ABB review

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The corporate technical journal

Integrating renewables

Balancing variable supply and demand has always been a challenge, but as the renewables share of total generation in many countries is growing, this challenge is also increasing. In response to this, ABB supports its customers along the complete power value chain, from consulting, generation and connection to transmission, monitoring and control, as well as maintenance and optimization.

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Integrating renewables

Claes Rytoft

Dear Reader,

The last decade has witnessed a remarkable transformation in renewable energy. Once experimental and idealistic ways of generating power have been transformed beyond recognition and now not only account for a notable share of the overall generating balance but are able to compete economically in the energy market.

Support of renewables is an important element of ABB's pledge (as expressed by the company's CEO, Ulrich Spiesshofer) to help "run the world without consuming the Earth." In our view, the future growth of renewables rests on two main pillars.

The first of these is cost effectiveness. If renewables are to expand further, they need to continue to attract capital, and this means investors must see competitive returns. Offering an attractive economical proposition is not just about optimizing the price tag of the initial purchase, but means looking at total costs over the life cycle of equipment and systems. This includes aspects such as service, reliability and avoiding unscheduled downtime.

The second pillar is the integration of this renewable energy into the grid. The grid must cope with intermittent if not unpredictable sources of generation, and must also (especially in the case of wind) transmit energy from regions in which the transmission grid is not traditionally prepared for such amounts of energy. ABB is very much at home in the area of grid integration: It can draw on well over 100 years of experience in developing and improving transmission and distribution grids.

This issue of ABB Review includes articles addressing both of these pillars. The lead article is an interview with Gerard Reid, founding partner of Alexa Capital, in which he discusses the future growth of renewables and ongoing challenges, especially in relation to capital and regulatory aspects.

In the area of supporting the production of renewable energy, we look at control and optimization aspects in generation. The strengthening of grid capacity as well as energy storage solutions and grid codes are also covered.

Moving away from fields strictly and directly connected to renewables, but with broad implications nevertheless, this edition of ABB Review continues its "Taming the power" series on mastering oscillations by addressing inter-area oscillations in power grids. We also look at noninvasive measurements in a vodka distillery and modeling energy flows in steelmaking.

On a personal note, as my tenure as Chief Technology Officer comes to an end, I would like to thank you for being loyal readers and supporters of ABB Review. May this continue for years to come!

Enjoy your reading.

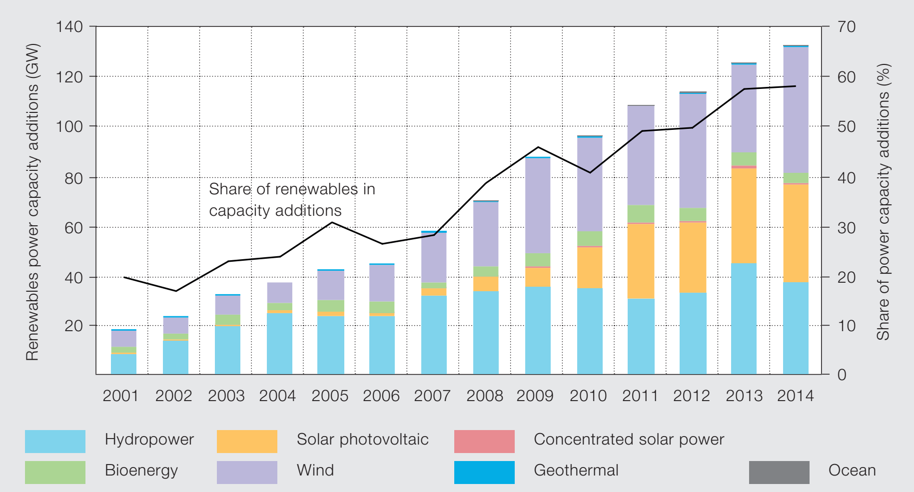
Claes Rytoft
Chief Technology Officer and
Senior Vice President
ABB Group

Capital questions

Why the future of renewables depends on the costs of capital and other questions around renewable energy

Gerard Reid, founding partner of Alexa Capital, and Jochen Kreusel, head of ABB Smart Grids Industry Sector Initiative, discuss renewables and new business models in the energy sector in an interview with ABB Review.

1 Annual renewables capacity addition by technology (2001 – 2014)



Source: IRENA, REthinking Report 2014

ABB Review (AR): The renewables transformation is advancing at dizzying speeds ➔ **1.** What are the drivers of this development?

Gerard Reid (GR): We really wouldn't be seeing renewables rolled out across the world without a government mandate. Particularly in Europe this has been the major driver ➔ **2.**

There are two other important factors. One of them is cost. We've seen very rapid reductions in costs, especially in solar but also in wind. Renewables are rapidly becoming too cheap to ignore ➔ **3.**

The other factor is strategic advances in technology. And I don't mean just the renewable technologies themselves, but how they are integrated into the system. Ten years ago most people in Germany would have said that it would be impossible to integrate 10 percent of renewables – today they are at 30 percent. In my own country, Ireland, it's 25 percent.

Those drivers are going to remain, but their balance will shift. I think we will be seeing a move away from the importance of the government mandate and toward costs and technology.

Jochen Kreusel (JK): And both technology and the cost of that technology is where industry is flexing its muscles. Electricity demand is growing rapidly and CO_2 emissions have to be reduced. These two countertrends can really only be addressed by technology – front-end renewable technology per se and the associated technology that supports it. In-depth knowledge of renewable power generation technologies and experience installing these around the world are required to serve the renewable energy industry. This comprehensive approach will become ever more significant as the renewable business continues its rapid evolution.

AR: Where is the government mandate coming from? Environmental concerns?

GR: Yes. If you take the case of Europe, there would never have been such a massive build-out of renewables without a green movement that pushed in terms of legislation on pollution and emissions.

AR: With the new technology becoming so affordable, do we still need continued government support in Europe?

GR: Yes. The power markets as we know them are broken. No generation of any type can be built without some form of very clear regulation in place. The reason is that, in Europe, you are not going to get your capital expenditure back, except maybe in the United Kingdom.

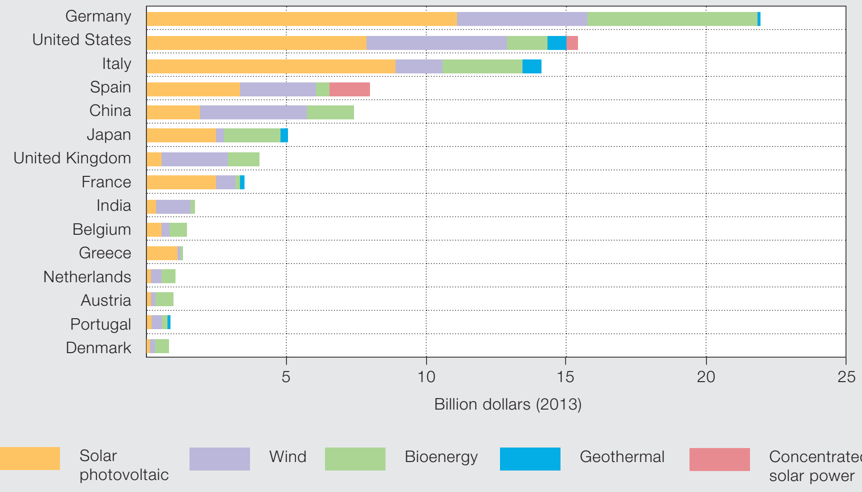
We really wouldn't be seeing renewables rolled out across the world without a government mandate. Particularly in Europe this has been the major driver.

Without that return, there is going to be no investment in power generation. This is why renewables – and energy in general – will need a support or market mechanism.

From the power-market perspective, there is a new phenomenon that renewables have brought about, namely that they have zero marginal costs. They don't have fuel costs and the running costs are very low. A gas- or a coal-powered station needs fuel for every kWh generated and needs a lot of people to make sure that the power station just keeps working. With renewables you have the exact opposite. If a utility has a whole range of power generation assets available, when it has to decide what it's going to take as part of its generation mix, it's likely to use the renewables preferentially – based on the variable costs. As we keep putting more renewables on

Government mandates, cost and strategic technology advances are driving the advancement of renewables.

2 Renewables power subsidies by source in the top 15 subsidy-supplying countries



Source: International Energy Agency (IEA), WEO 2014

the grid, eventually what will happen is that the wholesale price of power will tend toward zero.

That can be seen in particular in Germany. The German power prices are at 30 to 35 euros/MWh (about $33 to $39/MWh). Nobody will build conventional generation at those prices because they can't recover the variable cost, let alone the investment cost. And that's the big opportunity that renewables have brought to the market.

JK: ABB sees a large part of the renewable cost equation and the power markets issue being addressed by products that make the integration of large amounts of renewable power into the grid cost-effective and straightforward. I'm thinking here about automation and control systems for flexible power generation, HVDC, FACTS and a whole host of other enabling technologies on one side and a market design giving flexibility and dispatchability at an adequate price on the other.

AR: You say the variable costs are going toward zero, but what about the fixed costs?

GR: In terms of CAPEX, people might say the costs of solar are $1 million/MW and say the figure for gas is about the same, and so assume they are at parity. But that's not true because what you really have to look at is the CAPEX per MWh. If a gas generator is going to run 60 percent of the time and a solar park is going to run 15 percent of the time, the CAPEX cost per unit generated is going to be four times higher for the solar park. If we want to get renewables onto the system, we have to get the cost of capital down. Capital costs are going to be determinant in getting renewables onto the grid.

This can have different implications across regions. For example, the cost of capital in India is almost twice as high as in Germany. However, as India has nearly twice as much sun, the cost of electricity production is more or less the same in both countries.

We've never had this scenario with conventional generation because we recovered CAPEX through the power price, and the power price was determined by the marginal cost. So if fuel costs went up, they went up for everybody, and so the power price went up.

With renewables, we don't live in that world anymore. Based on the low marginal costs of renewables, a utility or power producer can offer consumers a power purchase agreement with a set price for the next 20 years. No utility would do this with gas or coal. However, with competition in the market, a consumer can switch suppliers quickly, and thus sign only short-term contracts. This does not align to renewables as investors need the security of power prices to recover the capital costs. This requires a fundamental change in the way we look at power markets.

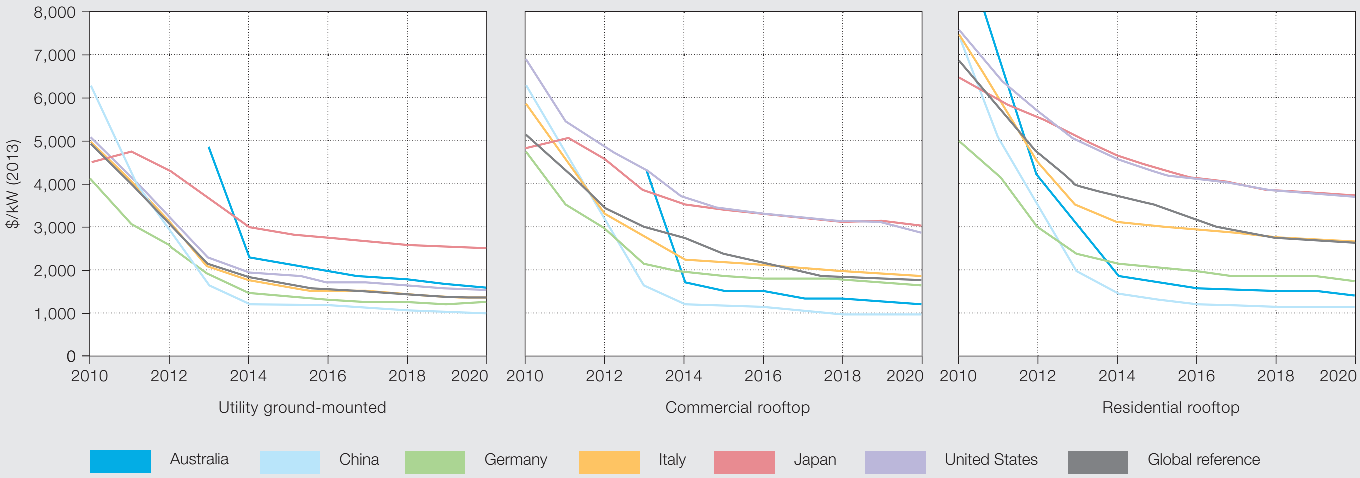
AR: How must the power market be reformed to support this different way of looking at things?

GR: I think that the best way to do it is to allow the power price to determine everything. Rather than 15-minute pricing we will need one-minute prices. If you price on a minute basis you get a lot of volatility in the power price, but that would mean power suppliers can recover their cost through that volatility.

JK: In my opinion, this approach may indeed help to give incentives for demand response or other dispatchable types of generation, but I do not see how this will help the renewables. The reason behind the current market mechanism in which the power price is determined by the marginal cost is that it delivers the lowest operational cost to run a given group of power plants. The task of particularly spot markets is to determine the optimal load dispatch. This task is becoming obsolete in a system with zero marginal cost. Therefore, short-term markets will not be an adequate tool anymore. We already see different market approaches in other fixed-cost dominated markets, such as telecommunications. We see flat rates and incentives to sign longer-term contracts – admittedly two rather than 20 years. In this case, competition is indeed strongly determined by the cost of capital.

GR: Another approach to the market is that you give a regulated return to the owners of renewable assets, which in

3 Historical and projected typical solar PV investment costs at the beginning of the year



Source: International Energy Agency (IEA), Renewable Energy Medium Term Market Report 2014

some cases is happening already. But one way or the other, radical changes are required. Recent attempts at reforming the market have just been about tinkering. We need far more radical restructuring.

AR: We have talked about solar. What about other renewables?

GR: For me, solar is a revolution and wind is not – it's an evolution. We've had wind for the last 50 years and it has got steadily better and better and it's very clear that it is and will remain part of our energy system. In Ireland we're producing electricity below the wholesale power price, so it is a game changer.

The biggest problem we have with wind is that it is not easy to predict. Even in a country like Germany where power traders are trying to predict it on a daily basis, they rarely get it right. Solar is much easier to predict. In addition, what makes solar so attractive is its flexibility. You can put it in your calculator, you can put it on your roof, you can build a big plant, and it's quick to install. It doesn't have the same visual or spatial impact as a wind turbine, and its installation doesn't face the same level of opposition. We've never had a technology like solar where you can do something so locally, cheaply, quickly and effectively.

Other renewables such as biomass, geothermal and wave are all evolutionary technologies. Please don't get me wrong, they're all great, but they're not revolutionary in the same way as solar. Ten years ago the global market for solar was 1 GW. This year it's projected to be at least 50 GW. Looking at the cost roadmaps of companies in the future, I see cost reductions of another 40 percent over the next five years. Meanwhile, for wind I only see a cost reduction potential of maybe 5 percent a year, but not 10 percent.

AR: So lower costs in solar mean it will continue to lead in terms of growth in renewables. What effects do you foresee for other renewables?

GR: There is only so much feed-in tariff money to go around and the majority of it is going into solar. Solar was able to add 7 GW of new capacity every year in Germany for three years in a row. Wind wasn't able to match that. I think wind has a huge role to play in generation, but I also think solar is competing against offshore wind at the level of investment capital. Why? The costs of offshore wind haven't come down. On the contrary, they've gone the opposite way.

JK: I do agree that solar power has revolutionized the power generation landscape, bringing new opportunities, but also challenges especially to the power distribution system. However, I think we should not undermine the huge potential wind power still has to offer. Wind power has become the least-cost option for new power generation capacity in many countries and new markets in Asia, Africa and Latin America have continued to

Both in technology and in the cost of that technology is where industry is flexing its muscles.

In-depth knowledge of renewable power generation technologies and experience installing these around the world are required to serve the renewable energy industry.

emerge during the last year. In addition, if we take for instance the findings of the IEA World Energy Outlook 2014, we can expect the global installed wind power capacity to triple by 2040. Therefore, I believe that further interesting developments in this field will continue.

AR: Who is or should be putting up the money for new renewables capacity? Will the traditional incumbents defend their market dominance and take the lead, or will new investors move in and gradually take over the market?

GR: Let's look at the telecoms space. We actually still have all the old incumbents: British Telecom, Deutsche Telekom, etc. Some of them have merged, some have changed their names, but they're still there. But we also have a whole pile of new companies that came into being. The problem the incumbents have is that after 100 years of doing the same thing, they may face a challenge in adapting to the sudden revolution.

JK: If you look at the telecoms companies as you say, the old ones are still there, but much of the money in value-added telecommunication-based services is being made by new players. The incumbents are still providers of the commoditized infrastructure, but the money is being made by the users of that infrastructure, or in one prominent case, by a device manufacturer. Do you expect there to be a similar development in the power market?

GR: I think it's a good analogy. Another analogy that I see is the automobile industry, which is going through big changes as it electrifies and is thus bringing itself closer to the utilities. One of the main reasons for this is that the costs of batteries is going down. Looking at automobile manufacturers, I ask myself, what they will be in 10 years' time. I think some of them will be service companies. Some might use the automobile as a platform, but will be providing energy services and a whole range of other services into them. This is why I think that the players they should be watching out for are the likes of Apple and Google. After what these companies have done to the telecoms space, they are now looking at the automobile and electricity space and seeing it's also all about data. They can say, "We are already in the data space and we are already in the home. Let's go and run the electric vehicle, install the solar panel and connect them all together."

So in the future it's not just going to be about the power market but the power market will be interconnected with these other spaces in a convergence of two if not three industries.

AR: So if the photovoltaic panel and the battery of the future are going to be commodities, where is the added value in the renewables market?

GR: I agree that the solar panel is going to be a commodity. I do question though, whether the battery is going to be a commodity. There's a huge complexity around the battery, and there is real intellectual property in it. In addition, with all second-life batteries being dumped into the stationary power market, the entire storage scenario is going to change.

JK: I don't think that second-life batteries are going to have a big impact on power markets as long as battery prices continue to come down at the present rate, making new batteries with higher performance cheaper than used ones. I think grid-side battery storage will use purpose-manufactured rather than pre-owned batteries.

From the power-market perspective, there is a new phenomenon that renewables have brought about, namely that they have zero marginal costs.

GR: We will probably not see second-life batteries used for critical applications such as the primary reserve market, but I am convinced we will see them being used in our homes and our businesses. The key advantage for the battery manufacturers is they get to delay the recycling of the batteries and they can generate more money using them. And as it now stands today second-life batteries are half the price of new batteries.

AR: Won't the technology differentiation flatten out at some point as the technology approaches an optimum, driving batteries into the commodity corner?

GR: Yes. But let's look at the TV business. I think there are now three global TV manufacturers. At some point they got so big that nobody else could compete and enter the market. I think the same is going to happen in batteries and that's to some extent how manufacturers can protect themselves against commoditization a little bit. In contrast, in photovoltaic panels there are about 40 manufacturers around the world all competing with more or less the same product – and that's leading to commoditization.

The real value is in managing the complexity and integrating it into something the customer wants. The differentiation is in the software and the service.

JK: Talking about commoditization with respect to your example of the TV industry, consolidation could actually de-commoditize that industry. This could similarly happen to the photovoltaic panel manufacturers.

GR: We may eventually see consolidation in the solar market as we have seen in TVs but I don't think this will happen until the global growth for solar slows, and I think we are probably five to 10 years away from seeing peak annual installations for solar.

AR: The newcomer companies are best known for their ability to redefine the market with disruptive technologies. Can you say something about disruptive technologies in the energy sector?

GR: Let's not talk just about disruptive technologies but about disruptive technologies and business models. If we look at the so-called disruptive businesses that are out there, what they really are is a mixture of technology and business model.

If your customers have a battery in their car, you can aggregate those batteries and use them to trade in the power market. The idea might sound crazy, but it makes sense from the battery manufacturer's or automobile maker's point of view. He wants to make sure that the charging of that battery is controlled. He wants to control the charging by giving you a service package. So he could say, "Here is a flat rate for your battery, you can plug it in wherever you want and it will cost you, say, $35 per month." He has all the data about you: He knows where you are. He realizes you're in the airport and are going to be in France for two days. So he takes that battery, aggregates it across a country, and participates in the power market. That is a revolution. And manufacturers and consumers will sign up to this agreement because it is in their interest.

You are thus going to get customers signing up for long-term purchase agreements. Many of us do not want to go out and buy a $500 smartphone but accept those costs when they are hidden in our mobile phone bills.

JK: Revolutions typically start as evolutions and at some point gather their own momentum. The last real revolution we had in the energy sector, in my opinion, was the introduction of electricity. I believe back then people did not foresee or imagine how quickly it would catch on or how ubiquitous it would become – with maybe the exception of a very few visionary people.

GR: I agree, but looking elsewhere in the energy sector, looking at oil and gas, we are also seeing a huge revolution in terms of what's happening with shale gas. Who would have predicted that the United States would be the biggest oil and gas producer in the world? This has not happened in the energy world for a long time.

> Based on the low marginal costs of renewables, a utility or power producer can offer consumers a power purchase agreement with a set price for the next 20 years.

AR: We have talked about the importance of batteries in mobility, but looking at e-mobility in the context of renewable energy, what trends do you foresee?

Gerard Reid

Gerard Reid is a founding partner of Alexa Capital, which delivers corporate advisory, financing and asset management solutions across the energy, energy infrastructure and energy technology sectors.

He has spent the last decade working in equity research, fund management and corporate finance with a focus on energy and in particular the revolution he calls the Digital Energy Revolution. He is also an author, energy blogger (www.energyandcarbon.com) and monthly columnist for Biz Energy Today, the German energy industry publication.

He has also recently been appointed to the World Economic Forum's Global Agenda Council on the Future of Electricity. Prior to founding Alexa Capital, Gerard Reid was managing director and head of European Cleantech Research at Jefferies & Co.

I don't think that second-life batteries are going to have a big impact on power markets as long as battery prices continue to come down at the present rate.

JK: One trend that is already shaping up is that more and more players are becoming active in the e-mobility renewable energy chain. This brings its own challenges, so we have to be sure we have the right products available and that we can make it easy and safe – for both the customer and the grid itself – to swiftly adapt and bring in new products and practices. In other words, increased flexibility will be a major trend.

GR: My view is that everything is going to go electric and everything is going to go digital. The consumers are also beginning to change their behavior. Young consumers don't need to own the latest top-of-the-range car. They are quite happy to actually just rent a car. And this means they can rent the best car for the job rather than having a one-size-fits-all car.

I've heard that some car manufacturers make twice as much money on a car that they put out to car sharing. That's impressive in terms of margins – but of course it doesn't help them in terms of volumes as they're going to make fewer cars overall. But it's very clear that they're moving from thinking in terms of ownership models to service models. This is a very courageous strategy, but in a revolution you need to be brave. You cannot predict the future but you can try to shape it.

AR: As new service models come online, larger and larger amounts of data will need to be collected and exchanged. Placing a device online also means making it potentially vulnerable to cyber attacks. If you hack into a home or building automation system, you can essentially control the house or factory. How are we going to mitigate these aspects?

GR: The electricity company is going to need to know what I'm doing in the home. Of course there are privacy issues coming out of this. But look at the amount of data Google collects, and yet most people simply don't care.

Cyber security is not an enormous issue yet, but it's going to become one. The power world has not needed a lot of software until now, but this is changing. So there is a threat not just for utilities and customers but also for hardware producers. However, I don't think the move toward digitalization is going to stop, but obviously security is going to become a much bigger challenge.

AR: We have talked a lot about the market situation and services, but at the beginning of this interview you also mentioned that technological advances for system integration are a main factor in enabling the further deployment of renewables. How do you see the impact of such technologies on the development of the future power grid?

GR: I think there is a tradeoff of sorts between the grid and storage. With more and more batteries on the distribution-level grid, the grid itself will be relieved of peak situations – peak referring both to load and feed-in. Storage is thus emerging as an alternative to transmission. To return to our telecoms analogy: The fixed-line telecom network – although still important – is no longer the ubiquitous backbone it once was.

JK: I think there is an important difference, namely that the mobile networks have in part replaced the functionality of fixed lines in a one-on-one manner. In the power grid, there is the challenge of providing electricity in regions with strong seasonal variations. For example, winter in the northern hemisphere. Batteries can shift the load within the day, but you cannot shift loads over months in an economical manner using batteries.

I see only two ways to deal with that. One is to not go beyond, say, 50 percent renewables. The other is to connect regions with transmission. Areas with the best wind and solar resources are often situated in remote locations. Tapping into these resources will require efficient ways to transport a large amount of power to the consumption centers. Power transmission interconnections need to be enhanced to facilitate optimum utilization of renewables and balancing of loads.

GR: Fair enough. Nevertheless, I see the main need for investment in the distribution grid. We are blind in the distribution grid. And this is where most of the changes are going to take place.

I also think we're going to see flexibilization on the demand side. The utilities are going to use cost-driven models to sell electricity to consumers. I know this is already happening with commercial customers, or in the home sector if you are using electric storage heaters. You give the customer the opportunity to buy at the cheapest price.

AR: Thank you, gentlemen, for this very interesting and valuable discussion. ABB Review runs regular articles on renewables technologies, so it is good to extend our scope and hear about the business model and capital investment implications too. Even just driving around you can see how dramatically the major renewable businesses – both solar and wind – are surging and how important they are becoming. We are all aware too, of course, of the climate-driven necessity for change. It is obvious that, as direct government supports ebbs, the contribution of the private sector will become ever more important and that flexibility and nimbleness will become key attributes.

It has become apparent, too, just how important the balance between capital costs and marginal costs is, and the implications this has for the directions of future technology development.

At the moment, ABB supports customers along the complete power value chain to plan, generate, connect, transmit, monitor and control power from renewable installations as well as to maintain and optimize their systems, and it is clear from our discussion that all these areas of technology are critical to the future of renewable energy.

This interview was conducted by Andreas Moglestue, chief editor of ABB Review. Please direct inquiries to Norma Guentert, communications manager for ABB Smart Grids and Wind Power Industry Sector Initiatives: norma.guentert@ch.abb.com

Symphony orchestrates

Symphony® Plus automation delivers flexibility and optimization for conventional and renewable power plants

ADRIAN TIMBUS, MARK BITTO – The power output variability of renewable power generators challenges not only renewable plant operators but also conventional plant operators, who have to be flexible in their response to changing load conditions caused by that variability. Modern control systems for power plants must, therefore, be able to deal with a greater number of activities and a higher volume of information than traditional control systems – as well as comply with strict national grid codes. They must also achieve total plant automation by providing a system platform that improves efficiency, productivity and operations. Further, when used as remote management systems, they need to optimize multiple power plants.

1 Featuring modular DIN rail packaging, the SD Series is the newest addition to ABB's Symphony Plus S+ Control and I/O family.

The fluctuating and intermittent nature of renewable energy plants – such as wind farms and solar power arrays – exporting their energy to the grid increases the challenge of achieving greater cost efficiency, improved environmental compatibility, and better and more flexible plant operation. The variability of renewable power generators also creates demands on conventional plants, which have to be flexible in their response to changing load conditions caused by that variability. The ability to respond quickly and cost-effectively to rapidly changing load requirements is crucial for power generators.

Today's power plant control systems must be able, therefore, to deal with a greater number of variables and activities, and a higher volume and complexity of information than is the case with the control systems of traditional plants. Naturally, they still also have to comply with the strict requirements of national grid codes. Further, when used as remote management systems, these control systems need to optimize the operation and production from multiple power plants.

In other words, the new generation of control systems must achieve complete plant automation by providing a system platform that increases energy efficiency, improves engineering productivity, and supports a more effective, flexible and reliable plant operation with an enhanced energy and maintenance management strategy. The remote monitoring of process information in real time is another important prerequisite for economical and operational stability.

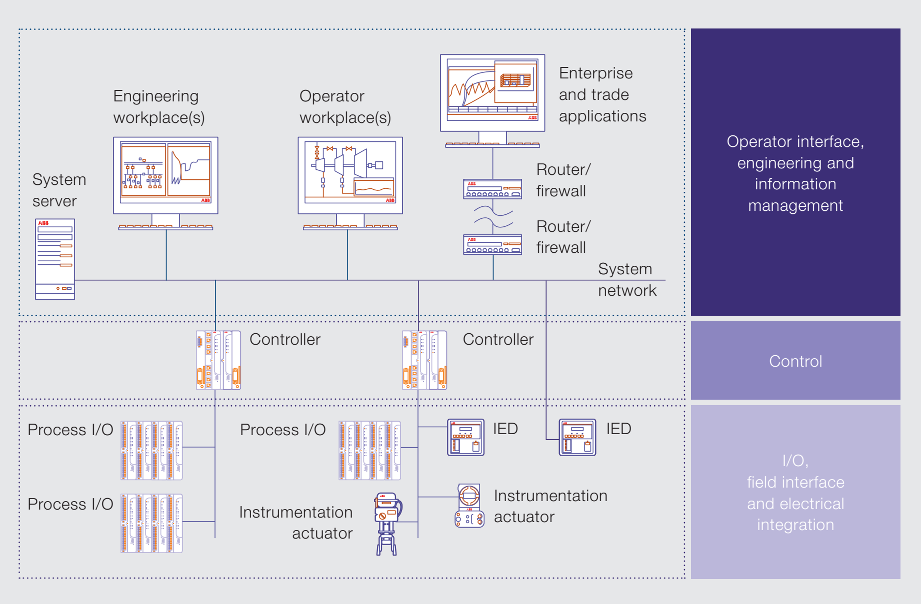
Today's power plant control systems must be able to deal with a greater number of variables and activities, and a higher volume and complexity of information than was the case with the control systems of traditional plants.

Modern control system requirements

Modern control systems require system architecture flexibility to meet the diverse configurations of today's power plants. While traditional fossil-fuel-fired or combined-cycle power plants are configured as central "block" architectures, renewable plants require the automation system to coordinate control of hundreds or thousands of smaller control units, such as those of wind turbines, solar trackers, remote terminal units or pipeline sensors, that are geographically distributed over a very wide area. All of these units need to be brought into a common operations hierarchy to provide better visibility and control of the entire plant or network.

Control systems, such as ABB's Symphony® Plus automation system, adopt a future-oriented process control concept comprising high-performance technologies, methods and tools that link autonomous systems together and produce total plant automation with increased functionality and reliability. Smaller equipment size, lower power consumption for on-site services and the ability to operate effectively in extreme and demanding environmental conditions are fundamental requirements. Improved avail-ability, reliability, redundancy, remote monitoring and communication are all also essential.

Title picture
The viability of a modern, complex power plant depends on a sophisticated and capable control system. ABB's Symphony Plus is the newest generation of ABB's total plant automation for the power and water industries. How does it help power plant operators run their plants in the most efficient and cost-effective way?



When used as remote management systems, modern control systems need to optimize the operation and production from multiple power plants.

Integration of the industry's latest communication standards into modern control systems allows more information to be available than in traditional solutions. Innovative and intelligent technology ensures that information is seamlessly distributed and provided in a role-based context to control room operators, maintenance engineers, plant optimization engineers and plant managers via a common system environment. The ability of the control system to capture more data and transform that into contextual information through a high-performance human-machine interface (HMI) leads to greater awareness, faster response and, ultimately, better decisions.

Historically, process systems and substation automation systems have been segregated and have not been able to communicate easily with each other. Making data available from the individual electrical elements – instrumentation, and low-voltage, medium-voltage and high-voltage systems – to process control systems has been problematic and costly, with each system communicating via different protocols and parallel cabling. To obtain higher levels of availability, operator visibility and operational reliability, the integration of the process and substation automation systems is essential.

Symphony Plus

ABB's Symphony Plus is the latest generation of the Symphony family distributed control system (DCS), developed to meet the unique and demanding requirements of the power generation and water industries.

Symphony Plus provides easy and flexible data access in order to facilitate operational decisions. S+ Operations, the system's versatile HMI, provides the user with intuitive process overview displays designed to overcome system navigational problems associated with autonomous control systems. Using high-performance graphics, operators have direct access to easy-to-use displays, clearly illustrated trend data, alarms and events monitoring (complying with the EEMUA 191 guidelines), and various reports that can be used to optimize system performance.

Centralized, consolidated operations are made possible through the integration of industry standard communication protocols such as IEC 61850, IEC 60870-5/101/103/104, OPC and Modbus TCP. Use of these standards allows for greater and more reliable access to plant data in a way that is less costly than custom interfaces and hardwired connections. A common operations environment and consolidated alarms and events lead operators to better abnormal situational awareness and overall effectiveness. For service engineers, maintenance schedules are optimized through the timely reporting of condition-based and predictive asset performance degradation, thus preventing unexpected and costly downtime.

Renewable plants require the automation system to coordinate control of hundreds or thousands of smaller control units that are geographically distributed over a very wide area.

Design and maintenance of the entire plant automation system are performed through a unified engineering workbench environment. Efficient engineering, configuration, administration, security, commissioning and maintenance of any system device – from a field and electrical device to control, I/O, operator workplace and communication interface – is performed via the system S+ Engineering tool. The tool features a multi-user, distributed engineering environment that isolates engineering activities from runtime activities and provides access based on user function. This is achieved via simplified user interfaces and workflows operating on a common database. A single point of configuration data entry provides versioning, documentation and backup functionality according to local standards.

Symphony Plus is backwardly compatible with all previous generations of the Symphony family, which allows seamless DCS upgrading and retrofit works to be carried out, thus maximizing production uptime and ensuring the project will be completed in the most cost-effective manner while protecting the investments made in the installed system assets.

SD Series

The Symphony Plus SD Series has been developed specifically to address the criteria for improved performance and to meet the requirements of geographically distributed process applications.

The SD Series uses a set of high-performance, scalable process controllers that support all of a plant's control requirements, from discrete and continuous to batch and advanced control applications ➔ 1. Supported by a comprehensive range of I/O options, the SD Series delivers powerful and versatile automation solutions for plant applications of all sizes and types. The common controller environment executes process control applications that are both data- and program-intensive. Redundancy options are available at all levels of control, I/O and communication, resulting in maximum flexibility and availability.

Using ABB's extensive set of field-proven standard function code algorithms and S+ Engineering's graphical design tools to develop control strategies, S+ Operations and other applications communicate with the SD Series control and I/O over a flexible high-speed, high-throughput and high-security network. This permits the integration of field devices, process and electrical systems, and business enterprise systems in a simple, scalable, secure and sustainable manner ➔ 2.

The SD Series controllers integrate intelligent field devices, including transmitters, actuators, motor control centers and intelligent electronic devices (IEDs). The use of IEC 61850, IEC 60870-5-104, Modbus TCP, PROFIBUS DP, and HART standard protocols results in reduced wiring and system footprint and, thus, lower installation costs.

SD Series products have a modular, high-density design and streamlined architecture that reduces control and I/O hardware requirements and cabinet footprint, thus lowering design, installation and operating costs. With a –20°C to +70°C temperature rating and G3 coating, these products are also designed to withstand extreme environmental conditions, which makes them ideal for remote I/O applications such as those found in renewable power applications.

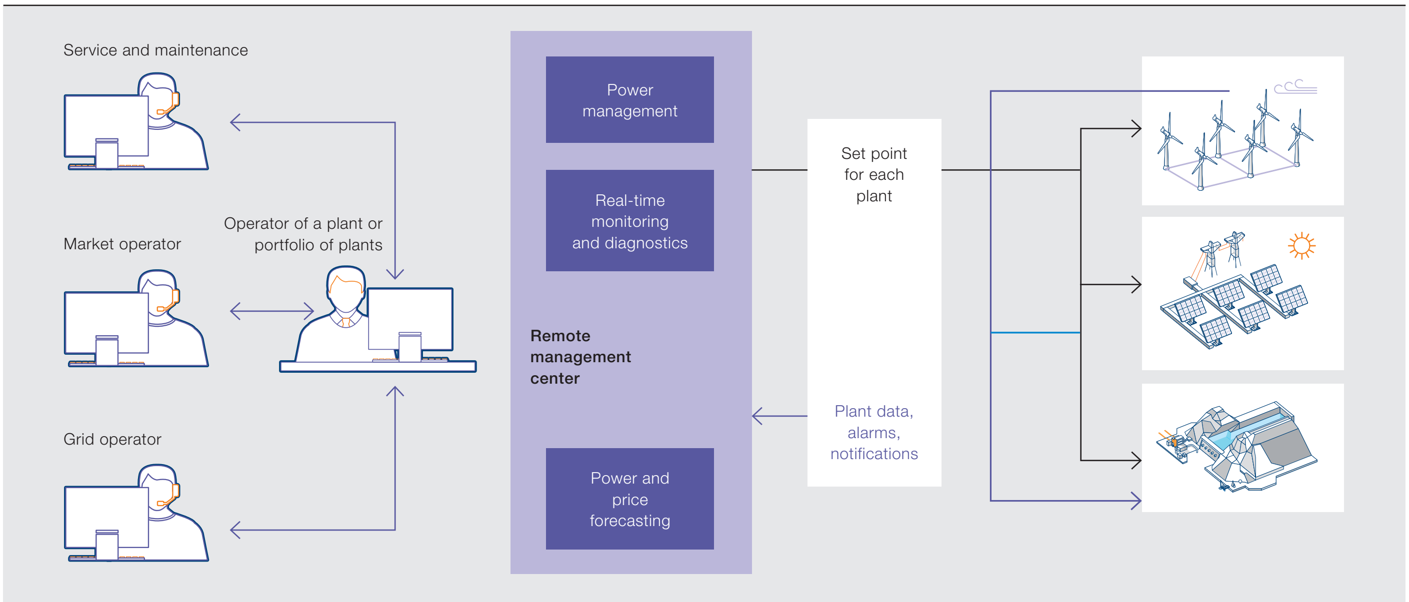
Significantly higher efficiency means lower power consumption (SD Series products use 50 percent less power than typical DCS and other I/O products), lower heat dissipation and the elimination of environment cooling equipment such as cooling fans, louvers, air filters and purging systems. This obviates the use of parts that can negatively affect reliability and productivity, reduces the equipment footprint and lowers installation costs.

The benefits of electrical integration

By utilizing modern automation systems, such as Symphony Plus, that fully integrate the industry's latest communication standards, power plants will achieve optimized operation through:

- The use of only one automation control system for the entire installation
- Smaller and less complex equipment designs
- Shorter engineering, installation and commissioning periods
- Simplified spare parts lists and associated maintenance activities
- Reduced training requirements
- Reduced project risk when working with integrated project teams

3 Overview of Symphony Plus automation solution for remote management of a portfolio of plants



- Optimized life-cycle costs that come with a future-proof system
- Lower energy costs through effective energy management – eg, optimizing the purchase and generation of electricity

Optimization of power plant production

Control system optimization has emerged as the primary solution for the optimization of conventional and renewable power plant production. Achieving complete automation of power plants with a single control and I/O platform has become a major focal point in promoting effective asset performance.

Power plant automation that provides a common operating platform for the control of both process and power systems will allow increased levels of productivity and maximized system uptime to be achieved. All of the operating information may be archived in a common database so that it can be available to any of the users and plant managers involved whenever they require access.

Design and maintenance of the entire plant automation system are performed through a unified engineering workbench environment.

The entire power plant production is therefore covered by one optimized process control system.

Remote monitoring and virtual power plants

The remote monitoring capabilities of modern automation systems present both the operators of individual plants and those managing energy power plant portfolios with a high level of plant operating visibility – providing dynamic decision-making tools that help operators optimize power plant availability, detect any abnormal functionality and ensure that energy efficiencies are being maintained. The operator benefits from improved operation and maintenance regimes, and a consequent reduction in operating expenditure leads to increased business profitability.

With greater numbers of small solar and wind power producers exporting energy to the grid, there is an increasing need for the creation of virtual power plants (VPPs) and smart grids. Centralized remote monitoring of VPPs allows the energy production from various geographically remote power plants to be accumulated and aggregated. This permits participation in the power purchase market by VPP operators so that they may achieve better energy prices, improved load balancing and the optimization of a power plant's on-site electrical production and consumption ➔ 3.

Ultimately, ABB's Symphony Plus automation solution ensures that the optimization of VPP operations is accomplished.

The article, "Virtual Reality," on page 24 of this edition of ABB Review provides a more detailed description of VPPs.

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Changing wind

New technologies for wind-turbine and wind-farm control

ADRIAN TIMBUS – Throughout time one of man's greatest aspirations has been harnessing the power of the wind. However, capturing this raw energy and transforming it into another energy form has always been a significant challenge. The modern day example is wind turbines and the utilization of wind energy to generate electrical power. Effective optimization of wind farms and independent wind turbines requires innovative, leading-edge control technologies. Through better monitoring and control ABB's automation system Symphony Plus for Wind is increasing the value of wind energy.

Title picture
Wind power needs advanced control technologies to further improve its levelized cost of energy (LCOE).

Symphony Plus for Wind has been configured to provide the control functionality required for grid-code compliance using bespoke control libraries implemented in a high-performance controller.

As the power industry moves away from subsidized markets based upon feed-in tariffs and toward greater participation in the wholesale energy market and long-term power purchase agreements, today's technologies must enhance wind power generation within the competitive marketplace for renewable energy.

To do this, new technology is needed to facilitate optimized grid integration by improving the performance and reliability of wind turbine operation and reducing the cost of generation, and by improving production forecasting and power production management throughout the life cycle of a wind farm.

Understanding both the harsh environmental conditions in which wind turbines operate and the overwhelming demands placed on wind-farm operators is paramount to achieving the desired levels of improvement.

Consequently, modern control systems and new sensing devices must be developed to meet the specific and exacting requirements of the wind-farm operators. Automation control must have an intuitive human-machine interface (HMI), providing operators with timely access to the actual operating parameters and production data that will be used to ensure wind-farm production is optimized.

Market requirements

Using extensive experience gained from the successful operation of conventional power plants, ABB automation control systems can be harmonized for the optimized production from wind farms. The same supply challenges of flexibility and security of supply must be overcome. By ensuring that power quality is maintained through proper control systems, power production can be accurately forecasted and planned, and a power output to match system demand can be provided.

Grid codes

Electricity generators are required to comply with the stringent requirements of the network codes respective to each country of operation. These codes, also known as grid codes, specify the technical conditions and processes required for a generator's compliance with all aspects of planning, connection and operation.

The essential requirement of grid codes is to ensure wind power plants behave in a similar way to conventional power plants and provide the necessary grid support functions.

Modern control systems and new technologies have to support the challenges associated with grid integration and the contrasting variables in operating parameters required for grid-code compliance worldwide.

Beyond grid codes

ABB's automation system for the wind industry, Symphony Plus for Wind, has been configured to provide the control functionality required for grid-code compliance using bespoke control libraries implemented in a high-performance controller.

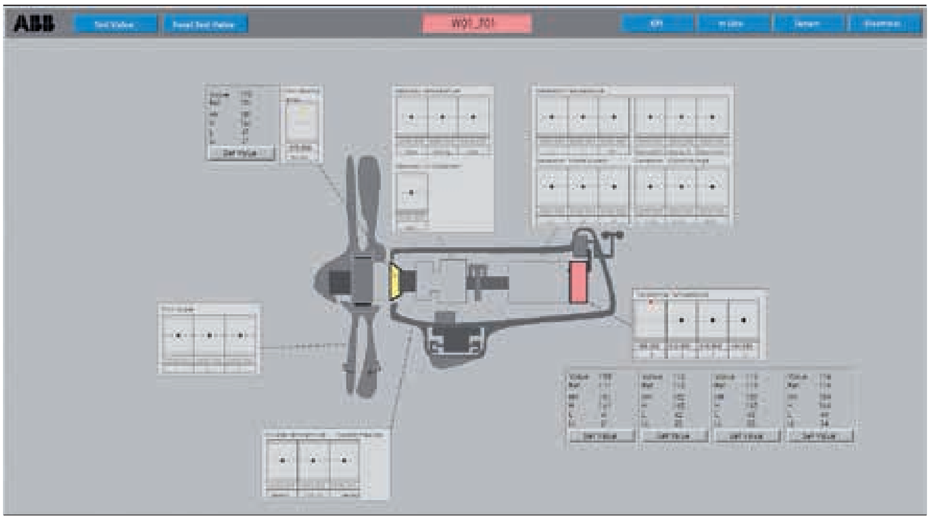
This latest technology provides frequency containment by modulating active power and steady-state voltage control by changing reactive power.

Importantly, by treating the wind farm as an integrated power plant, substation influence is also included in the system.

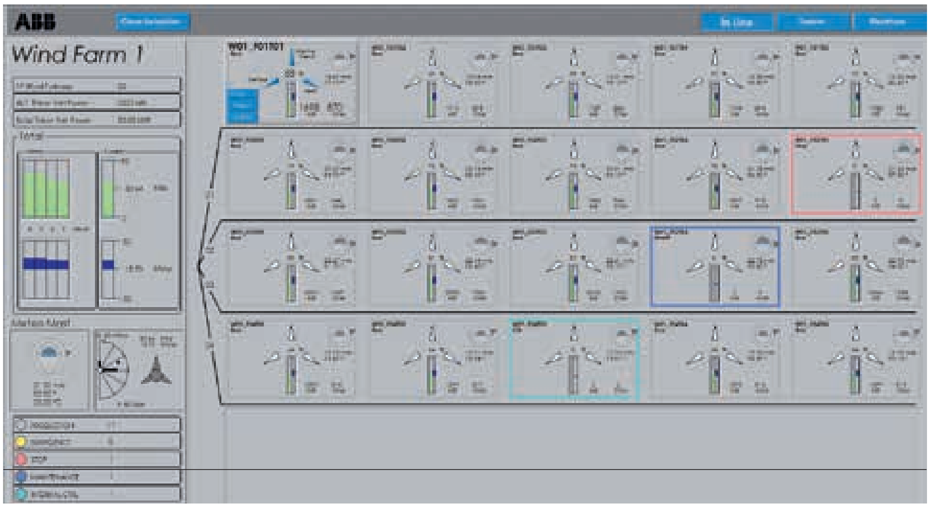
Information can be seamlessly distributed to control operators, maintenance engineers and plant engineers via a common database management system.

An optimized control system considers the capacity of each turbine to produce reactive power; checks the level of reactive power at the substation level;

1 Symphony Plus' simple yet advanced ergonomic human-machine interface (HMI) for the wind power industry



1a Ergonomic view of wind turbine nacelle information displayed in relation to the normal operating point and upper and lower arms



1b Wind farm overview display illustrating overall power production and individual turbine status and production values

Using standard protocols, such as IEC 61850, Modbus TCP and IEC 104, the number of control systems across a plant and the complexities associated with the engineering, installation and commissioning of individual control systems are reduced.

interfaces with the tap changer of the main transformers to help regulate the voltage inside the wind farm; considers the voltage levels within the wind farm collector grid; and controls the reactive power resources to minimize losses in the collector grid to maintain voltage levels within the constraints.

Managing voltage and reactive power inside the wind farm reduces tripping risks and losses in the collector grids.

Unique automation systems

Symphony Plus for Wind automation has been uniquely developed to integrate wind turbine generation and electrical infrastructure (substations, capacitor banks, STATCOMs, etc.) into a single monitoring-and-control system for the power plant. The integration of the process power plant and the substation automation systems results in higher levels of availability, operator visibility and operational reliability.

Using standard protocols, such as IEC 61850, Modbus TCP and IEC 104, the number of control systems across a plant and the complexities associated with the engineering, installation and commissioning of individual control systems are reduced. Information can be seamlessly distributed to control room operators, maintenance engineers and plant engineers via a common database management system.

Having all assets integrated into a single control system is intrinsic to the optimization of wind power plant production.

Optimization of plant production

Generally, wind power plants have a faster response than conventional power plants. However, there are challenges mainly associated with the most significant variable – the availability of the wind energy and how this affects plant-production output levels.

By continually monitoring both the individual output of each wind turbine and the cumulative output from the wind farm – collecting the large amounts of operating data, such as wind speed/direction and rotor speed, and interpreting this in line with production data, such as active/reactive power – decisions can be made to ensure that each wind turbine, and the wind farm as a whole, is operating effectively and at optimal efficiency, modulating the output of the turbines to meet the required loads → 1.

Having all assets integrated into a single control system is intrinsic to the optimization of wind power plant production.

2 SpiDAR technology is used for wind measurements, forecasting and site assessments.

Overcoming wake effects in wind farms is an efficient and viable way to increase revenues from the wind turbines, as this can account for a few percent of power, depending on the wind farm layout, compared with non-wake, free-stream wind conditions. Optimizing the aerodynamic interaction between turbines is also critical for wind energy to gain advantage in the renewable energy market.

To maximize power production of the wind farm through wake effect optimization, Symphony Plus for Wind models the aerodynamic interaction between turbines, and calculates the effect of wake on electrical power output. Using a powerful online optimization engine, it then optimizes the active power of each turbine so that the power production from the entire plant is maximized and combined with the reactive power control in order to minimize overall losses in the collector grid.

By integrating new sensing devices such as SpiDAR and iSpin, Symphony Plus for Wind can further optimize the production output of wind turbines and wind farms.

New sensing devices

With its strategic investment in two companies – Pentalum Technologies and ROMO Wind – whose products have been designed to improve wind turbine performance and operations by measuring actual wind conditions more accurately, ABB is positioned to offer the latest technology in wind control systems. Integrating Pentalum's and ROMO Wind's technologies with Symphony Plus for Wind opens up the possibilities for the next level of wind turbines and wind farm controls.

Pentalum's innovative LIDAR (light detection and ranging) technology remotely senses the wind vector in front of wind turbines in order to optimally align the turbine with the incoming wind flow. Known as SpiDAR, the technology is also used for wind forecasting and site assessment, and is designed to significantly increase wind-farm efficiency at a lower cost per site than with other wind-vane measurement technologies, which less effectively sense air flow from behind the wind turbine.

3 iSPin technology provides accurate measurements of wind variables.

Standardized communication protocols allow multiple power plants to be connected together, so that all relevant assets are interfaced with the other systems to become one centralized management system away from the geographical location of the remote power plants.

Ultimately, Symphony Plus for Wind provides an effective system platform that increases energy efficiency, improves engineering productivity and supports a more flexible and reliable plant operation and overall maintenance strategy.

Symphony Plus for Wind has been developed with a hierarchical architecture for plant-level equipment and remote center systems using the proven technology S+ Operations.

SpiDAR also identifies wake effects and the compounded effect of turbulence. When integrated with Symphony Plus for Wind, the operator is provided with all of the relevant and timely information necessary to react appropriately to changing weather conditions that could seriously affect wind power plant operations → 2.

ROMO Wind's iSpin technology provides accurate measurements of wind variables such as speed, direction and turbulence → 3.

The combination of iSpin and Symphony Plus for Wind enables online and historical performance analysis of individual wind turbines on a wind farm, enabling operators to implement essential efficiency-improvement programs and consequently increase profitability. Yaw misalignment, rotor efficiency, maximum-power-point-tracking effectiveness and accurate power curves can then be calculated and monitored in order to detect any underperformance of wind turbines. Dedicated software applications use iSpin and wind turbine data to define and report next-level key performance indicators for wind turbines, with the clear goal to maximize turbine performance.

Modern control systems

By integrating new sensing devices such as SpiDAR and iSpin, Symphony Plus for Wind can further optimize the production output of wind turbines and wind farms.

Using dedicated applications and real-time monitoring, the parameters measured by the field sensing devices are used to forecast and optimize power production output from the wind turbines and to determine the best energy prices. The field data is also used to provide diagnostics and prognostics of wind turbine operations, alerting the operators and maintenance personnel to any potential equipment malfunctions.

Symphony Plus for Wind has been developed with a hierarchical architecture for plant-level equipment and remote center systems using the proven technology S+ Operations. It can be used as a complete power management function, turning renewable plants into reliable generation.

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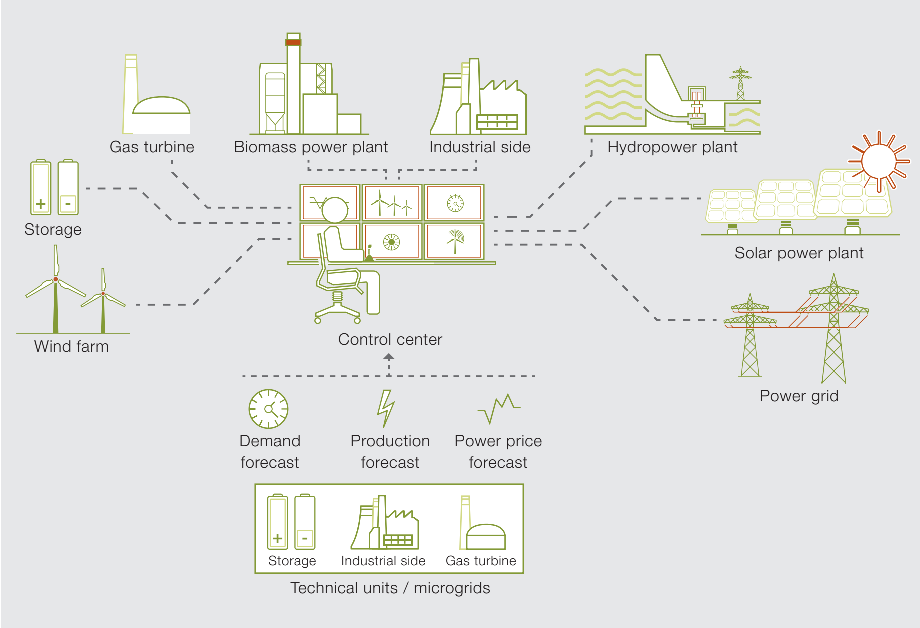
Virtual reality

ABB's central control and optimization system enables cost-effective virtual power plant operation

SLEMAN SALIBA – A virtual power plant (VPP) is a collection of power generator units, power storage devices and flexible power consumption units that is directed by a central control system. A VPP can enable the participation of small- and medium-sized renewable power generation units in the electricity market or in the provision of grid services such as power balancing. Hence, the penetration of and the revenues from renewables can be increased significantly. ABB's central VPP control and optimization system not only allows operators to run their VPPs in real time, but it also enables them to operate their plants in a cost-optimized manner according to their own particular needs.

1 ABB's central VPP control and optimization system simplifies VPP operations.



Potential VPP power generation assets encompass almost the entire spectrum of power-producing technology: biogas, biomass, combined heat and power (CHP), microCHP, wind, solar, hydro, power-to-heat, diesel engines and fossil-fuel. Typically, VPPs will pool production from hundreds of small- and medium-sized renewable energy plants into a large-scale VPP that has the size and flexibility to participate in the electricity market – especially in lucrative ancillary grid services.

In addition, a VPP can make use of many kinds of energy storage solutions – like batteries, thermal storage, compressed air or pumped storage. Finally, some consumers can also become a part of the VPP topology – by, for example, varying their processes to suit prevailing power economics or by timeshifting production loading → 1.

Broadly stated, the goals of a VPP are threefold: to attain better prices for produced energy on the spot and derivatives markets, to participate in the power balancing market and to optimize internal production and consumption.

Title picture
How do virtual power plants enable the integration of renewable and distributed power?

Typically, VPPs will pool production from hundreds of small- and medium-sized renewable energy plants into a large-scale VPP that has the size and flexibility to participate in the electricity market.

Markets

One of the main challenges involved in operating a VPP is to place available power on the different energy markets to maximize returns.

The first step in accomplishing this is to establish the available power capacities in the VPP, the renewable production forecast, the foreseen load demand and the long-term obligations. These are then passed to a market optimization system that distributes available power generation capacities from the VPP to the different energy markets.

Energy trading takes place in three different markets: the balancing market, the spot market and the derivatives market. Additionally, there are over-the-counter (OTC) trades in which partners trade energy bilaterally. This article deals with the opportunities that arise for VPPs in the liberalized energy market and uses the German energy market and the European Energy Exchange as references. The concepts, however, apply to most international power grids and energy markets.

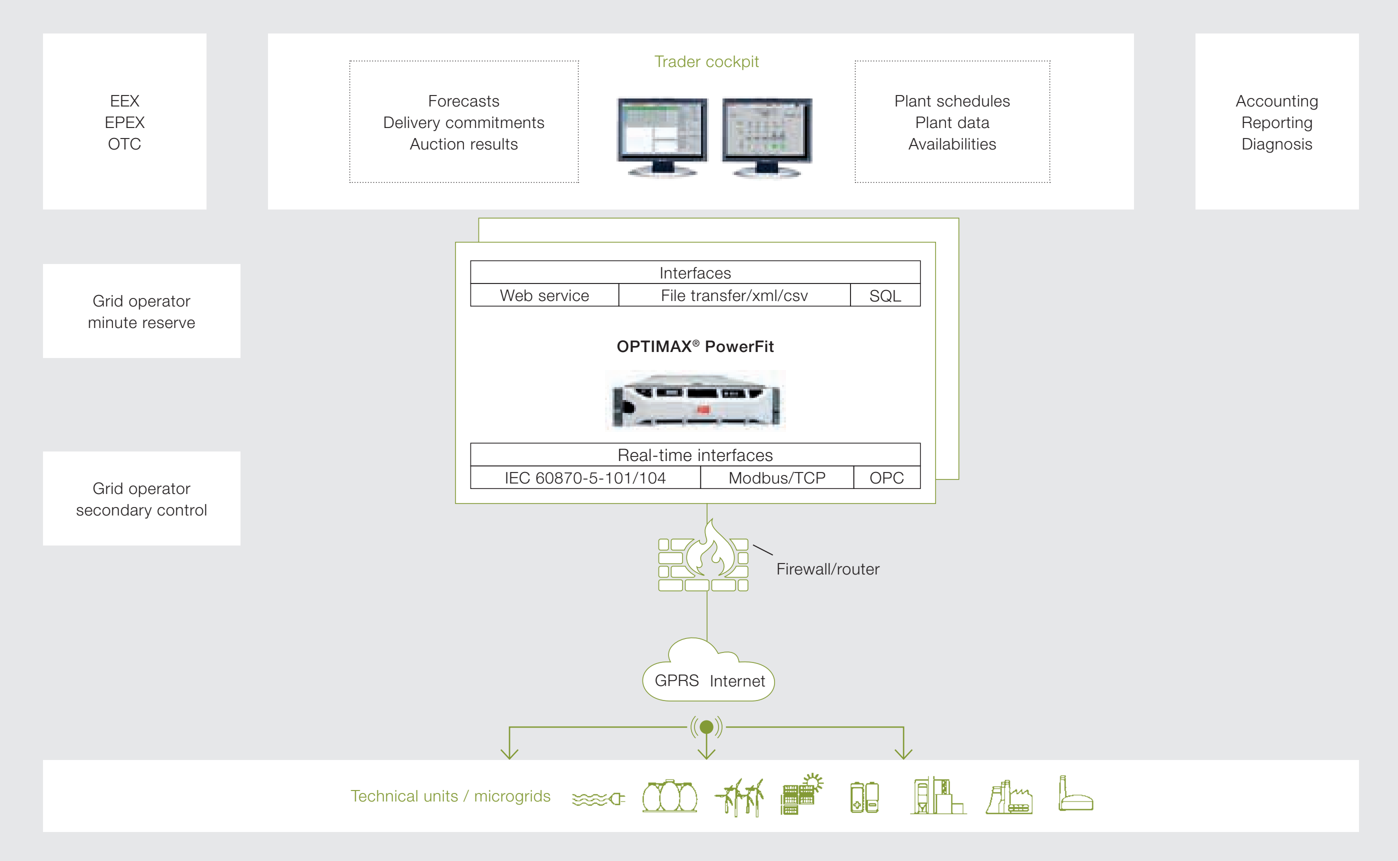
The balancing power market

The prerequisite for stable operation of the power grid is a balance between power generation and power consumption. So-called balancing power is injected if any difference between the two should arise. The goals of balancing power are to ensure that the frequency stays, within a defined tolerance, at 50 Hz and to compensate for regional differences in power generation and power consumption.

To achieve these goals, three types of balancing power interact dynamically: primary balancing power, secondary balancing power and minute reserve.

Balancing power is obtained from ancillary grid service providers responding to offers to tender issued by the transmission system operators (TSOs). Before the VPP operator can bid on this balancing power market, each of his power generation units has to undergo TSO prequalification.

2 Integration of the central control and optimization system into the IT landscape



Broadly stated, the goals of a VPP are threefold: to attain better prices for produced energy on the spot and derivatives markets, to participate in the power balancing market and to optimize internal production and consumption.

Traditionally, conventional power plants were the only source of balancing energy. Now, however, a VPP can interconnect multiple smaller power generation units to reach the minimum offer size for placing bids in the balancing power market. Generally, the VPP operators proffer a certain amount of balancing power and market agents place these bids in the energy market.

The European spot market

The European spot market, EPEX, offers two opportunities for short-term trading of energy: the Day-Ahead market and the Intraday market. In the former, electricity is traded for delivery the following day in hourly blocks or blocks of hours. The daily auction takes place at noon, seven days a week, all year round, including statutory holidays. In the latter, electricity is traded for delivery on the same day or on the following day in single hours, 15-minute periods or in blocks of hours.

Power derivatives market

The third market is the European Energy Exchange (EEX) power derivatives market. In this market, the broker can financially settle power futures and options on these.

The derivatives market is often used to hedge against the price fluctuations on the spot market.

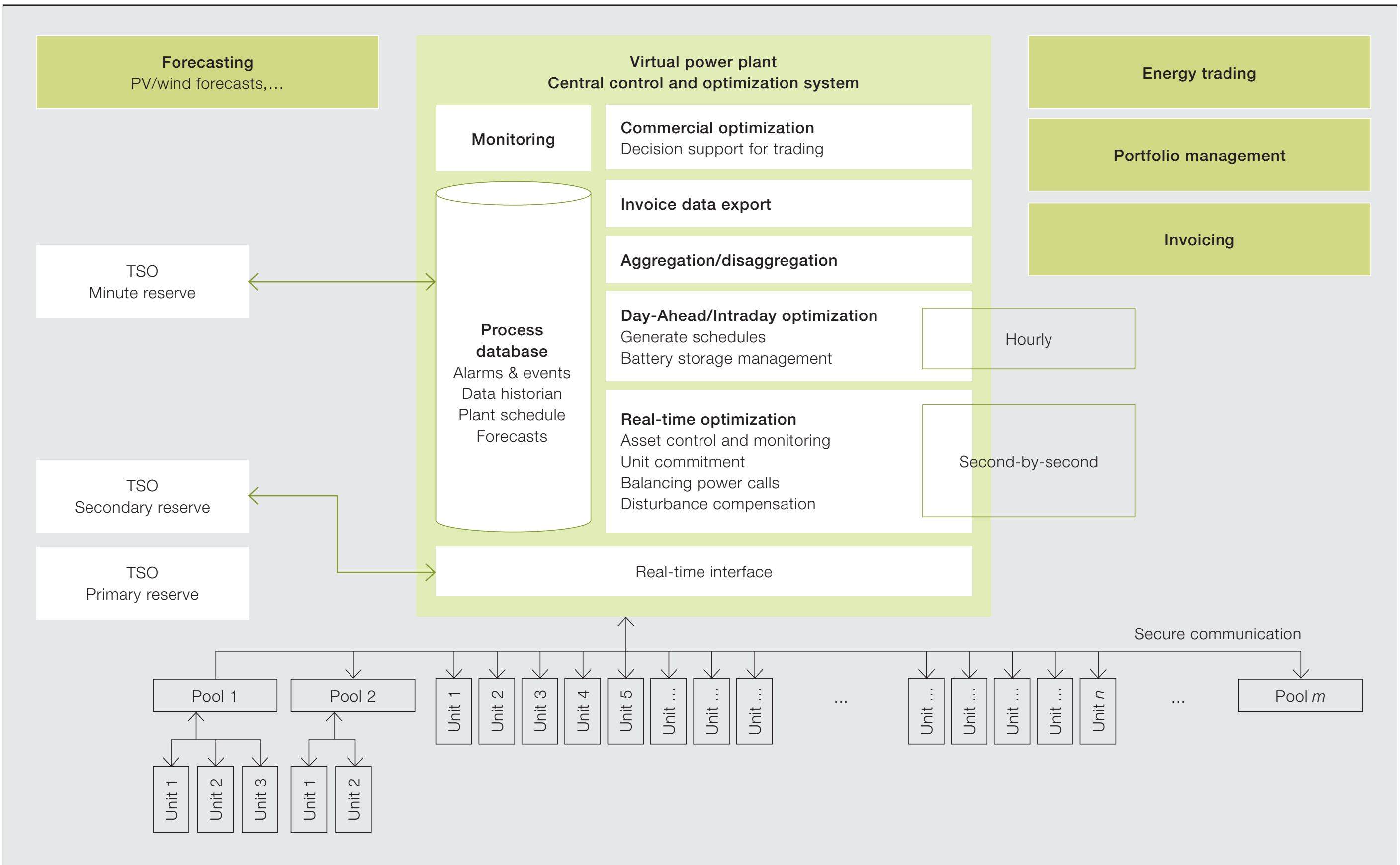
Optimal operation of VPPs

As can be inferred from the above discussion, a VPP operator not only has to have a clear overview and control of his power generation assets, but also a means of managing the commercial side of the enterprise in a cost-effective way → 1. ABB's central control and optimization system provides the foundation for the VPP to accomplish both these aims. It connects the decentralized assets and optimizes the operation, planning and commercial considerations → 2.

The control system needs to have high availability to comply with the strict requirements for providing grid services and all operational optimization results must be available in real time.

VPP operators often face the challenge of a rapidly growing installed base. Therefore, it is essential that the central control and optimization system is highly scalable so it can be grown from a few units to a few thousand in a short time. In one of ABB's installations, the

3 VPP control and optimization system modules



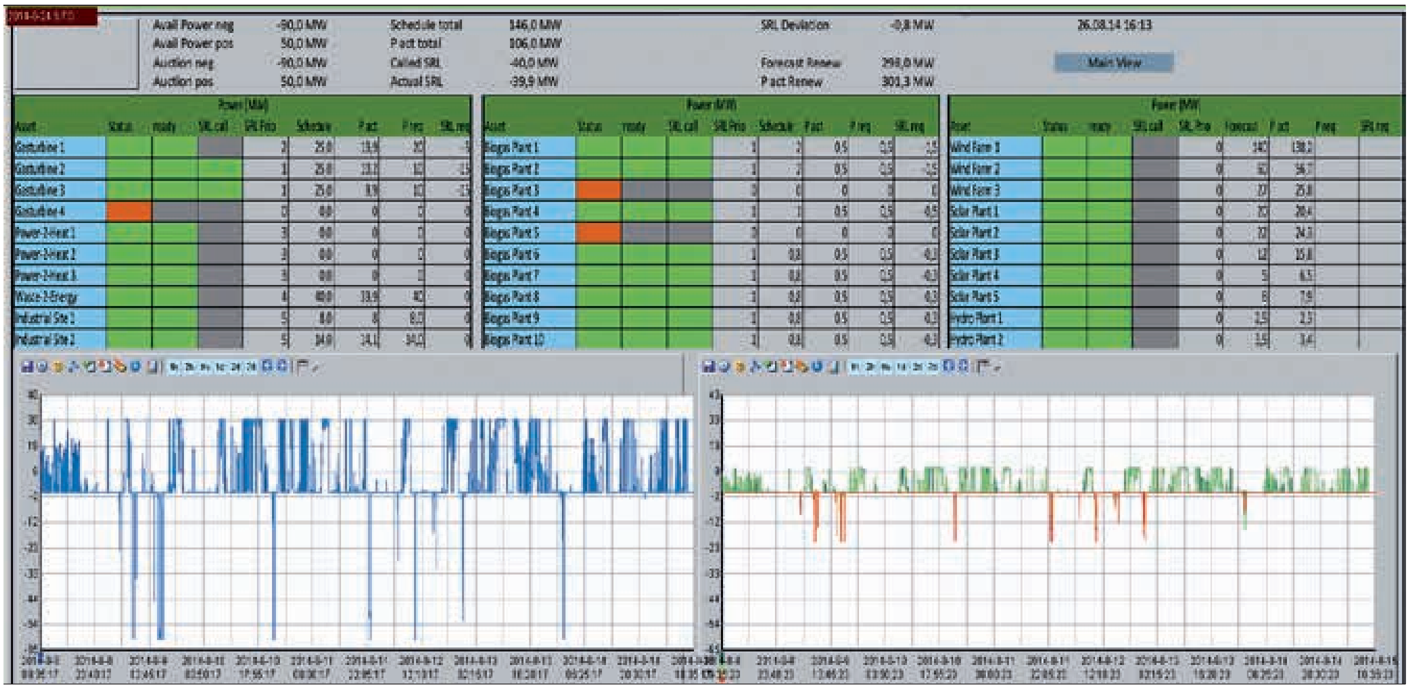
customer installed base grew from 20 to over 2,800 units in under three years. As all hardware and software additions were hot-swappable, ABB was able to add all the units without interrupting operations.

Connections to the decentralized assets are wireless-based. Therefore, it is crucial to meet the highest cyber security standards for transmitting set points and balancing power release calls from the control system to the units in the field. This is achieved by equipping the assets – or pools of local assets – with remote terminal units that employ VPN tunnels to transmit signals using private GSM or encrypted Internet connections → 2.

In the optimization on the commercial side of the control system, the forecasts for renewable power generation requirements, the committed long-term obligations, the load demand and the available capacities of the assets are aggregated. In this way, the VPP operator gets an overview of the available capacities and the marginal costs. Based on this information, optimal bidding strategies for the different electricity markets are proposed to the trading department, which then submits offers to the energy markets. Successful bids – ie, power deliveries and grid service commitments – are returned to the control and optimization system, which generates the necessary schedules for the power-producing units, tak-

ABB's central control and optimization system gives the operator a clear overview and control of his power generation assets, and a means of managing the commercial side of the enterprise in a cost-effective way.

4 Balancing power calls are distributed to the available units. Overall balancing power calls (lower left); and positive calls in green and negative calls in red (lower right).



Connections to the decentralized assets are wireless-based. Therefore, it is crucial to meet the highest cyber security standards.

ing all current restrictions and disturbances into account → 3.

Further, instant-by-instant incoming balancing power calls are also incorporated into the individual schedules to provide the optimal set points for all relevant units → 4.

The standardized open interfaces supplied by ABB make it easy for the VPP operator to integrate the control system into the IT landscape and automate the information and signal flow from the field level to the energy management level → 2.

The ABB solution utilizes a mathematical optimization program to distribute the optimal set points in real time. Plant properties such as power limits, disturbances or schedule deviations are measured online and directly factored into the control of the assets. In this way, the optimization program ensures that the VPP is always run in the best possible configuration.

With its solution portfolio, ABB covers all aspects and requirements for the optimal operation of VPPs. In particular, the central control and optimization system runs redundantly on servers that are located in geographically dispersed data centers. In this way, ABB can ensure the high availability that is an essential characteristic of a control system running in such a high-criticality environment.

As the world introduces ever more renewable energy sources, the role of the VPP in sustainable power generation will increase in significance. The growing complexity of generating power in the most optimal way, matching it with demand and marketing it in the most cost-effective way means that ABB's central control and optimization system will continue to be a crucial tool for the VPP operator.

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Potential improvement

Transmission technologies to support the integration of renewable energy

ROLF GRUNBAUM, SIMON VOGELSANGER, ANDERS GUSTAFSSON, JANISSA AREVALO – In recent years, high-voltage transmission networks have been presented with unprecedented challenges. These stem largely from deregulation, a rapid increase in inter-utility power transfers and impediments to building new transmission systems due to economic and environmental constraints. Added to this is the difficulty of controlling the flow of power and maintaining stability, especially when integrating very large amounts of renewable energy (RE) – from remote, offshore wind farms, for example – into the grid. Periods of strong wind or high solar radiation and low load can exacerbate problems. These challenges can be addressed by products such as ABB's FACTS (flexible alternating current transmission systems) and HVDC (high-voltage direct current) technologies, which allow more power to be transferred in a very flexible, controllable and stable way.

1 Asmunti 400 kV series capacitor, Finland

In theory, limitations on power transfer capacity or power flow control can always be circumvented by adding new transmission and/or generation facilities. ABB's FACTS devices help to achieve the same goals without such major system additions – and HVDC technology is the ideal complement to cope with even more demanding power transmission tasks.

A FACTS solution is justified when rapid response, frequent output variations or a smoothly adjustable output is required. The main devices in the FACTS family are:
- The static var compensator (SVC)
- Series capacitors (SCs)
- The STATCOM (static compensator) devices SVC Light® and PCS 6000

The static var compensator

An SVC can rapidly regulate line voltage and bring it to the required set point. Following a power system incident – eg, a network short circuit, or line or generator disconnection – the SVC will supply dynamic, fast-response reactive power. In addition, an SVC can also increase transfer capability, reduce losses, mitigate active power oscillations and prevent overvoltages at loss of load. The fast var capabilities of an SVC make it suitable for:
- Steady-state and dynamic voltage control to give increased power transmission and reduced voltage variations.
- Synchronous stability improvement to bring increased angular stability and improved power oscillation damping.
- Power quality improvement in grids feeding heavy industrial loads.

ABB recently implemented two SVCs – each rated at ± 250 MVAr – in the Norwegian 420/300 kV power transmission network. These were installed at Viklandet and Tunnsjødal substations to increase power import capacity into the region by up to 400 MW.

Series capacitors

Series compensation of power transmission circuits by capacitors has several benefits:
- An increase of active power transmission, without violating angular or voltage stability
- An increase of angular and voltage stability for a given level of power transmission
- A reduction of transmission losses in many cases
- A reduction in the number of transmission lines required

A FACTS solution is justified when rapid response, frequent output variation or a smoothly adjustable output is required.

Series compensation requires control, protection and supervision to enable it to perform as an integrated part of a power system. Also, since the series capacitor is working at the same voltage level as the rest of the system, it needs to be fully insulated from ground potential.

The main protective device in the series capacitor is a varistor – usually of the zinc oxide (ZnO) type – that limits the voltage across the capacitor to safe values and protects against any short-circuit currents. A fast protective device is often used to bypass the series capacitor when the varistor cannot absorb excess fault current.

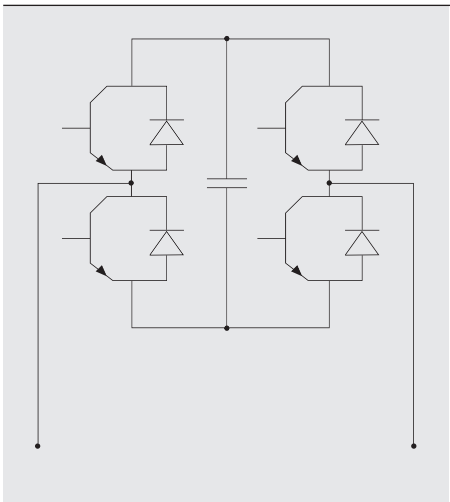
Fingrid, the Finnish transmission system operator, enlisted ABB to install two such series capacitors (301 and 369 MVAr) to help meet internal transmission demands, improve grid stability and boost the export corridor to Sweden by 200 MW ➔ 1.

SVC Light

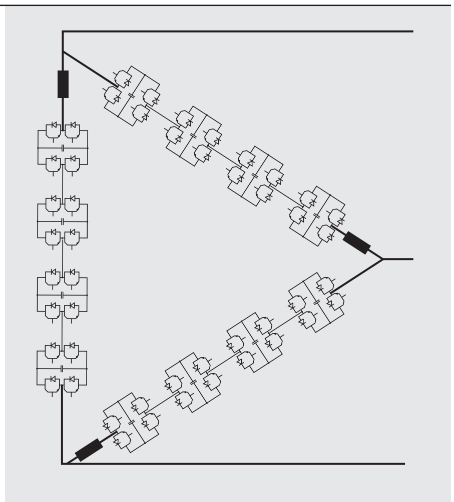
SVC Light is a STATCOM (static compensator) device based on a chain-link modular multilevel voltage source converter (VSC) concept that is adapted for power system applications. It can deliver

Title picture
How do ABB's FACTS and HVDC technologies allow network operators to increase power transmission levels? Shown is the SVC at the Viklandet 400 kV substation in Norway.

2 Multilevel chain-link converter setup



2a H-bridge cell with IGBTs (one single phase)



2b Three-phase chain-link of H-bridges

3 Modular H-bridge units

reactive power to the grid with a highly dynamic response. SVC Light can, for instance, support weak grids, improve large wind farm availability under varying grid conditions and relieve grids in hot countries that are loaded by a large number of air conditioners.

IGBTs (insulated-gate bipolar transistors) are key components of SVC Light. The multilevel chain-link solution is built up by linking H-bridge modules in series to form one phase leg of the VSC branch ➔ 2.

An SVC can rapidly regulate line voltage and bring it to the required set point.

SVC Light is available for system voltages up to 69 kV and converter ratings up to ± 360 MVAr ➔ 3. For higher voltages, a step-down transformer is used to connect SVC Light to the grid.

To increase the dynamic stability and capacity of their network, Transelec S.A. – Chile's main transmission owner and operator – decided to install SVC Light. The device is rated at 65 MVAr inductive to 140 MVAr capacitive at 220 kV and is located in the heavily loaded Cerro Navia 220 kV substation in Santiago de Chile. As well as increasing the capacity, SVC Light regulates and controls the 220 kV grid voltage under steady-state and contingency conditions, and provides dynamic, fast-response reactive power following system events.

PCS 6000 STATCOM and offshore power transmission

Because the wind out at sea is strong – particularly in the afternoon, when electricity consumption is high – wind farms are increasingly being built offshore.

An offshore wind turbine delivers its power via a platform-based transformer and AC cable to shore, where the voltage is stepped up and the power fed into the grid. The remoteness of the wind generator from the main part of the grid can raise stability and reliability issues, which is why transmission system operators are strengthening grid code requirements – specifically those related to reactive power, voltage control and fault ride-through capability.

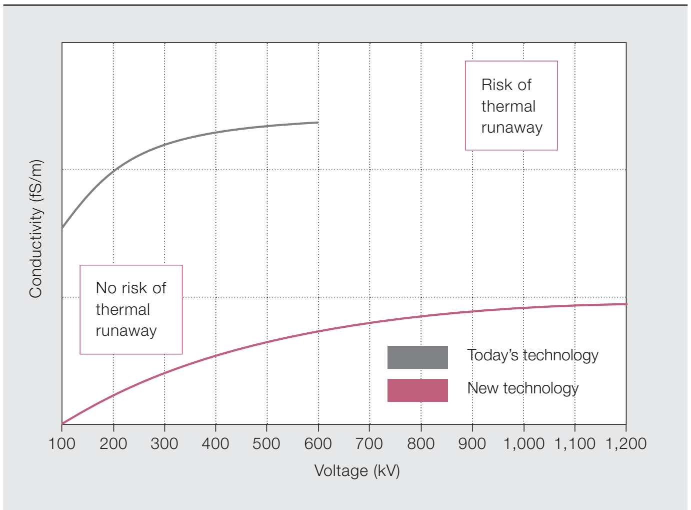
FACTS can provide the fast, dynamic voltage control required by these grid codes, whereas conventional, mechanically switched reactive power components such as capacitor and reactor banks cannot.

On top of the usual grid reactance, wind farm transformers and cables add reactance that varies with active power output. These additional, variable sources of reactive power also need to be compensated for. This can be done by using ABB's PCS 6000 STATCOM.

Series compensation requires control, protection and supervision to enable it to perform as an integrated part of a power system.

4 Type testing of the 525 kV extruded HVDC cable system

5 Comparison of conductivity vs. voltage for the new and previous HVDC cable insulation system



The PCS 6000 ensures full grid compliance and dynamic power compensation for any wind farm, and is designed as a compact, modular system for applications up to 38 MVAr per unit.

The PCS 6000 ensures full grid compliance and dynamic power compensation for any wind farm. It is designed as a compact, modular system for applications up to 38 MVAr per unit. Higher power requirements can be achieved by simply paralleling multiple PCS 6000s. More than 20 PCS 6000s are already in operation in various wind farms.

SVCs, series capacitors and STATCOM devices enhance AC transmission; ABB's HVDC technology makes DC transmission simpler.

HVDC Light (VSC technology)

Typically, HVDC is a more cost-efficient technology for transmission of large amounts of power over distances exceeding 600 km by overhead lines and about 50 to 100 km in the case of underground or subsea cables. However, many other factors make HVDC technology (particularly VSC-based HVDC such as ABB's HVDC Light) the ideal complement for evolving AC grids. For example, HVDC Light systems enable neutral electromagnetic fields, oil-free cables and compact converter stations. Further, they help manage the increasing challenges of renewable energy integration with rapid control of active and reactive power (independently), the provision of voltage support and improvement in power quality. Other advantages – such as black-start capability and the ability to connect to weak AC grids – make HVDC Light especially attractive for grid interconnections and power provision to isolated systems or crowded metropolitan areas. Strong transmission connections contribute to reduced variability and increased forecast accuracy of renewable generation due to the geographical smoothing effect over large areas.

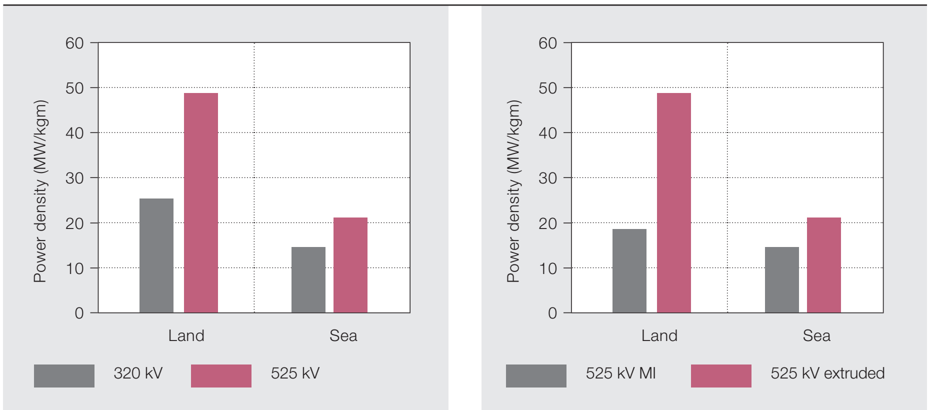
HVDC Light – highest voltage and longest cable

Recently, ABB set an HVDC Light voltage world record with the 500 kV Skagerrak link between Norway and Denmark. ABB has delivered all four of the Skagerrak system's links: Skagerrak 1 and 2 in the 1970s, Skagerrak 3 in 1993 and now Skagerrak 4. The system spans 240 km and provides 1,700 MW of transmission capacity to enable hydrogeneration and reservoir storage in Norway to be used to balance wind generation in Denmark.

Skagerrak 4 comprises two 700 MW VSC stations. The new link operates in bipolar mode with the Skagerrak 3 link, which uses classic line-commutated converter HVDC technology. This is the first time the two technologies have been connected in such a bipole arrangement. ABB's advanced MACH control system was used to master the different ways power reversal is handled between the two technologies.

ABB will also deliver the world's longest extruded HVDC cable – NordBalt, between Sweden and Lithuania. NordBalt (300 V/700 MW) comprises a pair of cables with a total length of 53 km over land and 400 km under the Baltic Sea. The cable route has to pass through formerly mined areas and explosives dumping grounds, as well as pass through a Natura 2000 nature protection area on

6 525 kV cable system power density comparisons



6a With a 320 kV extruded DC cable system; comparison for 1.5 GW or less (525 kV Al, 320 kV Cu)

6b With MI cable (Al conductors)

the Lithuanian side. The cable strengthens electricity supply and energy security on both sides of the Baltic Sea and integrates the emerging Baltic electricity trading market with the Nordic market.

A new, more powerful cable system

Extruded HVDC cable system technology is appropriate when power needs to be efficiently transported through populated or environmentally sensitive areas, or in coastal and open-sea applications.

ABB developed and successfully tested a 525 kV DC cable system with a power rating well above 2 GW for both subsea and underground applications. This innovative system utilizes a new cross-linked polyethylene (XLPE) DC insulation material, an oil- and porcelain-free termination based on ABB's technology for bushings, a land joint and a flexible sea joint. This new 525 kV HVDC cable system opens up an exciting future for power transmission and is a major step toward a DC grid vision for the integration of energy markets and greater utilization of renewables ➔ 4. A single 525 kV extruded HVDC cable pair – with each cable the diameter of a compact disc – can transmit enough power from large offshore wind farms to supply 2 million households.

> HVDC is a more cost-efficient technology for transmission of large amounts of power over long distances.

A good HVDC cable insulation material should have a low DC conductivity to avoid thermal losses. The conductivity of insulation materials increases with the electric field and temperature. Therefore, higher conductivity increases the risk of thermal runaway and electrical failure. ➔ 5 compares the conductivity of the new cables with that of other cables. In the latter, the risk of thermal runaway increases when the type test voltage exceeds 600 kV, in the former, this risk is negligible – even with much higher voltage levels.

The new terminations are based on existing ABB HVDC bushing technology. The polymeric composite insulator used offers maximum safety without the risk of shrapnel from explosions. This safety is provided by elastomer elements (adapters and stress cone) – including a material with highly nonlinear electric properties and geometric elements.

The 525 kV extruded DC cable system can transmit 50 percent more power over extreme distances than previous solutions (eg, the 320 kV extruded DC system). The technology enables the lowest cable weight per installed megawatt of transmission capacity and the higher voltages provide reliable transmission and low energy losses.

Compared with the 320 kV level, the transferred power given as MW/kgm (power per kilogram of one meter cable) is about double that of a land cable circuit and 50 percent more than a submarine circuit ➔ 6a.

When compared with "classic" HVDC cables with their insulation comprising paper impregnated with a highly viscous oil (also called mass-impregnated or MI cables), the extruded DC cable system has an advantage in terms of MW per kg and meter cable ➔ 6b. Also jointing time is significantly shorter for an extruded cable system compared with the MI cable.

The trend toward more and larger renewable energy plants is very clear and very strong. FACTS and HVDC technologies will help support interconnected, flexible and reliable grids. Many innovative and sophisticated products are already available to help overcome the challenges involved with RE integration and enhance the power system flexibility and efficiency required to satisfy the ever-growing need for energy around the world. New possibilities will be opened up by new technologies and products, such as ABB's 500 kV VSC converter stations or the new extruded 525 kV HVDC cable. Advances such as these reflect ABB's commitment to remain leaders in the development and use of power transmission technologies.

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Regulating life's ups and downs

Increasing grid capacity to connect renewable energies

MARTIN CARLEN, ADAM SLUPINSKI, FRANK CORNELIUS – José González sang, "I see problems down the line, I know that I'm right," and while that may be the case in some situations, ABB's line voltage regulator prevents problems down the line by automatically adjusting voltage to a regular level and making the distribution grid "smarter." Many countries have important targets to increase the amount of electric power generation from renewable energies. Wind and solar energy are especially in focus. With this shift from traditionally centralized power generation to decentralized local generation, the conditions in the electric grids are also changing. The distribution grids experience not only voltage drops due to the loads, but also voltage rises caused by local generation, and so large variations of voltage may occur. A line voltage regulator manages these variations, which means that, as far as renewables in the electricity grid go, Mr. González is wrong.

Because generation is higher than the load power, the voltage rise can be very pronounced and exceed the allowed voltage band.

By the end of 2014 a total power generation capacity of about 195 GW was installed in Germany. The capacity of wind power and of photovoltaic (PV) power each contributed, with 38 GW, close to 20 percent of the total. During sunny and windy weekends, up to 80 percent of electricity is generated from renewable resources. Germany's target is to increase the share of renewables in the electricity mix from the existing value of 27 percent to 50 percent by 2030, and to 80 percent by 2050.

Due to Germany's "Energiewende" (energy transition) decision, the country is quite advanced in the conversion from traditional power generation to renewables, but many other countries are following that path. Globally, China is leading the investments in renewable energy, where renewable power capacity now surpasses new fossil fuel and nuclear capacity. In the United States, a number of states have set mandatory targets for the percentage of renewable power generation, eg, the State of New York with 30 percent by 2015 and California with 33 percent by 2020. By the end of 2014, global installations of wind power exceeded 350 GW and PV power exceeded 180 GW.

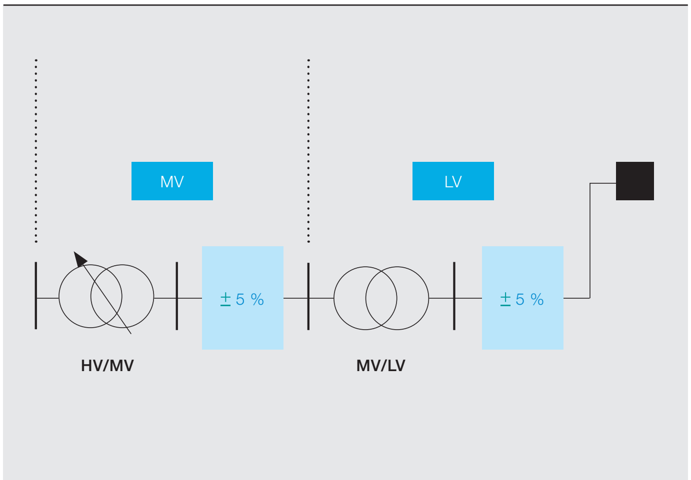
Contrary to large centralized power plants, many of the renewable energy generators feed into the local distribution grid, either at low voltage (LV), which is mostly for PV, or at a medium-voltage (MV) level, which is mostly for wind power. Traditional distribution grids are designed to cope with the existing and expected future power flow of connected consumer loads, but were not designed for decentralized in-feed, which can sometimes be much higher than the load power.

Traditional distribution grids were not designed for decentralized in-feed, which can sometimes be much higher than the load power.

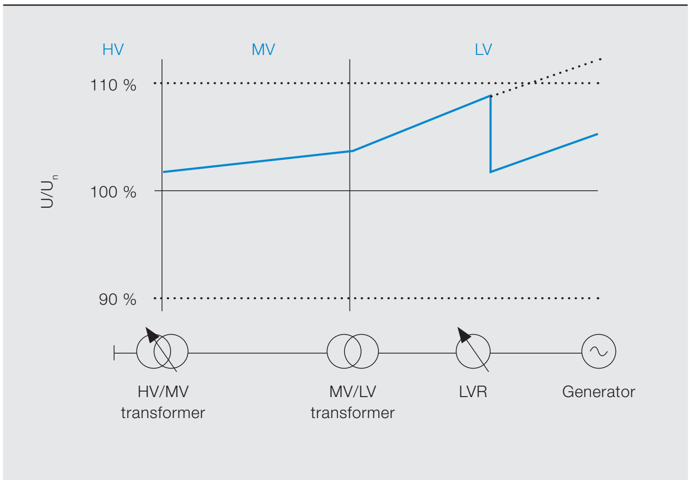
Especially in rural areas, generation of wind or PV power can quickly exceed the planned load power by a factor of 2 to 3 but can be as much as a factor of 10. Instead of a voltage drop along the electricity line from transformer to consumer, a voltage increase occurs near the producer. In many cases, the current-carrying capacity of the existing cable or overhead line is not a limiting value, and the line is not thermally limited. However, because generation is higher than the load power, the voltage rise can

Title picture
An LV LVR installed between the distribution transformer, which is used by multiple customers, and the PV inverter.

1 Voltage range in the MV and LV distribution grid available for voltage drop or rise



2 Voltage rise caused by infeed of a local generator and reduction of voltage by an LVR



There are different solutions to the voltage rise problem. Which solution is the most economically effective depends on the specific case.

be very pronounced and exceed the allowed voltage band. This may result in the need to disconnect the generator.

There are different solutions to the voltage rise problem, like grid extension, installation of a voltage regulator, or use of reactive power. Which solution is the most economically efficient depends on the specific case.

European requirements for the grid voltage

The European standard EN 50160 [1] defines the requirements for voltage in public distribution networks. Under normal operating conditions the voltage at the customer site has to be within a range of ± 10 percent of the nominal voltage U_n. In other regions, demands can be even more stringent. In the United States, for example, ANSI C84.1 [2] requires the utility to deliver power at the building's service entrance within a range of ± 5 percent for LV and within −2.5 percent to +5 percent for MV.

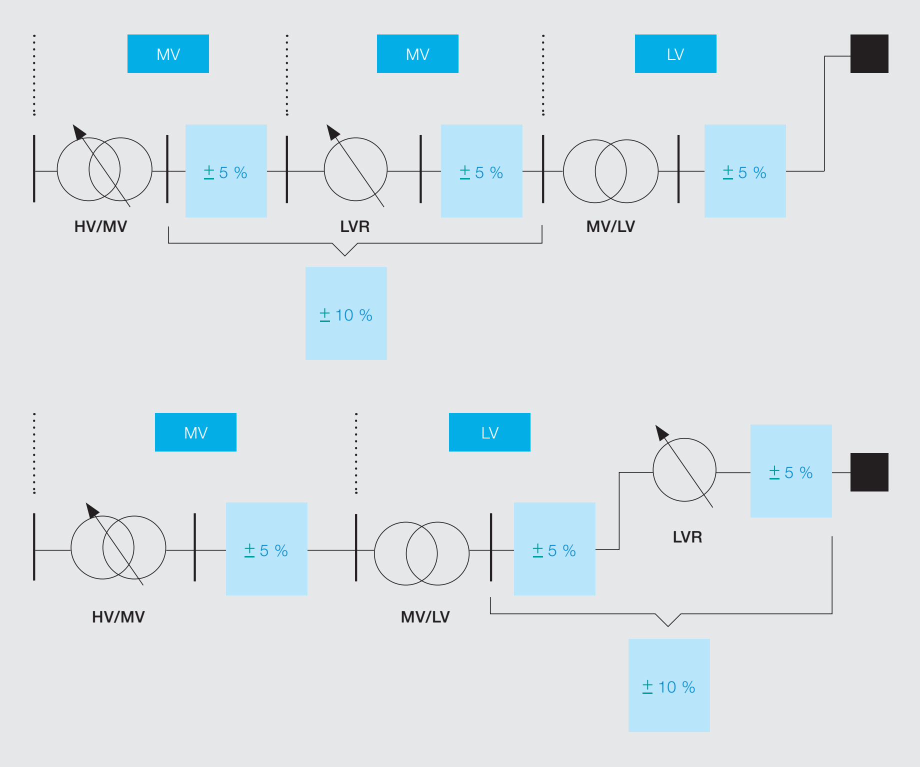
However, when considering today's methods for the design of distribution grids in more detail, it becomes evident that the different voltage levels are firmly coupled and individual network levels do not have the full voltage bandwidth available. The last transformer able to adjust the voltage is the high-voltage HV/MV substation transformer. The total voltage bandwidth must therefore be distributed between the subsequent MV and LV networks. This results in a reduced voltage available for a voltage rise caused by local generation.

In → 1 the ± 10 percent voltage bandwidth is equally distributed between MV and LV. In order to cope with all the different conditions at individual feeders, the grid design engineer needs to have defined fixed values. In this case ± 5 percent of the voltage bandwidth is attributed to each network level. It is also possible to asymmetrically distribute the voltage between the network levels. In Germany the LV grid typically gets only +3 percent for voltage rise. This quite quickly limits the amount of power that can be fed into the LV grid.

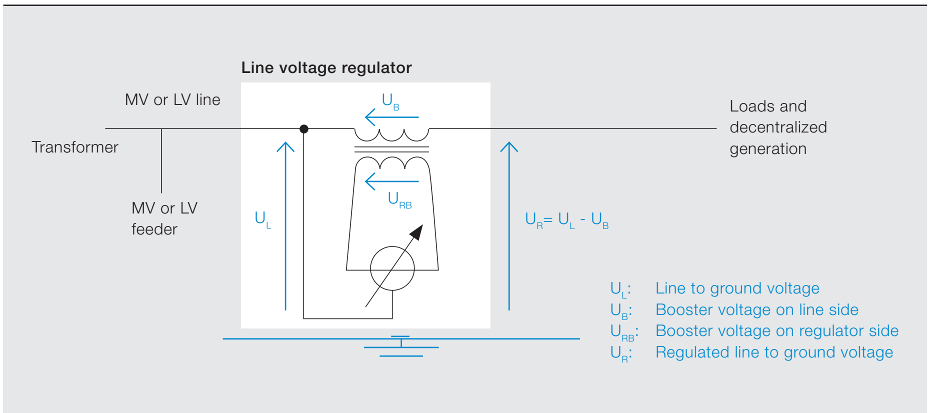
By using an LVR the available voltage range is significantly increased and additional power can be fed into the grid without exceeding the allowed voltage range.

The voltage drop in a typical copper cable with a 3 × 50 mm² cross section caused by the current, corresponding to a transmission power of 120 kVA at 400 V, reaches 3 percent after 45 m.

3 MV line (top) and LV line (bottom) with an LVR doubling the available voltage range



4 Functional principle of an LVR



An LVR is able to adjust or “recalibrate” the voltage level in the part of the grid subsequent to the LVR.

Recalibrating the voltage

By using a line voltage regulator (LVR), the available voltage range is significantly increased and additional power can be fed into the grid without exceeding the allowed voltage range. An LVR is able to adjust or “recalibrate” the voltage level in the part of the grid subsequent to the LVR ➔ 2. In this example a generator is located at the end of an LV line. Without an LVR the voltage exceeds the allowed range.

An LVR can be installed at any place in the grid. Depending on whether the installation is done in a single feeder line or at a bus having several feeders, only the voltage of the one feeder or of all feeders is regulated.

Voltage adjustments by the tap changer of the HV/MV transformer influence all MV and LV networks on its secondary side, although voltage drop and rise can be very different on individual feeders. The same is the case for regulated distribution transformers where voltage adjustments also influence the whole LV network.

In the case of a feeder with a high amount of generation power, the LVR decouples it from the rest of the network. The reduction in voltage allows an increase in the available capacity while staying within the allowed voltage range ➔ 3.

A transformer with an OLTC allows the transformer to change the voltage step-wise within ± 10 percent.

5 Medium-voltage LVR installed in a compact substation

Mode of operation of an LVR

An LVR creates an additional voltage, which overlays the existing line voltage U_l. This additional voltage is coupled in via a booster transformer and can be additive or subtractive. In → 4 a variable voltage supply, fed by the line itself, creates a voltage U_{RB}, which is transmitted as U_B into the line, resulting in the regulated voltage $U_R = U_L +/- U_B$.

A transformer with an on-load tap changer (OLTC) is used as a variable voltage source. It allows the transformer to change the voltage stepwise between ± 10 percent. The OLTC has a linear configuration, uses mechanical switches and introduces resistors in the diverter. The switches of the OLTC allow up to 3 million mechanical operations without the need for any maintenance.

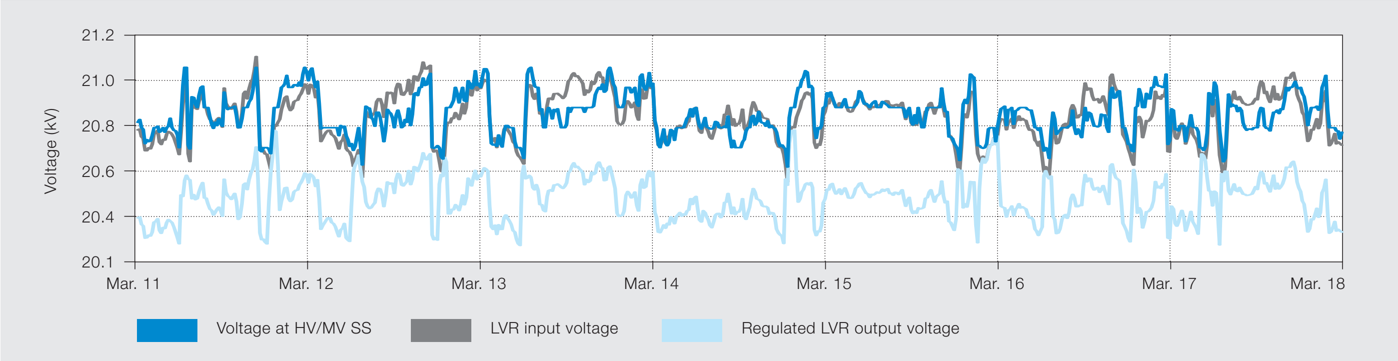
The switches of the OLTC allow up to 3 million mechanical operations without the need for any maintenance.

Dry-type transformers with RESIBLOC technology are used, making all components free of oil and elimintating any risk of fire or explosion. The RESIBLOC transformers are especially suitable for this application since they have high energy efficiency, offer high flexibility for providing any tap configuration, are mechanically very stable, are not sensitive to quick changes in load or temperature, and are qualified for temperatures down to – 60°C.

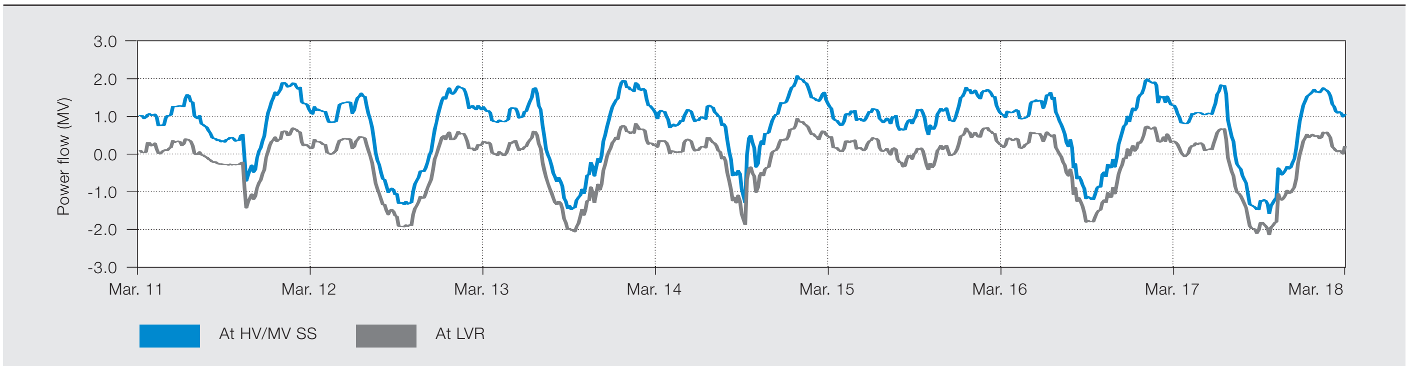
The ABB LVR does not create a galvanic separation in the regulated line and introduces a minimal additional impedance. The variable voltage supply circuit on the other hand is galvanically separated from the line. This feature makes the LVR equally suitable for use in grounded, impedance-grounded or insulated grids.

The LVR contains, in addition, disconnecting and/or earthing switches at the input and output sides, sensors for the measurement of voltage and current, as well as a bypass switch, allowing com-

6 Voltage and active power measurements during a one-week period in March 2015



6a Voltage



6b Active power

plete shunting of the LVR. The same functional principle is used for LV and MV.

An MV LVR installation in Germany

Westnetz is a subsidiary of RWE Germany and the major distribution system operator (DSO) for the western part of Germany. One of their 20 kV MV networks in the Eiffel region has over 200 generators connected (PV, biomass, small hydro) providing a total generation power of over 5 MW. The network currently extends over a length of 26 km and additional renewable power is to be connected in the coming years.

The LVR is equally suitable for use in grounded, impedance-grounded or insulated grids.

A grid study showed that neither active regulation of the HV/MV transformer nor broad use of regulated distribution transformers (totaling more than 60 MV/LV transformers) could solve the voltage rise problem. Westnetz therefore decided to use an MV LVR → 5. It is installed at a distance of 10 km from the HV/MV transformer. This solution turned out to be substantially cheaper than an upgrade of the grid. Also, in this case, the existing cables have a higher current-carrying capability and are not a limiting factor [3]. The whole installation, including planning and issuing of authority permissions, was realized within a few months, ie, in a much shorter period than a grid extension would allow.

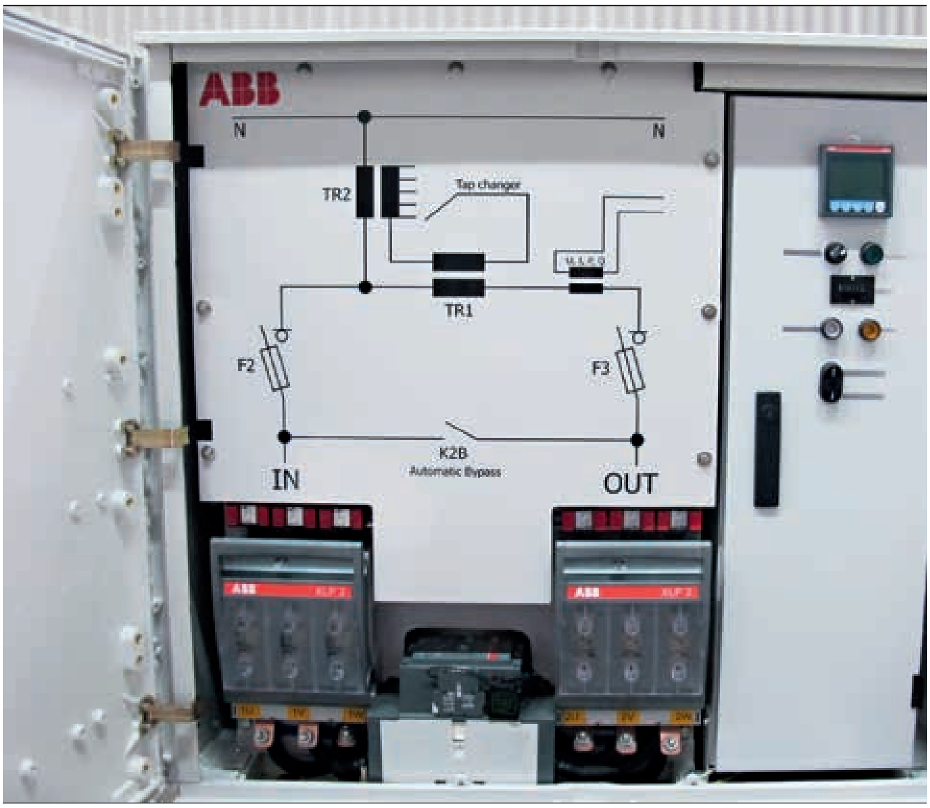
The LVR is able to adjust the voltage of transmitted power of up to 8 MVA by ± 10 percent. The voltage regulation is done in steps of 2 percent. The LVR has high short-circuit capability and voltage regulation occurs automatically. It is connected via RTU and GPRS communication to the grid control system. Westnetz has access at any time to measured values like voltage, current and power flow, as well as the status of the regulator. The LVR can also be operated in remote or local control mode.

Different modes for the control settings are available. It is possible to select a fixed voltage set-point value. The set-point value can be modified via remote control, or can, for example, be based

The LVR has a high short-circuit capacity and voltage regulation occurs automatically.

An LVR is able to automatically adjust the voltage of an LV or MV line, within a certain range, to a desired value and prevents the need for costly grid extensions.

7 Interior of a low voltage LVR



on a voltage measurement at a different location. The Westnetz LVR is operated by using a control curve, which is a function of the power flow and the flow direction on the MV line.

The graph in ➔ 6a shows the input (non-regulated) and output (regulated) voltage of the LVR and the voltage at the HV/MV substation (SS). The graph shows that during periods of high local power generation the LVR input voltage exceeds the substation voltage, while at night this reverses. The set-point voltage for the LVR is set to 20.5 kV. The regulated voltage remains well within a voltage control band set to ± 1.5 percent of this value. LVR input and SS voltage exceed 21 kV. Without LVR and with the maximum in-feed power of 5 MW, the voltage at the end of the network, 26 km away, would increase much more.

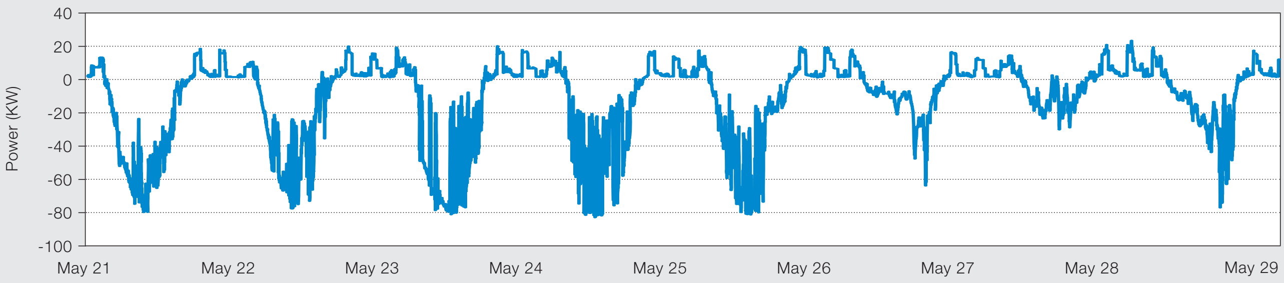
The set-point value can be modified via remote control, or can be based on a voltage measurement at a different location.

In ➔ 6b it can be seen that toward midday the power flow becomes negative, meaning that a power of up to 1.5 MW is fed from the MV network into the HV network. Overnight, typically between 5 p.m. and 9 a.m., the power flow reverses and up to 2 MW is supplied from the HV grid. March 15 seems to have been a rainy or very cloudy day since only a little power was locally generated.

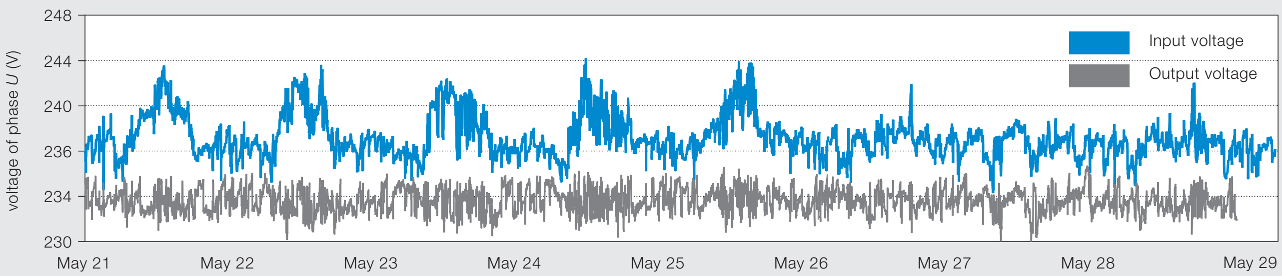
An LV LVR installation in Switzerland

The roof of a farmhouse was to be covered with PV modules, providing a maximum power output of 134 kW. The farm is connected to the distribution transformer by a 250 m long 400 V cable. Several other customers are connected to the same transformer. A grid simulation carried out by ABB showed that the cable does not have a thermal limitation, but that the voltage rise will exceed the allowed range. An LV LVR was therefore installed in the middle, between the distribution transformer and the PV inverter ➔ 7 [4]. The LVR is installed in an LV

8 Voltage and power measured during a period of eight days in May 2014



8a Active power



8b Voltage

cable distribution cabinet. Also, in this case, the installation of an LVR was much less expensive than adding additional cables.

The LVR can regulate the voltage for a transmitted power of up to 250 kVA. The standard regulation range is ± 6 percent, or ± 8 percent, in voltage steps of 1.2 or 1.6 percent. Differences in the daily power profile seen in → 8 represent the different weather conditions: While it was mostly sunny during the first five days, on day seven there was hardly any sun. Especially on days three, four and five the varying voltages indicate that there was broken cloud cover. During the night there was a load of 20 kW that was regularly connected.

Problem solved

Distribution grids are traditionally designed to cope with the expected power of existing and future loads. While the feed-in of renewable generation is increasing, the peak power of the generation can easily become a multiple of the peak load, bringing distribution grids to their limits. In many cases the limiting factor is not the transmission capability as such, but complying with the allowed voltage range.

An LVR can easily solve this problem. An LVR is able to automatically adjust the voltage of an LV or MV line, within a certain range, to a desired value and prevents the need for costly grid extensions.

The ABB LV LVR is installed in standard LV cable distribution cabinets. In most cases utilities do not need to get special permission to carry out such installations and LV LVR installations can therefore be realized very quickly. The MV LVR is installed in a concrete substation, completely mounted and tested, and only the MV cables need to be connected to the integrated MV switchgear. In both cases the LVR can easily be relocated and installed at another location if the situation in the grid is changing or further connection of generators requires a reinforcement of the grid.

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Energy storage

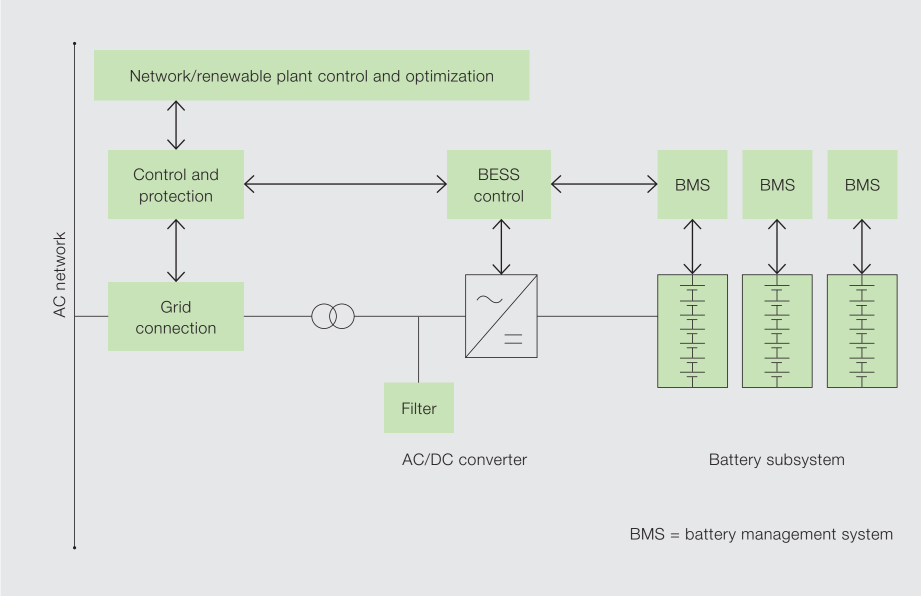
The benefits beyond the integration of renewables

PAT HAYES, JANISSA AREVALO – Many countries are currently in the early stages of a renewable energy revolution. However, as solar- and wind-based generation capacities in electrical power networks soar, operators are finding it increasingly difficult to maintain grid stability and reliability. Two of the principal reasons for this are the short-term variability and low predictability inherent to renewable sources. Energy storage systems can address these issues and thus provide an important contribution to the evolution of the electrical power grid. However, energy storage can do even more than that: Placing energy storage strategically across utility fleets can also offer new ways to enhance the provision and pricing of electrical energy and associated services and provide a way to optimize the entire power system.

Title picture
Strategically placed energy storage systems can transform the business model of enterprises involved in the supply of electrical energy.

The benefits of energy storage span power generation, transmission and distribution – ie, from the generator all the way to the end user.

1 Functional block diagram of a battery energy storage system



Electric energy storage encompasses a broad range of technologies: batteries, flywheels, pumped storage, heat storage and compressed air. Even electric vehicles can be used to store energy. At present, most utilities favor battery energy storage systems (BESSs) as these are easily scalable and can be located almost anywhere.

Regardless of which technology is being used, a complete energy storage system (ESS) – ie, one that can operate in standalone mode or be connected to the grid – has four major components: the storage medium, the control system, the power conversion system and the balance of plant (BOP). The design of these components strongly depends on the energy storage application and the power rating required. The storage medium can be based on one of many battery technologies – eg, lithium-ion, sodium-sulfur, nickel-cadmium, lead-acid, or flow batteries. For higher power requirements, several power converter systems can be connected in parallel to provide dynamic control of active and reactive power flow in both directions. Furthermore, monitoring and control systems that allow manual and automatic operation of all components supplement the energy storage system. Communication protocols support remote control and monitoring and may provide load and weather forecasts. In addition to the system components, BOP equipment such as transformers, protection equipment and switchgear are needed to ensure a safe and reliable grid connection and operation of the system [1] ➔ 1.

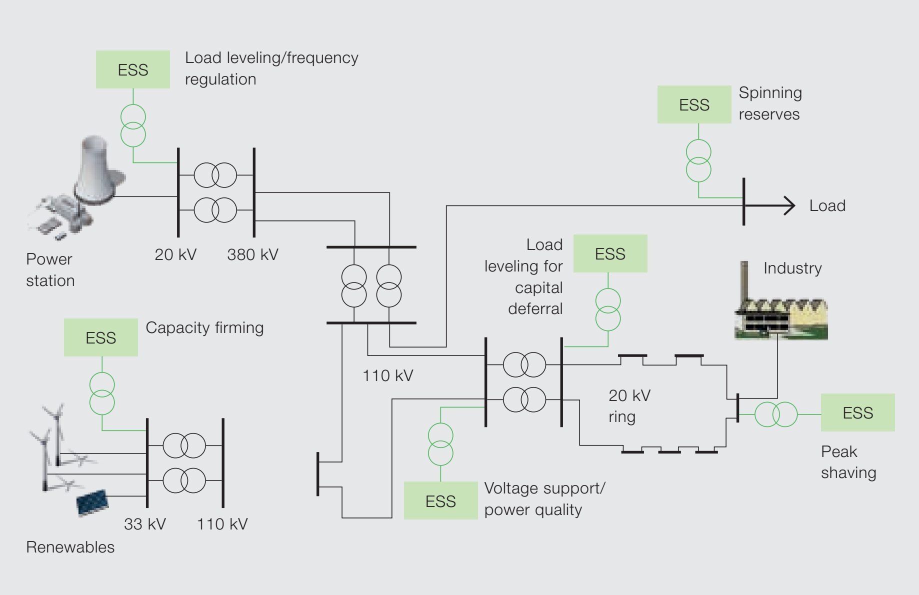
ABB's Enterprise software builds a link between the energy storage system and the consumer.

Applications and benefits of energy storage

The benefits of energy storage span power generation, transmission and distribution – ie, from the generator all the way to the end user. Further, modern storage technology and power electronics can support the operation of large, interconnected infrastructure – as well as small, isolated power system setups – across a wide range of applications ➔ 2.

Frequency regulation

Using energy storage to provide ancillary services such as frequency regulation or



To provide an effective spinning reserve, the ESS is maintained at a level of charge ready to respond to a generation or transmission outage.

to act as spinning reserves for the electrical grid is proving to be a successful business model that has minimal operation and maintenance costs – with a significantly lower carbon footprint than conventional generation. For frequency regulation applications, the ESS is charged or discharged in response to an increase or decrease, respectively, in grid frequency caused by a sudden misalignment of energy supply and demand. This approach is particularly attractive due to its rapid response time and emission-free operation.

Peak shaving is similar to load leveling, but is for reducing peak demand rather than for economy of power system operation.

Spinning reserve
To provide an effective spinning reserve, the ESS is maintained at a level of charge ready to respond to a generation or transmission outage. The system can respond within milliseconds to supply power to maintain network continuity while the backup generator is started and brought online. This enables generators to work at optimum power output, without the need to keep idle capacity for spinning reserves.

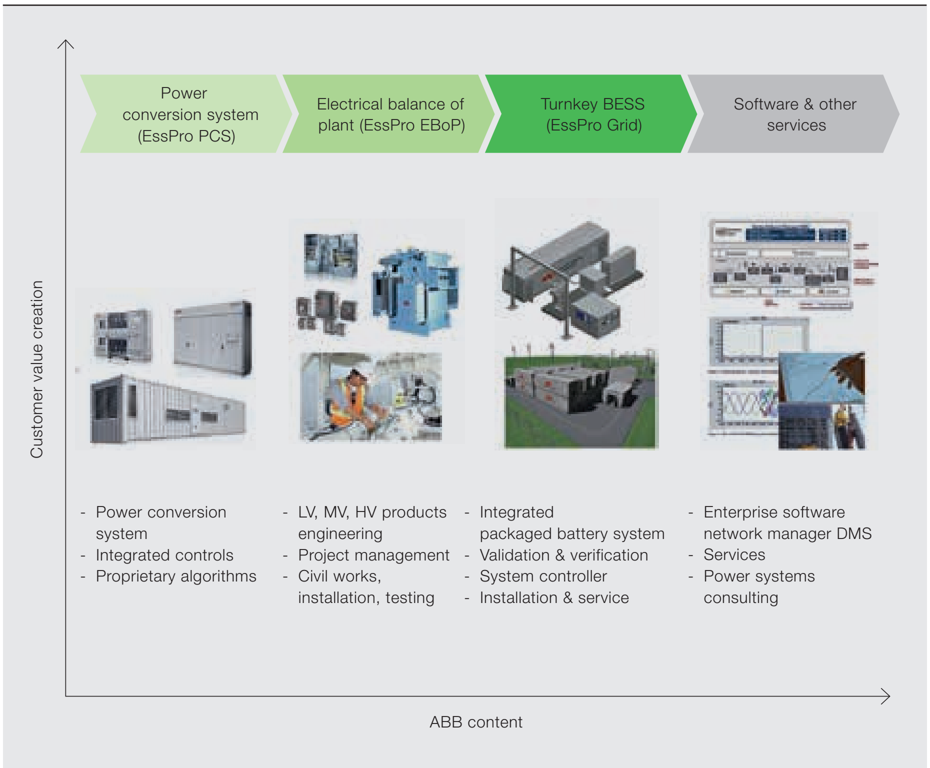
Load leveling
Load leveling usually involves storing power during periods of light loading on the system and delivering it during periods of high demand. During the periods of high demand, the ESS supplies power, reducing the load on less economical peak-generating facilities. Since utilities must design their network according to the peak power usage capacity, having energy storage strategically located next to the load allows for the postponement of investments in grid upgrades or new generating capacity.

Peak shaving
Peak shaving is similar to load leveling but is for reducing peak demand rather than for economy of power system operation. Peak shaving installations are often owned by the electricity consumer rather than by the utility. Commercial and industrial customers benefit from optimized time-of-use energy cost and demand charge management.

Power quality
For power quality applications, an ESS may help to protect downstream loads against short-duration events that affect the quality of the power delivered. For instance, voltage fluctuations due to

For every application, ABB offers optimized energy storage components and complete solutions that help to maintain grid stability and ensure reliable and high-quality energy supplies.

3 ABB's offering: From power conversion systems to integrated solutions



events such as power equipment failure, tree branches falling on the power line or the variability of power output from solar photovoltaic (PV) plants and wind farms, can have adverse impacts on the quality of power delivered to electricity consumers. These power quality issues can lead to brownouts and possibly a complete power interruption. ESSs can provide instantaneous voltage support by injecting or absorbing both active and reactive power. In addition to voltage support, the ESS may serve as an uninterruptible power supply (UPS) that can bridge unplanned disruptions in service, thus further enhancing the quality of power supplied to the energy consumers.

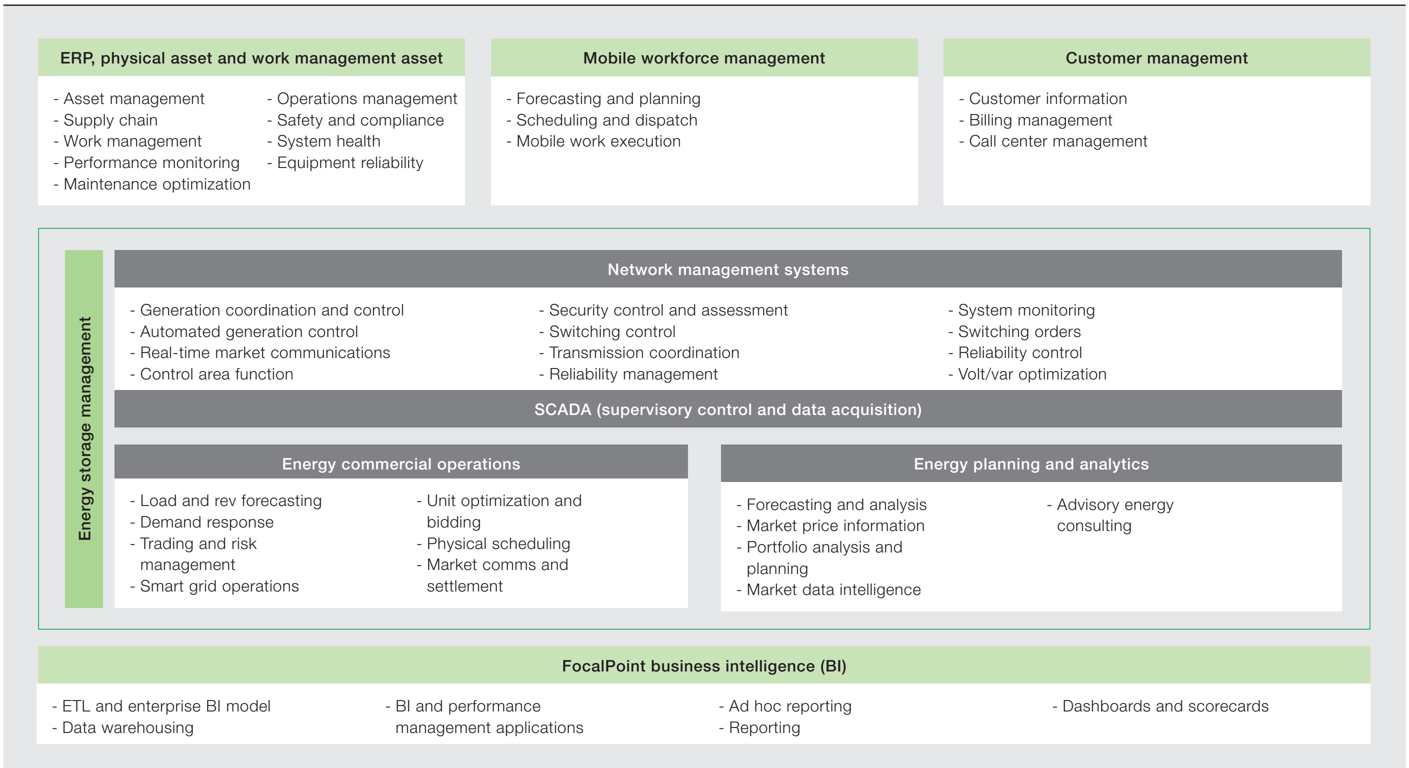
ABB's solutions are available for power requirements ranging from hundreds of kilowatts to tens of megawatts and are ready for connection to medium- or high-voltage grids.

Capacity firming
Maintaining the variable, intermittent power output from a renewable power plant at a committed (firm) level for a period is called capacity firming. The ESS smooths the output and controls the ramp rate (MW/min) to eliminate rapid voltage and power swings on the electrical grid.

For every application, ABB offers optimized energy storage components and complete solutions that help to maintain grid stability and ensure reliable and high-quality energy supplies. ABB's solutions are available for power requirements ranging from hundreds of kilowatts to tens of megawatts and are ready for connection to medium- or high-voltage grids [2] → 3. For example, ABB's EssPro™ Grid system features include dynamic active and reactive power control, active filtering of harmonics, islanding mode and black start capability. Furthermore, the implemented advanced control algorithms ensure compliance with the utilities' standards through in-depth knowledge of grid codes.

Taking a strategic approach
To realize these benefits, energy storage has to be an integral part of utility net-

4 Enterprise software solution map



works, not an isolated component to meet an immediate local need. Adding energy storage is more complicated than simply buying the hardware, connecting it to the grid and normalizing the voltage. Utilities need to look beyond the tactical or local level and take a holistic – or strategic – view of both the physical and financial components of energy storage.

The first step should be to develop a long-term resource plan to meet the utility's portfolio goals, independent of the particular energy storage technology at the outset. This enables the utility to determine how best to dispatch stored energy based on energy-price forecasts and, critically, how to provide electricity at the lowest cost.

Utilities that operate distribution grids need first to identify the weak points on the networks where energy storage can help to enhance system reliability and then determine the optimal point of common connection for it. ABB has a long experience in performing grid studies and can support the process for an optimized BESS design in relation to the technical and economic aspects.

Furthermore, grid operators are required to make decisions based on the performance of their network. These decisions are based on electricity price predictions and the use of those prices to forecast how often their energy storage facilities will run and how profitable they will be over a particular period. This requires additional inputs involving forecasts based on weather, forecasted load, grid knowledge, and system lifetime and lifecycle costs. By considering all of these key elements, the energy storage system can facilitate operational efficiency and enhance grid reliability.

Maximizing performance

Once this strategic analysis is completed, the utility will be in a position to determine the optimal storage technology and its size for each application. To get the maximum benefit from its investment in energy storage, a utility has to employ it as efficiently as possible – and for the greatest return at any given time. This requires software capable of monitoring and controlling more than just a single energy storage facility – the software has to enable grid operators to visualize their entire network.

ABB's Enterprise software builds a link between the energy storage system and the consumer. It can map distributed energy resources on the grid while also employing advanced algorithms to analyze weather forecasts and projected load

For frequency regulation applications, the ESS is charged or discharged in response to an increase or decrease, respectively, of grid frequency. This approach is a particularly attractive option due to its rapid response time and emission-free operation.

ABB's EssPro Grid system features include dynamic active and reactive power control, active filtering of harmonics, islanding mode and black start capability.

5 1 MW/15 min EssPro Grid BESS at EKZ in Dietikon, Switzerland

profiles to help utilities optimize the energy storage system's charging and discharging schedules ➔ 4. This not only enhances operational efficiency but also provides immediate access to those who need to use energy storage resources.

Improved power storage and grid stabilization

In 2012, together with EKZ – one of Switzerland's largest energy distribution companies – ABB commissioned the largest battery energy storage project of its kind in Switzerland ➔ 5. To enable additional power to be provided to the grid on demand, ABB supplied and installed a lithium-ion battery BESS that can provide 1 MW for 15 minutes. The storage facility is integrated into EKZ's power distribution network and is being evaluated for balancing peak loads, handling intermittent power supply and optimizing the grid. In island mode, it can power a complete office building. The BESS enables reactive power control and it can serve as a primary regulatory reserve for the transmission network. Significant experience has also been gained with the integration of a solar PV plant and electric vehicle charging stations.

A BESS to support solar power integration on Kauai Island

As a cluster of islands situated thousands of miles from the mainland, the state of Hawaii in the United States needs to import nearly all the fuel used to generate electricity. This leads to high energy costs. As a result, the state is embracing renewable energy sources with the intention of these meeting its entire energy needs by 2040. Kauai Island Utility Cooperative (KIUC) – a local not-for-profit utility in Hawaii serving 32,000 customers – is looking to BESS technology to help maintain its system reliability and efficiency as it continues to procure significant amounts of renewables.

As electricity systems becomemore complex, the importance of BESSs along the entire power value chain will further increase.

6a Indoor package

6b Outdoor package

As part of a new 12 MW solar energy park under construction in Anahola, KIUC deployed a 6 MW/4.63 MWh lithium-ion BESS consisting of eight battery containers supplied by SAFT (a leading producer of advanced batteries) and two containers housing an ABB 6 MW power conversion system. The main purpose of the BESS is to regulate the distribution voltage on the AC bus to prevent undervoltage and overvoltage conditions; serve as a spinning reserve to provide instant backup power supply in the event of unplanned outages; and help maintain frequency levels during the loss of generation or a sudden increase in demand.

Energy storage to support wind power integration in Canada

In 2013, the Cowessess First Nation installed an 800 kW Enercon wind turbine along with a 400 kW/744 kWh lithium-ion battery storage system and an ABB EssPro power conversion system on tribal land in Saskatchewan, Canada. Along with smoothing out the ebbs and flows of power from the wind turbine, the storage system also reliably dispatches power at times of peak demand.

On a windy day, the Cowessess system can dispatch 1 MW of electricity for a full hour – 800 kW from the wind turbine and 200 kW from the batteries. In addition, the system can be employed to firm the turbine's output for extended periods. The project verified that the system is compliant with anti-islanding standards when the grid was absent and the wind turbine was still in production. The system was also used in coordination with the Sask Powers utility's demand response programs and proved to be a valid technology for this application.

ABB's turnkey BESSs provide an essential contribution to the enhancement of system flexibility that is needed to accommodate significant amounts of renewable energy on the grid and to optimize power generation management around the world → 6. As electricity systems evolve and become even more complex, the importance of BESSs along the entire power value chain will further increase.

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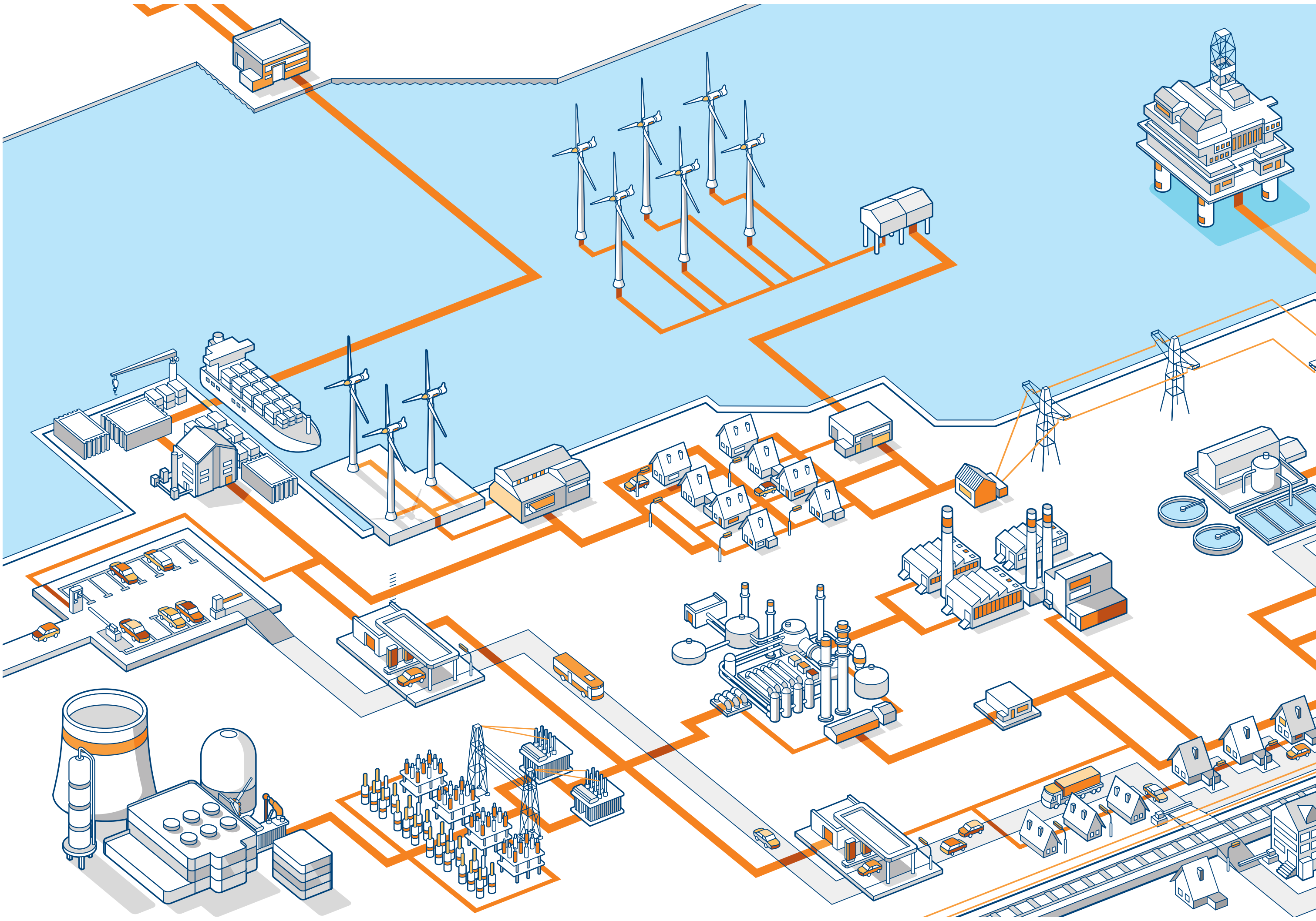
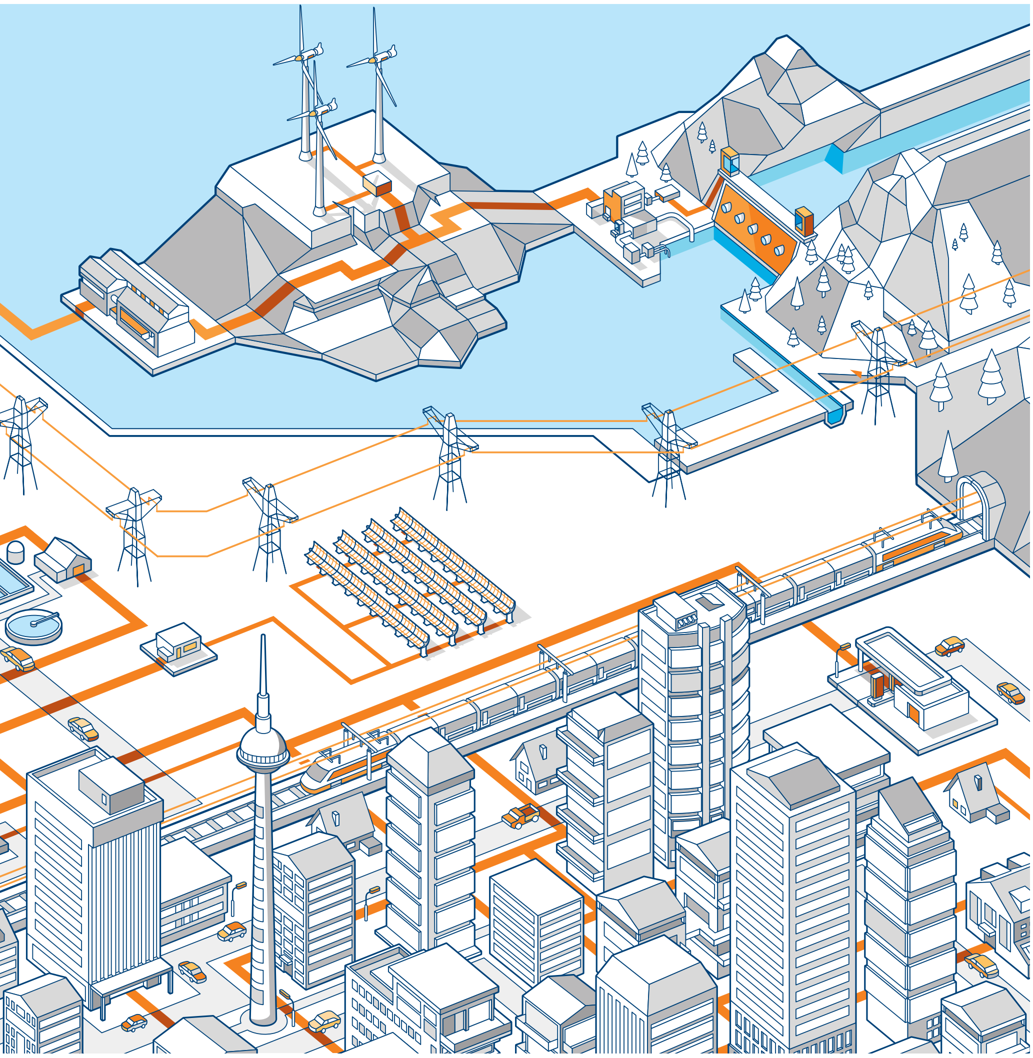


Consulting the grid code

ABB and its power consulting experts are helping networks integrate renewables and meet grid code requirements

INÉS ROMERO, JOHN DANIEL, DIOGO PEREIRA, FAHD HASHIESH, NIHAR RAJ, BRITTA BUCHHOLZ – Renewable generation is very different to conventional generation in terms of predictability and availability, inertia and the ability to provide both active and reactive control. Additionally, much has happened in the market since the first renewable power plants were built. Facility sizes now range from some kilowatts up to gigawatts and may be part of an isolated and/or weak system or be part of a strong developed network. Therefore, transmission system operators (TSOs) and distribution system operators (DSOs), who are responsible for guaranteeing a continuous, reliable and high-quality power supply in the grid, are constantly working on more demanding operational requirements (grid codes) to ensure the controllability of these resources.



The increasing penetration of large amounts of renewable energy in transmission and distribution networks has increased the concerns of TSOs and DSOs, who need to guarantee a continuous and reliable power supply in the grid.

Through onshore and offshore power connections, the presence of renewables is a reality today in both transmission and distribution networks, coexisting with and/or substituting more and more conventional generation. Wide experience in the renewables sector and a large number of projects performed worldwide allow ABB experts to offer customers high-level technical and economical assessments to cope with these changing demands and requirements.

Evolution of grid codes

The increasing penetration of large amounts of renewable energy in transmission and distribution networks during the last decades has increased the concerns of TSOs and DSOs, who need to guarantee a continuous and reliable power supply in the grid.

Title picture

Renewable generation is diverse and is part of a varied power network. Grid codes are essential to ensure a continuous, reliable and high-quality power supply.

The concerns include:

- Continuity: The uncertainty related to the unpredictable capability of renewables may have an impact on the grid stability and therefore on the continuity of supply.
- Quality of supply: Introducing new technology and connecting to lower short-circuit networks may result in higher harmonic emissions, voltage fluctuations and resonances. Reactive power capability is also critical in order to guarantee acceptable voltage levels.
- Reliable and secure supply: Disconnection of large amounts of renewable resources may impact the overall stability of the grid. Available spinning reserve is needed to ensure a secure operation.

Grid codes traditionally focused on static reactive-power control, power factor and dynamic requirements such as low-voltage ride-through (LVRT) capability. The codes are now evolving into more demanding requirements including dynamic control of reactive-power, voltage and frequency at the point of connection, and power quality – ie, full control of the facility. The key changes from the TSO perspective are outlined in → 1. Challenges to various distribution systems in different countries are presented in [1].

Grid codes are evolving into more demanding requirements including dynamic reactive power, voltage and frequency control at the point of connection and power quality.

1 Key changes to grid codes

Requirement topic	Traditional requirements	New requirements
Active power and frequency control	- Steady-state frequency control according to TSOs' acceptable frequency ranges - Protection settings	- Frequency control from individual equipment (inverter/wind turbines) expected at point of connection (POC) according to TSOs' defined time response ("plant controller")
Reactive power and voltage control	- Power factor at the POC - Dynamic capability to support faults - Steady-state voltage control according to TSOs' acceptable voltage range - Protection setting	- Reactive capacity mapping at POC according to individual equipment - Dynamic voltage/reactive power control at POC (plant controller)
Power quality	- Harmonic distortion and flickering levels	
LVRT	- Capable of enduring the fault with highly demanding requirements in terms of reactive power injection to the grid	
Modeling, testing and certification	- Steady-state network model - Dynamic black-box models if required to fulfill reactive power requirements during the fault - Individual and/or aggregated generation model - Applicable tests to demonstrate compliance with connection requirements for individual equipment (turbine/inverter) - Certification required for new equipment	- Fully dynamic network model to ensure reactive power/voltage/frequency control at POC (plant controller) - Harmonic equivalent network model
Operation and maintenance	Basic maintenance expected	TSO and owner generator shall agree on the appropriate maintenance plan of production facilities in a timely and orderly fashion
Ancillary systems	Not applicable	- Power oscillation damping control - Virtual inertia - Ancillary service (primary/secondary frequency control) - Accurate forecast

Environmental concerns and political regulations, in parallel with available technology, are the main drivers for progressive renewable integration.

Grids with low potential for growth in energy consumption

North America and Europe have experienced progressive renewable penetration during the past two decades. Environmental concerns and political regulations, in parallel with available technology, are the main drivers for the change. Transmission power networks are well interconnected, robust and dimensioned with sufficient reactive power margins and spinning reserve to be correctly balanced. In addition, well-known operational and market rules exist.

To keep pace with the ambitious targets for 2020 and 2050 these networks are facing three main challenges. Specifically how to:

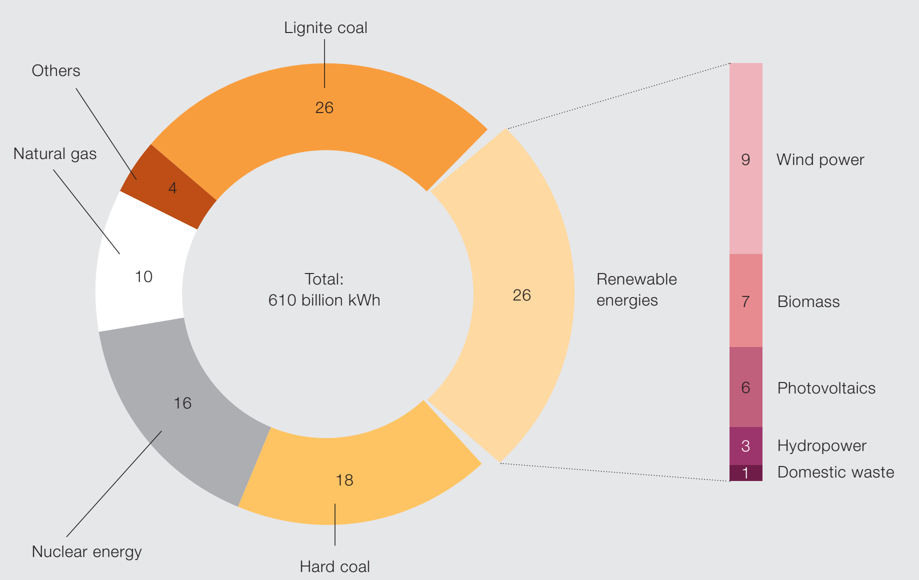
– Reinforce/adapt the existing power networks to allocate more renewable resources
– Integrate and control renewable generation in the distribution grid
– Cope with the expected new requirements from TSOs/DSOs for voltage control and frequency regulation.

United States

The installation of renewable energy, particularly wind energy in the United States, has often required reinforcement of the transmission infrastructure. One example is the transmission system within the Texas Interconnection with the Electric Reliability Council of Texas (ERCOT) as the system operator. In 2005, the Texas Legislature ordered the Public Utility Commission of Texas to designate Competitive Renewable Energy Zones (CREZ) and to order specific transmission improvements that would allow connections from the CREZ to load centers primarily around the Dallas/Fort Worth metroplex, Austin and San Antonio [2].

This reinforcement included over 3,700 km of new 345 kV transmission lines to accommodate an incremental 11,500 MW of wind generation capacity in western areas of the state. ABB performed an initial reactive power assessment in 2009 concluding at the outset with nearly 4000 MVAr of shunt reactors, about 960 MVAr of shunt capacitors, and 1,400 MVAr of static var compensators (SVCs).

2 Power sources contributing to the German power production grid



Source: AGEE-Stat and AGEB. © Statistisches Bundesamt (Federal Statistical Office of Germany), Wiesbaden 2015

ABB has been a pioneer in developing innovative components such as voltage regulators to solve individual challenges of power quality for distribution grid operators.

With regard to grid codes, there are some special provisions for renewable developers to comply with Federal Energy Regulatory Commission (FERC) Order 661-A for LVRT and reactive capability requirements, in addition to the general standards applicable to all power generation.

Spain

Spain has been a leader of renewable intergration for the past 15 years. A new draft for the local grid code is under discussion in which, on top of the traditional requirements, frequency regulation and voltage control are being considered.

Providing flexibility to the existing networks to maximize the use of the installed renewable capacity (about 23 GW vs. a peak load of about 40 GW) is a challenge today. Flexible AC transmission solutions (FACTS), energy storage and increasing the interconnecting capacity with HVDC are some solutions under study. ABB, in collaboration with the Spanish TSO Red Eléctrica de España (REE), has participated in the EU TWENTIES consortium, contributing with an important package of R&D studies to develop a real prototype [3] capable of redirecting the excess of renewable power flowing from one corridor to another with available capacity.

Germany

In Germany, over 1 million small generators are already connected to the distribution grid. Wind turbines and photovoltaics (PV) represent a total installed capacity of more than 76 GW, related to a peak load of about 80 GW → 2. Initially, small-sized generators were not required to be equipped with communication technology or remote control access. Today, the situation is the opposite. In the event of power quality problems, the grid operator is empowered to reduce feed-in. In general, fluctuating generators create challenges to keep the voltage within the defined band and the thermal load of assets is also a challenge.

In Germany, rules issued by Bundesverband der Energie- und Wasserwirtschaft (BDEW) and Verband der Elektrotechnik Elektronik Informationstechnik e.V. (VDE) cover grid codes for generators and storage in distribution system. ENTSO-E network codes such as “Requirements for generators” are also expected to become effective for Europe soon [4, 5]. ABB has been a pioneer in developing innovative components such as voltage regulators to solve individual challenges of power quality for distribution grid operators [6, 7].

United Kingdom

In the United Kingdom, apart from solar panels installed on domestic rooftops, the rest of the renewable infeed is large enough to follow the grid code, with which National Grid and users of its transmission system are required to comply. The UK electrical network (especially the southern part of it) has one of the highest electric energy densities

In South America, the Middle East and Asia the networks continue to develop at the same time that a large integration of renewables is taking place.

3 ABB is also supporting the integration of large PV plants.

in the world, causing a lot of difficulties when designing power plant networks and achieving grid code targets. High short-circuit levels; the need for power transformers with high impedance; voltage stability and power quality issues; and fast fault clearance demand are some of the challenges.

Grids with high potential for growth in energy consumption

In South America, the Middle East and Asia the networks continue to develop at the same time that a large integration of renewables is taking place, driven mainly by available technology, more accessible electricity prices, and investors bringing in successful experiences from other countries. The challenges of integration are:

- Stability issues due to limited margins of reactive power
- Lack of interconnection with neighboring countries and limited spinning reserve
- Poor power quality levels due to low short-circuit ratios
- Networks generally weaker in the areas away from the main cities

South Africa

ABB has participated in numerous local studies, exporting expertise worldwide [8]. Recently ABB experts have faced the challenge of developing a high-level plant controller in South Africa able to fulfill the new grid code requirements from Eskom in terms of voltage, power factor, reactive power control and power curtailment in a very short time → 3.

Brazil

In Brazil figures for wind and solar power generation in 2013 were 28 percent and 5 percent, respectively. The rapid integration of renewables is bringing new challenges in terms of power plant design and operation. To comply with the Brazilian ISO (ONS – Operador Nacional do Sistema Elétrico) grid code, ABB has been working on assuring appropriate modeling for wind turbine control → 4 and providing solutions to improve power quality.

The rapid integration of renewables is bringing new challenges in terms of power plant design and operation.

The ISO has been tracking measurement campaigns and participated in task force working groups to share and develop methodologies to define the grid code in terms of filtering optimization.

4 ABB has been ensuring appropriate modeling for wind turbine control in Brazil.

Changing and evolving grid codes are necessary for changing and evolving grid supply and demand.

Jordan

Jordan is facing a serious challenge on the energy front. It imports more than 97 percent of its energy, leading to high energy bills. This situation highlights the need to utilize alternate sources of energy, which are abundant in the country. The country aims to raise its dependency on local and renewable energy resources from 4 percent (in 2013) to 13 percent by 2016 and 39 percent by 2020.

ABB has studied the market trends, expectations and the renewables grid code to leverage opportunities posed by the booming renewable sector. The market has been approached proactively, an initiative that has been very well received by NEPCO, the transmission utility and renewable investors. Promoters have now approached ABB to extend grid integration support in Egypt. To get approval to connect the proposed RE plant to the grid, RE developers have to comply with all the requirements as per the grid code, something which ABB is well placed, and well experienced, to help them do.

Code connection

For many power network providers, keeping up with the ever changing and increasingly demanding grid codes is a draw on resources. It takes time to keep up, and to interpret changing or new grid codes, and to then extrapolate how those codes may affect the situation and what may need to change in order to remain compliant. ABB supports power providers through these changes, and their vast experience brings clarity and effectiveness to the review, assessment and decision making activities required.

Changing and evolving grid codes are necessary for changing and evolving grid supply and demand. But rather than these changes being a burden, ABB sees them as a positive opportunity for grid evolution: Much like the Chinese proverb that says, "When the winds of change blow, some people build walls and others build windmills."

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TAMING THE POWER

ABB Review series
Part II

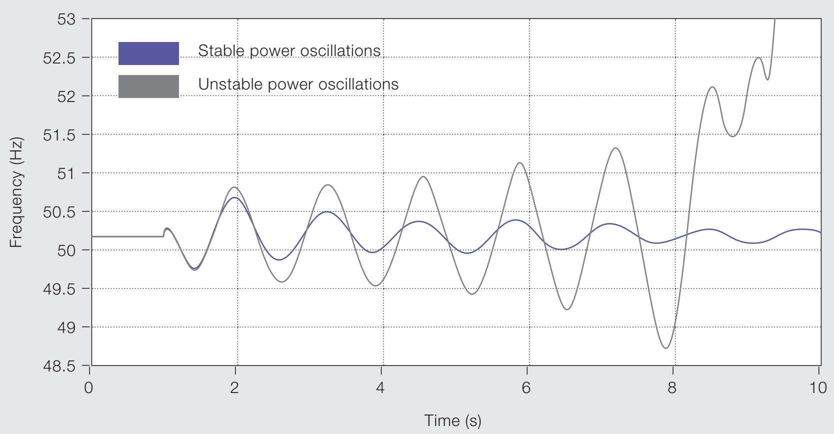
Balance the swing

Real-time monitoring and elimination of inter-area oscillations in large interconnected power systems

MATS LARSSON, LUIS-FABIANO SANTOS – Low-frequency, inter-area power oscillations are always present in large interconnected transmission grids. Usually, the oscillations are harmless, but certain fault conditions can create oscillations that steadily grow and lead to a partial or total power system breakdown. To avoid this, a power system operator should be able to monitor the ability of the system to damp the oscillations and should also have the facility to reduce power transfers if deemed necessary. In addition, the monitoring system should display valuable information on relevant events in other parts of the interconnected power grid, ie, parts not directly supervised and controlled by the operator in question. ABB's solution for synchronized phasor measurements and wide-area monitoring – called PSGuard – makes it possible to do all this. This article is one of an ABB Review series that looks at technologies that help keep the power grid under control.

Title picture
Harmful oscillations can arise between interconnected power grids. It is essential to monitor these closely and take action before they become destructive. How does ABB's PSGuard help with this?

1 Generator speed responses to a local fault with different power network characteristics



The phenomenon of inter-area oscillation can arise when grids are interconnected. In a large grid like the European one, thousands of power stations work together to supply the total load on the grid. The electrical machines in these power stations are kept rotating synchronously through their interconnection with power transmission lines. Should a machine rotate slower than the average machine speed in the system, it will automatically absorb energy from the grid to bring its speed up to the average value again. On the other hand, a machine rotating faster than the average will supply extra energy to the grid to reduce its speed.

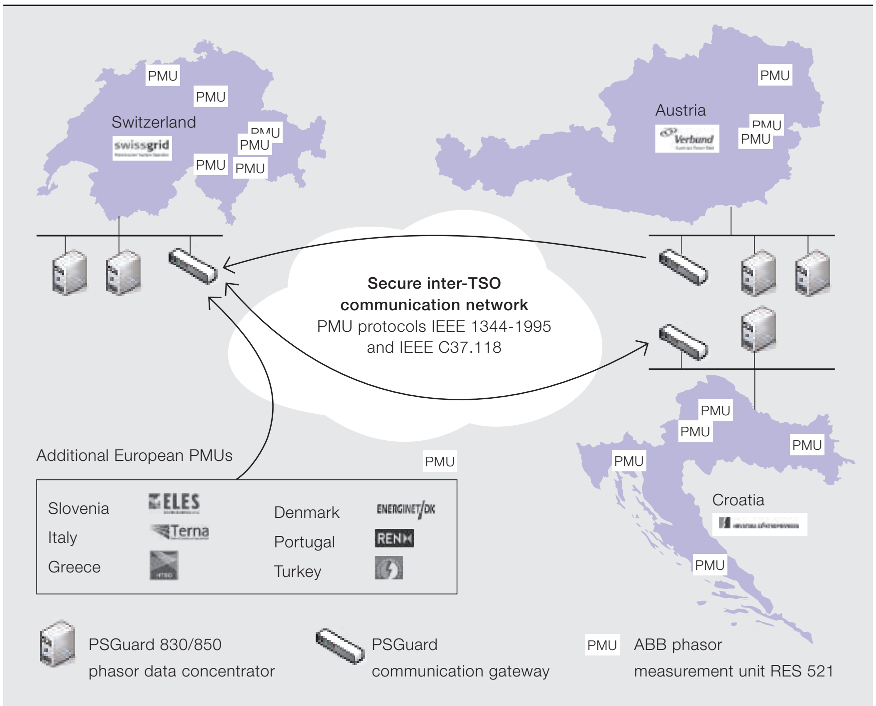
The torque that is applied to the generator shaft due to this self-stabilizing effect is called synchronizing torque and is the most fundamental mechanism in making the interconnection of power grids possible. However, this mechanism also makes it possible for speed variations to propagate and spread across entire interconnected power grids.

Also, there are control systems connected to each generator that have the task of keeping the rotational speed, and consequently the frequency, at the generator site constant. A typical generator frequency variation occurring as a result of a local fault is shown in → 1. Initially, the frequency increases since electrical energy cannot be supplied to the grid because of the fault, resulting in a higher speed. When the fault is cleared by disconnecting the faulty component, power transfer capability is restored and the machine – now operating above its rated speed – can again supply power to the grid, which decelerates the machine. When the generators' control systems are well-tuned to the operating conditions the result is similar to the blue line in → 1, where the oscillation is damped out in a matter of seconds. However, if the control systems are poorly tuned or malfunctioning, the result can be a growing oscillation – as illustrated by the grey line – that will eventually lead to a break-up of the interconnected system and possibly blackouts.

Detecting poorly damped oscillations

ABB has developed a real-time analysis tool called Power Damping Monitoring (PDM) that can detect poorly damped oscillations based on a system identification procedure using a phasor measurement unit (PMU). A PMU is a device that measures the grid voltage and frequency using a common synchronization time source.

2 Wide-area monitoring system at Swissgrid



PSGuard is the basic platform for wide-area solutions, enabling power utilities to introduce WAMS technology step-wise with minimal investment.

Time synchronization allows synchronized real-time measurements of multiple remote measurement points. A PMU can be either a dedicated device or the PMU function can be integrated into a device such as a protective relay. ABB's latest PMU – released at the start of 2015 – is called the RES670.

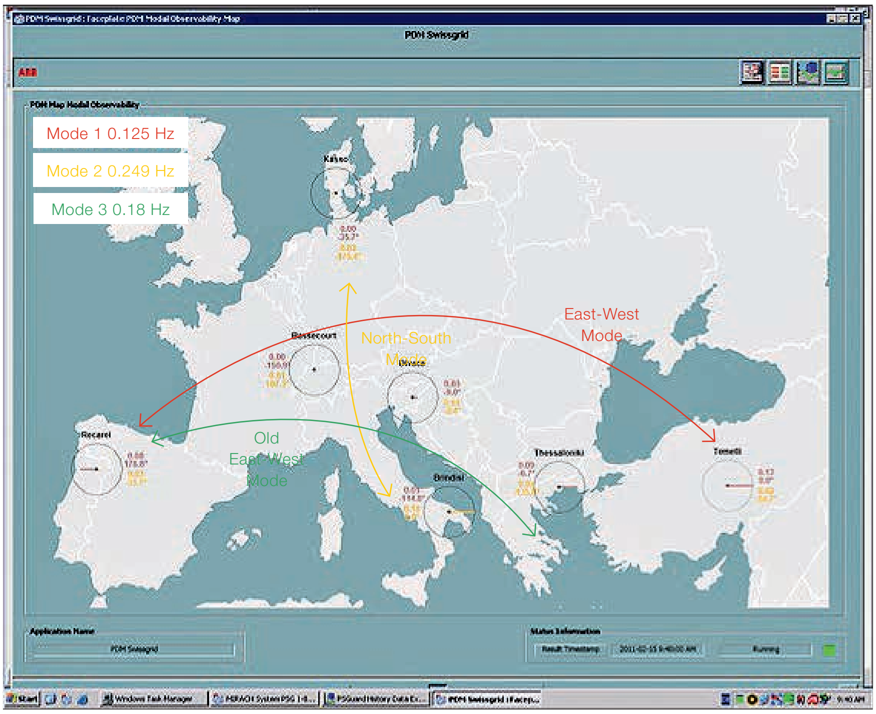
The PDM application provides information such as:
– The number of detected active oscillation modes.
– The frequency and damping of each mode.
– The amplitude of the oscillations in each mode and in each measurement signal.
– The modal observability, ie, a measure of how visible each oscillatory mode in each measurement signal is, as well as the relative phase in each measurement.

The mathematical background of the algorithm, results from simulation experiments and measurements in the Scandinavian power grid are described in [1]. It was benchmarked against other damping monitoring algorithms [2].

Wide-area monitoring system at Swissgrid

Since 2004, Swissgrid has been monitoring the Swiss transmission grid using a PSGuard wide-area monitoring system (WAMS) [3–6]. PSGuard enables integration of existing or newly installed PMUs into a WAMS, which allows phasor – ie, PMU – data to be collected at a central location. PSGuard is ABB's platform for wide-area solutions based on synchrophasors and it enables power utilities to introduce WAMS technology step-wise with minimal investment. PSGuard provides the operator with system supervision displays, trends, and event and alarm lists. The Swissgrid system was successively extended and is now interconnected with PSGuard systems in Austria and Croatia, enabling the real-time exchange of phasor data. Additionally, phasor measurements are exchanged with WAMS systems from other vendors in Denmark, Slovenia, Italy, Portugal, Greece and Turkey. Phasor data is transferred using the synchrophasor standard protocol (IEEE C.37-118) over a secure Inter-TSO (transmission system operator) communication network.

3 Map display showing the dominant inter-area modes in the ENTSO-E grid. The circles indicate the location of the PMU frequency measurements.



Since September 2010, the Turkish power grid has been connected to the ENTSO-E CESA system. The connection of Turkey resulted in a new dominant mode.

In total, the Swissgrid WAMS system collects data from 22 PMUs with a time resolution of 10 Hz. The setup now has excellent capabilities for monitoring inter-area oscillations in the ENTSO-E (European Network of Transmission System Operators for Electricity) Continental European Synchronous Area (CESA). The architecture of the hierarchical WAMS system at Swissgrid is illustrated in → 2.

Inter-area oscillations in the ENTSO-E power system

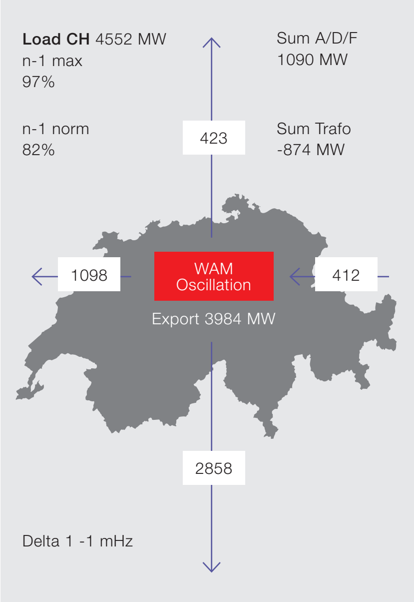
An extensive interconnected power system such as the ENTSO-E CESA – which encompasses Portugal to the west, Denmark to the north, Italy to the south and Turkey to the east – harbors a large number of oscillatory modes. These modes range from local plant modes with a relatively high frequency of 0.9 to 2 Hz to the slow, dominant inter-area modes that relate to differences in the coherent speed of generators in one entire network and that of generators in other network areas. Although the damping monitoring application will also detect local modes, the investigation here focuses on the inter-area modes.

In September 2010, the Turkish power grid was connected for a period in a trial mode to the ENTSO-E CESA system. The addition of Turkey resulted in a new dominant mode.

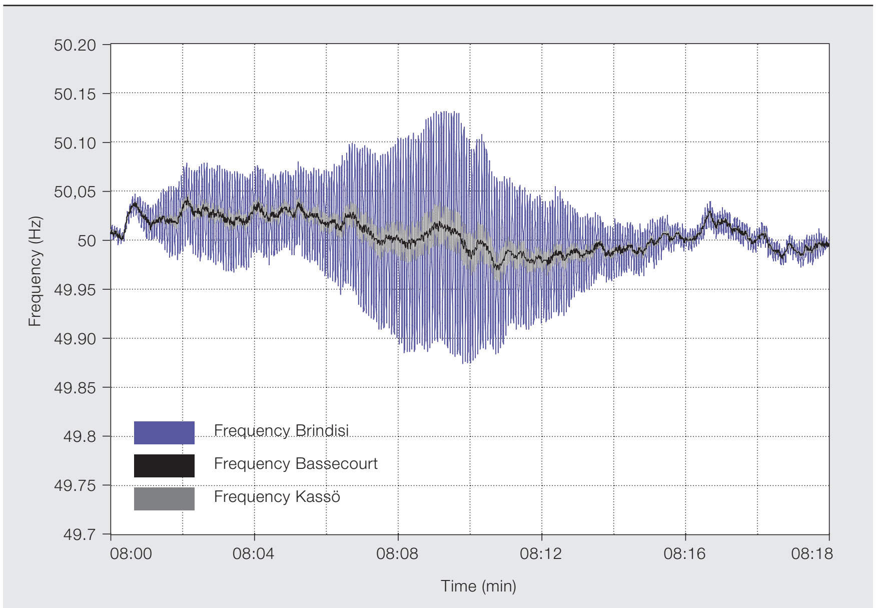
A damping monitoring application has been in operation at Swissgrid since December 2010 and it has continuously monitored the damping and frequency of inter-area modes in the CESA system. The application has been configured to use real-time frequency measurements with a time resolution of 10 Hz from the seven PMU locations shown with circles in → 3. This figure also illustrates the inter-area oscillation modes that have been detected by the damping monitoring application in the CESA system.

The east-west mode involves the coherent movement of generators in Portugal and Spain against those in Turkey. This mode typically displays a frequency of 0.13 to 0.15 Hz and appeared following the connection of Turkey. Under normal operating conditions, this is the dominant mode with the most oscillatory energy. Prior to the connection, detailed simulation studies and measures were taken to ensure damping of this anticipated

4 SCADA system screenshot during a detected inter-area oscillation



5 Recording of frequency measurements provided by the WAMS system at Swissgrid from the oscillation event of February 19, 2011



mode. Those measures included, for example, retuning power system stabilizers and the addition of active shunt methods such as static compensation (STATCOM) and static var compensation (SVC) with damping modules. The field recordings using WAMS indicate that those measures have been effective. The estimated time-domain damping is, most of the time, in the interval of 45 to 70 percent, which ABB considers adequate [3].

Detection and mitigation of critical oscillations

The dominant modes depicted in ➔ 3 are continuously monitored by performing online modal analysis and related parameter identification. If the system damping for one of the significant modes becomes too low and there is a large oscillation amplitude for longer than a few oscillation cycles, specific alarms are transmitted from the WAMS to the SCADA (supervisory control and data acquisition) environment at Swissgrid. The operators are then notified through a red box that pops up on one of the main SCADA overview displays as illustrated in ➔ 4.

As an example, one critical inter-area oscillation occurred on February 19, 2011 – a Sunday morning – when the Italian power system oscillated against the rest of the continental European system [7]. The event occurred in the early morning after generation was redispatched to accommodate a large injection of solar power in southern Italy. In contrast to most conventional power plants, solar power plants typically lack the control systems needed to damp out oscillations. The solar power injection resulted in a growing oscillation ➔ 5. This large oscillation was successfully detected by the PDM analysis tool and the operators were notified promptly. The operators could then redispatch the generation to reduce power import to Italy after around 8 minutes. Had the oscillation gone unnoticed and been allowed to grow further, it is likely that a breakup of the European power network would have occurred. This proves the value of the synchrophasor technology and the new monitoring application in increasing the security of the power supply.

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Absolut zero invasion

Noninvasive temperature measurement keeps things tight

TILO MERLIN, ANDREAS DECKER, JÖRG GEBHARDT, CHRISTIAN JOHANSSON – The majority of measurements made in the process industry are of temperature and pressure. Around half of the temperature measurements are used for monitoring purposes to secure product quality, increase process efficiency and ensure plant safety. There are virtually no chemical processes in which temperature measurement is not required. Suitable conventional temperature measurement instruments are widely available and the cost of these has decreased over time due to high volumes, technological progress and competition. However, these devices are mostly intrusive in nature. ABB's noninvasive, wireless and energy-autonomous temperature sensor is now changing the face of industrial temperature sensing, as has been illustrated in a recent pilot installation in The Absolut Company's vodka distillery in Sweden.

1 First transmitter for mounting inside the sensor head (TR01)

2 First autonomous temperature instrument TSP331-W

The heyday of technological advancement in temperature measurement was in the 19th century. Thomas Johann Seebeck (thermoelectric effect, 1820) and Carl Wilhelm Siemens (platinum resistance thermometer, 1871) were two of the most prominent pioneers. ABB's activities in industrial temperature measurements date back to 1881 when Wilhelm Siebert melted platinum in his family's cigar-rolling factory in Hanau, Germany and mechanically worked the material into wires. Though subjected to continuous improvement, the main design – with a measuring inset, protected from the process medium by a strong thermowell and a connection head – changed little over the years and many of today's devices are based on these early discoveries.

A game changer was introduced in 1978 by ABB (Degussa at that time) with the implementation of an electronic transmitter inside the connection head → 1. This allowed the measuring circuit and the sensor element to be combined – even in harsh environments – thus reducing the need for long sensor wires, which tend to be sensitive to electromagnetic interference that impacts sensor accuracy and introduces signal noise. This major innovation paved the way for today's distributed smart sensors that deliver standardized and linearized measurement values to a central control system [1].

Almost 40 years later, ABB has now transformed the temperature sensor once more, making it autonomous by introducing wireless communication as well as an energy-harvesting power supply that feeds the instrument from the temperature gradient between the process and its surroundings → 2. ABB has integrated these two technologies into the fully autonomous temperature instrument TSP300-W series. This ABB innovation was a major milestone in temperature sensing and an enabler for wireless communication in process automation.

ABB has now transformed the temperature sensor once more, making it autonomous by introducing wireless communication as well as an energy-harvesting power supply.

One remaining shortcoming of industrial temperature measurement devices, however, was the thermowell.

Thermowells

The thermowell protects the sensitive measuring inset from the hot, chemically aggressive, abrasive or pressurized flow inside pipes, boilers and vessels → 3. However, the thermowell obstructs flow, leading to a pressure drop. This phenomenon creates low-pressure vortices downstream of the thermowell → 4. Vortex shedding causes the thermowell to vibrate and if the vortex shedding rate matches the eigenfrequency of the assembly, resonance occurs and dynamic bending stress increases substantially.

In terms of plant safety, thermowells are the most critical part of a temperature instrument: At high flow speeds and pressures, thermowells can easily burst if they are not designed properly. Accordingly, standards have been developed by organizations such as ASME (American Society for Mechanical Engineers) to assist engineers in selecting suitable designs. However, for applications where the standard is not applicable, the engineer is fully responsible for the proper design of shape, length, diameter, coating and interface type. Altogether, this leads to a greatly enlarged number of variants – resulting in higher cost, stock levels and logistic effort.

Title picture
Noninvasive temperature measurement in industrial processes brings a multitude of advantages. However, how is it to be accomplished?

3 Thermowells typically used for heavy-duty oil and gas applications

4 Alternating vortex shedding – vortices occur at one side of the thermowell, then the other. The effect is also seen in a flag waving in the wind.

Besides the safety issues, a thermowell is a nuisance to the process: It reduces the effective pipe cross section and the pressure drop it causes may result in higher pump power consumption.

5 TSP341-W noninvasive temperature measurement

Besides the safety issues, a thermowell is a nuisance to the process: It reduces the effective pipe cross-section and the pressure drop it causes may result in higher pump power consumption. It also forms an obstacle to pipe cleaning. Food, beverage and pharmaceutical plants are reluctant to use thermowells due to increased risk of contamination. In brownfield installations, the plant has to be shut down and the pipes emptied prior to the installation of intrusive devices. Thermowells also have a detrimental effect on the measurement itself as they introduce a temperature drop between medium and sensor, and latency. Last but not least, they are often the most difficult and expensive part to install as they frequently require welding.

In 2010, in response to some these challenges, ASME updated its basic standard for thermowell calculation [2], resulting in more robust thermowells with larger diameters, stronger materials and shorter lengths. These changes merely amplified the measurement disadvantages mentioned above.

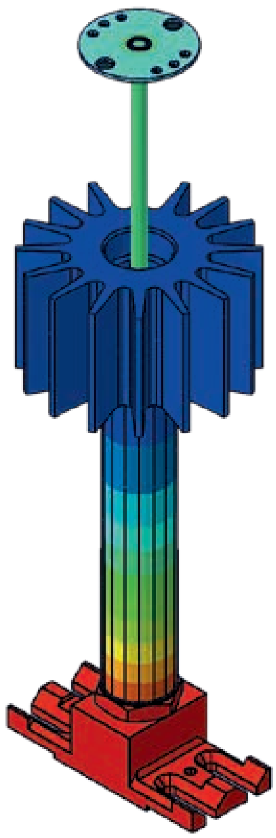
Noninvasive methods

Thermowells can be eliminated by using a noninvasive temperature measurement. Noninvasive instruments leave pipes and vessels unaffected, with many advantages:

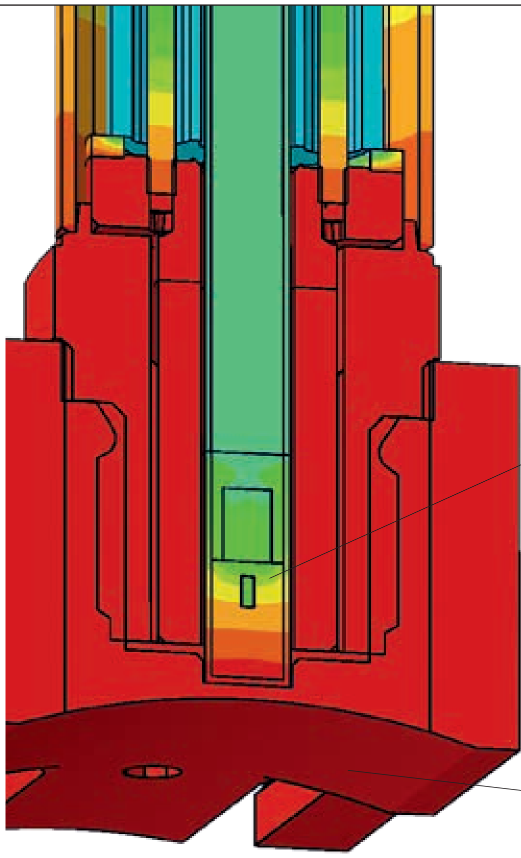
- The shells of pipes and vessels are not penetrated.
- There is no need to empty the pipe for installation.
- No welding is required on site and no special permission for hazardous areas is needed.
- The possibility of contamination is eliminated.

These advantages have considerable implications: Measurement points are now easy to install and can thus be used on a temporary basis – eg, during setup and test of a new process or, if there are issues in production, for root-cause analysis. As soon as a satisfactory situation has been arrived at, the number of measurement locations can be reduced to an economically and technically appropriate long-term value.

6 Finite-element result for the temperature field in a typical setup before optimization



6a Entire device



6b Interface to target surface

Thermowells can be eliminated by using a noninvasive temperature measurement. Noninvasive instruments leave pipes and vessels unaffected.

Why have noninvasive methods not been used before?

There are good reasons why noninvasive technology has not been used in the majority of temperature measurement installations so far.

The easiest way to obtain a noninvasive temperature measurement would be to attach an existing instrument to the surface of a pipe or vessel instead of introducing it into a thermowell. However, the temperature sensor is then further away from the process medium so that the response time would be impaired, and ambient conditions would have a bigger influence on the measurement.

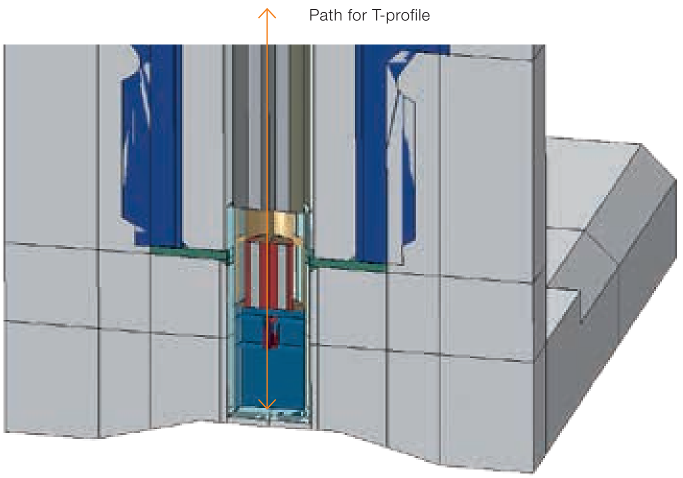
A good noninvasive temperature instrument, therefore, has to have an appropriate design of the thermal pathway from the process to the sensor, which includes all materials and all interfaces through which the heat has to be transferred. It would also be beneficial if the existing (thermowell design) instrument could be adapted to fit as this would reduce the development effort significantly, keep the number of variants and additional parts low, and make it easy for the customer in terms of familiarity and certification retention.

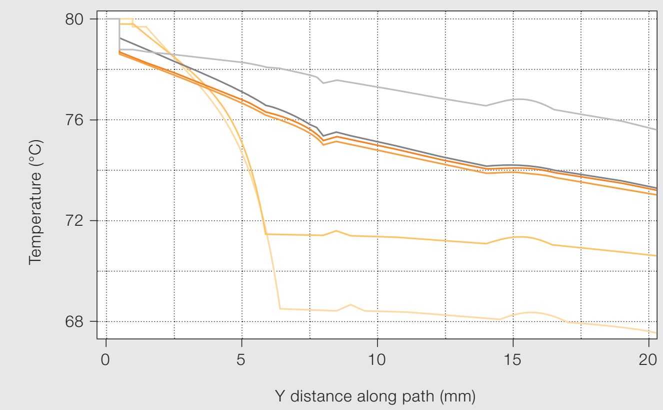
A challenging case

Two autonomous [3], noninvasive temperature instruments were given to The Absolut Company in Nöbbelöv, Sweden so they could explore the device's capabilities without having to interrupt the processes in their vodka distillery → 5. To keep the effort on ABB's side low, adapters were manufactured to mount existing (thermowell design) instruments with adjusted inset length to the pipes.

The sensors were easy to integrate into the existing ABB Extended Automation System 800xA. The System 800xA automation platform has a built-in field device management system. This allows users to have one single system that covers operations, engineering and field device management – including functions such as device configuration and condition monitoring. Such an approach has significant advantages – reduced engineer-

7 Systematic search for relevant design parameters





7a The temperature field is plotted along a path through the device during measurement.

7b Sample temperature profiles across the device for various design iterations

The sensors were easy to integrate into the existing ABB Extended Automation System 800xA, which has a built-in field device management system.

ing hours, for example – since the complete solution, including field device configuration, is engineered in one system with one common engineering workflow. Another advantage is speedy commissioning as complete signal checkout can be done by one single person from one screen.

After installation, the automation engineers from The Absolut reported that the energy harvesting functionality, as well as the wireless communication, were working well. However, measurement accuracy and the response time of the instruments failed to meet their expectations.

Improving the measurement

A series of measurements at The Absolut revealed a detailed picture of the thermal situation at and around the instrument as well as at the adapter that connects the instrument to the pipe. After determining the cause of the measurement issues, the design of the adapter was improved and tested. The measurement inset and thermal interface materials were also modified. In the final configuration, measurement error was reduced to approximately 1 K (from several degrees Kelvin). At the same time, response time was decreased by 75 percent, such that both performance parameters were close to those of an invasive temperature instrument.

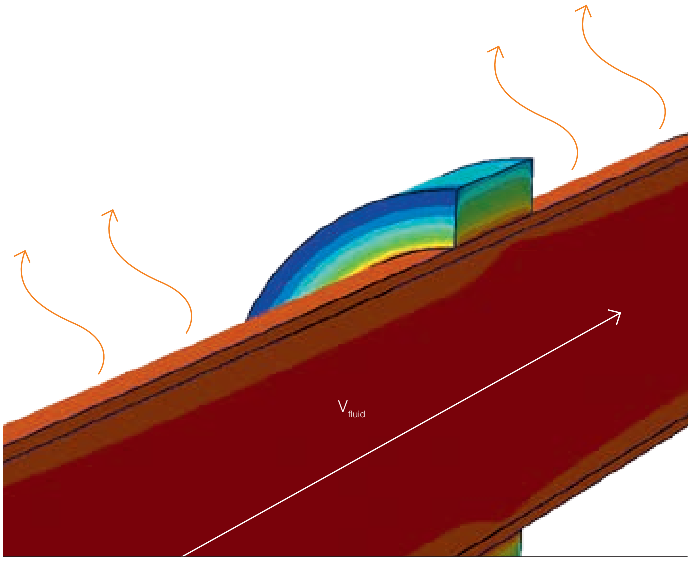
Modeling

Physical understanding of the measurement point and subsequent modeling and simulation of the thermal situation were important for arriving at a good design. Finite-element simulations and extensive automatic model-tuning [4] were used to identify the relevant design parameters → 6. Geometry, materials and interface properties could be effectively represented in the models → 7.

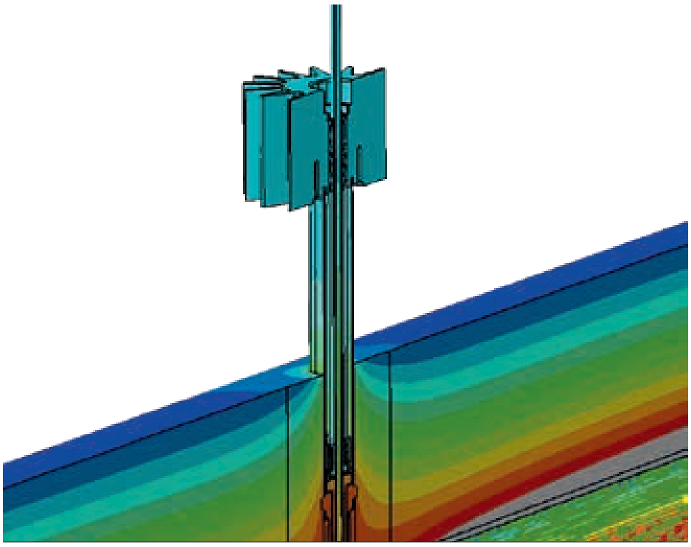
Furthermore, it was important to understand how the sensor temperature can be affected by details of the measurement situation – eg, by different insulation types or different flow conditions. An understanding of these influences was generated via conjugate heat transfer calculations in which a hot or cold fluid is modeled flowing along a pipe where the instrument is mounted and/or where some axially homogeneous or spatially varying insulation is applied to the pipe. Typical temperature fields generated by these calculations are shown in → 8.

Finite-element simulations were used to identify the relevant design parameters.

8 Conjugate heat transfer has been analyzed in cosimulations of coupled finite-element and fluid-dynamic calculations.



8a Temperature field distortion in the case of a locally insulated fluid-conveying pipe



8b Temperature field in the structure and velocity field in the fluid for a typical measurement situation

Easy installation

The newly designed adapter can be mounted onto a wide variety of pipe diameters; only the length of the clamps (simple steel bands) has to be adjusted, thus greatly reducing the number of variants and increasing flexibility. The design's lower complexity requires less machining and allows simpler installation, which is especially beneficial in hard-to-reach locations. The installation does not require calibration or extensive parameterization.

Following this optimization, The Absolut Company installed four TSP341-W units and the predicted improvements in measurement accuracy and response time were confirmed.

A new flexibility

Noninvasive, wireless and energy-autonomous temperature measurement ushers in a new era of flexibility. With temperature measurement and the job of engineering it into a System 800xA DCS now made so easy, applications that add a high value – but traditionally have been difficult to justify from a cost perspective – are now well within reach. One good example of such an application is short-term instrumentation of processes during optimization and continuous improvement exercises or energy efficiency initiatives. Another example is to supply ABB's System 800xA heat exchanger asset monitor (HXAM) – a condition monitoring tool that identifies heat exchanger performance changes and operational degradation – with the temperature inputs it requires to guarantee more energy-efficient operation and reduced maintenance costs. In large facilities, improved heat exchanger performance delivers substantial energy savings.

Only applications with extreme spatial or temporal gradients pose a challenge to the complete closure of the gap between the performances of the noninvasive sensor and its invasive counterpart – both in terms of measurement accuracy as well as response time. A next logical step, once the thermomechanical options are exhausted, is to use advanced model-based algorithms that can correct the measurement.

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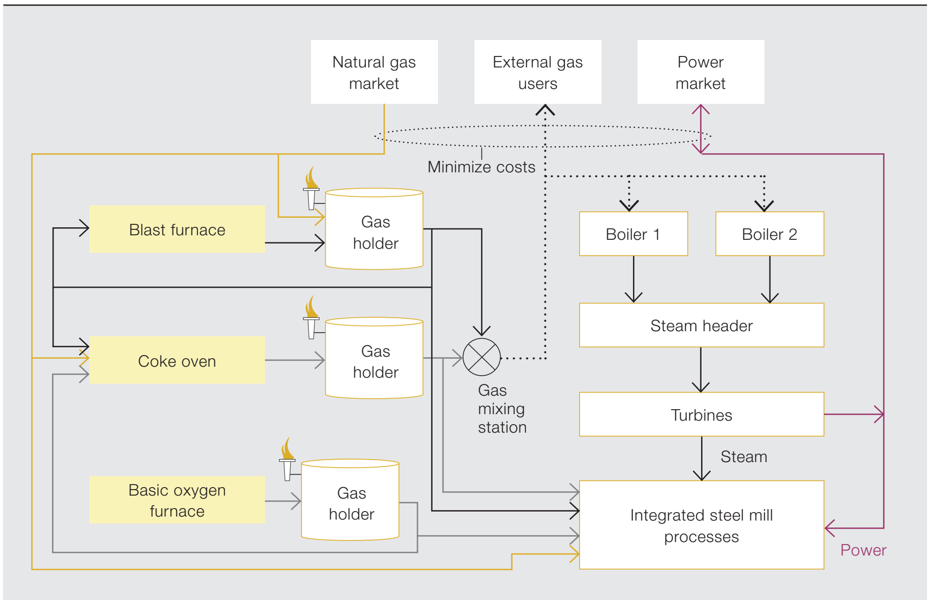
Optimizing energy flows

Improving energy efficiency in steelmaking by modeling and managing energy flows with ABB's cpmPlus Energy Manager

JOUKO KARJALAINEN, TONI KYMÄLÄINEN, JUHA MÄNTYSAARI, TUA KAUPPALA – Energy constitutes about 20 percent of the total production cost in an integrated steel mill. Energy efficiency is, therefore, crucial for profitability. Within the mill, energy is distributed through complex networks carrying electricity, steam, by-product gases and imported fuels. Understanding this system and controlling it in an optimal way is the key to improving energy efficiency and competitiveness while reducing environmental impact.

1 Gas and energy optimization



Making iron and steel requires complex gas networks that can reliably supply a wide variety of gas grades and blends to a large number of process consumers → 1. Due to the critical nature of production scheduling, these gases must always be available when needed. This necessitates the use of gas storage holders to accommodate temporary shortages or surpluses.

When gas demand exceeds supply, supplementary fuel must be bought at volatile – and often higher – market prices. When supply exceeds demand, excess gas must be flared off from the holders. This wastes energy and increases the plant's carbon footprint.

In addition to process needs, many mills have power plants in which the boilers are fired with a combination of fuels, including by-product gases from blast, coke and basic oxygen furnaces. This energy is balanced with electricity purchased from the grid to meet the total plant demand. If the plant is able to predict this electrical power demand accurately, it can be purchased at a lower price.

Title picture
With intricate flows of electricity, steam and gas, the energy topography of a steel mill is complex. How does ABB's cpmPlus Energy Manager help master the complexity of the energy flows and improve energy efficiency?

The challenge is therefore to optimize the plant's entire energy system so that the needs of all consumers can be met at minimum cost. This results in reduced flaring, reduced purchases of electricity and supplementary fuels, and lower prices for the electricity that does have to be purchased.

The challenge is to optimize the plant's entire energy system so that the needs of all consumers can be met at minimum cost.

Systematic solution

Since the different forms of energy generated and consumed at a steel mill are highly interdependent, it makes sense to optimize them as a whole. This can produce the greatest benefit for the mill's competitiveness in terms of energy costs and carbon emissions, as well as minimizing the penalties for underestimating or overestimating demand.

ABB's cpmPlus Energy Manager (EM) is a software solution that models and visualizes the entire plant's energy flows. It calculates optimum schedules for by-product gas distribution to process consumers and power plant boilers. This optimization ensures 100 percent by-product gas availability while minimizing wasteful flaring.

Additionally, cpmPlus EM accommodates plant processes – such as the gas network and mixing station configuration – as well as financial considerations, including boiler start-up costs. It can help maintain optimal energy efficiency despite unplanned production changes or energy price volatility. The system can even help optimize the export of electricity or by-product gases when this is feasible and economical.

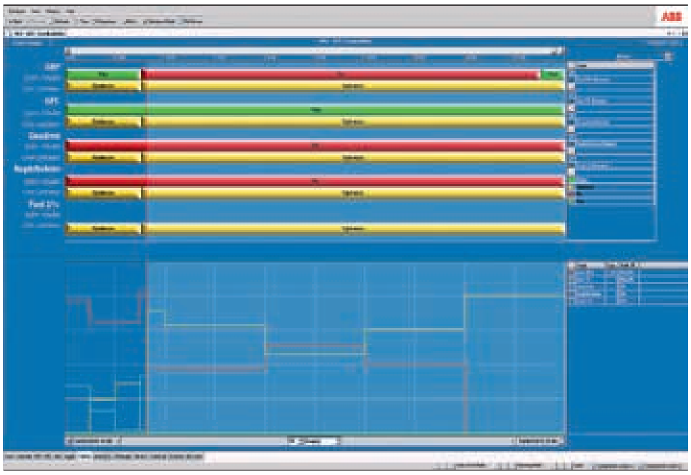
Efficient modeling tools

In cpmPlus EM, the modeling principle is known as the economic flow network (EFN). The EFN provides tools that graphically configure the entire energy system model as an interconnected flow network, where each flow is represented with an allowed range of values and a unit price. Logical constraints can be specified for the various process conditions. Based on the configured model, the optimization problems are automatically created and solved by a mixed-integer linear programming (MILP) solver.

Energy efficiency dashboards

Another feature of cpmPlus EM is that it provides dashboards to display energy

2 Boiler fuel usage control view



3 Gas utilization overview

Since the different forms of energy generated and consumed at a steel mill are highly interdependent, it makes sense to optimize them as a whole.

performance, from the level of individual production processes to the entire plant → 2–3. This allows energy performance indicators to be monitored and targeted, and enables analysis and reporting to verify the performance improvements that result from the implemented activities and projects.

Dedicated dashboards for each production station allow operators to act on deviations from the optimum that are often hidden behind different energy and material flows. Operators can also validate the planned schedules for gas, electricity and steam demand, as well as the generation of by-product gas compared with the day's production schedule.

At the same time, site power plant operators can use optimization results to select the best combination of on-site power generation and external supply. This allows energy efficiency to be managed as a key performance indicator, alongside production quality and throughput.

The power plant and process schedules calculated by cpmPlus EM can also be implemented automatically by sending scheduled set points to the advanced process control level, which then coordinates the power plant control systems to run the processes in an optimal way.

Case study at ArcelorMittal steel mill

Steel mills utilize production planning systems to enable them to manufacture to order. In ArcelorMittal's Fos-sur-Mer mill, in France, such a system allowed the company to plan production and predict energy consumption in the production planning process. However, the mill set itself a more ambitious goal: to optimize its energy procurement, steam yield and consumption of by-product gases – and thereby optimize the energy consumption of the entire mill's steelmaking process.

ArcelorMittal's own research center had conducted preliminary studies and developed models to manage energy and by-product gases at the mill. They had clear requirements and expectations for the modeling process, but they still needed to find the right industrial supplier.

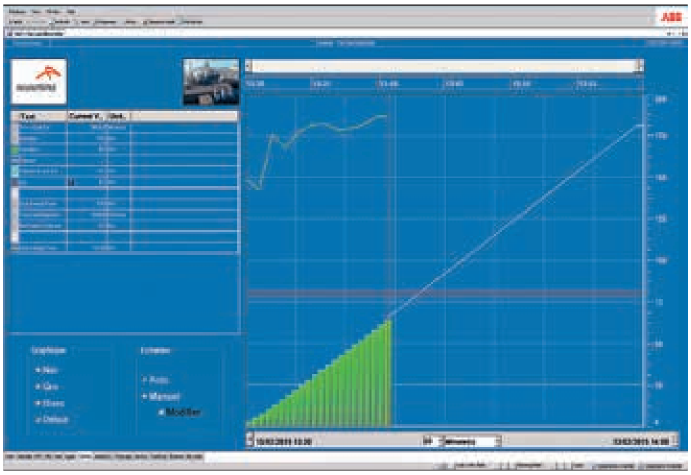
Successful prototype model

ArcelorMittal chose to work with ABB because there was no other supplier with an equivalent industrial-scale product. The project was demanding, but the ABB team approached it in a systematic way by performing modeling on the basis of ArcelorMittal's preliminary investigations, ie, by carrying out a case study. As soon as ABB had completed its prototype modeling, the work was submitted to ArcelorMittal for evaluation and was approved.

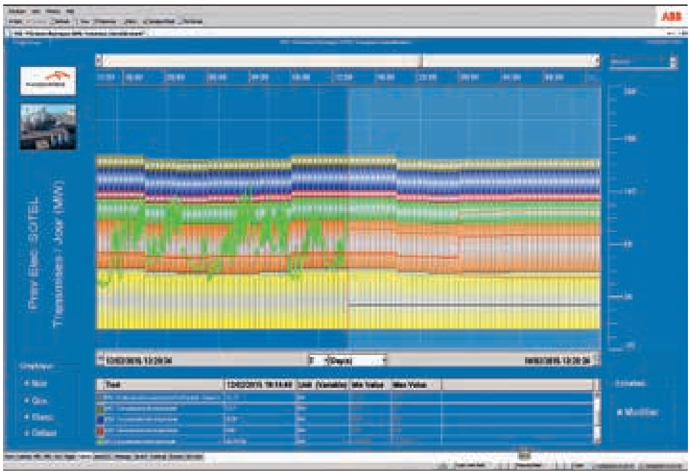
Insights and innovations

The ultimate aim of the project was to model the mill's entire energy procurement and production processes. As mentioned above, the steel manufacturing process involves both the production and consumption of gases. A mill's external energy procurement is usually regarded as including only electricity and steam, but this time the modeling process also covered the management of by-product gases and gases sourced from elsewhere. The ABB system indicates how much gas needs to be purchased from outside sources.

4 Electricity tie line monitoring view



5 Department electricity forecast view



The system is in continuous use in an industrial environment and therefore faces special challenges. Finding high-quality optimal solutions – as input data constantly changes – reliably and quickly enough was something that needed to be given extra attention.

In ArcelorMittal's case, the optimization time horizon must be continuously calculated. In other words, the optimal production plan must be repeatedly resolved on an ongoing basis. In the context of optimization modeling this is a major challenge; to make it possible ABB had to develop completely new techniques and solutions.

Technical solutions for industrial-scale optimization

The system supplied to the ArcelorMittal mill incorporates three technical solutions that support fast and high-quality optimization with varying input data. These are: two-level optimization with base model inheritance to different time levels; the sliding time horizon approach; and the use of multiple search parameters for solvers.

Two-level optimization using base model inheritance

To make it possible for the whole power generation process to be continuously optimized, it was initially necessary to produce state decisions for the major equipment in the production plant by projecting a crude resolution into the future. Based on these, it was then possible to calculate the use of energy storage equipment like boilers or gas holders with a finer resolution.

This was done using modeling in two different time resolutions: one of 2 hours, in which the optimal states of key equipment such as boilers were fixed, and one of 30 minutes, in which these states are taken as given and fine-granularity optimization of continuous operation is performed. The models used in both time resolutions are inherited from a base model containing common structures and constraints.

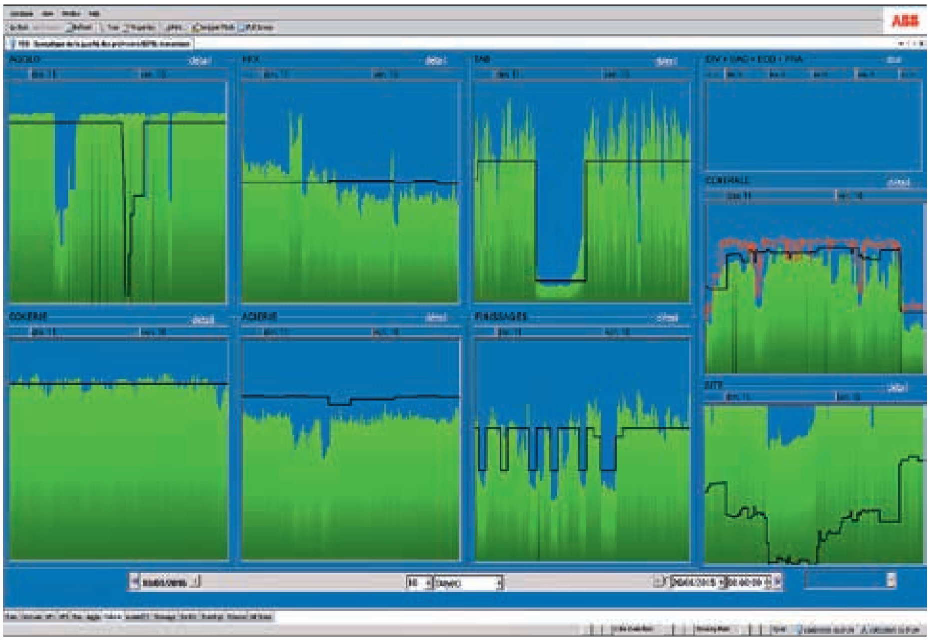
Because electricity is billed in periods of 30 minutes in France, the customer required the system to update twice during that time, ie, approximately every 15 minutes. At this 30-minute level it is possible to make major state decisions and resolve utilization two days ahead. The two-day plan provides optimized data for all external energy procurement, electricity and gas forecasts, and gas holder levels. The system also enables forward monitoring of the weekly plan.

Sliding time horizon

The second technique incorporated into the system supplied to the ArcelorMittal mill was the sliding time horizon approach. When data that updates every half hour is used to predict two days ahead, this forecast cannot be done in a single step that incorporates the whole time horizon in the model. This would be too resource-intensive and time-consuming for the optimization. The sliding time horizon approach looks ahead over a shorter time slot and provides an initial solution for that. Then this solution is entered into the system, the slot is moved forward by one period and the process is repeated. This is done until the whole two-day time slot has been processed.

ABB's cpmPlus Energy Manager models and visualizes the entire plant's energy flows. It calculates optimum schedules for by-product gas distribution to process consumers and power plant boilers.

6 Forecast quality monitoring view



The cpmPlus EM accommodates plant processes such as the gas network and mixing station configuration, as well as financial considerations, including boiler start-up costs.

The time horizon therefore moves forward one period at a time. This maintains the continuity of results over time, allowing for more stable solutions. If a whole 24-hour period is optimized at one time, the continuity from one day to the next is lost because the determining factor is the 24-hour time slot and the optimization model cannot "see" far enough beyond that.

Broad selection of solver search parameters

The third technique made it possible to achieve a sufficiently fast numerical solution with varying input data. Most of the time, the system can quickly solve optimization problems with a given selection of parameters. However, there are occasions when solution times can be long. The ABB team came up with the idea of allowing the system to send the problems simultaneously to two different solvers with different search parameters. Then it is simply matter of waiting to see which solver finds a solution first and cancelling the slower one. This competitive solving is constantly repeated around the clock, in line with the requirements of an industrial-scale system.

cpmPlus EM objectively searches for the most economical solution

cpmPlus EM shows the operator the most economical way of running the mill. It can also identify completely new operating practices → 4–6. This was the case with the turbines at Fos-sur-Mer: The ABB system suggested an operating practice that differed significantly from what had been done before. This new method was adopted at the mill.

Optimizing all energy procurement processes has brought significant savings in raw materials and costs at ArcelorMittal's Fos-sur-Mer mill, boosting the productivity of the steel manufacturing process. At present, the most clearly visible result of this is an improvement of some 15 percent in the accuracy of the mill's external electricity procurement forecasts. This translates into savings of around 15,000 euros ($17,000) per month (averaged over 2013).

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Innovation

Necessity is the mother of invention, the saying goes. In which case, perhaps constraint is the father of innovation? Economic, resource, physical and many other constraints continually present new questions and challenges for human life and endeavor. However, far from constraints being a limit to progress, it is often the existence of challenging conditions that inspire people to overcome and which creates an environment for innovation.

The constraints facing people and corporations today are manifold and constantly in flux – an environment that motivates ABB and its engineers and scientists to constantly innovate for a better world. Therefore ABB Review dedicates the first edition of every year to celebrating innovation. In issue 1/2016 ABB's recent innovations will be highlighted. From power production to smartphones, the subject of ABB's innovations will be shared and explored.

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