules of production in ways that can be addressed effectively only by automation. Today's expectations of small-parts assembly involve higher product volumes, shorter product life cycles, shorter lead times and a growing trend to customize goods – particularly electronics – close to the final markets.

This new world of small parts assembly requires robots to be very flexible and easily trainable in new tasks. With YuMi, the operator simply has to activate a "record" program, manually guide YuMi through the desired movements and, while doing so, log waypoints and gripper actions on a paired tablet running the YuMi app. The app then turns those movements into the underlying code for the controller → 2. In this way, YuMi can learn new tasks in a matter of minutes. Best of all, no special operator training is required. Known as lead-through programming, this is the future of robot programming, and is so easy anyone can use it.

For tasks too complicated for this lead-through approach, ABB's high-level RAPID programming language can be used to train the robot in a more traditional manner.

Set up and sit down

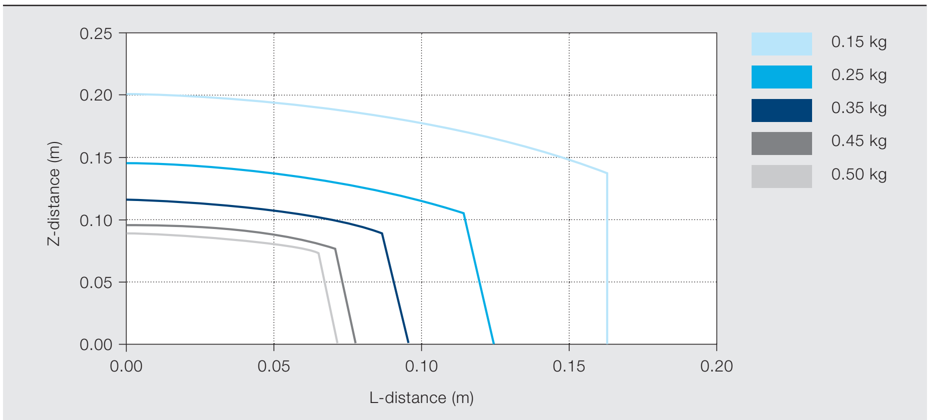
YuMi is easy to set up, too. At only 38 kg, it is very portable and mounting holes allow it to be simply and securely bolted to the work table → 3. The enclosed design means cables, electronics and hoses are inside the robot – this eliminates clutter and facilitates relocation. With such easy training and set-up, redeployment to another work area and task is quickly done.

A gripping story

YuMi is compact – its torso is about the same size as a human's – but it has a long reach – about 70 cm above its mounting plane and about 30 cm below. Horizontally, it can reach about 55 cm. These distances depend on the weight being carried → 4. Its dual arms each feature seven axes of movement and endow the robot with great dexterity and pinpoint precision – YuMi can return to the

3 There is ready access to the interface panel (lower right), which provides a wide range of communications options.

4 YuMi: payload capacity



5 YuMi's main specifications. A repeatable accuracy of 0.02 mm is achieved.

IRB 14000 – 0.5/0.55	
Payload	0.5 kg per arm
Reach	559 mm
Accuracy	0.02 mm
Customer interface	Foot interface
Weight	38 kg
Mounting position	Table
Temperature	5 – 40 °C
IP protection	IP 30
Clean room/food grade	No

YuMi has a light-weight, yet rigid, magnesium skeleton covered with a floating plastic casing wrapped in soft padding that absorbs any unexpected impacts.

same point in space repeatedly with a 0.02 mm accuracy and a maximum velocity of 1,500 mm/s ➔ 5. Contact force assembly between the arms is also possible. Its dual arms, of course, also allow multitasking.

YuMi has a standard tool-mounting interface. So that Yumi can be used to handle the great variety of parts that are seen in today's small-parts assembly environments, it can be supplied with integrated and highly flexible grippers, including servo grippers, single/dual suction cups and vision-enabled grippers ➔ 6–7. This allows for customization so that the demands of most assembly tasks can be met. YuMi is ESD (electrostatic discharge) compliant, so it can handle even the most electrostatically sensitive components.

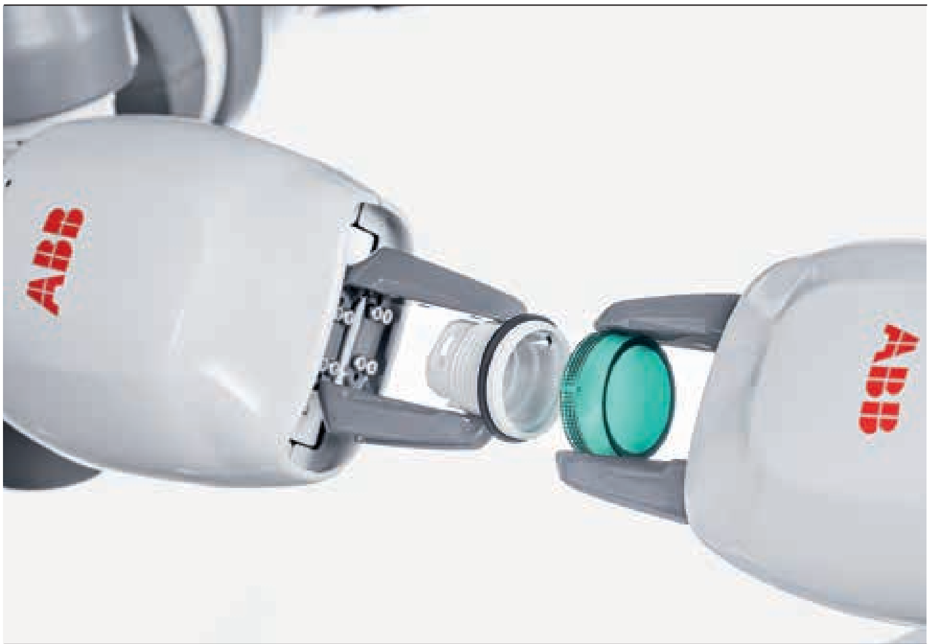
Stock feed

Small-parts assembly is about more than dexterity – supplying the parts for a given task effectively is also key to an efficient operation. To address this, ABB developed the sophisticated parts-feeding FlexFeeder™ system for parts delivery. The FlexFeeder stores a large number of parts, ranging from 3 mm to 30 mm in size, in a bin. Picking parts directly from the bin is a very complicated three-dimensional problem, so the FlexFeeder turns this into a much easier two-dimensional picking operation by placing parts from the bin onto a flat surface, where YuMi's integrated gripper cameras can easily locate the parts and pick them up.

Benefits

Manufacturers who employ YuMi will benefit from faster production, higher-quality

6 High accuracy, dexterity and ESD compliance enable YuMi to handle the most delicate and electrostatically sensitive components.



7 YuMi's grippers can deploy vision-enabled, single/dual suction cups and servo grippers.

Like the human arm, YuMi has no pinch points, so there can be no crushing between two opposing surfaces as the arm flexes.

products, lower waste, greater efficiency, increased flexibility and a high return on investment. While YuMi was specifically designed to meet the flexible and agile production needs of the consumer electronics industry, it can be applied equally effectively in any small-parts-assembly environment thanks to its dual arms, flexible grippers, universal parts feeding system, camera-based parts location, lead-through programming and state-of-the-art precision motion control.

YuMi benefits not only the manufacturer, but also the entire value chain: the worker, through a safer working environment and a higher quality of life; the environment, with less waste; and the consumer, with a better quality product.

Creating an automated future

With the introduction of YuMi, ABB is pushing the boundaries of robotic automation and fundamentally altering the types of industrial processes that can be automated with robots. YuMi is the result of years of research and development and heralds a new era of robotic coworkers that are able to safely work side-by-side with humans. While YuMi is specifically designed for small-parts assembly and has significant benefits in its own right, it is the first solution from ABB that is designed with a new era of human-robot collaboration in mind. The benefits of this type of collaboration are clearly not limited to a single industry – in fact, almost any industry stands to reap the benefits of collaborative robotic solutions.

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Transformer health in the real world

Maximizing transformer reliability on a budget

JOHN VINES, BERNARD BANH, CRAIG STIEGEMEIER, POORVI PATEL, LUIZ V. CHEIM – Many companies that utilize transformers are seeing significant reductions in maintenance budgets and expert resources, as well as new, tougher regulatory requirements and higher expectations from shareholders. This new reality requires a fresh approach to equipment management – instead of maintaining the status quo, different methodologies must be implemented. Many transformer maintenance methodologies are currently time-based. Because some units simply do not need as much maintenance as others this approach can result in unnecessary maintenance. The answer is the much more efficient approach of condition-based maintenance. With this method, the units that need maintenance are prioritized based on risk and importance, and money is spent where it is needed most. So what techniques are used to make sure the maintenance is properly prioritized? The answer lies in data analytics.

1 Outdoor equipment is especially prone to power system and environmental stresses.

Companies tend to rely on the same equipment experts year after year to keep assets running ➔ 1. However, many of these experts are reaching retirement age and are not being replaced. This reduction in manpower is part of an overall cost reduction trend that is also seeing maintenance budgets decreased.

Many companies would like to rely on monitoring and data analysis to fill these knowledge gaps. However, the amount and complexity of the data quickly overwhelms even the best-intentioned organizations. This has initiated a search for a way to handle the large amounts of data involved and compensate for the loss of expertise.

Transformer health index reliability issues

One option available is the transformer health index calculation. There are several approaches to this concept, the majority of which utilize a list of technical parameters that experts may classify as essential for transformer operation and health. A weight is given to each item on the list to indicate its relative importance. It is then a matter of assessing the condition of each parameter and assigning a score (eg, between zero and 100), multiplying individual weights by the respective scores, and dividing the result by the sum of all weights times the maximum score per individual parameter.

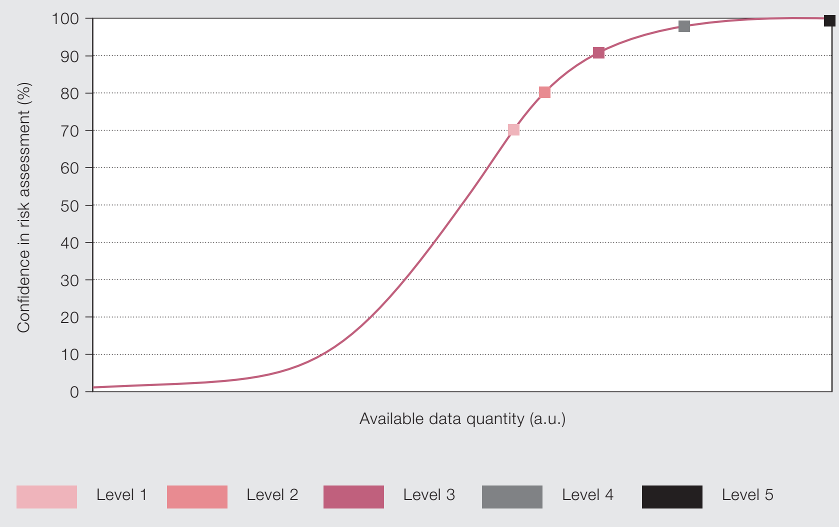
This approach has its disadvantages:
– The weights chosen by the experts are subjective and different experts may propose different weights.
– Poorly-chosen weights may easily overshadow the importance of other parameters or functions, consequently underestimating eventual problems with parameters whose weights are low.
– A robust sensitivity analysis is typically lacking – most approaches do not stress test the proposed solution to a point where real-life cases are tested and compared with the output of the procedure.
– Strangely enough, the method described will render the same output for any given selection of weights as long as all scores are at their maximum.

The ideal system includes a determination of the relative importance of the asset and the risk of failure.

Title picture
Approaching transformer maintenance in an intelligent way can reduce outlays and make better use of the dwindling numbers of experts. How can data analytics be exploited to achieve the best result?

It is important that the system provides recommendations and risk-mitigating advice to help keep the transformer healthy.

2 As available data increases, so does the confidence level of the assessment.



An ideal solution would be able to gather and analyze large amounts of data from many different sources. Flexibility is key here as data would come from many different types of sensors, monitors and systems. Whether it is hourly, daily, monthly or yearly, the data needs to be captured. Once organized, it should then be analyzed using expert algorithms that look at the system as a whole, not just at its individual parts.

Regular checkups

Comparing a person's year-to-year health checkups helps to spot any poor health developments and maintain well-being. The same approach has proven to be very effective for transformers. A transformer's condition needs to be assessed – information is collected, evaluated and compared with previous data in order to identify condition trends, then a diagnosis is made. The ideal system also determines the relative importance of the asset and the risk of failure. It is also important that the system provides recommendations and risk-mitigating advice to help keep the transformer in good condition.

Confidence level

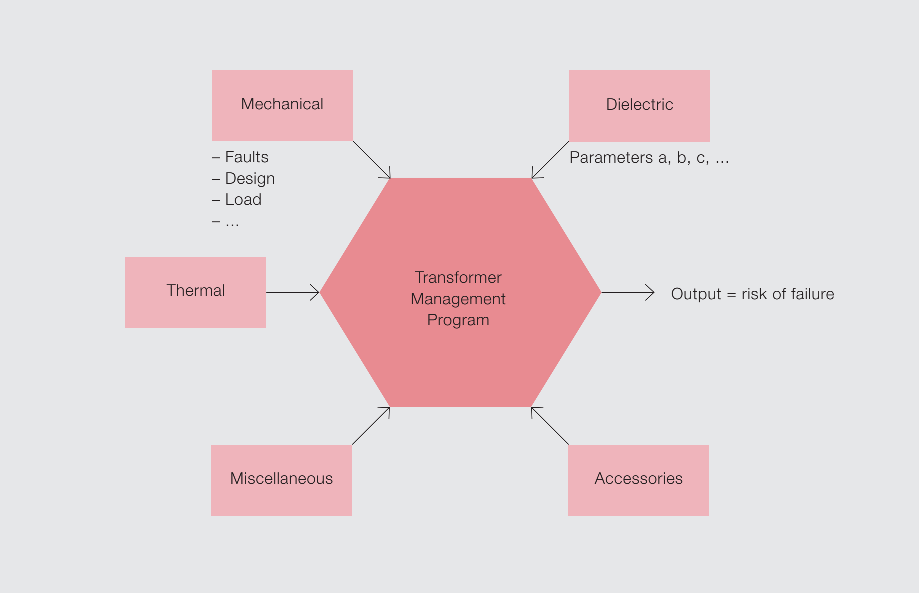
The initial condition assessment must be very thorough and result in a risk-of-failure calculation for the unit → 2. Rather than simply creating a health index view of individual features and then adding them up, a better approach is to take advantage of transformer subject matter experts (SMEs) to assess functional aspects of the transformer, along with taking a view of the entire picture.

As a start, the following data should be collected:
- Nameplate information, dissolved gas analysis (DGA) and oil quality parameters
- Loading, transformer turns ratio (TTR) and insulation power factor
- Bushing – capacitance and power factor, porcelain condition, thermal scan, oil level, and type and vintage
- Load tap changer – type, maintenance data, DGA and condition

To handle the constantly changing data, ABB developed the Dynamic Transformer Management Program.

- Cooling system and oil preservation system condition, tank oil level, and age of accessories
- Tank integrity, leaks, rust, paint, main cabinet condition and controls
- Protection (Buchholz relay, arresters, pressure relief, etc.) and product history.
- Sister unit failure data, design and reclosing practice

3 Mature Transformer Management Program approach based on functionality



The algorithms employed by the DTMProgram are able to analyze each of the functional aspects of a transformer then aggregate these into the five functional areas used by the MTMProgram.

- Special test results such as furan testing, degree of polymerization (DP), field-induced voltage test, sweep frequency response analysis (SFRA), dielectric frequency response (DFR), etc.
- Geomagnetically induced currents (GIC)

The data collected can be analyzed by ABB's Mature Transformer Management Program (MTMProgram™). The MTMProgram groups data into five functional groups – thermal, mechanical, dielectric, accessories and miscellaneous – to provide a complete condition assessment → 3–4. Reliability improvement recommendations are made for individual transformers. The main transformer functions covered include typical stresses, network solicitation, and short-circuit, thermal and dielectric capabilities.

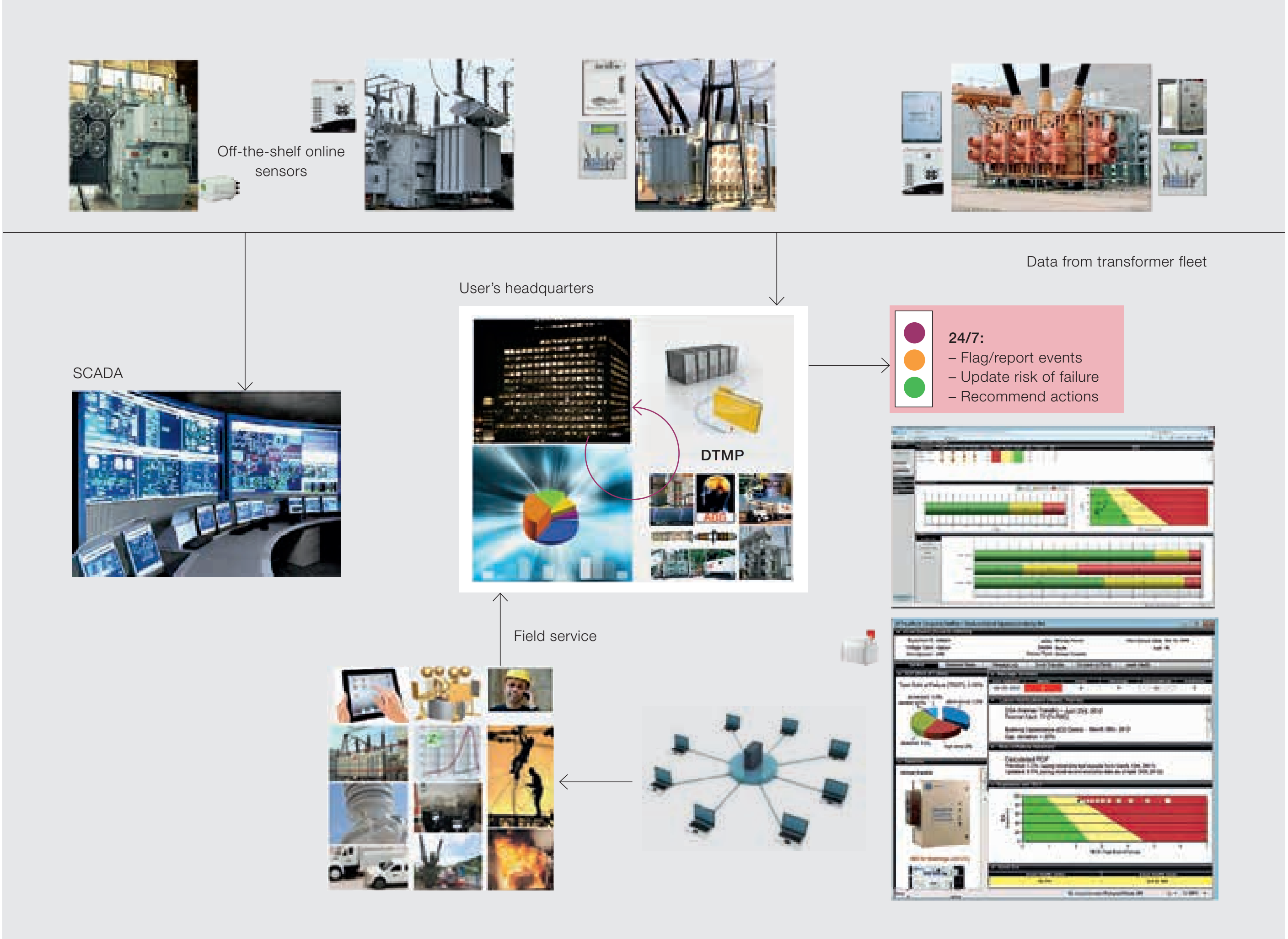
The approach establishes a close connection between the most stressed conditions, the requirements for each individual transformer and the contribution of individual parameters to achieve that functionality. It then calculates the risk of failure for each of the specified transformers in the fleet. After more than a decade and close to 10,000 transformers assessed globally, this program has proven to have benefits for many end users of transformers in different applications.

The program provides a one-time snapshot of the transformer's overall health. Therefore, as conditions change or new data is added, the risk of failure and maintenance or operation recommendations need to be updated daily. To handle the constantly changing data, ABB developed the Dynamic Transformer Management Program (DTMProgram™). The algorithms employed by the DTMProgram are able to analyze each of the functional aspects of a transformer then aggregate these into the five functional areas used by the MTMProgram. An expert system algorithm is then able to look at a transformer as a whole instead of at its individual components, as a health index would → 5. This expert system operates on a fleet-wide basis and is also capable of looking for cross-correlations among any issues found on the transformer.

ABB SMEs have also created algorithms for batteries and breakers using an approach similar to that described above. Many more algorithms are under development to support other critical assets throughout the industry. The key to the success of these algorithms is the utilization of SMEs during the design phase. The transformer algorithms are very flexible and can be integrated into multiple software platforms. No matter what the data sources and existing software systems are, there is a solution to support a condition-based maintenance approach.

Asset Health Center – further solutions

One of these further solutions is Asset Health Center (AHC), which incorporates ABB operational technology (OT) subject matter expertise and ABB information



An expert system algorithm is then able to look at a transformer as a whole instead of at its individual components, as a health index would.

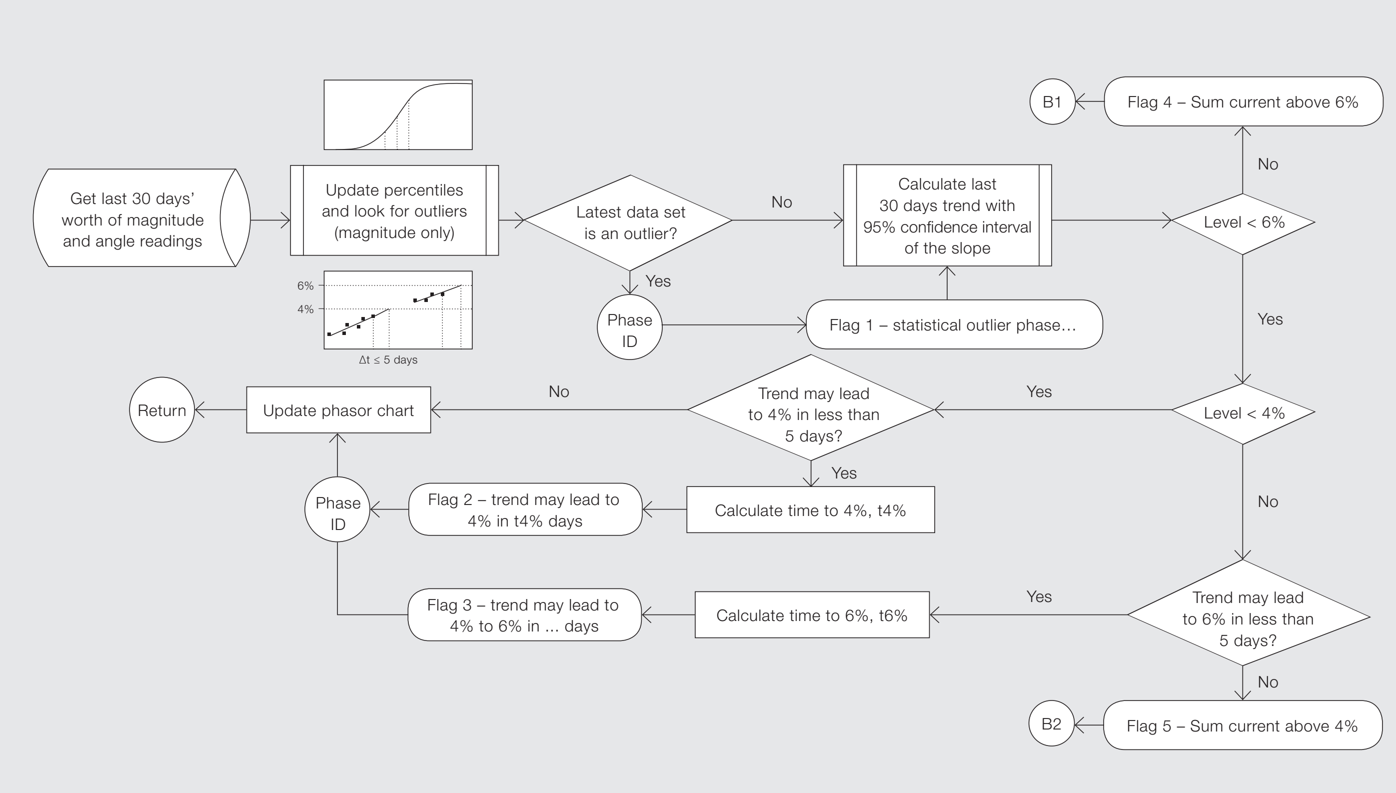
technology (IT) software knowledge to provide the latest online offering in fleet condition monitoring.

After a baseline assessment, the software uses online sensor data and/or manually entered traditional offline test data to perform automated condition assessments on a daily basis, and provide expert recommendations based on that analysis. Also included are condition monitoring, risk of failure, trend analysis, family comparisons, email and SMS alerts, reporting options and fleet scalability inputs.

Straightforward and easy-to-use dashboards allow users to see the transformer fleet health at a glance. Using traffic light indicators (green, yellow and red) users can quickly identify the units or areas that need more attention so maintenance budgets and resources can be allocated to where they are most needed. Most importantly, this helps avoid unplanned outages. The interface allows the user to drill further down into the information – down to a single transformer's sensor information – if needed. When conditions start to deteriorate past a predefined point, users

ABB subject matter experts have created algorithms for batteries and breakers and many more algorithms are under development to support other critical assets throughout the industry.

5 Example of an online performance model



can be automatically notified of the issues via email or SMS alerts.

Aging assets, rising energy demand and the critical need to avoid unplanned outages are challenging utilities and industries around the world. While financial constraints are reducing maintenance budgets and expert resources, demand for increased return on investment is undiminished. Maintenance managers facing these demands should utilize assessments, sensors, data analytics and software to adapt to condition-based maintenance planning. These methodologies can provide a much better understanding of asset risk and strengthen the confidence level of the actual condition as power equipment ages.

Avoid failures, increase asset reliability and predictability

The ABB DTMProgram expert system algorithm provides recommendations to optimize the maintenance and operation of transformers. By prioritizing maintenance, budgets can be concentrated where needed. Failure avoidance and risk mitigation with condition-based maintenance, structured and prioritized replacement plans, and the use of sensors for near real-time data delivery all allow the industry to maximize the return on transformer assets by ensuring high reliability, reduced life-cycle costs and optimized overall performance. The result of this data analysis helps create a prioritized list of maintenance actions for the entire fleet. Avoiding unnecessary service on assets in good condition and focusing attention on more risky assets with higher importance will satisfy shareholders and support adherence to new regulatory requirements.

The key to the success of these algorithms is the utilization of subject matter experts during the design phase.

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Dicing the load

Flexible production saves energy costs

IIRO HARJUNKOSKI, LENNART MERKERT, HUBERT HADERA, ANTTO SHEMEIKKA, DRAGOLJUB GAJIC, LUCA ONOFRI – Many energy-intensive industries such as steel, pulp and paper, and cement face the challenge of how to deal with the effect of increasing and fluctuating energy prices on daily production operations. New collaboration schemes offered to these industries through intelligent and flexible electricity networks (smart grids) significantly reduce total production costs by optimally timing electricity consumption. The main concern is how to make the production process flexible enough that a company can buy electricity when it is cheap – and even sell it back to the grid during peak hours. At perhaps a hundred times the purchase price. ABB has investigated and developed new approaches to this business proposition.

Title picture
Shifting production in energy-intensive industries to times when energy is cheaper can result in significant savings. How can the many variables, constraints and industry-specific aspects be taken into account to produce an optimized model?


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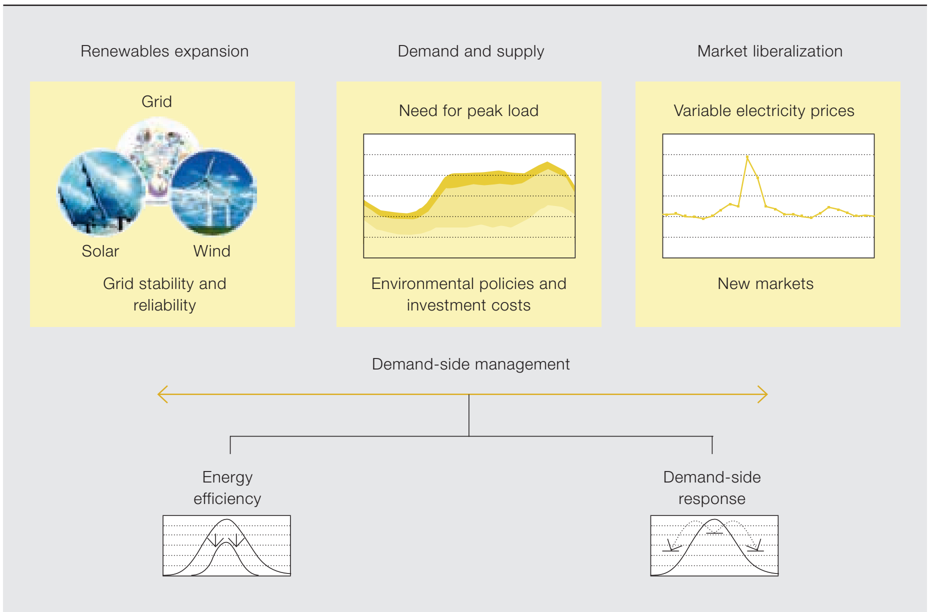
Large consumers have started to consider including energy forecasts in their production planning.

1 Energy demand-side management concept and the motivation for having it



Replacing traditional stable and controllable energy sources with fluctuating renewable sources means energy supply and price can no longer be taken for granted. Because of this, market tools for purchasing and selling electricity have become almost a necessity for large consumers. Since the price of electricity has a direct impact on production cost, large consumers have also started to consider including energy forecasts in their production planning. This concept, coupled with energy efficiency, is called demand-side management.

In contrast to energy efficiency strategies, which aim to produce the same using less energy, demand-side response focuses on profitable time-shifting of the load → 1. In practice, this means that an industrial plant needs to adapt production according to the energy cost situation. If future electricity pricing information is available – and this discussion will assume it is – many processes can take it into account in short-term planning or scheduling.

Energy management solution

ABB already offers a solution for optimizing the energy portfolio for a given production plan: cpmPlus Energy Manager has been available for more than a decade and covers energy conversion (eg, fuel to energy), purchasing from various markets and also some production planning decisions – especially for continuous processes. The solution has been installed by many types of customers – including pulp and paper, metals and mining – as a part of ABB's collaborative production management (CPM) solution and has demonstrated significant benefits.

→ 2 shows the Energy Manager solution for a thermomechanical pulp (TMP) mill, with the production lines displayed in the upper diagram and the fiber storage tank level in the middle diagram. A mathematical optimization is used to simultaneously consider all energy-consuming and energy-producing units together with the option of purchasing from or selling the energy to the grid based on current prices. The electricity consumption of the three TMP lines is shown in the bar graph in the lower part of → 2 and the varying electricity price is indicated by the yellow line.

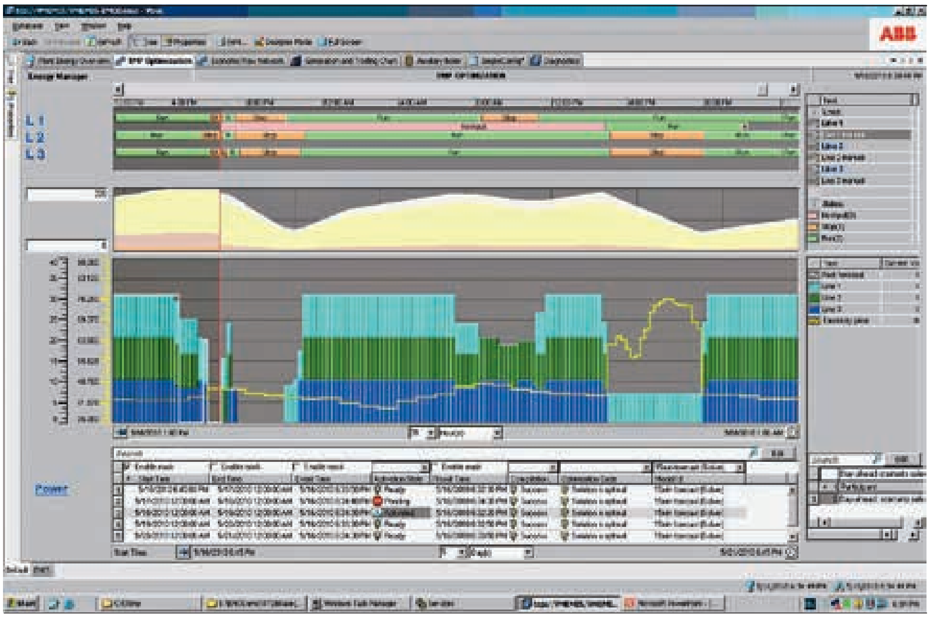
This example illustrates how a CPM solution can collect and connect information from various sources and generate the most cost-efficient production strategies, while also taking into account electricity costs. As the solution also includes other production units, it decides when to run which production line, taking into account, for example, total downstream steam demand, the capacity and cost of alternative steam sources, the production plan of the paper machines, and the minimum and maximum production limits of each refiner line.

Holistic optimization

The TMP example assumes that there exists at least a partly prespecified production schedule → 3a. The scientific challenge arises in simultaneously optimizing the production schedule and the electricity purchase strategy → 3b. The main idea is to optimally schedule production while considering aspects from the control, scheduling and supply chain layers. Mixed-integer linear programming (MILP) techniques represent a very promising way to arrive at holistic optimization solutions to problems like this that have partly competing targets. MILP solvers have improved significantly and

In contrast to energy efficiency strategies, which aim to produce the same using less energy, demand-side response focuses on profitable shifting of the load in time.

2 Energy management solution for a TMP mill. All lines are stopped during the highest electricity price peak.



The scientific challenge arises in simultaneously optimizing the production schedule and the electricity purchase strategy.

can now solve problems that are several magnitudes larger than those of a decade ago.

The problem of simultaneously optimizing energy management aspects and production planning needs has still not been completely solved and researchers are currently trying to find ways to handle this in realistic production environments. Nevertheless, ABB has collaborated with a steel company on this topic to come up with some feasible concepts that are currently being tested live in production.

Scheduling the steel-making process

Scheduling production in a steel melt shop is not easy, partly due to the extreme processing and material temperatures. For example, each production delay leads to cooling and later a reheating need. Therefore, there is a strong demand in the industry for automatic production schedule optimization. Attention must also be paid to other implementation aspects such as enabling different melt shop configurations and product portfolios; appropriate graphical user interfaces (GUIs); integration with other IT systems, eg, enterprise resource planning (ERP), energy management systems and process control systems. Without all these aspects, even the most sophisticated scheduling optimization model can never be deployed in a real production environment.

Industrial demand-side management

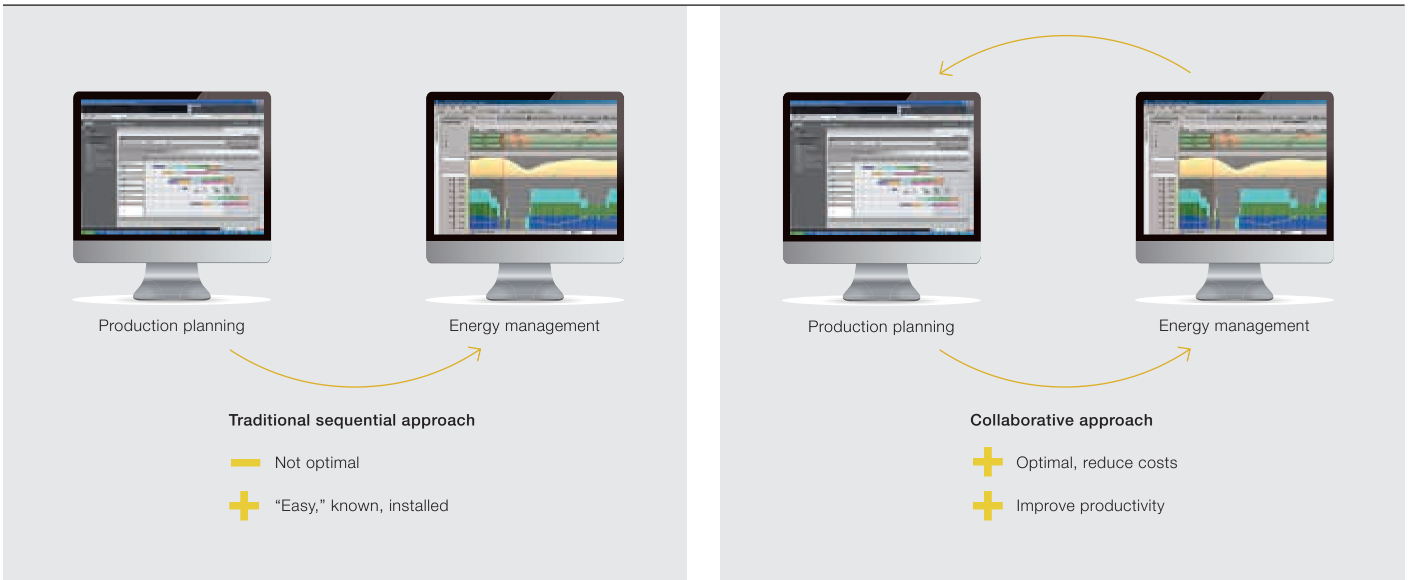
ABB developed new concepts allowing industrial demand-side management (iDSM) by automatic optimization of the production schedule against the electricity costs. The first step toward the iDSM solution was to investigate the use of monolithic models for the integration schemes shown on the far right in → 3.

→ 4 depicts the idea in which an additional time grid is added to the original scheduling formulation in order to check the electricity consumption in each of the slots formed. The electricity provider or the electricity market defines the energy price for each of these time slots (15 to 60 min). Theoretically, this holistic-model-based optimization may lead to a so-called global optimum, ie, the best possible solution with respect to both the production and electricity costs. However, holistic models are very often complicated or impossible to solve within a reasonable time, so some refinement is required.

Refining the models

In production processes that require multiple production steps, such as batch-oriented steel manufacturing, typically not all equipment is continuously occupied. This allows flexibility to adapt production according to energy management needs. Multistage production processes also usually have buffers to store raw material, and intermediate and final products – for limited periods of time. In

3 Collaboration between energy management and production planning



3a Here, at least a partly prespecified production schedule is assumed.

3b Here, the production schedule and the electricity purchase strategy are simultaneously or iteratively optimized.

MILP solvers have improved significantly and can now solve problems that are several magnitudes larger than those overcome a few decades ago.

the melt shop process, for example, intermediate products are very hot so inadequate coordination of subsequent production stages causes energy loss through cooling. Another constraint is that large electricity consumers commonly have to commit their forecasted load pattern upfront and suffer financial penalties for deviations from it.

In the work done by ABB, the continuous-time (exact) melt-shop scheduling model has been refined to take into account both the electricity price as well as deviations from a committed load curve. The benefit of this approach is that the energy considerations can be included in the original scheduling model by adding new decision variables to map the electricity consumption for each grid-defined time slot. This results in feasible solutions with clear energy savings potential. However, this basic approach is not efficient for more complex instances. Therefore, various alternative approaches have also been looked at including other modeling philosophies – eg, resource-task network – as well as decomposition algorithms.

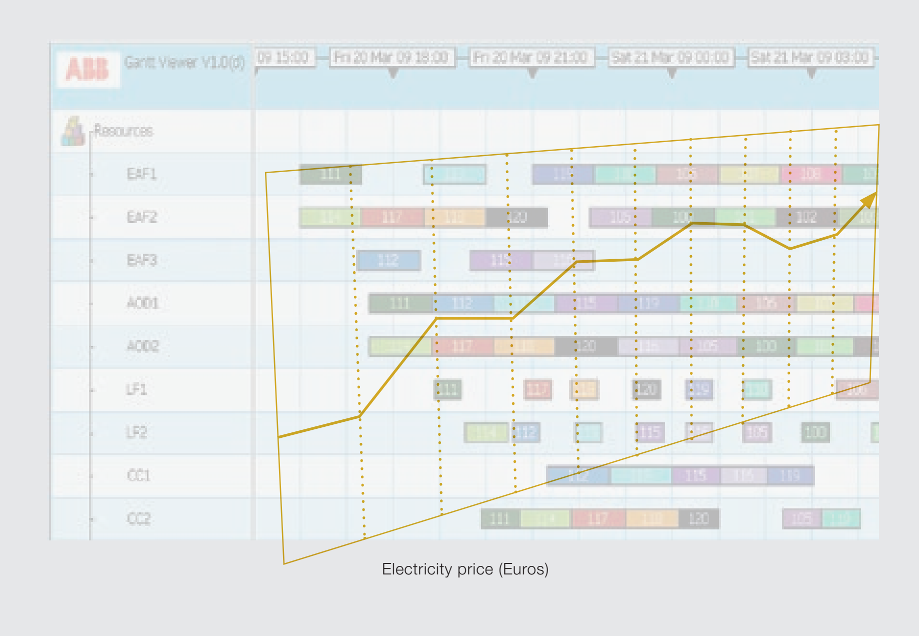
ABB has collaborated with a steel company to test a number of approaches and come up with some feasible concepts that are currently being tested live in production.

Energy pricing and usage scenarios

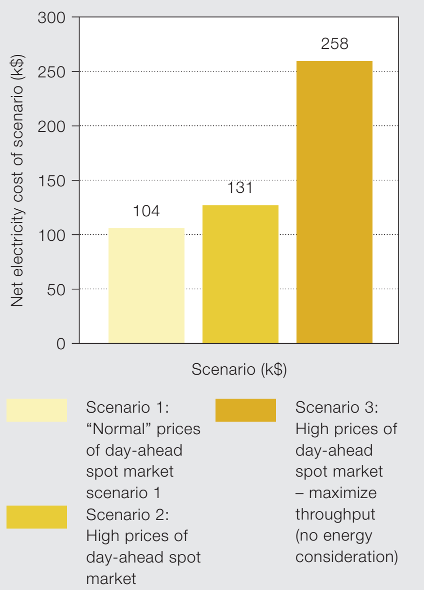
Based on realistic data, a hypothetical case study has been carried out to investigate how strongly three different energy tariff scenarios might influence the energy bill for a typical 24-hour scheduling problem → 5. The scenarios are each assumed to buy a fixed amount of electricity at a known rate using a base load contract. The total energy bill can be reduced by reselling any surplus electricity. The committed load aspect is also taken into consideration.

The first scenario represents a day with “normal” electricity prices in the volatile day-ahead market. When the scheduling driven by energy price is employed, the net electricity cost is around $110,000. The second scenario uses weather-driven prices, which result in an additional cost of $27,000. The third scenario ignores energy price considerations, ie, only production throughput is optimized

4 The grid delineating the electricity price time slots



5 Total electricity cost for various energy prices and optimization strategies



– resulting in a cost double that of the second scenario. This demonstrates how much the plant could potentially save by collaborative scheduling and energy optimization on a day with extreme prices.

In this case study, energy-driven scheduling contributes to significant reductions of the electricity bill. However, comparison of the schedules of scenarios two and three clearly shows that the energy-driven schedule tries to avoid extreme prices of the peak hours (marked in red and orange in → 6) at the expense of extending the overall makespan (the total time needed for production) → 6. Some of the production operations are delayed – perhaps incurring reheating costs. In the study, the cost of thermal losses has not been included in the savings calculation. However, with realistic cooling models it is certainly possible to account for potential costs that can be associated with production delays.

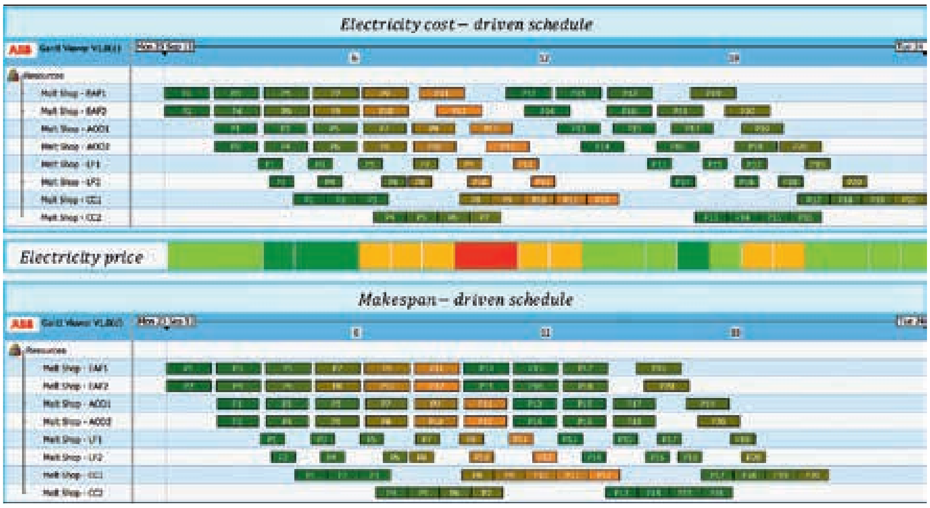
Scheduling solution

A new ABB production scheduling system based on MILP technology was deployed in a very complex melt shop belonging to Acciai Speciali Terni SpA, a member of ThyssenKrupp and one of the world's leading producers of stainless steel flat products. With the new system in place, the production scheduler is able to automatically and optimally create a new schedule, or manually update an existing one, for up to seven days of production within just a few minutes. The system is flexible enough to support different melt shop configurations, as well as to include all other information necessary – such as processing, transportation, setup and cleanup times – to generate a feasible production schedule. It also takes into account maintenance plans, the current status of the melt shop and availability of different equipment, due dates, penalties for lateness and violation of holdup times between stages in the process, etc. In addition, the steel plant created a Web-based GUI that allows the user to flexibly select what to optimize and schedule → 7. The list on the left in → 7 shows production steps or units, such as the electric arc furnace (FEA) and ladle furnaces (ASEA). For each unit, there are two rows. The "monitoraggio," row is related to monitoring and shows the current status of the unit and what really has happened there. The "programma" row shows what has been planned/scheduled in each unit. Thus, the GUI also enables other departments to initiate appropriate actions in order to minimize potential losses and production delays – for example, reschedule or postpone production slightly due to a high electricity price. The new scheduling system is not only linked to other internal IT systems such as ERP and process control, but also to the external day-ahead electricity market, in order to dynamically cater for volatile electricity prices.

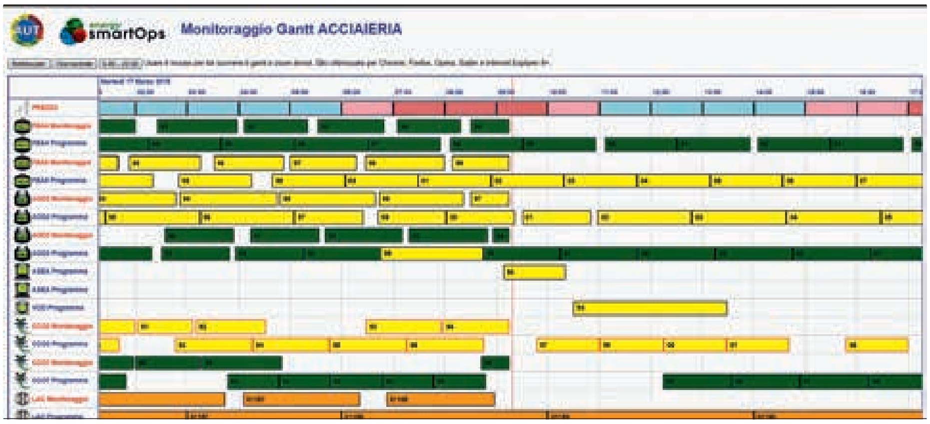
The continuous-time melt-shop scheduling model has been refined to take into account both the electricity price as well as deviations from a committed load curve.

The production scheduler is able to automatically and optimally create a new schedule, or manually update an existing one, for up to seven days of production within just a few minutes.

6 Comparison of schedules driven by energy cost and makespan cost



7 Web-based GUI of the new production scheduling system. Prices can change by the hour.



Furthermore, in cooperation with ABB, the steel plant has also integrated into the new scheduling system an advanced solution for optimization of the production schedule, taking into account electricity prices as well. This advanced solution enables the plant to optimize its electricity costs and makespan and thus play a more active role in demand-side response programs and support grid reliability and safety.

It has been shown that the implementation has improved the coordination between different production stages in the melt shop and thus decreased the hold-up times between these, reducing energy consumption. The system has also been recognized as a very useful tool for running various simulations and what-if analyses. The benefits are estimated to be in the range of 2 to 5 percent – a considerable saving given the large energy budgets involved.

Flexibility is key

The complexity of production scheduling is increasing in industries outside of steelmaking too, mainly due to smaller and more customized orders. Production plants now have to be agile and flexible to respond to short-term changes. These industries also face the complexity arising from variable, but potentially more affordable, electricity pricing on an hourly basis in the day-ahead market. Consequently, combined energy and production planning processes must always be well integrated with real-time data. Having a full offering of process and grid automation, ABB has the tools to realize a proper matching of supply and demand using internal buffers in the process and production load shifting for a wide range of industries.

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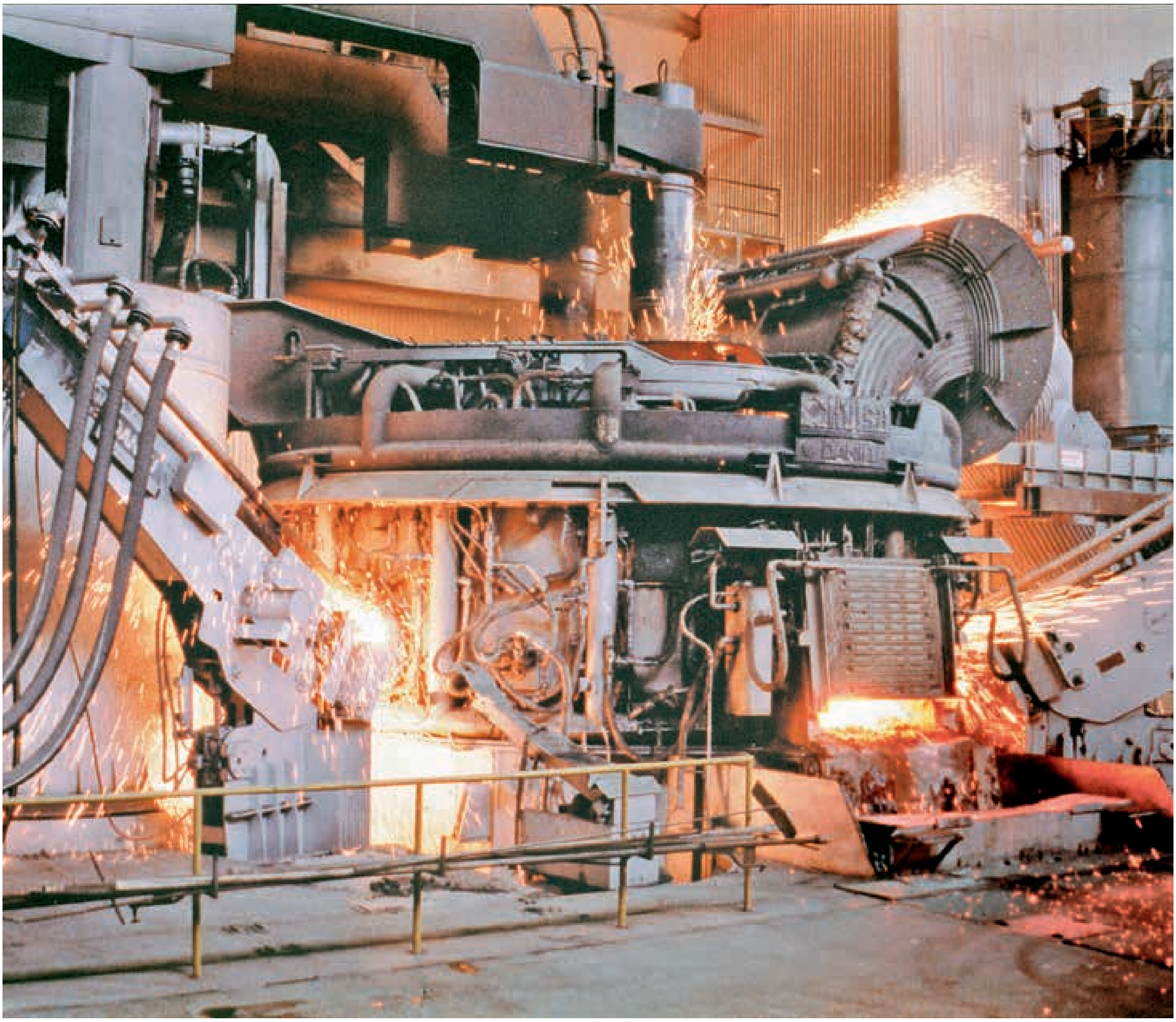


Causing a stir

ArcSave® increases productivity and lowers costs in electric arc furnaces

LIDONG TENG, AARON JONES, MICHAEL MEADOR, HELMUT HACKL – ArcSave® is a new generation of ABB electromagnetic stirrer (EMS) for electric arc furnaces (EAFs) that helps to improve safety, increase productivity and reduce costs. The first ArcSave system was installed in 2014 on a 90 t arc furnace. The hot test results show that it has stabilized the arcs and enhanced the heat and mass transfer in the arc furnace process. This results in a faster scrap melting rate, a lowering of the slag superheat during arcing, a more homogenous melt bath, a higher decarburization rate and a higher free opening frequency of the eccentric bottom tapping (EBT). ArcSave has also reduced the tapping temperature and tapping oxygen in the steel, which brings a higher scrap yield and saves ferroalloy consumption in the downstream ladle furnace operation. The lower energy consumption, short tap-to-tap time and consistent furnace operation greatly increase the productivity and operation safety.

ABB has been committed to the development of new electromagnetic products to improve quality, productivity and safety in the steel business over 70 years.

ABB has been committed to the development of new electromagnetic products to improve quality, productivity and safety in the steel business over 70 years. The first electromagnetic stirrer for electrical arc furnaces (EAF-EMS) was delivered in 1947 to Uddeholms AB in Sweden and since then more than 150 units have been installed worldwide. Recently, a new generation of EAF-EMS – ArcSave – has been developed by ABB to fulfill the requirement for a stronger stirring power in the EAF process for both plain carbon and high-alloyed steel production.

The main difference ArcSave makes to the EAF is the intensity of convection in the melt bath.

In July 2014, the installation and commissioning of the first ArcSave was completed on a 90 t AC EAF at Steel Dynamics, Inc. (SDI) in Roanoke, United States. SDI is a company with a tradition of improvement using the best technology available. In order to remain competitive, SDI believes that every ton of steel has to be produced as efficiently and safely as possible. For this reason, SDI entered into the project with ABB to install ArcSave on the EAF.

Stirring principles

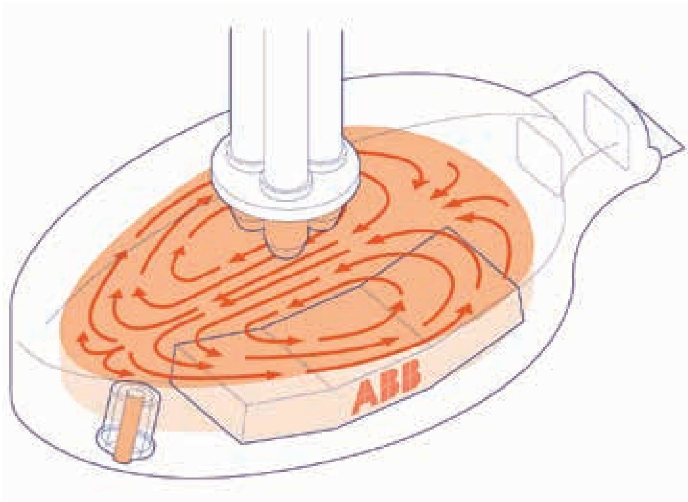
The ArcSave stirrer was placed under a nonmagnetic (austenitic stainless steel) steel plate bottom → 1a. Low-frequency electric current in the stirrer windings generates a traveling magnetic field that penetrates the furnace bottom and generates physical forces in the molten steel → 1b. Stirring can be customized to match the needs of different EAF process steps such as scrap heating, homogenization, melting of alloys, decarburization (reduction of carbon content), deslagging and tapping.

The designed average melt velocity induced is around 0.5 m/s. → 2 shows a simulated example of the horizontal cross-section of the mean flow pattern for the horizontal plane about 25 cm below the melt surface in a 150 t EBT tapping EAF. It can be seen that the flow is slightly asymmetric. However, com-

Title picture
Electromagnetic stirrers are essential for the efficient operation of arc furnaces. ABB's new generation of stirrer – ArcSave – has been in operation for a year in a steelworks – what are the results so far?

1 Arc furnace at the SDI site

1a Showing the ABB stirrer mounted underneath



1b Furnace top view schematic showing the stirrer underneath and flow patterns

pared with the more localized bottom gas stirring via porous plugs, the EMS creates a global circulation in the arc furnace bath and thereby provides a more efficient mixing of the complete bath melt. This mixing effect accelerates the homogenization of the temperature and chemical composition of the steel, as well as that of the chemical reactions between steel and slag.

The complete ArcSave system comprises the electromagnetic stirrer, a frequency converter, a transformer and a water station → 3. It has the following features:
- No physical contact with the steel melt
- Normal refractory lining can be used
- The stirring direction can be reversed by changing the current direction
- Very little maintenance is required

The hot test results from SDI show significant process benefits have been achieved due to the improved kinetic conditions for heat and mass transfer with ArcSave. It is worthwhile to examine these benefits in detail.

Arc heating efficiency and energy saving

Due to the homogenization, the temperature gradient in the melt with EMS is reduced to only 25 percent of what it was before. This means that the EMS reduces the melt surface superheat and the heat from the arc zone is quickly transmitted to the melt bulk. The decrease in surface superheat will reduce heat losses to the furnace wall and roof, and thereby reduce electricity consumption. Simultaneously, the stirring will increase the scrap melting rate and decarburization rate and therefore save furnace process time, which also reduces the heat loss. In the ArcSave test at SDI, the total energy saving includes the chemical energy decrease from the lowered consumption of natural gas, carbon and oxygen, and the reduction of FeO in the slag. The total energy saving is about 14 kWh/t, which is equivalent to 4 percent of the total. Because of the higher power input efficiency and higher heating efficiency, ArcSave reduces the power-on time by around 5 percent.

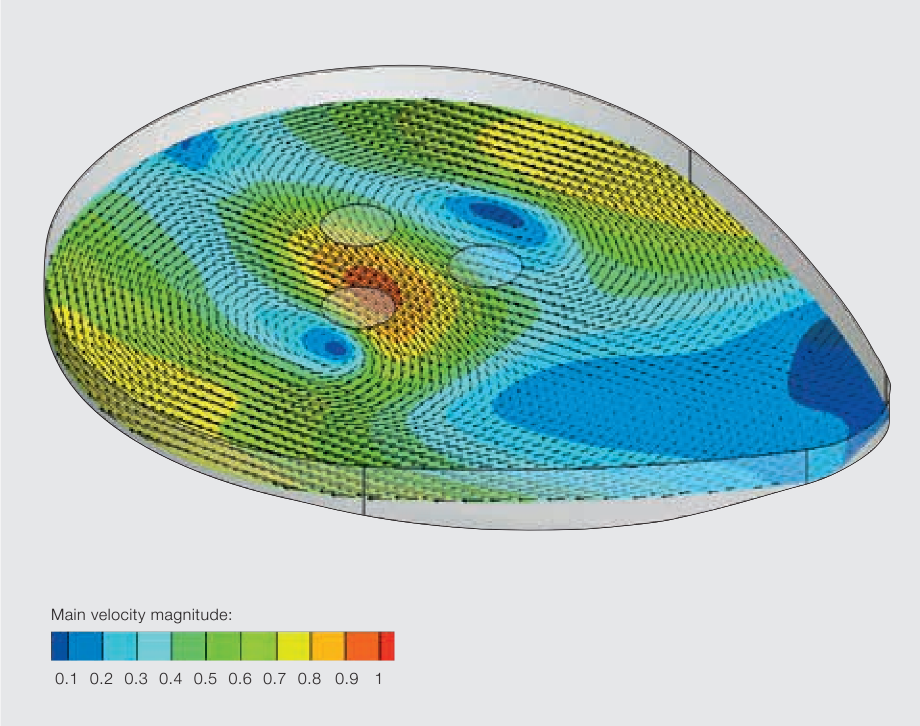
> At SDI, the total energy saving is about 14 kWh/t, which is equivalent to 4 percent of electrical energy saving.

Scrap melting

The main difference ArcSave makes to the EAF is the intensity of convection in the melt bath. The forced convection in-

EAF bath stirring can push the carbon-oxygen reaction closer to the equilibrium value. It is also seen that the Fe_2O_3 content in the slag is reduced by 2.5 percent.

2 Melt flow pattern created by electromagnetic stirring [1]



duced by electromagnetic stirring will enhance the melting of larger scrap pieces and bundles, contribute to a homogenous temperature and composition distribution, and make scrap stratification less significant. Without stirring there is only the very low convection caused by the difference of densities.

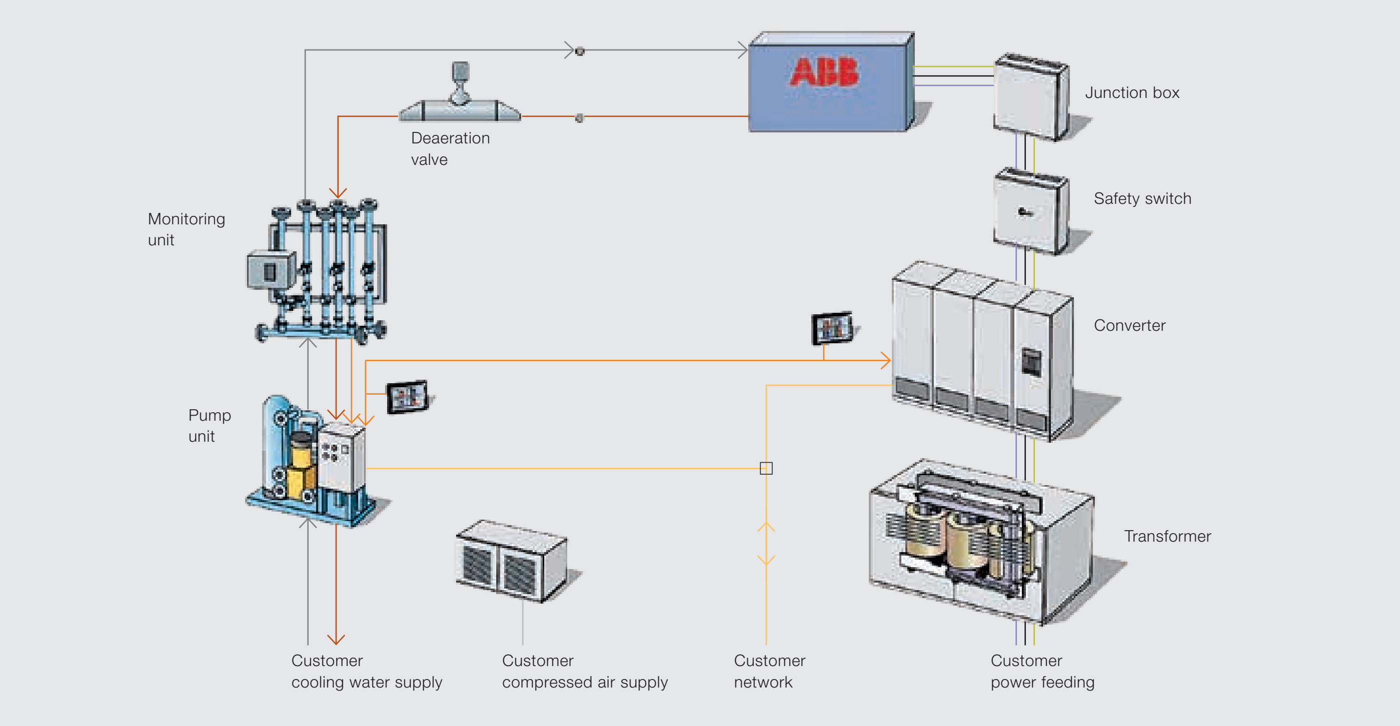
Stirring also reduced electrode stabilization time (by some 10 percent) after bucket charging at SDI ➔ 4a. In addition, it has been found that the EMS stabilized the arc by melting big scrap bundles faster and by reducing scrap caveins (surges in scrap movement in the melt that disturb process continuity). The standard deviation of current changes for a three-bucket melting period is reduced by about 50 percent with ArcSave ➔ 4b. The reduced current swings result in higher power input and, therefore, increased productivity.

A homogenous temperature distribution in the melt bath also gives a hot EBT and smooth tapping without delays and makes it possible to obtain an exact tapping temperature for the different steel grades.

A homogenous temperature distribution in the melt bath also gives a hot EBT and smooth tapping without delays and makes it possible to obtain an exact tapping temperature for the different steel grades.

Decarburization and O_2 yield

After the scrap is completely molten, the refining period starts. This mainly involves decarburization by injecting oxygen. This injection creates a highly turbulent reaction zone where carbon from the bulk metal can react with oxygen or FeO. If the steel carbon content is high, the decarburization reaction rate is determined by the rate of oxygen supply. However, if it is lower than a certain level, the rate of carbon transport to the reaction zone would consequently normally be lower, as



would then be the decarburization reaction rate. But ArcSave facilitates carbon mass transfer to the reaction zone and can double both these rates and reduce oxygen consumption – by 5 percent at SDI.

> ArcSave facilitates carbon mass transfer to the reaction zone and can double the decarburization reaction rate, and reduce oxygen consumption.

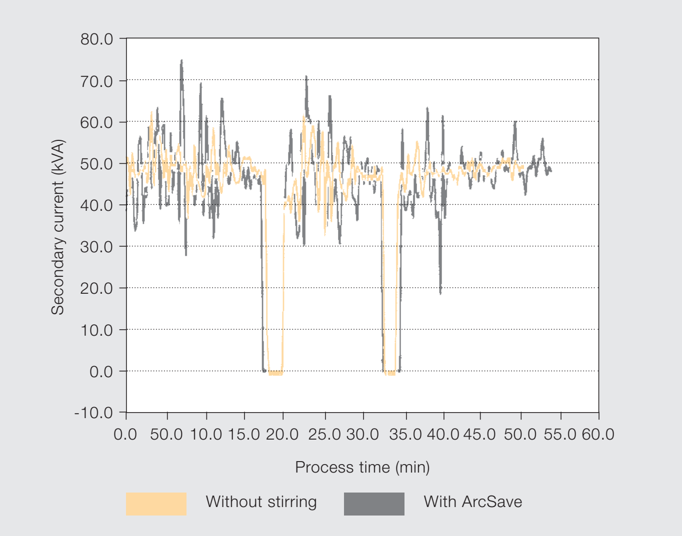
Steel deoxidation
It is known that EAF bath stirring can push the carbon-oxygen reaction closer to the equilibrium value [2]. This has been proven by the test results from SDI, where the tap oxygen was reduced from 618 ppm to 504 ppm, with a slight tap carbon increase. These results indicate that ArcSave makes it possible to reach lower carbon and oxygen levels at the same time. It is also seen that the Fe_2O_3 content in the slag is reduced by 2.5 percent with ArcSave. This, according to the materials balance calculation, gives a 0.2 percent steel yield increase, which reduces scrap and conversion cost.

Steel yield
Besides the FeO reduction in slag, another big contribution to the steel yield increase is the reduction of metallic scraps in the dumped slag – it is found that the scrap in the recycled slags is reduced by about 40 percent. This gives some 0.6 percent steel yield increase in the EAF. The reason for the reduction of steel droplets in the slag with stirring is under investigation, but the intensive slag/metal interaction and the more homogeneous slag with ArcSave are possible causes.

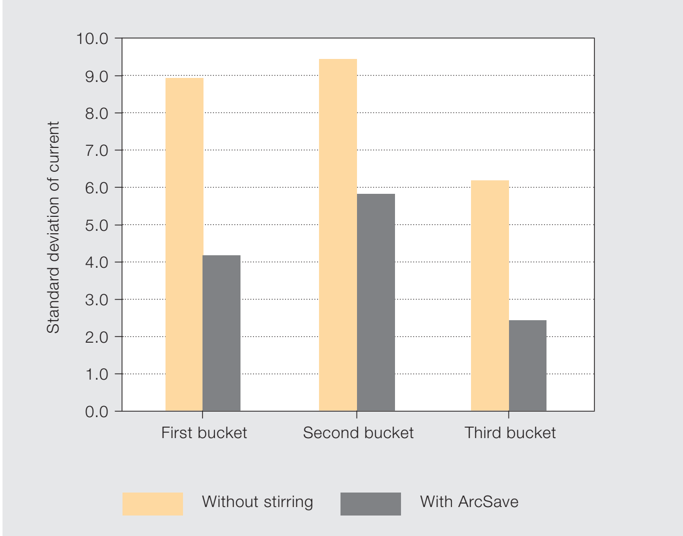
Yet another contribution to the steel yield increase is the metallic yield increase due to lower tap oxygen in the steel.

Vortex formation and slag carryover
Theoretically, an EBT hole should result in slag-free tapping. However, slag carryover is always evident in the tapping ladle, the main reason being vortices in the later stage of the tapping. Water modeling results show that vortex formation can be suppressed by the stirring force from ArcSave. The slag thickness in the tap ladle was measured by the aluminium-

4 Effect of ArcSave on electrode current swings



4a Comparison of the electrode secondary current without stirring and with ArcSave. The current swings were reduced using ArcSave.



4b Standard deviation of current change for a three-bucket melting period. It is reduced by about 50 percent with ArcSave.

steel pole method. The results show that the carryover slag amount is reduced by 50 percent with ArcSave.

Furnace refractory

Six months of hot test results at SDI show that stirring with ArcSave reduced furnace refractory repairs by some 15 percent. The superheat reduction is probably the main contributor to this since the most critical refractory damage is in the slag-line area. The reduction of the FeO in the slag and the oxygen in the steel also helps. A third contribution to reduced refractory wear is the lowered tap temperature – down by 14 °C without affecting the ladle furnace arrival temperature → 5.

Process reliability and safety

Safety and reliability are always of great importance for EAF operation. The positive effects of ArcSave on the EAF process discussed above will have a significant impact on improving process reliability and safety. ArcSave decreases the tap temperature and reduces the superheat in the hotspots area, and increases the EBT free opening ratio, thereby increasing furnace safety.

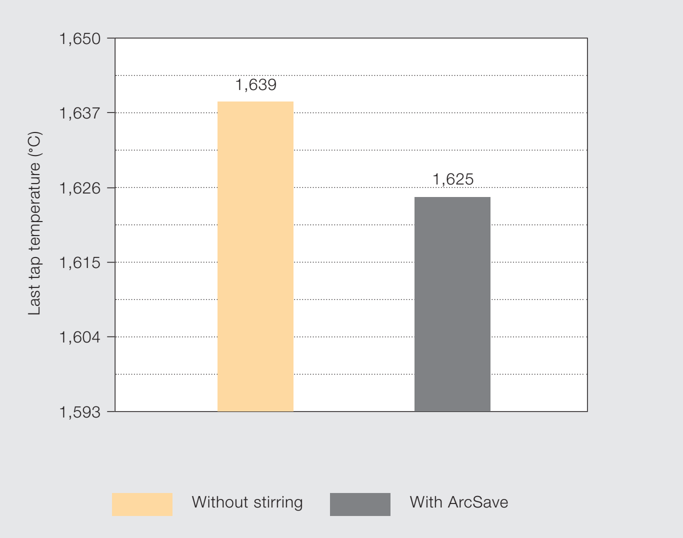
> The review of results from the SDI plant has shown that ArcSave has produced multiple benefits for the steelmaker.

The following process disturbances could be decreased or eliminated with the aid of ArcSave:
- Scrap cave-ins
- Residual non-molten big scrap or pig iron
- Carbon boiling-out (sudden boiling phenomena in the melt) – a significant topic if charging with pig iron
- Off-target tapping weight and temperature
- Low EBT opening ratio → 6

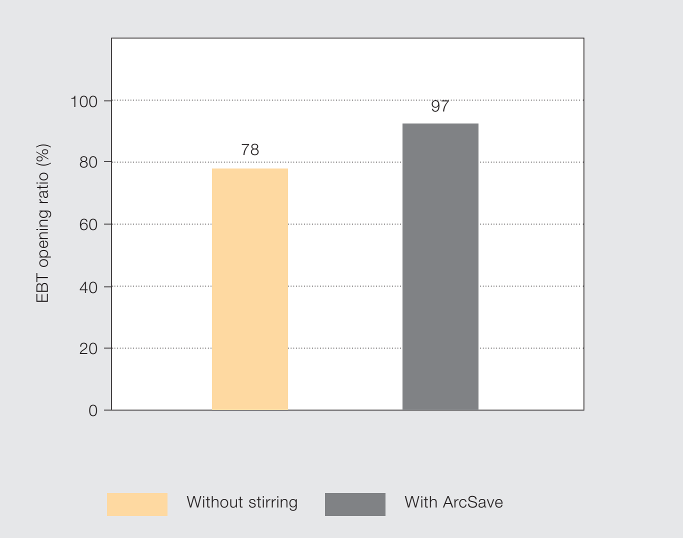
Safer, quicker and cheaper steel-making

The review of results from the SDI plant has shown that ArcSave has produced multiple benefits for the steelmaker → 7. ArcSave helps the melting process make liquid steel more safely, quicker and with lower cost. ArcSave improves the heat and mass transfer of the EAF process; speeds up the scrap melt-down; accelerates the homogenization of the temperature and chemical composition of the steel bath; forces the metal/slag reactions closer to the equilibrium state; increases the decarburization rate; and improves the operation safety, reliability, and productivity. The

5 Change of tap temperature after ArcSave



6 Change of EBT opening frequency after ArcSave. High EBT opening frequency is beneficial for operation safety and productivity.



7 Process benefits summary

Process items	Benefits
Total energy	- 3~5%
Electrode	- 4~6%
Power on time	- 4~6%
Oxygen	- 5~8%
Deoxidants	-10~15%
Steel yield	+ 0.5~1.0%
Productivity	+4~7%

Six months of hot test results at SDI show that stirring with ArcSave reduced furnace refractory repairs by some 15 percent.

impact of ArcSave will be particularly significant in those EAFs requiring a productivity increase.

The authors would like to acknowledge the kind support from and valuable discussions with Paul Schuler and Nuno Vieira Pinto at SDI (Roanoke) during the ArcSave hot test work. Thanks also to Chris Curran from ABB Metallurgy, Canada, for the kind help with the carryover slag measurement work. Thanks to Boo Eriksson and Jan Erik Eriksson from ABB in Sweden for the useful technical discussions during the test work.

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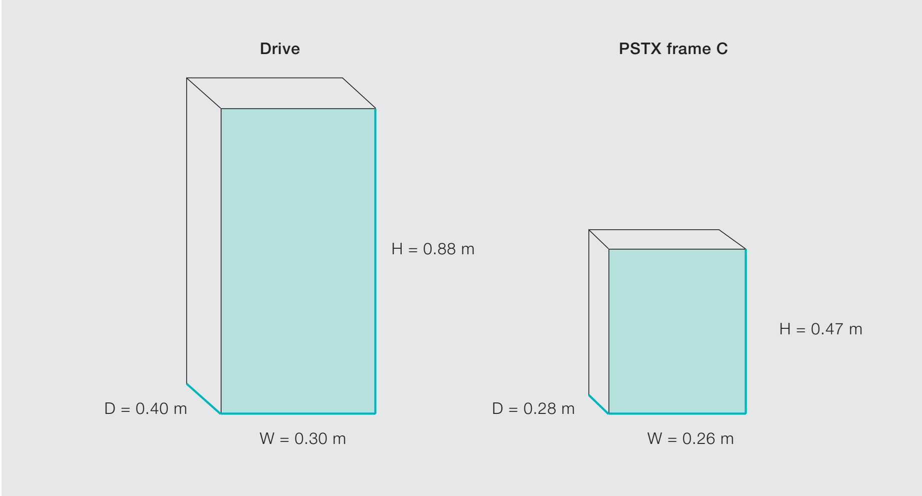
A motor’s best friend

Narrowing the gap between softstarters and drives

CARL THORSTENSSON, JOAKIM X. JANSSON – ABB has been at the forefront of the development of electrical motors for more than 100 years. Wherever there is a motor, there is the challenge of starting it without being too harsh on both the electrical supply and the mechanical load. It is thus hardly surprising that ABB has been supplying motor-starting solutions for as long as the company has been making motors. In the early days, these focused on different approaches to making direct starts and stops using such devices as disconnectors and contactors. Later the variable-speed drive was introduced, making it possible to control the speed of the motor. In the 1980s the softstarter was introduced as a compromise between the soft start and stop that a drive can provide and the compact size and lower cost of the direct online connection (a softstarter is a solid-state device rather like a drive but that is normally bypassed once the motor is at speed). Since then ABB has developed several generations of softstarters. When the company asked customers how they wanted to see softstarters improved further, the feedback was for the gap between softstarters and drives needed to be narrowed. ABB’s answer is the PSTX softstarter.

1 The PSTX softstarter requires significantly less space than the equivalent drive.



To narrow the gap between softstarters and drives, ABB has equipped the PSTX with many features for full-speed applications that were previously only available in the drive – and achieved this without transgressing the softstarter's core strengths of compact size → 1, lower heat generation and lower cost. The PSTX features, for example, over- and under-voltage protection, limp mode, motor brake and motor heating. One of the most innovative features is the slow-speed jog. Slow-speed jog is a function bridging the gap to the drive by allowing the motor to run at reduced speed.

Value of function

By using PSTX softstarters, it is possible to speed regulate a motor without using a drive. With slow-speed jog, the motor can be run at three different reduced speeds, both forward and backward. By reducing the output frequency of the softstarter, the speed of the motor can be reduced due to the proportionality between the frequency and motor speed.

Title picture
ABB's PSTX softstarter narrows the gap between softstarters and drives.

It is then possible to temporarily speed-control a motor without a large and expensive drive.

A reoccurring problem in pumping applications can be clogged pipes or jammed pumps. By combining the backward jog with the kickstart function the PSTX provides a solution for pump cleaning. However, the jog can be applied in many other situations, eg, positioning of conveyor belts, simplifying maintenance inspections of machinery and ensuring full functionality of an application during commissioning.

> By using PSTX softstarters, it is possible to speed regulate a motor without using a drive

Technical explanation

There is a fundamental relationship between the motor speed and the frequency:

$$n = \frac{2 \times f \times 60}{p} \Rightarrow n \alpha f$$

where n is the number of revolutions per minute of the motor, f is the frequency and p is the number of poles of the motor. If the frequency from the softstarter is reduced, the speed drops accordingly:

$$f \downarrow n \Rightarrow n \downarrow$$

In contrast to a drive, the PSTX generates undertones of the fundamental frequency (normal grid frequency 50 Hz or 60 Hz) by triggering the thyristors in a specific sequence.

An undertone is similar to an overtone, but instead of a higher frequency the undertone has a lower frequency than the fundamental frequency. One can consider the fundamental frequency an overtone or a harmonic of the generated undertone. In order to generate the lower frequency the thyristors are triggered when the curves of the fundamental frequency and sought undertone intercept.

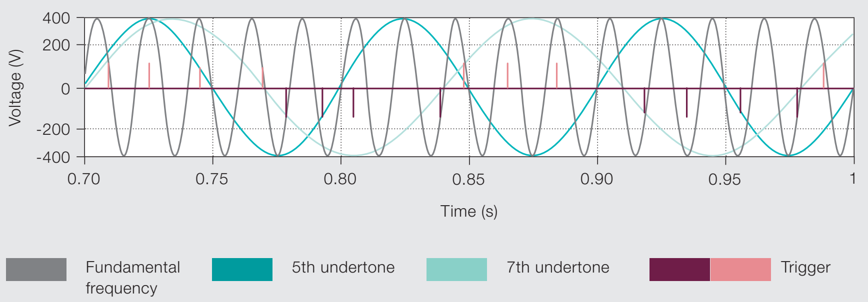
In → 2 the broken green line is the seventh undertone and the full green line is the fifth undertone, representing two different motor speeds. The purple and red vertical markings represent the trigger signal to the positive and negative thyristor, respectively.

This approach of generating a lower frequency has many advantages over using a drive. For example, it doesn't come close to generating the amount of harmonics a drive would create in this situation because the PSTX does not chop up the incoming signal but rather uses only the necessary parts of it. The thyristors conduct parts of the half-periods to create the desired output frequency. All three phases are illustrated in → 3, showing how the seventh undertone is generated.

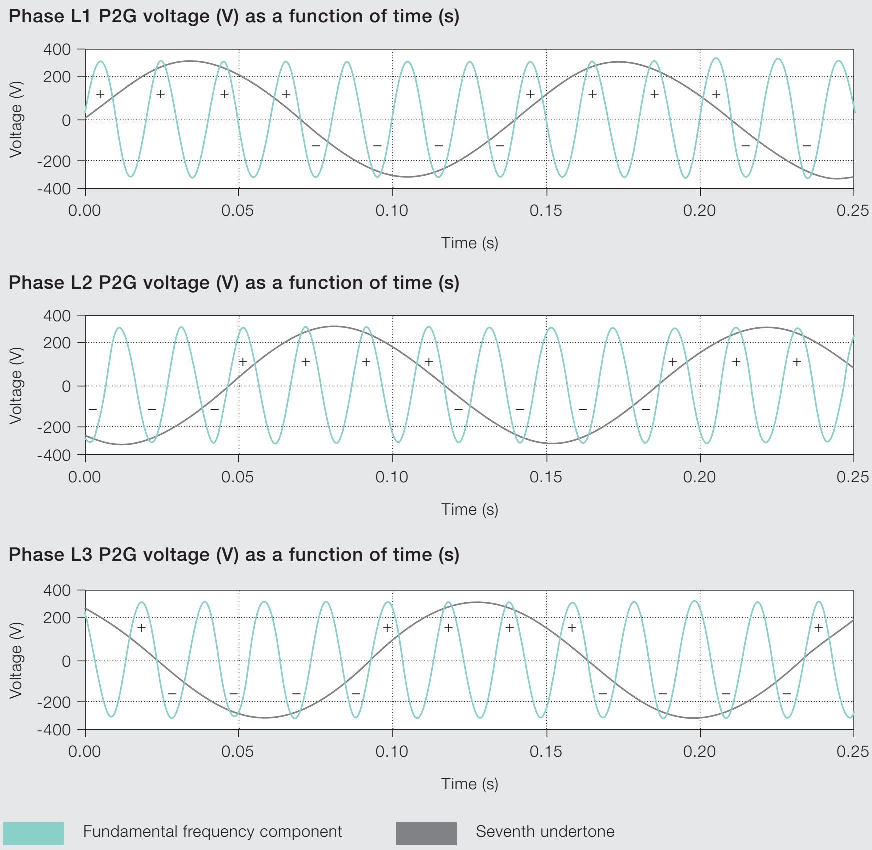
Backward slow speed

The PSTX can run the motor at different slow speeds in the forward direction. The same method of generating lower frequencies can also be used to run the motor backwards.

2 Undertones permit slower speeds



3 Generating the seventh undertone across all three phases



4 The PSTX softstarter runs at three speeds in both directions

The PSTX softstarter permits the motor to be run at three different speeds in both directions:

- Fast jog forward
  3th undertone ≈ 33.3 percent of rated RPM
- Jog forward
  7th undertone ≈ 14.3 percent of rated RPM
- Creep forward
  13th undertone ≈ 7.7 percent of rated RPM
- Creep backward
  11th undertone ≈ 9.1 percent of rated RPM
- Jog backward
  5th undertone ≈ 20.0 percent of rated RPM
- Fast jog backward
  3th undertone ≈ 33.3 percent of rated RPM

There is significant value in having the option of a temporarily reduced speed.

To change the direction of the motor, the magnetic field must reverse its direction of rotation. This can be achieved by changing the order in which the phases are triggered. Normally this affect would be achieved by using two contactors to swap two phases, but the PSTX provides a simpler way of obtaining the same effect.

Different speeds

The PSTX can run the motor at three different speeds forwards and backwards. This corresponds to the different undertones shown in → 4.

Always in control

With the PSTX, ABB has made the slow-speed jog basic speed control available in the compact size and lower cost of the softstarter, thereby making this functionality available for more installations and customers. There are significant advantages in having the option of a temporarily reduced speed, such as the ability to run waste water pumps backward to clean them or to position a crane or a conveyor belt. To ensure the function is easily operated, the jog can be controlled in several different ways: with the detachable keypad, with push buttons or via fieldbus communication.

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Medium-voltage, premium performance

ABB's PCS100 medium-voltage UPS

PERRY FIELD – Launched in 2014, and inheriting many of its features from its low-voltage counterpart, the medium-voltage (MV) PCS100 MV uninterruptible power supply (UPS) is already becoming established in the market. Medium-voltage UPSs have been available for some time now, the incumbent in the sector being the dynamic rotary UPS (DRUPS). While a DRUPS system uses a rotating machine to generate the power to the load, the PCS100 MV UPS uses modular power electronic inverters. Such a design is referred to as a static solution as it has no moving parts. The UPS's modular architecture allows the basic 2 MVA unit to be easily expanded as customer power needs increase.

1 ABB's PCS100 MV UPS

Energy efficiency is a topic that is rising to the top of the agenda for many facility managers. In the case of data centers, for example, energy consumption is one of the few operating costs the data center manager can influence. A static UPS is well placed in this regard to deliver real savings: With an efficiency of 99.5 percent, the PCS100 MV UPS leads its class.

Improving power quality is always a vital task for UPS systems. Many large, critical industrial processes – like semiconductor fabrication, chemical manufacture and food production – rely on a power quality level that often cannot be provided by the public grid. In these industries, major production losses caused by mains interruptions simply cannot be tolerated. The situation is further complicated by the fact that economies of scale mean single locations have grown larger and have generated a correspondingly higher demand for a safe power supply – often well into the tens of megawatts. In addition, production areas requiring large amounts of electrical power are often widely scattered over a particular site. Long distances in power distribution also have to be overcome in places like large airports, or in some of the vast electronics manufacturing facilities now operating around the globe.

These issues can all be solved by using MV-rated equipment such as MV UPSs and distributing electrical power at MV levels.

Medium is premium

Providing premium quality power at medium voltage does not have to be costly. The capital costs of a static MV system are often lower than those of a rotary or paralleled low-voltage (LV) system – at high power levels LV requires large conductors, sizable switchboards and multiple circuit breakers. Also, looking after all of these can add considerably to the maintenance budget, especially if a rotary system is employed. Of course, with MV, losses are lower and less space is required for equipment by virtue of the lower current required to transmit the same power.

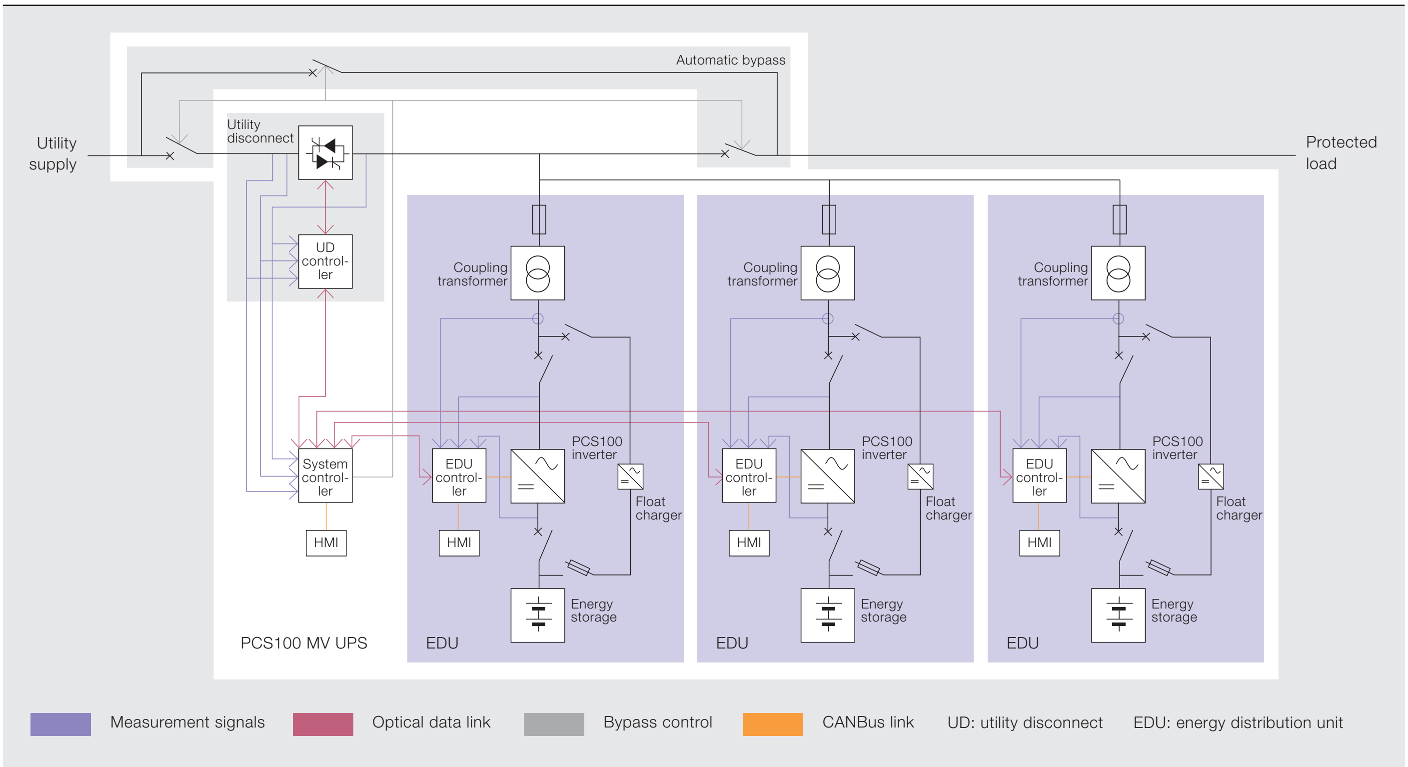
The modular design of the PCS100 MV UPS allows a simple replacement of the LV grid-to-load interface with MV components. The core parts of the UPS, such as the highly reliable LV power electronics and battery storage, remain the same as for LV applications. In this way, the tried and tested functionality and maintainability of the LV UPS is kept but the advantages of MV can be exploited, ensuring high levels of availability and reliability.

Single locations have grown larger and have generated a correspondingly higher demand for a safe power supply – often well into the tens of megawatts.

In large, high-technology manufacturing facilities, such as semiconductor fabs, the role of MV UPS systems is already well established. The MV UPS provides plant-wide security of power, protection from all grid disturbances and a buffer period before a switchover to local generation (in the case of a major outage).

Title picture
ABB's PCS100 MV is an all-electronic, high-power UPS suitable for protecting critical process or data center applications.
Pictured: ABB's PCS100 MV UPS.

2 Single-line diagram of ABB's PCS100 MV UPS



More frequently, the UPS is required to condition the incoming power – removing sags and short-duration phenomena caused by faults in the external power network. Here, ultracapacitor energy storage is used. For such high-power demands, the small footprint of ultracapacitor energy storage – with a power density of 1,000 kW/m² a reality – has a clear advantage.

In large data centers, the philosophy is similar. There are also many design options – one being, for example, to perform the UPS function at MV levels and distribute MV to the individual floors of the data center. Transformers complemented by static transfer switches close to the IT equipment can be used to create an isolated redundant back-up line with two alternative power supply paths to the loads [1].

Advantages of MV UPS technology

Using an MV UPS system to protect critical applications will reduce the required feeder ampere capacity. For example, 1 MW in a 400/230 V AC system involves 1,443 A current per phase. With 15 kV, this current is only 115 A for the same power transmitted. Another feature of the MV UPS is that the system can be centralized, which helps manage floor loading and allows freedom in the floor plan – lack of space being one of the major cost issues in a data center or a production facility. Reducing the space needed for infrastructure equipment like power supplies results in additional space for IT or manufacturing equipment.

Often, the area available for the UPS system is given and limited – particularly in existing buildings – but the power rating required increases remorselessly. High-power, compact MV static UPS products are well-suited to overcome this challenge.

As well as footprint, electrical losses are also an important consideration. Particularly at long distribution distances – in large industry facilities or in spread-out places like airports – losses can become significant. For longer distribution lengths, the influence of the cable will become more significant. Here again, operating at MV levels would give a better result.

Scalability and modularity

Scalability and modularity are key features of the PCS100 MV UPS. With a basic rating of 2 MVA, the PCS100 MV UPS system can grow in size as the factory develops → 1–3. The PCS100 MV UPS is the only static MV UPS on the market today that can provide this feature. As well as EDU (energy distribution unit) modu-

MV distribution reduces losses and needs less space for equipment by virtue of the lower current required to transmit the same power.

3 MV equipment takes up less space than LV. Modules are easy to add as power requirements grow.

As a key component in the infrastructure of a large data center, the UPS can also benefit from being operated at MV.

larity the PCS100 MV UPS has inverter modularity, giving extremely high levels of availability through inverter redundancy. This has the advantage that the customer has a lower initial capital investment and can flexibly grow the infrastructure as the business grows.

The PCS100 MV UPS is available in multi-megawatt ratings and provides tailored solutions to large IT, business and production facilities. The PCS100 MV UPS has been designed to provide clean, reliable and efficient power at a low cost for customers consuming high levels of power. The single-conversion topology used is a natural choice for MV as losses are extremely low, meaning efficiencies well in excess of 99 percent can be achieved. The PCS100 MV UPS can be installed to protect the complete supply or just selected sensitive loads.

Exclusively MV UPS for large-scale applications?

Increasing power density and total power demand at single sites, combined with a growing requirement for high-reliability power in IT, business and production facilities are growing trends in industry. Suppliers have to respond with suitable UPS and distribution designs, and the step up to MV is a logical one. MV systems reduce cable size and losses, which increases overall efficiency. Additionally, integrated, high-power MV UPS systems can reduce the number of components, such as switchgear and cabling, as well as shrink footprint – an invaluable aid where real estate is expensive or limited. An MV UPS enables a clearly laid out high-power system configuration and keeps its complexity within manageable limits.

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Further reading
To learn more about ABB's power protection solutions, please visit www.abb.com/ups

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[1] Frank Herbener, (2013, March). *Isolated-Parallel UPS Configuration* [PDF]. Available: http://www.piller.com/documents/en/2129/isolated-parallel-ups-configuration-en.pdf

Looking into Windows

Windows XP has reached the end of its life – what are the implications?

VOLKER JUNG, ANTHONY BYATT – Microsoft's successful and very popular Windows XP operating system is now well over a decade old. While about 30 percent of Windows users worldwide still rely on XP, an operating system as old as this cannot be supported forever. Accordingly, Microsoft ceased XP support on April 8th, 2014. This means there are no new security updates, no new patches and no active support. The effect of this is that XP will slowly become unsecure, unreliable and incompatible with most newly released IT hardware, such as PCs, PC components, network equipment and printers. In other words, the end of the XP era is affecting many industrial applications and requires a proactive response from users.

At one time, the idea of running an industrial application using Microsoft Windows would not have been entertained. However, when Microsoft introduced their Windows XP operating system over a decade ago, industry sat up and took notice. Windows XP provided the stability, flexibility and functionality needed by many industrial users and soon appeared in every imaginable type of application.

However, all good things come to an end: On April 8th, 2014 the Windows XP era concluded when Microsoft support for the product ceased. Of course, Microsoft had given ample notice and companies had been preparing for the switch for some years. Yet many questions had to be answered: Could a standalone XP system continue to run unaffected? What would happen if the XP system was integrated into another system? Would new hardware be needed and what would be the cost of this across the entire organization? What would the budget for the switch likely to be? Could virtualization fix the problem? What support would be available to migrate over onto a new system?

Title picture
Microsoft support for Windows XP ceased on April 8th, 2014. What are the implications for industrial users?

The answers to these questions were not always straightforward and easy, and it became clear that there were indeed significant issues raised by the end of XP support. The most significant issues can be grouped into four major categories:
– Security
– Compliance
– Lack of independent software vendor support
– Hardware manufacturer support

Of these, security issues are the most critical.

Windows XP security updates

In 2010, the Stuxnet worm made headlines around the world. With a size of just 500 kB, this malicious software attacked at least 14 industrial sites in Iran, including a uranium-enrichment plant. Stuxnet attacked in three phases: First, it targeted Microsoft Windows machines and networks, then it sought out software (also Windows-based) used to program industrial control systems and finally it insinuated itself into the programmable logic controllers used to control machinery.

Since Stuxnet, the target-rich landscape of industrial IT has been under a sustained assault that has grown ever more sophisticated. For example, the so-called watering hole strategy has been devised as a way to introduce malware into the target systems. In this strategy, the malicious party guesses or observes which websites the company often uses, then they infect it and sit back and wait for the victim to visit the site and unwittingly download malware onto their computer. This strategic Web compromise (SWC) tactic catches victims unawares because the infected websites have previously been trusted.

> An intruder can manipulate authentic user profiles on a system to allow outsiders access.

Further, an intruder can manipulate authentic user profiles on a system to allow outsiders access. PC configurations can also be manipulated and PCs can then, for example, become the homes of remote access trojans (RATs) – malware programs that give an intruder administrative control over the target computer. RATs can be infiltrated into a PC via an email attachment.

1 Control/HMI (human-machine interface) systems to be evolved

System/HMI	Comment
System 800xA	800xA core systems (V5.0 and older)
Freelance	Freelance systems (V6.2 – V9.1)
Power Generation Portal/Tenore	All Windows-based versions
Conductor NT	All Windows-based versions; count is number of servers, not number of systems
Process Portal B	All versions

Once the host system is compromised, the intruder may use it to distribute more RATs to form a botnet – a collection of compromised computers that are manipulated in concert to cause further disruption.

Because a RAT enables administrative control, it allows the intruder to monitor user behavior through keyloggers or other spyware; activate a webcam; access confidential information; format drives; delete or alter files; and so on.

In June 2014, the Havex malware family made headlines by attacking control systems in different branches of industry, including the energy sector. A RAT is a main component of Havex. The RAT trojanized websites of industrial control system (ICS) and supervisory control and data acquisition (SCADA) manufacturers. In total, 146 servers were attacked by Havex; 88 variants of the Havex RAT were used; and 1500 IP addresses were traced in an attempt to identify victims. Clearly, Havex represented a serious attack on industry.

In July 2014, the “energetic bear” virus infected over 1,000 energy firms in Europe and the United States. This virus theoretically allows hackers to take control of power plants.

2 XP upgrade strategies

Windows XP		Controller				
800xA	3.1 4.0 4.1 5.0	All	→	800xA	5.1	6.0
Freelance	6.2 7.1 7.2 8.1 8.2 9.1	All	→	Freelance	2013	2015
Conductor NT	All	DCI	→	800xA	5.1	6.0
		Freelance	→	Freelance	2013	2015
			→	800xA	5.1	6.0
		Harmony	→	800xA	5.1	6.0
			→	Symphony +	2.0	
PPB	All	MOD 300	→	800xA	5.1	6.0
		Freelance	→	Freelance	2013	2015
			→	800xA	5.1	6.0
		Harmony	→	800xA	5.1	6.0
			→	Symphony +	2.0	
PGP/Tenore	All	Freelance	→	Freelance	2013	2015
			→	800xA	5.1	6.0
		Harmony	→	800xA	5.1	6.0
			→	Symphony +	2.0	

From these examples it is apparent that the industrial IT environment is quite vulnerable enough – and without critical Windows XP security updates, PCs are wide open to attack by viruses, spyware and other malicious software that can steal or damage business data and information. Antivirus software no longer provides full protection for XP systems. Any devices remaining with XP can be used by attackers as an entry point into IT networks. This means that even computers running supported operating systems can then also be compromised.

Hardware

Most manufacturers of PC hardware, printers and network equipment have already stopped supporting Windows XP on new hardware. This means that the software drivers required to run Windows XP on such new hardware are, in most cases, no longer available – ie, there will be no XP drivers for new hard disks, printers, graphic cards, network equipment, etc. Buying a replacement XP computer will not be easy or cheap. XP-based hardware will become obsolete and hard to find. Unplanned shutdowns caused by unavailability of hardware components will become more frequent.

Compliance

Businesses that are governed by regulatory obligations, such as the Health Insurance Portability and Accountability Act (HIPAA) in the United States, may find that they are no longer able to satisfy compliance requirements if they remain with Windows XP. With so much personal and private data now stored on servers, data security is a very significant concern.

Lack of independent software vendor support

Many software vendors no longer support their products that run on Windows XP as they are unable to receive Windows XP updates. For example, the new Microsoft Office package takes advantage of the newest Windows and does not run on Windows XP.

What to do

With so many issues to be overcome, what course of action should be taken? The recommendation made by Microsoft and all cyber security companies is to upgrade to Windows 7 or 8. This includes distributed control system vendors with control systems running operating systems with Windows XP and older → 1–2.

Of course, an evaluation can be made of the cost of keeping XP installations safe versus upgrade costs. Remaining with Windows XP is a high-maintenance undertaking and requires tools and support from experienced cyber security companies. Some of the actions that need to be undertaken include:
- Reduce the size of the registry to include only those services that are absolutely needed.
- Utilize domain name server (DNS) sinkholes to block access to the real website.
- Issue an alert when an endpoint-initiated remote desktop or virtual network connection is detected.
- Prevent binary execution for temporary users in the file system or issue an alert when this occurs.
- Whitelist service binaries in the operating system.
- Issue an alert for service starts/stops/changes.
- Audit access control lists, etc.
- Make regular control system backups.
- Buy a stock of compatible IT parts.

Retaining Windows XP is becoming untenable. It is an inevitable part of industrial IT life that an evolutionary software step has to be taken every so often and the move upwards from Windows XP is one of the more significant of these. The move will put users in a position where they are well placed to meet the security, hardware, software and compliance demands of the modern industrial IT world.

ABB strongly recommends that customers running Windows XP operating systems evaluate their system life-cycle plans and risk mitigation strategy. Simultaneously, ABB is offering solutions that can remedy or mitigate risks and help customers better protect their plants and personnel while ensuring safe operations and continuous production. Services are available to help meet the needs of every customer – including customers who are unable to upgrade immediately and those who elect to remain on Windows XP.

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PASS steps up

ABB hybrid switchgear technology is now available for 420 kV

ALBERTO ZULATI – ABB's trademarked Plug and Switch System (PASS) is a high-voltage hybrid switchgear that is preassembled, pretested and easy to transport. With no high-voltage testing required on-site, installation and commissioning is rapid. ABB recently stepped up the voltage level of PASS and it is now available for 72.5 kV to 420 kV applications.

With a PASS installed base of more than 8,000 units, in 2013 ABB announced the launch of the 420 kV high-voltage hybrid switchgear PASS M0S 420 kV.

For many, the world of high-voltage equipment has always been divided between air-insulated switchgear (AIS) and gas-insulated switchgear (GIS). Previously, space requirements usually predicated which option was chosen – with GIS allowing a far more compact, though more expensive, substation footprint. Stated simplistically: AIS was the preferred choice in rural areas while GIS was usually chosen in urban settings. This picture changed dramatically some 20 years ago when ABB introduced PASS.

Title picture
ABB's PASS switchgear combines the best features of air-insulated and gas-insulated switchgear into a hybrid product. PASS technology is now available for applications up to 420 kV.

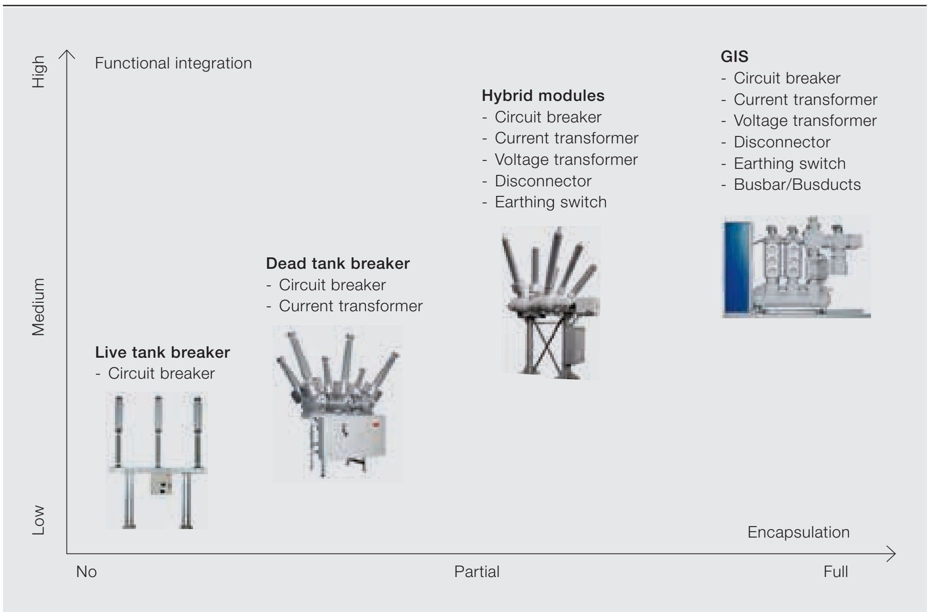
PASS

PASS combines the best of the AIS and GIS worlds into hybrid technology switchgear, or, as it is termed by CIGRE, mixed technology switchgear (MTS). Even if basic equipment costs are higher than AIS, MTS delivers a lower cost of ownership – usually related to lower land costs and shorter construction times. CIGRE states, "... the comparison of technologies indicates that MTS combines a lot of advantages of AIS and GIS and leads to a good compromise" [1]. In a case study, CIGRE concluded that"... substantial savings in total ownership costs, even when basic equipment costs are higher, could be achieved by adopting MTS equipment. The savings produced are directly linked to land cost. Overall construction times are also reduced. These conclusions were verified by a pilot project for the construction of three substations in suburban areas. Unanticipated benefits included easier permitting due to the reduced visual impact of the substation and less complicated negotiations with land owners due to the lower land take required" [2].

With the introduction of this new 420 kV module, the PASS product family now covers voltages from 72.5 to 420 kV with breaking currents from 31.5 to 63 kA.

The 420 kV PASS hybrid module is a technical breakthrough as, despite its larger size, it retains all of the PASS family benefits, so that each PASS module is equivalent to a complete switchgear bay.

1 MTS technology fits in between AIS and GIS



PASS adopts GIS for the main interrupting components of the circuit breaker and the disconnector/earthing switch, thus guaranteeing high reliability and compactness. At the same time, PASS uses AIS to connect to the grid, thus positioning itself between AIS technology and GIS technology → 1.

The PASS concept provides a reliable, low-maintenance solution to substation construction. Its modular and flexible design makes it a recommended solution in a number of cases:

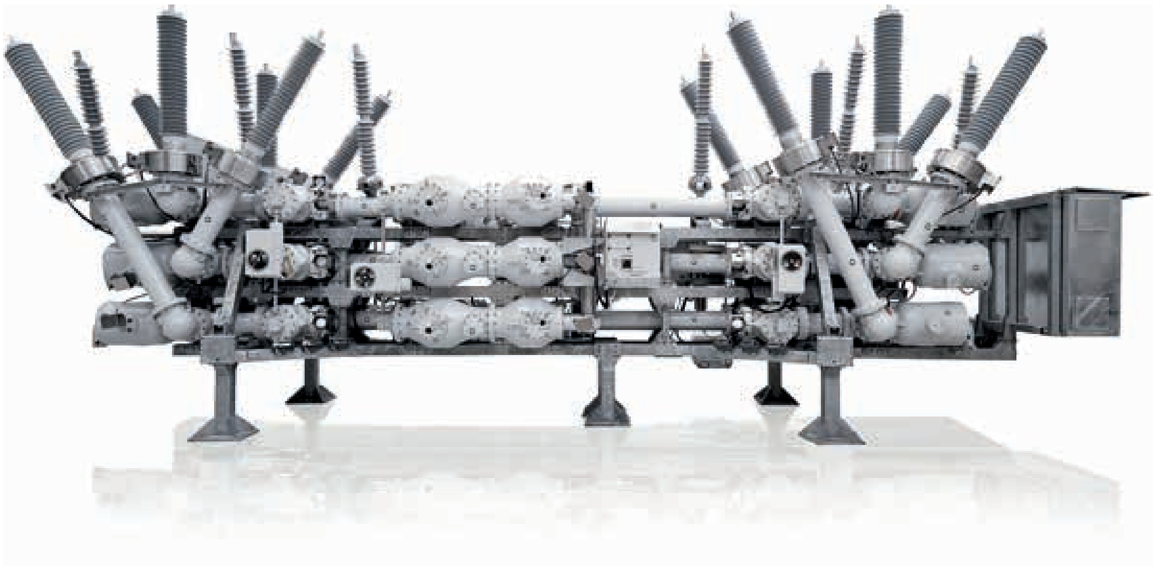
– Where space is a constraint, as it allows a 50 to 70 percent space saving when compared with a standard AIS substation.
– In harsh climatic conditions, or in heavily polluted sites like industrial or mining installations. PASS is very suited to these conditions as all live parts are SF_6-insulated and protected in a grounded aluminum tank. PASS already has a substantial number of such reference installations.
– Fast-track projects where a quick connection to the grid is required – eg, in emergency recovery situations, or in remote or dangerous areas. PASS is transported fully assembled and tested so no high-voltage test is required on-site and installation and commissioning is rapid.
– For railways, because single-phase or double-phase modules at various frequencies can be used. Over 200 modules are currently in service in frequency converters or traction substations.
– On skid-mounted or mobile applications because the compactness of the module itself allows the whole bay to be transported more easily.
– For extension and retrofitting, as it is compatible with any type of GIS, AIS or hybrid substation.

The preassembled and factory-tested PASS M0S 420 kV can be easily transported and quickly installed, without the need to assemble any active parts at the installation site.

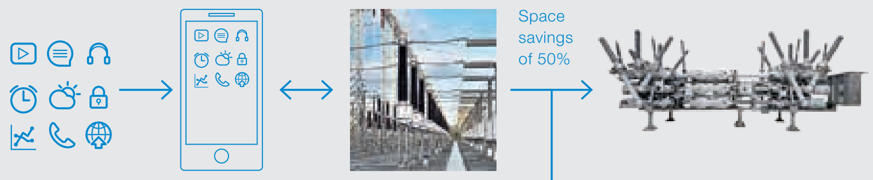
PASS M0S 420 kV

Since the launch of PASS, hybrid technology has become a very appealing alternative to AIS or GIS and other manufacturers have followed ABB's lead by adding hybrid switchgear to their offering. However, ABB maintains its technical leadership position by expanding the PASS portfolio to suit more applications and markets.

2 PASS M0H



3 A PASS module integrates the functionality of many sub-systems into one product.



The PASS M0S 420 kV is the only 420 kV switchgear module that can be mounted and transported on a trailer or skid as a complete mobile solution from the factory.

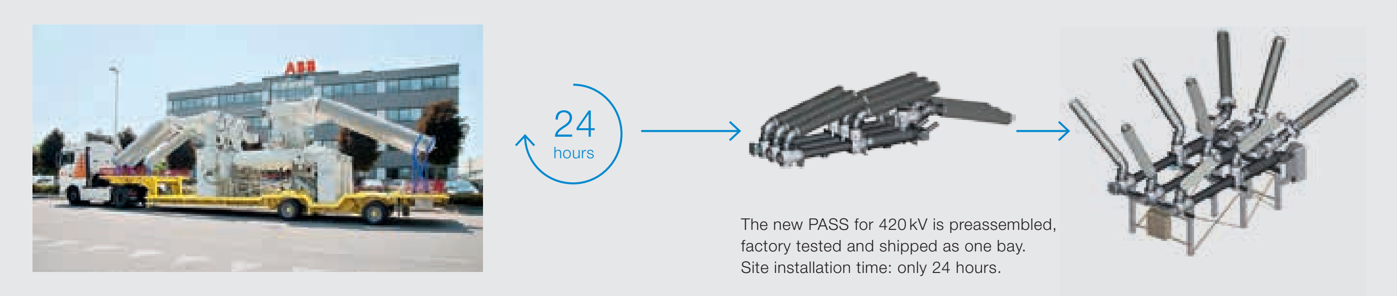
With a PASS installed base of more than 8,000 units, in 2013 ABB announced the launch of the 420 kV high-voltage hybrid switchgear PASS M0S 420 kV.

With the introduction of this new 420 kV module, the PASS product family now covers voltages from 72.5 to 420 kV with breaking currents from 31.5 to 63 kA. In addition to standard modules, a special solution called PASS M0H offers a complete high-voltage switchyard with an "H" configuration as a single transportable unit ➔ 2.

The 420 kV PASS hybrid module is a technical breakthrough as, despite its larger size, it retains all of the PASS family benefits – such as the integrated functionality of a circuit breaker, disconnector and earthing switch, as well as current and voltage transformers, so that each PASS module is equivalent to a complete switchgear bay ➔ 3. The preassembled and factory-tested PASS M0S 420 kV can be easily transported and quickly installed, without the need to assemble any active parts at the installation site. The PASS M0S 420 kV is the only 420 kV switchgear module that arrives on site completely assembled, so installation and commissioning is rapid ➔ 4. PASS M0S 420 kV has further advantages:

- Maintenance is easy. For example, since all active parts of the equipment are gas-insulated, there is no need to regularly clean the switchgear contacts. Encapsulation also reduces overall servicing time and cost, and enhances reliability and availability. Often, operations can be carried out without the need for an outage.

4 The ease of transport of the PASS M0S 420 kV is one of its unique features.



The key innovation in PASS 420 kV is its rotating bushing concept.

5 PASS M0S 420 kV bushings in the transport position

- It is highly customizable according to clients' needs, yet, due to the modular design, it still has a short delivery time.
- The steel structure is compact so less civil engineering is needed.
- It can be mounted and transported on a trailer or skid as a complete mobile solution from the factory.
- Energization time is shorter – less than one week for a 420 kV bay.

Rotating bushings

One of the biggest design challenges was the transportability of a fully assembled 420 kV module, given its large dimensions. As often happens, a major challenge like this provides the driving force for innovation. The key innovation in PASS 420 kV is its rotating bushing concept. To make transportation of the fully assembled product possible, the insulators (3.6 m, 350 kg) are rotated in the factory from the in-service position to the transport position, and back again at the installation site. This is made possible by an innovative and very safe bushing rotation design. The rotation takes less than 30 seconds per bushing.

The geometrical principle is simple: Each bushing is fixed to the rest of the equipment by means of two, curved, gas-insulated junctions, each made of an aluminum enclosure and internal electrical connections. This means the interface between the two parts is slanted, so that the rotation of the upper part (to which the bushing is mounted) moves the bushing from the nearly horizontal position required for transportation to a nearly vertical position for service ➔ 5–6.

The rotation is performed with the equipment filled by gas at 0.2 bar (relative), which is the pressure level typically used during transportation. One of the most significant features of the rotating interface is that it is exceptionally gas-tight during the rotation – as well as afterward, when the equipment is filled to the working pressure.

The curved junctions are well sealed. The lower enclosure hosts the grooves for two gaskets (one is a backup), protected by two backup rings that are located above and below the gaskets. The backup rings are made from a special composite material that can withstand huge radial loads with no deformation, while ensuring very low friction.

6 PASS M0S 420 kV bushings in the service position

To make transportation of the fully assembled product possible, the insulators are rotated in the factory from the in-service position to the transport position, and back again at the installation site.

The upper enclosure interacts with the gaskets and the backup rings via a machined cylindrical shoulder inserted in the lower junction.

Bushing rotation is performed typically only twice: into the transport position at the factory and back to the service position at the installation site. The sealing system was tested by performing over 50 rotations on the same equipment – with no leakage. ABB guarantees a leakage rate of under 0.5 percent/year, as is usual for ABB's SF_6 high-voltage devices.

Besides the insertion coupling for sealing, the two enclosures are also flanged and tightened with 12 bolts. Finally, a sliding ring is fixed to the flange of the lower tank in order to reduce friction during rotation.

The torque required for the rotation of such heavy components is provided by a commercial motor, which is applied to the rotation interface by means of a special tool, whose concept was patented by ABB in 2012. The rotation of the motor is fairly slow (around 2 rpm) but a complete rotation from the transport to the service position takes only around 30 s.

The bushing rotation facility is critical for the transport of this 420 kV device. Without it, the many benefits of PASS technology could not be made available to customers.

Since its launch, PASS 420 kV has caught the interest of several utilities with orders received from the United States, Italy and Algeria, among others, and advanced technical discussions have taken place with entities in Spain and the United Kingdom. These parties recognize the advantages of being able to quickly connect to the grid a solution that is delivered fully assembled and tested.

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[2] W. Degen *et al.*, Cigre Working Group B3-20, Brochure 390 "Evaluation of different switchgear technologies (AIS, MTS, GIS) for rated voltages of 52 kV and above, Appendix A: "Introduction to Mixed Technologies Switchgear," pp. 44–56, November 2008.

Intelligent living

Making home automation easier than ever with ABB-free@home®

ALEXANDER GRAMS – Once futuristic dreams, intelligent buildings are now a reality and ABB-free@home automation technology offers the lifestyle, comfort and safety people want in their homes.

1 Room temperature controller of ABB-free@home

2 The System Access Point is the central element of the ABB-free@home system.

Today's building automation delivers not only energy efficiency, but also comfort and safety, which are often the most important concerns for private residences. ABB-free@home combines all the useful functions of comfortable home automation and is easy to use as a system.

ABB-free@home is a central control system residents can use to monitor and control an entire living area: Light dimming and switching, timer, blind control, temperature regulation and ABB-Welcome Door Entry System integration.

The functions can be fully customized. All settings can be easily changed or extended at any time via the system's app. The configuration and operation of the system is as easy as surfing on a website, thanks to the app. No additional software is required. The initial configuration is performed by the electrical installer. Later settings and adjustments can be made by the user from any computer or tablet equipped, with HTML5 (independently of platform).

Title picture
The ABB-free@home control panel is surface mounted with a high quality color TFT touch display.

This, for example, allows the home automation to be easily adapted to changing living situations or to the changed use of the rooms. Effective lighting can be easily adjusted and individual timer programs can be entered to allow adjustments of heating and blinds ➔ 1.

The optimum room temperature can be adjusted using ABB-free@home individually or according to a specific requirement, depending on the time of day and the function of the room.

In ECO mode, the temperature is automatically lowered at night or when the house is empty. The heating can be automatically shut off when a window is open. This reduces the consumption of energy – whether for conventional heaters or under-floor heating.

The user interface is accessible on a computer, tablet or smartphone. All of the functions can be performed intuitively using any of the devices. The ABB-free@home app optimizes all images for display on mobile devices.

The System Access Point is the central element of the ABB-free@home system, supporting project, setup and visualization simultaneously ➔ 2. It provides access for computers, tablets or smartphones via a WLAN connection. This allows the functions of the system to be defined and remote controlled – also at a later point in time. The System Access Point can also be connected to a router in the network – via LAN or WLAN.

For convenient commissioning the System Access Point is equipped with its own WLAN and the software required for project planning and commissioning. This makes the fitter independent from the structural conditions and needs no additional software. As soon as programming has been completed, it can be saved as a backup on the System Access Point and restored if necessary.

The 2-wire bus technology makes the installation of the ABB-free@home easy. The bus cable can be fed through the same duct as the power cable; no special cable routing or its own installed cable duct are needed.

ABB-free@home offers different flush-mounted devices for switching and controlling of signals, such as light and temperature. They allow the desired functions to be installed as easily as a socket outlet.

The ABB-free@home actuators receive the signals from switches and sensors and convert them. The actuators are installed centrally in a flush-mounted cabinet or decentrally in flush-mounted wallboxes.

ABB-free@home is manufactured according to the international standard IEC 60669 as well as IEC 50428. All devices for ABB-free@home are manufactured ecologically compatible – according to the RoHS (Restriction of Hazardous Substances) directive.

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Wire ahead

Pluggable connections and prewiring solutions boost productivity

VINCENT MENAGER – The globalization of the electrical equipment business has forced original equipment manufacturers (OEMs) to venture into international markets. The intense competition they find there means that the traditional one-to-one wiring methods they previously employed to wire up control panels, field devices and the like are no longer economically viable. The new wiring techniques they have come up with include prewiring solutions using pluggable terminal blocks, in association with prewired harnesses.

There is an old, and very true, saying in industry that the top three causes of failure in the field are cables, cables and cables. Wiring errors can cause project delays or trigger severe financial penalties and are a sure way for a company to damage its reputation. These factors – and increased global competition – have forced manufacturers to come up with new and more efficient wiring concepts – namely modular, pluggable and prewiring techniques.

Modularity brings assembly flexibility

In a modular wiring concept, assemblies and subassemblies are manufactured separately – often by a specialist subcontractor – and are only put together for testing and final installation. Assemblies can be individually tested at the module level, thus reducing the complexity of the test equipment. Because the modules are standardized, swapping modules when wiring has to be rejigged – for example, for fault tracing – is simple. Modularity offers great flexibility to equipment manufacturers.

However, modular design would be pointless if not used in association with pluggable functionality.

Wiring flexibility with pluggable functions

In contrast to the traditional terminal block, a pluggable terminal block is equipped with a removable plug that allows quick assembly or disassembly of the equipment.

Pluggable terminal blocks are characterized by the type of technology used (screwless, screw, insulation displacement connection, etc.) and the number of connections, plugs and circuits. ABB provides the full scope of pluggable terminal blocks – for example, PI-Spring (combining push-in and spring technologies) and ADO System® for harsh environments, and screw clamp technology for general industry.

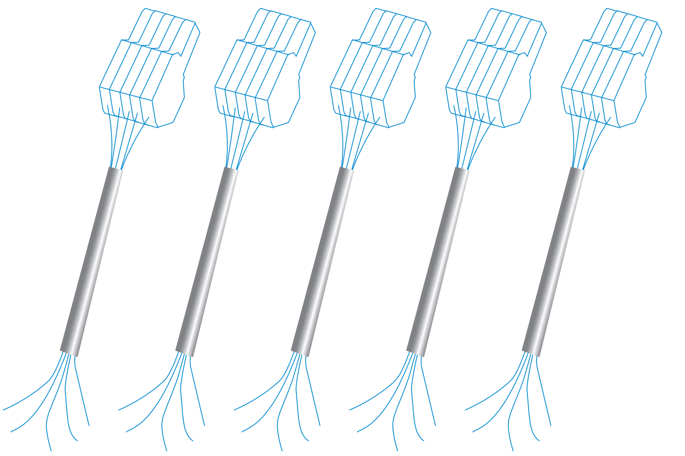
Prewiring

With plugs, wires can be easily combined into harnesses – a task that can be performed prior to complete equipment mounting and testing → 1. The ability to prewire and pretest removes potentially high-risk manufacturing steps from the project critical path and brings major positive benefits:

Serialized production and testing

Wiring is usually subcontracted to a specialist who uses automatic wiring machines for the time-consuming tasks of

1 Combining wires into harnesses simplifies assembly and testing



2 Pluggable and prewired connections are particularly useful in electronics-laden modern trains, where space is limited.

Pluggable terminal blocks facilitate and considerably accelerate assembly, test and factory commissioning.

wire cutting, stripping, crimping and identification or marking. This results in a high-quality product and is usually far more cost-effective than performing the task in-house. Pretesting can easily be automated and set up for serial production.

Equipment assembling and testing, factory commissioning

Before delivering equipment to the final customer, the equipment must be assembled in the workshop and fully tested – a procedure considerably accelerated when pluggable terminal blocks are used.

Transportation and installation

For larger items, transportation may involve dismantling before shipping and reassembly on site – a process greatly facilitated by pluggable terminal blocks. Further, screwless technologies such as ABB's PI-Spring or ADO system technologies guarantee a vibration-proof and shockproof connection, so are ideal for equipment that has to be shipped already wired up.

Railways

Prewired solutions are a major contributor to the efficiency increases sought by European railway manufacturers in response to global price erosion. ABB is a leading supplier of terminal blocks – particularly the pluggable type – to the railway market → 2.

ABB's PI-Spring terminal blocks, being compact (space for equipment on trains is limited) and resistant to shock and vibration, are ideal for making reliable connections in trains. ADO System terminal blocks offer significant productivity savings as well as secure and reliable connections. These connector systems are tested to the latest international standards for rolling stock, such as IEC 61373 for vibration and shock, and EN 45545-2/ NFPA 130 for flammability and toxicity of plastic material.

Process automation

Process automation applications typically handle thousands of signals and, here again, prewiring and pluggable solutions offer significant system simplification and better wiring reliability. ABB's Interfast prewiring system for programmable logic controllers (PLCs) and digital control systems (DCSs), for example, can reduce installation time by up to 98 percent.

Switchgear

Switchgear equipment is constantly evolving and newer products include high-end electronics as well as digital communication. ABB's SNK pluggable terminal blocks makes the expansion of these complex switchgear systems simple. The SNK series provides double-plug connection, which allows daisy chaining of signals and easy system expansion.

Railways, process automation and switchgear are just three areas where prewiring solutions are making a significant impact. There are countless others. Pluggable terminal blocks and prewiring solutions can create productivity savings in any applications that have a heavy dependency on wiring.

Title picture
Prewiring is an essential tool for electrical equipment manufacturers. (Shown is ABB's pluggable terminal block).

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Taming the power

Advanced control is achieving high availability and performance by mastering complex instability

ALF ISAKSSON, SILVIA MASTELLONE – A modern-day power system represents an increasingly complex engineering process – from generation, across transmission, distribution and power conversion, to the loads that convert the electric energy into a useable form. Every link of such a network contains heterogeneous dynamic subsystems that interact in complex ways. Predicting and controlling their individual and collective behavior is a major challenge, yet one that needs to be mastered in order for the network to be operated at an optimum defined by economic, reliability and safety requirements. ABB Review presents a series of articles looking at potential instabilities that arise in different stages of the electromechanical power system and the role of computation methods in controlling them.

Operational instability in the electrical network of an oil and gas plant may lead to a plant-wide trip that results in an irrecoverable loss in production.

Many fields of technology are experiencing an extraordinary increase in complexity being brought about by technological advances. The electromechanical power system is no exception. Once a system has been successfully designed, its operational boundaries are pushed for even higher performance.

Rising complexity in this context manifests itself primarily in two ways: (i) the high degree of interconnectivity of components and (ii) the heterogeneous nature of the components and the diverse timescales of their behaviors. These effects are compounded by the increased demand for faster dynamics, as well as the reduced size and weight of components brought about by technological advances.

To yield a stable operation, the hardware and control design are normally performed at the individual subsystem level. However, once the subsystems are interconnected the stability properties do not necessarily carry over to the whole system.

In fact, interactions between subsystems may lead to a poorly damped system response as well as undesired oscillatory behavior.

Such instability may express itself in ways ranging from mild derating of performance to severe system-wide shutdown.

For example, operational instability in the electrical network of an oil and gas plant may lead to a plant-wide trip that results in an irrecoverable loss in production. Another example relates to power oscillations in the transmission grid that can lead to extreme consequences, including a total power blackout.

It is precisely these complex scenarios that call for detailed, system-wide analysis and control designs meeting high performance criteria. In fact, an intelligent control design enables optimal system-wide operation at the physical limits without introducing any additional physical inertia that would slow down the system response and increase costs.

A key aspect that leads to smarter control design is the ability to perform detailed system analysis and develop a deep understanding of the system behavior in a steady state as well as during dynamic transients. Moreover, the available computational resources and actuation capabilities need to be taken into account. Traditionally, advanced methods required substantial computational resources that often prevented their applicability. However, with ongoing progress in the computational capabilities of control platforms, these advanced methods can now be applied.

ABB Review is launching a series of articles looking at electrical and mechanical oscillations and the advanced numerical methods of taming them across the entire electromechanical power network. The series will include the areas of power generation, distribution, low- and medium-voltage conversion, and mechanical loads and processes. This series is furthermore intended as an update on the research and development activities performed by ABB to enable continuous power availability and enhanced productivity.

The following article looks at oscillations in medium-voltage power converters. Further articles in upcoming issues of ABB Review will explore the other stages of the electromechanical power network.

Title picture
Oscillations are inherent in every technical system of a certain complexity. Engineers need to understand their behavior to ensure the stability of the overall system is maintained. The title picture shows the Golden Gate Bridge (United States).

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TAMING THE POWER

ABB Review series

Beating oscillations

Advanced active damping methods in medium-voltage power converters control electrical oscillations

PETER AL HOKAYEM, SILVIA MASTELLONE, TOBIAS GEYER, NIKOLAOS OIKONOMOU, CHRISTIAN STULZ – Power conversion in the medium-voltage range faces the challenge of performing power exchanges between electrical grids and loads that are both becoming ever more complex. The task is further complicated by the presence of electrical oscillations. Advanced control methods are therefore required to enable high-quality power conversion and to provide smart ways of attenuating resonant system behaviors.

Title picture
How do control methods tackle the challenge of resonant behavior in medium-voltage power converters?

A key requirement for soft damping is to provide the underlying control method with information on the content of the current and voltage signals around the resonant frequency and to allow the controller to react to actively damp the electric oscillations.

Medium-voltage (MV) drives represent a core ABB business that relies heavily on advanced power electronics, electromagnetic components, cooling technologies and automatic control technology. With more than one- fifth of the global market share, ABB is a key player in the MV drive global market. MV drives are ubiquitous in industrial applications that range from pumps and fans to compressors and rolling mills.

Traditionally, MV drives were used to connect an electrical machine that drives a mechanical load to the grid. However, with the growth of renewable energy sources and advanced transmission systems control, situations in which MV power converters inject current into a power network are becoming increasingly common. These situations include some types of solar and wind power generation, regenerative braking in rail systems, interfaces between HVDC (high-voltage DC) and AC transmission systems, and FACTS (flexible alternating current transmission systems). Power electronic systems are used within these applications to ensure the produced waveform and its frequency content are suitable for injection.

MV drives in a nutshell

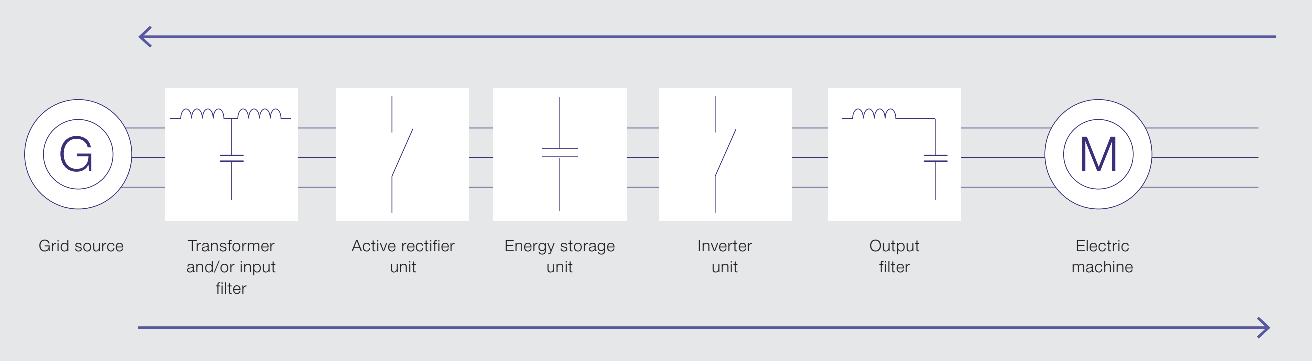
MV drives are power/frequency converters whose basic characteristics involve power flow and energy storage. Traditionally, the converter absorbs power from a three-phase AC power source (eg, the grid), stores this power as energy as DC using capacitors or inductors and then converts it back to AC – in a process called inversion – to drive an electric motor → 1. This scheme can be reversed – when harvesting wind energy, for example, where the wind turbine converts mechanical movement to electrical power that is rectified and stored as DC before being fed back into the grid in an AC form.

The rise of harmonics

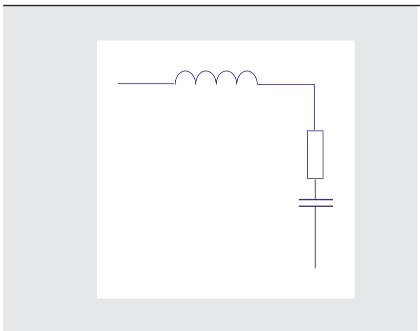
The power conversion processes of rectification and inversion are challenging. For example, since the actuation capabilities inside the converter are of a discrete nature, output voltage levels can only be generated in steps. This gives rise to electrical harmonics, which propagate through the system and are fed back to the grid or to the machine side.

A second, and equally important, challenge is presented by the inability to switch at high rates between the available voltage levels. Typically, switching frequencies range from several tens of Hertz to a few hundred Hertz. This is because the switching losses of the power converter – a major part of the overall losses of the drive – are proportionally related to the switching frequency.

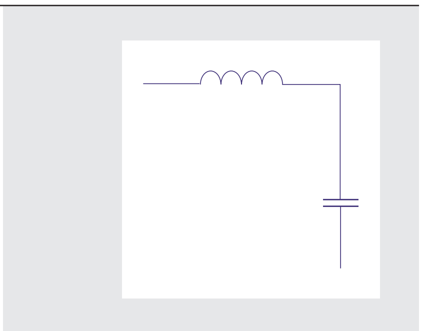
1 MV drive with power flow arrows



2 The two main types of filter



2a RLC filter



2b LC filter

Lower frequencies cut operational costs and increase the overall system robustness, reliability and overall efficiency.

From the control point of view, this constrained range of switching frequency is extremely limiting.

Even more limiting is the relatively high level of low-order harmonics generated. Ideally, the voltage at the inputs and outputs of the MV drive would be purely sinusoidal. This, however, is an elusive goal. A more realistic objective is to minimize the harmonics that are superimposed on the fundamental signal. This translates into what are commonly referred to as grid codes, which impose restrictions on the individual harmonics (other than the fundamental) and their allowed magnitude. On the machine side, this is characterized by the total harmonic distortion (THD) of the current. The THD is essentially a measure of the collective strength of all the higher-order harmonics compared with the fundamental component.

Resonant filters

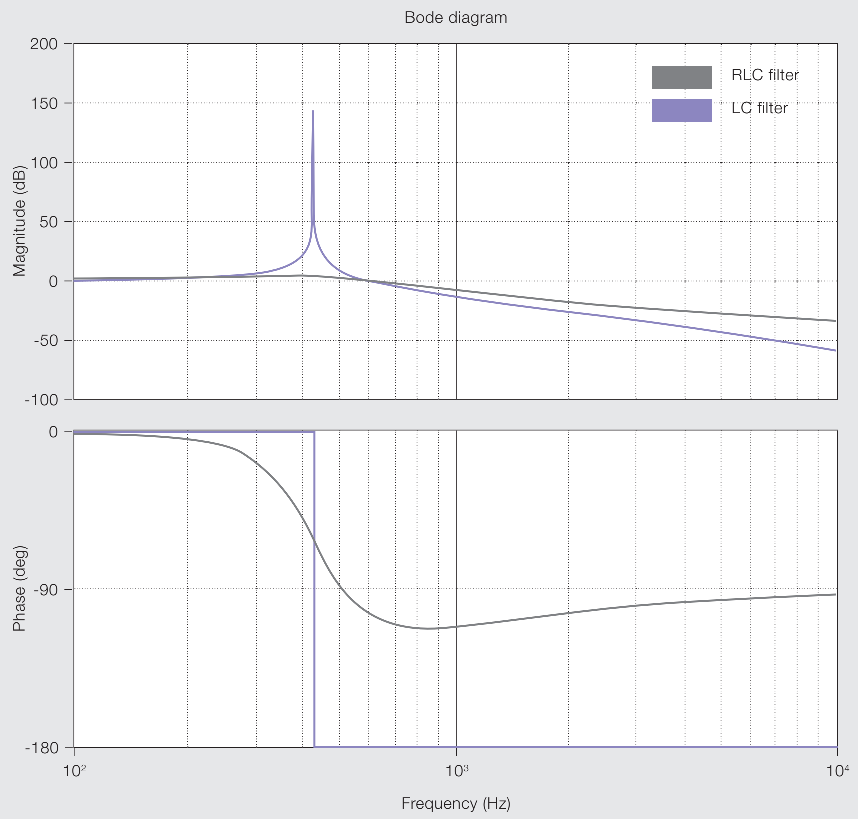
Hardware filters are often installed at the input and/or output of the MV drive in order to attenuate the effects of harmonics on the grid and/or the machine. Filters come in two main types: resonant (LC) or passively damped (RLC) → 2. Passively damped filters are attractive from the stability point of view as they do not amplify the low-frequency content of the signals and provide attenuation of the higher harmonics → 3. However, the resistive elements in the filter have high losses, which result in reduced efficiency of the overall power converter.

Two main questions arise from the control point of view: How to avoid generating harmonic content around the resonant peak of the LC filter; and if such harmonic content is present, how can it be attenuated?

The answer is provided by soft (or "active") damping methods.

With the growth of renewable energy sources and advanced transmission system control, situations in which MV power converters inject current into a power network are becoming increasingly common.

3 Frequency response of an LC resonant filter and an LRC filter



Soft damping methods incur no additional hardware costs at the system design level, but require a deep knowledge of the underlying system dynamics as well as expertise in control, estimation and optimization methods.

Soft damping methods

Soft damping methods pertain to smart techniques that attenuate the unwanted electrical oscillations of the system. These solutions incur no additional hardware costs at the system design level, but require a deep knowledge of the underlying system dynamics as well as expertise in control, estimation and optimization methods.

The discrete switched actuation levels that are intrinsic to a power converter result in harmonics of an infinite order – often referred to as switching ripple. These are present in all signals (voltages, currents, fluxes, torque, etc.) and may directly affect the control behavior. A key requirement for soft damping is to provide the underlying control method with information regarding the content of the current and voltage signals around the resonant frequency and to allow the controller to react to such information in order to actively dampen the electric oscillations. This requires very careful design of software filters (low-pass, band-pass, notch, etc.) and/or advanced estimators.

There is a plethora of methods – both in the academic and the industrial communities – to design controllers that attenuate resonances.

Single-input, single-output methods

The first attempts to tackle oscillations were mainly based on frequency-domain concepts and the shaping of the closed-loop system response. These attempts mainly used PID (proportional-integral-derivative) concepts for single-input, single-output (SISO) systems and relied on technical results – from the 1930s, 1940s and 1950s – regarding the design and tuning of parameters. This approach can be used in conjunction with available modulation and control schemes – for example, pulse-width modulation (PWM) [1] and direct torque control (DTC) [2]. However, there are many caveats: The underlying system is neither SISO nor continuous in nature. Instead, it exhibits very complex interaction dynamics between inputs and outputs.

Ideally, the voltage at the inputs and outputs of the MV drive would be purely sinusoidal. This is an elusive goal. A more realistic objective is to minimize the harmonics that are superimposed on the fundamental signal.

Multiple-input, multiple-output methods

Multiple-input, multiple-output (MIMO) methods that utilize the state-space representation (also known as the time-domain approach), developed in the 1960s, along with linear quadratic regulator (LQR) control design together represent a major evolution in active damping methods.

MIMO methods capture the dynamics of the system in a single set of first-order differential equations and use this information to predict the system behavior over the future time instances and hence generate optimal corrective control actions that result in long-term positive effects on the attenuation of the unwanted oscillations. MIMO methods offer a more precise handle on the complex interactions inside the system and their effects on the resonances than do the SISO-based methods that preceded it. MIMO-based design still retains the caveat of assuming that all the signals in the system are continuous in nature and it ignores the switching effect mentioned earlier.

The LQR approach, which generates the changes in the reference signals needed to attenuate the unwanted oscillations, has been used in two different control approaches as an outer loop: Model predictive direct current control (MPDCC) for the grid side and model predictive pulse pattern control (MP^{3}C) for the machine side [3].

Advanced time and frequency methods

Although extremely effective, MIMO- and LQR-based active damping control schemes still suffer from the fact that they only manipulate the reference signals in order to achieve the attenuation of the electric oscillations. More advanced techniques for attenuating oscillations use optimized pulse patterns (OPPs). The OPPs are usually designed in such a way that the harmonic content at the resonant frequency is eliminated. However, disturbances or slight changes in the switch positions may reintroduce this unwanted harmonic content, which is, in turn, magnified by the resonance peak of the physical filters. As such, it is more effective to look at each switching action in the system and analyze its effect on the attenuation or creation of harmonic content at the resonance peak.

This analytical information on the harmonic consequences of control actions is invaluable when making the following decision: Should the switch happen as planned, or should it be shifted so that it can help dampen the resonance? Such advanced methods require extremely low ratios between the resonance frequency of the hardware filter and the actuation/switching frequency. As such, the performance of the system can be pushed to a higher level and the size of the passive elements in the system, and consequently the cost, can be reduced.

The vision

A control engineer at ABB has nowadays a very effective and well-studied arsenal of methods for achieving active damping of electrical resonances. However, this is by no means the last word on the subject. With the presence of resonant circuits both at the load and at the source, as well as in the intervening subsystems, systems are becoming more and more complex. Control methods developed in the last century have provided the solution to the active damping problem for single power conversion systems, but the evolution of power conversion systems and the expansion from single- to multiple-system setups makes further research necessary. The challenges in future power conversion systems stem from scalability in scope and complexity, as well as practical aspects such as communication delays between the subsystems and computational constraints imposed by the control hardware platforms.

When it comes to attenuating resonances, it may well be that it is more effective to look at power conversion systems as a whole and design control methods that exploit the total system structure rather than the individual subparts. This will lead to optimized system design, cost reduction and better efficiency.

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$300,000 research award

ABB creates an award to honor and support outstanding postdoctoral research

REINER SCHOENROCK – ABB has created an international research award to honor Hubertus von Gruenberg, who stepped down from his position as Chairman of the Board of Directors of ABB in April 2015. The ABB Research Award in Honor of Hubertus von Gruenberg is intended to encourage world-class research in ABB's main fields of operation: power and automation, as applied in utilities, industries, and transport and infrastructure. The award will recognize outstanding postdoctoral research, in particular work that makes creative use of software, electronics and/or new materials, to pave the way toward groundbreaking industrial solutions.

1 Hubertus von Gruenberg stepped down as Chairman of the Board of Directors of ABB in April 2015.

Von Gruenberg, a theoretical physicist who wrote his doctoral dissertation in 1970 on Albert Einstein's theory of relativity, has been instrumental in setting ABB on a path to sustainable growth and in cementing its reputation as a leader in technological innovation. During his tenure as ABB Chairman from 2007 to 2015, the company achieved notable technological breakthroughs, such as the hybrid high-voltage direct current (HVDC) circuit breaker, which solved a 100-year-old engineering puzzle, and paves the way for an easy-to-manage DC grid → 1.

ABB has created the research award in his name to drive and inspire the work of some of the most promising technologists of the future. For ABB's "Next Level" strategy, innovation is fundamental. In an agile environment of global and open innovation, ABB also needs to look outside the box – outside the company – to further spur leading-edge innovations.

The award includes a $ 300,000 grant for postdoctoral research within the scope of power and automation and is open to PhD graduates from any university specializing in research in power or automation. The award will be presented for the first time in 2016 and thereafter every third year.

Judges will be professors from the Swiss Federal Institute of Technology (ETH) in Zurich, the Massachusetts Institute of Technology (MIT), the Tsinghua University in Beijing, the Imperial College London, along with Hubertus von Gruenberg and Claes Rytoft, Chief Technology Officer of the ABB Group.

For more information about the ABB Research Award in Honor of Hubertus von Gruenberg, please visit the award website http://new.abb.com/hvg-award, where information on application requirements is also available.

The application deadline for the first award is January 29, 2016.

Title picture
The ABB Research Award in Honor of Hubertus von Gruenberg will be presented for the first time in 2016 and thereafter every third year.

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Your opinion matters. Please tell us what you think!

Because reader perception and satisfaction are important in charting the future course of ABB Review, you are invited to take part in a short online survey (only 10 questions). All participants will have the chance to win a prize. We thank you for your time!

The survey can be found on www.abb.com/abbreview. Survey closes November 30, 2015.

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Preview 4|15

Integration of renewables

In issue 2/2015, ABB Review looked at solar power. In issue 4/2015, the journal revisits the world of renewable energy. The upcoming issue of the journal will take a broad perspective, covering not only the energy itself but the effects it is having on the grid, on industries and on users, and discusses how ABB's technologies are helping all these systems make the most of the ever increasing levels of renewables in the world's energy supply.

Further topics that will be looked at include pulp and paper manufacturing and temperature measurement in a vodka factory.

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