review

Africa

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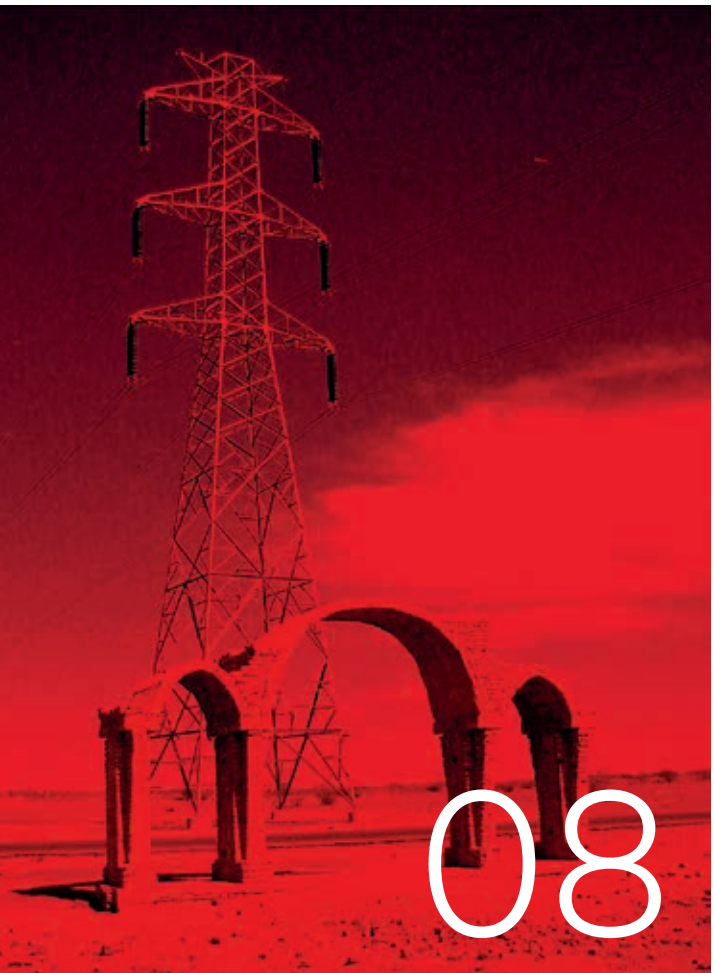
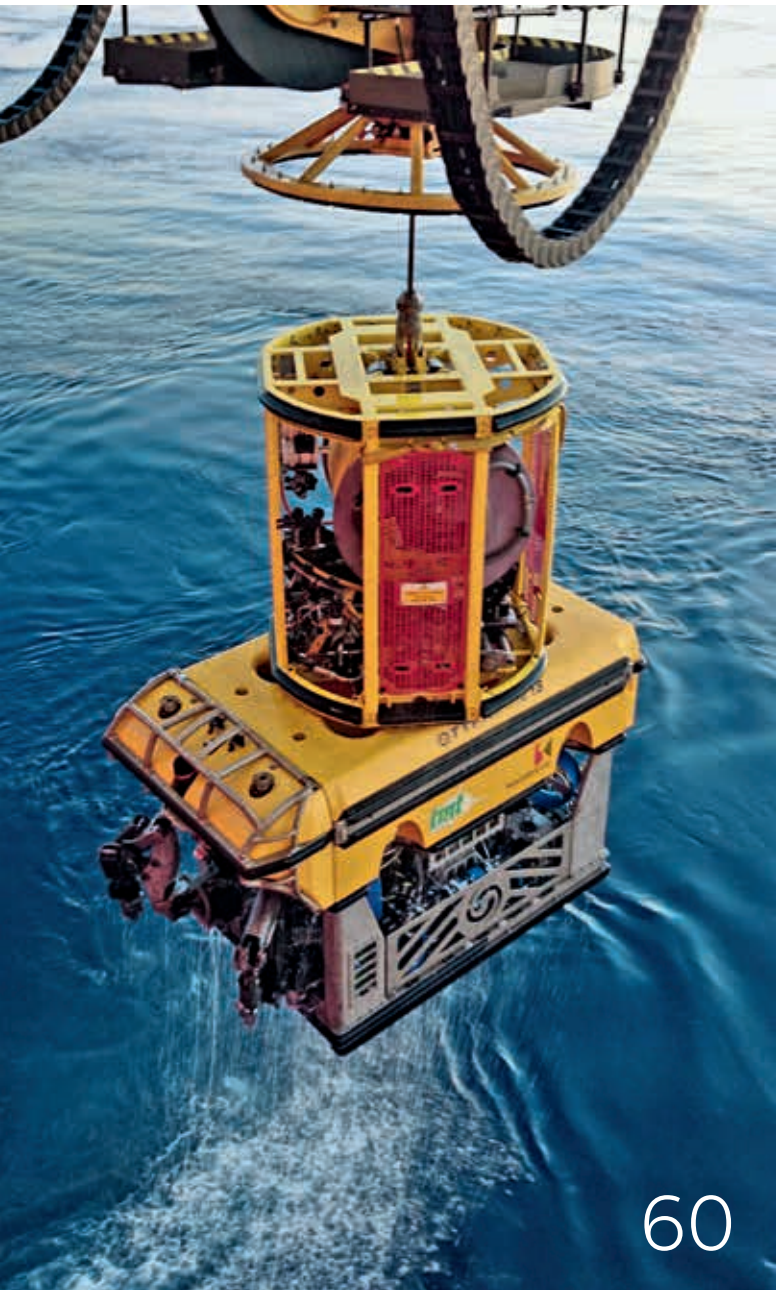


Electrifying a remote rail line

Rock-solid undersea electrics
3 km down



Eco-friendly
alternative to SF_6

Box of tricks for the ICRC

Modeling HV substation insulation

Africa is the planet’s second most populous continent. It is expected to grow nearly twice as fast as any other, reaching 4.4 billion people by 2100. Presently, half a billion live without electricity. Energy and transportation costs are among the highest in the world.
ABB is there, collaborating with its customers to innovate solutions that could power a new era of industrial development and economic success. This issue of ABB Review shows some of our latest news and thinking.

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EDITORIAL

Energy for Africa

Dear Reader,
Africa presents both vast opportunities and formidable challenges. Today only half of the continent's population has access to electricity. In sub-Saharan Africa the figure is even lower at one third. With electricity being key to most forms of commercial activity, addressing this issue can unlock vast human and economic potential.
Providing access to electricity is not just about knowing equipment and technology, but also about understanding the requirements and potential of the locations being served. In this issue of ABB Review, two guest contributions look at methods and tools for the geographic planning of energy supplies, including the selection of the best supply form, ranging from standalone generation through microgrids to full grid connection.
Although some of the technologies presented here may be unique to Africa, others are also applicable elsewhere. They reflect ABB's ability to draw on its extensive expertise in creating innovative solutions across the globe.
Enjoy your reading.

Bazmi Husain
Chief Technology Officer

Africa

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ABB's projects in Africa vary broadly. Challenges faced range from financing and the unique qualities of infrastructure and geography, to follow-on needs for service, support, and subsequent expansion. Yet everywhere, these projects create opportunities to improve industrial and economic productivity and, in doing so, living standards. The imperative to succeed is immense, and is why ABB collaborates with its customers and partners to bring its expertise to every project.

INTERVIEW

Energy for Africa

Mark Howells
Professor Mark Howells holds the chair of Energy Systems Analysis at the Royal Institute of Technology in Sweden (KTH). He is also an Honorary Affiliate Professor at the University of Technology in Sydney and Editor in Chief of Energy Strategy Reviews. His research topics include the development and application of quantitative models to support governments in answering difficult policy and investment questions → 1. In this interview, Professor Howells discusses some of the challenges of electrification and development in Africa.

For ABB questions, please contact Alexandre Oudalov, alexandre.oudalov@ch.abb.com

AR **ABB Review (AR):** Seeking to consolidate sustainability with ever-increasing demands for energy is a global challenge. In what ways is the situation in Africa particular?

MH **Mark Howells (MH):** Economic sustainability is a key challenge. Businesses need to know that they can make a profit. This is difficult in the context of under-resourced institutions, poor policy and limited planning capacity. However, a number of important steps are being taken to address this. There are also many private and informal initiatives that are taking advantage of the continent's bludgeoning growth.

AR Sustainable energy often develops first and foremost where government organizations provide incentives in support of it. Is this happening in Africa?

MH Yes, there are important initiatives coming from national governments, the African development bank, NEPAD, the African Union (AU) and others. One example is the AU's Agenda 2063 – a strategic framework for the socio-economic transformation of the continent over the next 50 years. It builds on, and seeks to accelerate the implementation of past and existing continental initiatives for growth and sustainable development. But the implementation and resourcing of a practical pipeline for market, finance and policy development for governments is difficult.

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01 Development models support electrification.

01a OnSSET optimal technology split for electrification (upper). Optimal levelized cost of electricity achieved by the selected technology (below).

01b OSeMOSYS results for optimal electricity generation mix of the Kenyan national grid (2012 – 2030).

DEVELOPMENT MODELS SUPPORT ELECTRIFICATION

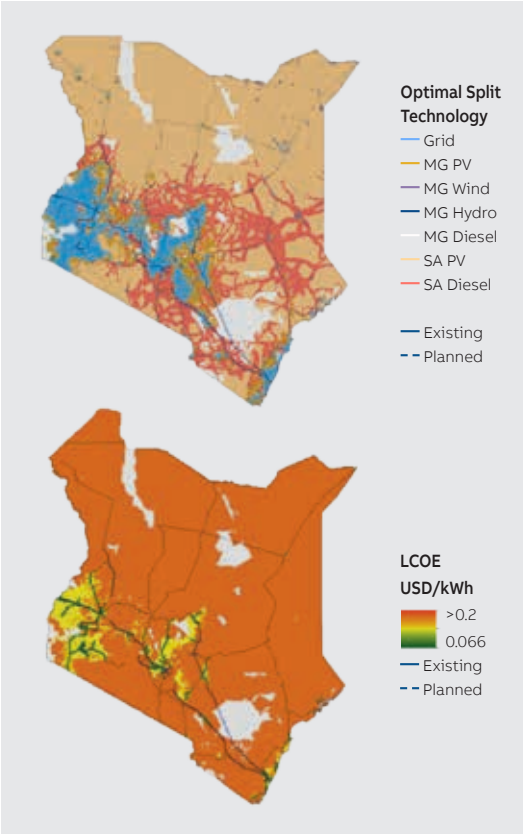
Decisions need to be based on knowledge. This is all the more so when it comes to complex and costly investments such as the development and expansion of the power grid. Even if a new infrastructure is being built in an area not previously served, it is not created in a vacuum. Geographical and economic facts influence the effectiveness of such a project. The division of Energy Systems Analysis (dESA) at The Royal Institute of Technology, Stockholm (KTH), led by Professor Howells has developed tools to support such decisions. The group collaborates with ABB and has performed some modelling and case studies together with the company.

OnSSET (Open Source Spatial Electrification Toolkit [2]) and OSeMOSYS (the Open Source Energy Modelling System [3]) are two optimization tools designed to study energy systems. OnSSET performs an analysis driven by household electricity demand and the electrification target of 100 percent by a target year. It is adjustable for different electrification objectives.

The other model, OSeMOSYS, models total electricity demand (not just residential) providing the cost-optimal electricity mix on an annual basis, both for grid-connected and distributed technology options.

While the tools can be used independently, their interaction yields a more holistic modelling approach, whose results can help guide long-term investment planning.

One example is that of Kenya. Iterative modelling using both tools showed that universal electrification by 2030 is achievable → 1a. The study aimed to provide 1,800 kWh/year and 2,195 kWh/year respectively for every rural and urban household by 2030. About 84 percent of the population will be served by expansion of the national grid whereas off-grid systems will cover approximately 16 percent of demand (9 percent from microgrids and 7 percent by stand-alone systems – mainly PV and diesel gensets). The estimated additional capacity for the national grid is 26 GW deriving mainly from new coal and natural gas power plants → 1b, requiring 21.6 GW of additional capacity in high voltage lines. The total cost of the identified plan was estimated at $ 46.31 billion [4] [5].



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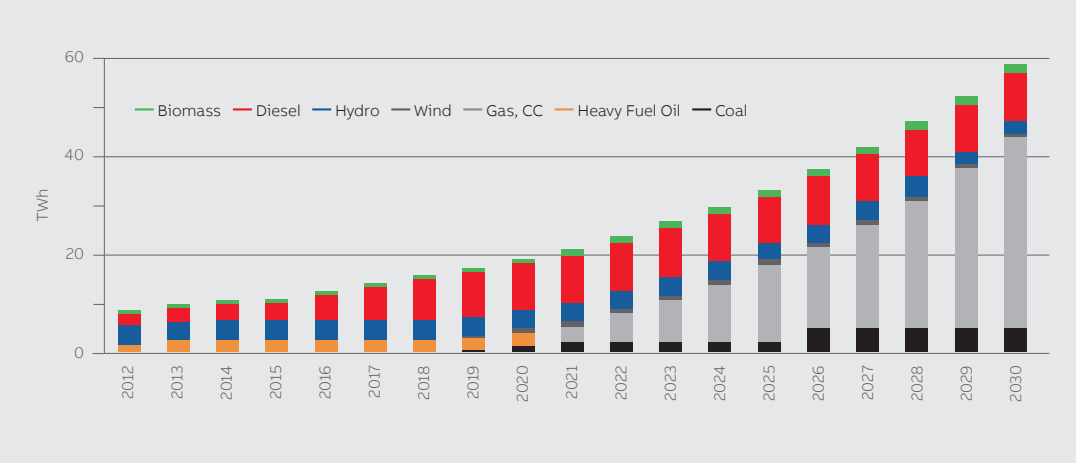

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Governments are often unaware of the technology, market and policy options available to them. Not knowing their benefits, they find it difficult to allocate appropriate priorities.

AR What are the main phases of development in terms of rural electrification and access to electricity?

MH Apart from some technological development, many similar challenges have been faced from L.A. to London to Lagos. In the early years of the grid, the United States adopted an approach that allowed for mines, industry and farms to form cooperatives. The development and deployment of the grid happened quickly. In the UK, much of the grid was developed during a time of heavy regulation. The government was concerned about market abuse and unfair tariffs for the poor. That forced many producers to go bankrupt and the state took control. The network developed into a centrally planned system that went on to provide reliable electricity for the UK. When, where and how the state should intervene is not an easy question to answer – and is subject to local specifics.

Yet there are interesting observations today. Where profit is to be made, we see a rise in auto-generation. If distribution is allowed with market-based remuneration, minigrids form. If low tariffs are mandated, minigrid development is retarded as there is little incentive for producers.

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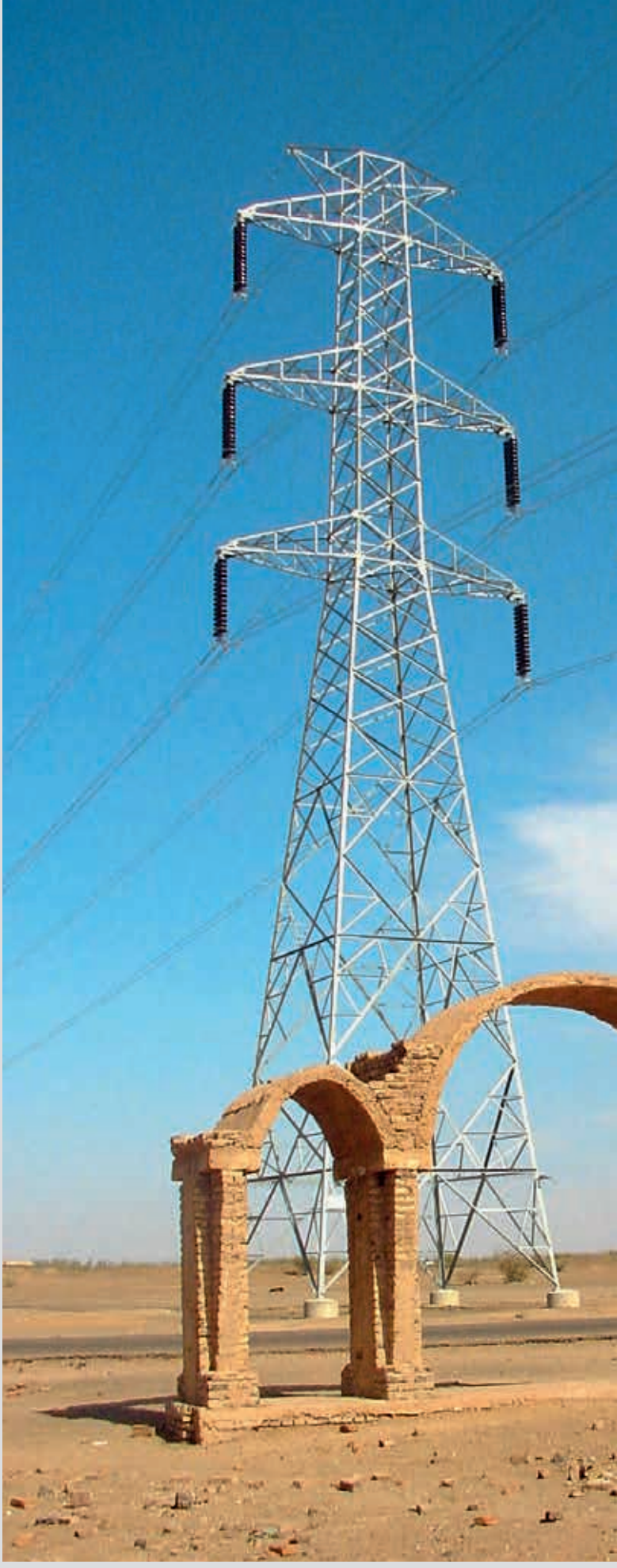
The Ghanan government uses subsidies to offset the difference between the tariff and production price, allowing minigrids to flourish.

In Ghana an interesting (and effective) minigrid hybrid model has developed that allows government subsidies to offset the difference between the tariff and production price in an effective manner. There are several concession programs that ensure competition drives prices down, with government (often in the form of the state utility) providing coordination and funding. In other cases, such as in South Africa, government driven and executed grid-based electrification programs have successfully connected millions of consumers.



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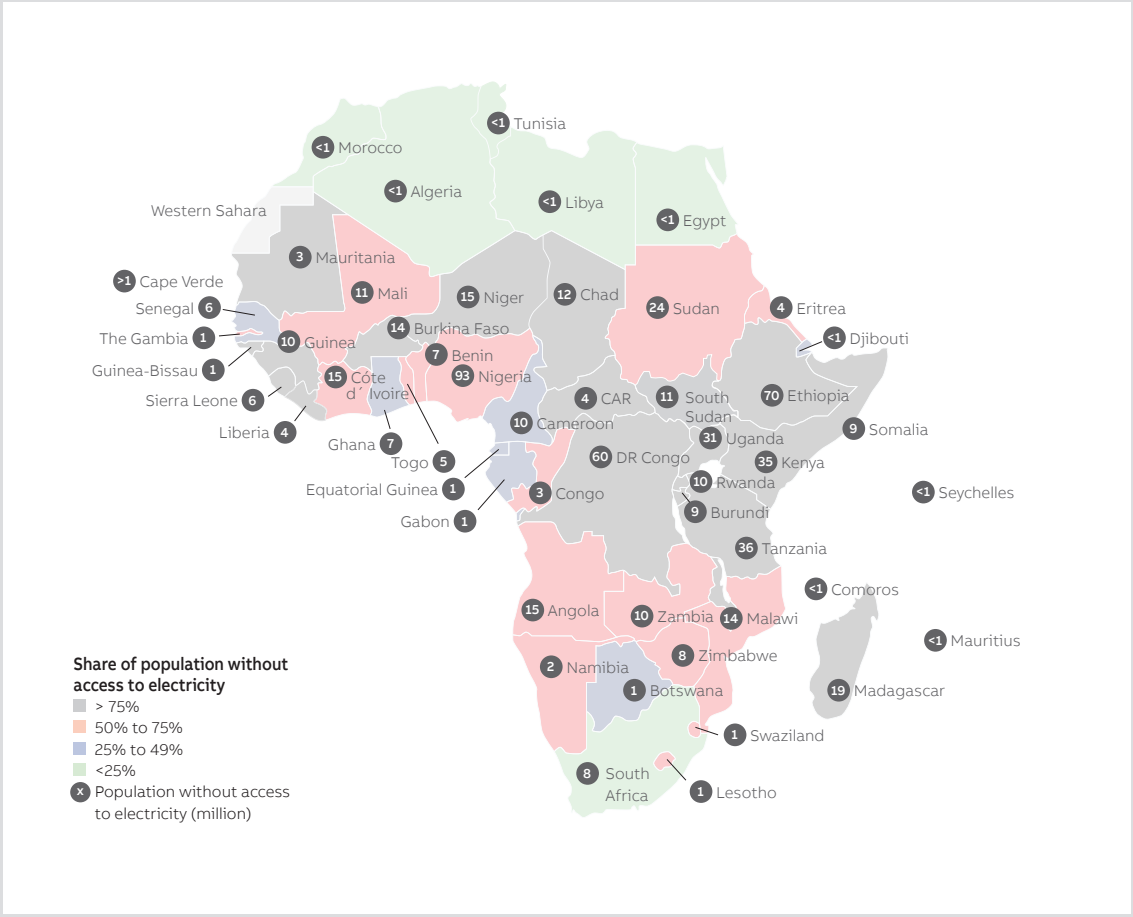
02 The 110 kv Eid Babkir transmission line in Sudan.

While some elements of electrification are not new, there are other key enablers that are. East Africa has become a leading light for off-grid business models to develop and for innovation to thrive. It is no coincidence that mobile banking is prevalent there too. Such schemes allow financial flows, economies of scale and a host of complementary services to be offered together with electricity. Smart information communication, technology (ICT) and finance are given space to move and support creative local entrepreneurs. Suddenly, small power companies are also suppliers of entertainment, credit and other services. Furthermore, goods that can be produced in micro-industries can easily be traded, providing more income to the power purchaser. Again – all facilitated by mobile payments.

AR What about large-scale energy projects such as concentrating solar power (CSP). Do they make sense? What are the barriers to seeing more such projects go forward?

MH In a functioning market with clear rules and low risk, large capital-intensive projects can make sense. However, those are often the exceptions. Such projects need power purchase agreements, concessionary finance and other guarantees to reduce risks. In Africa, this can be compounded by the large distances needing to be covered →2. Supply, demand and conventional balancing power are often in different locations. The grid is – and power markets are – still in a state of development. Yet despite this, there is important movement. In Africa's more developed power systems we are seeing the large-scale injection of fluctuating renewables, such as CSP, into the system. South Africa and Egypt are notable examples.

It is worth pointing out that the continent is home to some of the world's best solar and wind regimes. As well as untapped resources that will require large volumes of energy to extract, process and export at a profit. Thus, some key drivers are in place.



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03 Number and share of people without access to electricity by country, 2012 [1].

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[2] Howells, M., et al., 2011. OSeMOSYS: The Open Source Energy Modeling System: An introduction to its ethos, structure and development, Energy Policy, vol. 39 (10): 5850–5870.

[3] Mentis, D., et al.. A GIS-based approach for electrification planning – A case study on Nigeria. Energy for Sustainable Development, 29: 142–150, 2016.

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AR What special specific strengths / skills do you think ABB can bring to supporting development in Africa?

MH ABB is exceptionally well placed as a provider of knowledge, management systems and technology. This ranges from small control and management systems that can be scaled in the case of micro- (and micro-credit) systems up to national-level implementations and power pool market management software.

Further, it has key technologies, and technologies under development that can help with, large scale transmission, the integration of hybrid AC and DC networks (and much more). The latter becoming important as off-grid and grid – based systems start to mesh.

An important challenge is that of partnering, communication and capacity building. Policy makers and entrepreneurs are often not aware of what technology deployment, control and markets will be needed to support Africa's growth potential →3. Or what benefits one route may have over another. Effectively, "free feasibility analysis" and transfer of the knowledge that underpins these decisions will involve more than a quick sales pitch. Concerted and creative effort will be needed. But – as with many challenges thought difficult in the past by others, ABB has often led the way…

AR Thank you for this interview. ●

AFRICA

A hybrid-microgrid box of tricks for the ICRC

The largest logistics hub in Africa for the International Committee of the Red Cross (ICRC) is located in the Kenyan capital Nairobi, a city exposed to frequent power outages and power quality issues. ABB will be supplying the ICRC with a containerized microgrid to provide an uninterruptable power supply (UPS) derived from traditional and renewable energy sources. The microgrid will be supplied with all of the elements included in a single container, making this innovative solution of great use for other ICRC projects.

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The ICRC, founded in 1863, is headquartered in Geneva, Switzerland. The logistics hub in Kenya is the ICRC's largest in the field →1. Employing 170, the Kenyan logistics hub is the ICRC's largest storage facility and is responsible for the delivery of food and other essential items such as medicines and relief supplies across the African continent. ABB is building for the ICRC a containerized hybrid microgrid, with a battery energy storage system that runs on photovoltaic (PV) energy and a diesel generator to maximize the use of renewable energy and ensure a reliable power supply. The microgrid will work in parallel with the on-site solar/diesel generation, seamlessly disconnecting and connecting to the main grid as required. It is scheduled for completion by the middle of 2017.

ABB is building a containerized hybrid microgrid to maximize the use of renewable energy and ensure a reliable power supply for the ICRC.

Microgrids are used to integrate distributed energy resources and loads that can be operated in a controlled, coordinated way. They can be either connected to the main power grid or can provide power independently, ensuring utility-grade power quality and grid stability.

These small-scale grids are exceptionally flexible and can be transported, bringing power to remote communities and facilities that might otherwise have to wait years or even decades for a grid connection. They are also ideal as back-up power sources for grid-connected installations in places prone to power outages.

Microgrids integrate multiple distributed generation sources including conventional diesel and gas, and/or renewables such as solar, PV, wind, hydroelectric, tidal and even thermal schemes like combined heat and power (CHP), together with energy storage. The microgrid provides the overall control to coordinate these resources to meet the requirements of industrial, residential or consumer loads [1].

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01 ICRC logistics hub in Nairobi (©ICRC).

Microgrids have enormous potential in Africa, where more than 900 million people lack access to electricity. In sub-Saharan Africa, where two-thirds of the population – 620 million people – live without power, microgrids could dramatically speed up economic development [2].

ABB, a pioneer in microgrid technology, has installed over 30 microgrids around the world in remote communities, islanded electrical grids, research and industrial campuses and utility grid support applications.

Solutions with a purpose

The project has two main purposes. Firstly, to ensure the ICRC facilities are fed with uninterrupted and reliable power in order to avoid losses of critical items like drugs and medicines due to power outages. Power outages are not uncommon in Kenya so a UPS backup is essential for storage of critical supplies →2.

Secondly, to serve as a pilot project for the ICRC, so that they may, in a controlled environment, test and learn the technology before deploying it to refugee camps, where the issues with power are more severe than in Nairobi.

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Power outages are not uncommon in Kenya so a UPS is essential for storage of critical supplies.

Plug and… save

The containerized hybrid microgrid solution for the logistics hub in Nairobi will include:

- a control system – the Microgrid Plus system
- a stabilization system – the PowerStore system
- an energy storage system – based on Li-ion batteries.

In addition to the containerized items, ABB will also supply engineering services, transportation, erection supervision and commissioning.

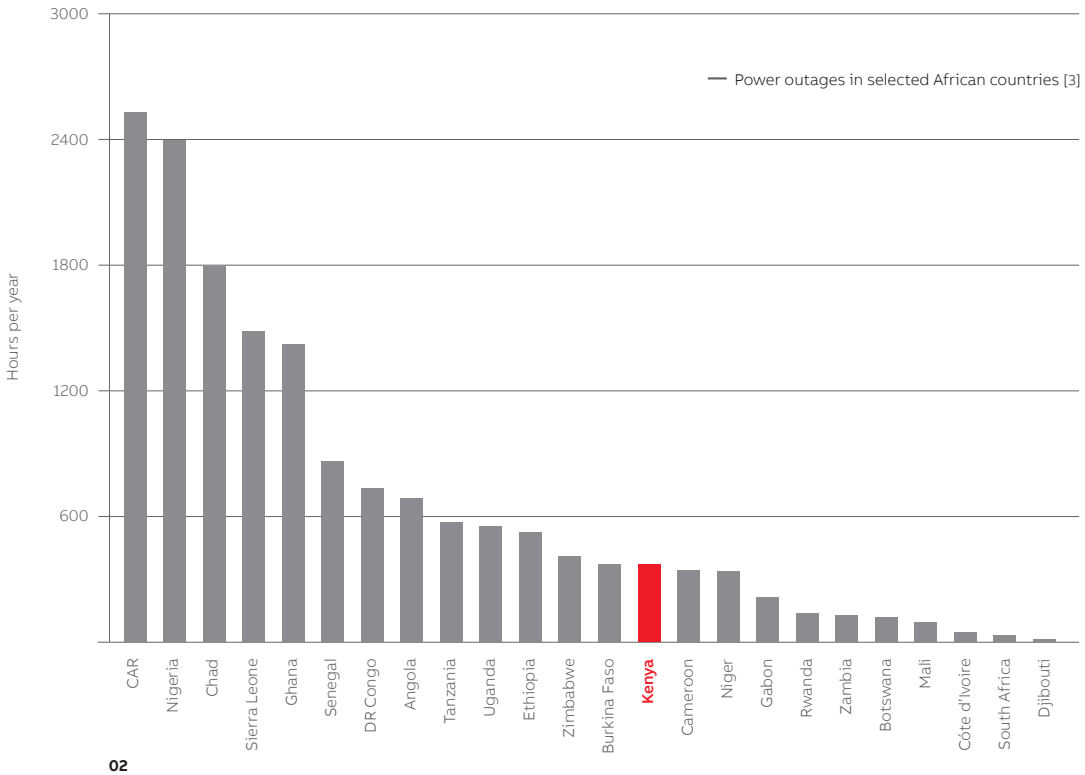
The project will allow the integration of renewable solar energy into the existing grid, which is nowadays fed by the electricity company Kenya Power (KPLC) and diesel generators. So in addition to protecting essential ICRC resources, the hybrid microgrid will assist in reducing carbon emissions.

"Reliable power is essential for our staff to continue their life-saving work uninterrupted in the field" said ICRC President Peter Maurer.

"In addition, the ABB microgrid solution is in line with the ICRC's goal to use environmentally friendly technologies. Solutions like this are proof that cooperation between the corporate and humanitarian sectors is not only possible but imperative. We are happy and proud to count ABB as a member of our corporate support group."

The agreement reflects an ICRC initiative launched in 2014 for greater technology collaboration with the private sector. ABB has been a member of the ICRC corporate support group for the past decade, contributing to water and habitat programs for victims of conflict in the Democratic Republic of Congo and Iraq. ABB also helps train ICRC engineers. ●

"Reliable power is essential for our staff to continue their life-saving work uninterrupted in the field" – ICRC President Peter Maurer.



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02 Duration of power outages in selected African Countries [3] Notes: CAR=Central African Republic. Data is from the latest available business survey for a given country. Sources: World Bank (2014b); I EA analysis.

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AFRICA

Station service voltage transformers for low-power applications

For small communities, the cost of a substation is often prohibitive. ABB's micro substation – a low-cost substation that exploits single-phase station service voltage transformers (SSVTs) – alleviates this situation. SSVTs step down power from high voltage levels to medium or low voltage in one step.

Mathew Paul
Former ABB employee

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All substations have metering and protection systems that run off a low-voltage (LV) power supply – the so-called control power supply. For reliability, every substation requires two redundant control power supplies. Usually, the main transformer in the substation is the primary source of control power.

If substation power is lost, the grid, via a power transformer, can provide the secondary power source. However, this is an expensive option, both in terms of capital expenditure and the cost of keeping the transformer energized. Drawing power from a feeder connected to a local LV distribution network is another option, but one that is also expensive and prone to disruption. In some cases, the main HV transformer is equipped with a third winding to provide the control power supply. However, this is not an ideal solution because of design, reliability and cost considerations. A further option is a standby generator – a solution with low initial financial outlay, but high lifetime costs.

Fortunately, an SSVT – or an SSMV, which is an SSVT for medium-voltage (MV) levels – can, in many cases, provide the secondary control power supply – for a fraction of the cost and much more easily [1].

The SSVT

An SSVT combines power and instrument transformer characteristics in a product with high reliability, low cost, simplicity and compactness that is ideal for small power applications. The SSVT's capabilities allow it or an SSMV to meet the power requirements of a remote community or a substation with just a single unit.

The SSVT has a small footprint, is easily configured by virtue of its single-phase design and can supply power from 25 kVA to 333 kVA, subject to certain limitations on voltage, at 50 HZ or 60 HZ. An SSVT or SSMV, though not a replacement for a full substation, can expand the reach of electricity to remote communities – for example, small villages in Africa →1. SSVT/SSMV units are significantly lighter and smaller than a power transformer – ideal for transportation to locations in Africa, or elsewhere, that are not easily accessible. SSVTs/SSMVs can be used as a power source during construction and later configured as a control power source.

An SSVT or SSMV has a single-phase, shell-type construction and is connected between the primary line and ground, with a grounded shield winding interposed between the high-voltage (HV) and low-voltage (LV) sides to protect the secondary from transient voltage surges.

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01 A 220 kV/100 kVA SSVT substation in the Democratic Republic of Congo, situated conveniently close to an HV power line.

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References
[1] M. Paul, "Small wonder – Station service voltage transformers for small power requirements," ABB Review 1/2016, pp. 12–17.

In the SSVT protection scheme, a current transformer (CT) on the HV neutral or ground connection will detect any line-to-ground fault on the secondary winding. A CT on the tank ground wire can detect a ground fault on the primary side. An optional, under-oil, sudden-pressure relay can also detect internal faults just as in a power transformer. In the event of a fault on the primary side, the line protection can isolate the SSVT. At present,

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An SSVT can provide the secondary control power supply – for a fraction of the cost and much more easily.

up to a 750 kV basic impulse level (BIL), HV dropout fuse protection is available to isolate a defective SSVT/SSMV from the transmission line. Above 750 kV, a single-phase circuit breaker can be used.

Further, a substation using a single-phase SSVT or SSMV can be unmanned and very straightforward, with just an arrestor, HV circuit breaker, isolator, earthing grid and LV distribution board – all in a single-phase configuration. This simple arrangement also reduces footprint.

By eliminating one or more intermediate transformers, no-load losses and copper losses are reduced, making the system more energy-efficient. Also, the SSVT's oil volume is a fraction of that of a comparable power transformer. SSVTs are virtually silent in operation.

SSVTs with higher kVA ratings are under development, which will allow larger isolated communities to benefit from the convenience of grid electricity. In many countries in Africa, for instance, the direct access to grid power that SSVTs can provide will have a dramatic and fundamental positive effect on their economic and social development. ●

AFRICA

Innovating Ethiopia's connections to the world

At first glance, it seemed that ABB's Awash-Kombolcha-Hara Gebaya rail line project would be straightforward, encompassing an array of standard, engineered substations and power supply equipment. What soon became apparent was the complexity of bringing a weak high-voltage network to the rough topography of the Ethiopian countryside. A nine-month innovative development approach yielded the right solution, and established a process that can help sell other projects in Africa (and around the world).

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In late 2014, ABB was chosen by the Turnkey Project General Contractor Yapi Merkezi Insaat from Turkey to help build a new rail line for the Ethiopian Railway Corporation (ERC), linking its northern and eastern traffic corridors with a recently opened line connecting its capital to the port of Djibouti →1–4.

The reliability of ABB's products and services was key to its selection, and encompassed the design and supply of engineered equipment packages for five 230/27.5 kV traction substations, eight section posts, six neutral zone substations and about 30 auxiliary substations. Key products to be supplied included a range of high and medium-voltage switchgear, traction transformers rated at 25 MVA, Dynacomp dynamic response compensator to improve power factor (cos φ), FSK II+ railway circuit breakers and auxiliary power supply equipment.

And then the real work began. Once ABB began deeper discussions with Yapi Merkezi, both companies began to understand the magnitude of the challenges, such as where the project should connect to the grid, at which voltage level, which type of catenary system was expected, and how it would behave in degraded mode.

ABB's initial approach was to use 245 kV to connect to the grid, but Ethiopian Electric Power came back and said the first 200 km could only connect at 132 kV. Upgrading to 245 kV would require building overhead lines from 100 km away.

Finding a solution meant conducting a full power simulation. ABB partnered with its customer to customize its software model with the unique attributes of the project. For instance, the 400 km line went from 800 m to as high as 2000 m, and these altitudes had not been in the original plan.

> ABB prides itself in offering more than a collection of products, and this was an ideal opportunity to demonstrate that value.

A recommendation on substation locations was submitted to the ERC, and then began a collaborative back-and-forth dictated as much by the exigencies of real estate purchasing as by technology requirements.

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01 B24 and B25 Bridges Construction (ILM Method), KM 186+000 (Image Courtesy of Yapi Merkezi).

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02 Artist's rendition of Amibara Station, (Ethiopia Image Courtesy of Yapi Merkezi).

It took about nine months, and a team effort by ABB, Yapi Merkezi and the ERC to reach a solution that met the diverse demands of the project.

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The collaboration process yielded a number of innovative and necessary insights.

The process yielded a number of innovative and necessary insights, such as:

- Single vs double 25 kV catenary system – The initial solution was 2 x 25 kV, which would help improve the line's voltage profile, however, this solution requires a strong high voltage grid. Since the high voltage grid is weak, the solution evaluated as unfeasible. ABB adapted the supply system to meet the project's requirements.

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- Catenary system specifics – ABB is not in the business of catenary system design, but as this had a significant impact on the overall system performance, Yapi Merkezi asked for support.

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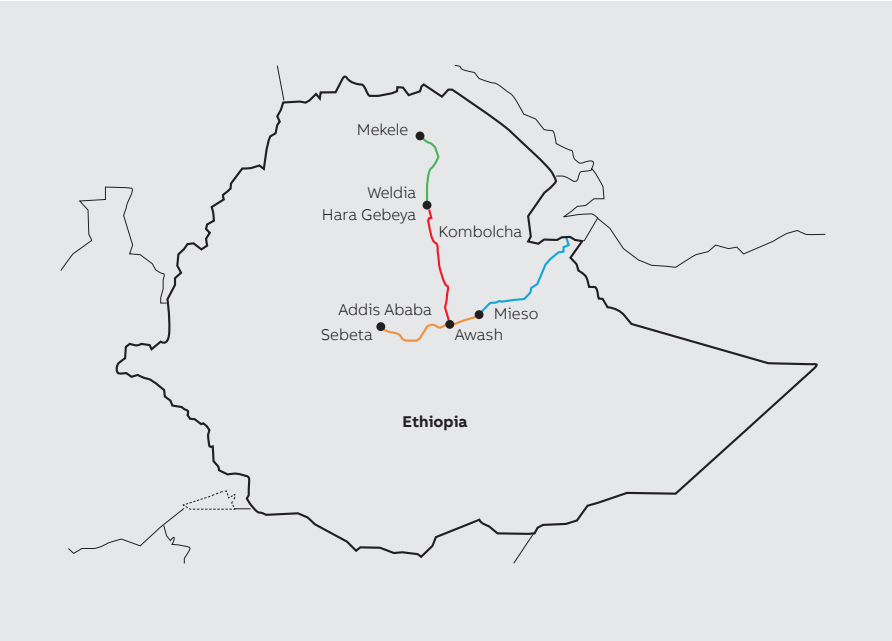
ABB implemented various simulations to find the optimum solution in terms of price, catenary voltage profile and reliability.

ABB held several meetings with its catenary team to discover and explore potential solutions, and then implemented various simulations in collaboration with them to find the optimum solution in terms of price, catenary voltage profile, and reliability.

- Degraded mode – ABB had to build a solution that allowed trains to run even when there are power failures. A “pure” degraded mode provision would have ensured that trains could still run when one complete traction substation was down, but this proved to be impossible with the defined number of substations within the context of the country’s existing network conditions.



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03 Typical river crossing bridge (Image Courtesy of Yapi Merkezi).

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04 The project (in red) connects Ethiopia's northern and eastern economic and traffic corridors (Image Courtesy of Yapi Merkezi).

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05 CPB170 ABB Capacitor Voltage Transformer.

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06 IMB145 ABB HV Current Transformer.

Alternatively, ABB's approach was to ensure that the trains could keep running in case one transformer of one substation was down, but the ERC did not find this approach convincing.

The ERC was expecting to have units of a unique (or rare in European market) type of traction transformers (three-phase Vv connection) because that is the transformer normally used in East Africa →5–6.

According to ERC's knowledge this type of transformer would avoid degraded mode in the substation if one failed, so ABB had to revisit this expectation and, after further studies, presented the final solution of using three single-phase transformers per substation.

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07 ABB HV Disconnector SDF.

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* Vector connection

This innovative answer was more practical than using two three-phase Vv* transformers, as well as much more reliable, because power could be supplied to the trains not just when one of the transformers is out of service in one substation, but also when there is one out of service in each substation.

- Line extension – Even though ABB ran the simulation for the complete line (400 km), the first phase of the project (and ABB contract) only covered the first 270 km. ABB was asked to ensure that the train could reach the final station at km 270 without having the second part of the line built (it's likely that the final 130 km will be in operation one to two years from now). For this reason, it brought one traction substation from the second part of the line to the first, changing the scope of phase one from 5 to 6 substations, while the second phase was reduced from 3 to 2 substations.

ABB's deliverable also meant proactively making allowances for the broader context of Ethiopia's potential plans for future development, considering the project and two others nearing completion would put significant demands on the country's installed power system.

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ABB's deliverable also meant proactively making allowances for the broader context of Ethiopia's potential plans for future development.

In addition to changing its remit to include over-dimensioning to protect the existing connections, ABB provided insights for the ERC on how it could build on its installed equipment.

Yapi Merkezi has achieved 80 % Overall Physical Progress for the section between km 0+000 and km 270+000. ●

AFRICA

A model for better electrification planning

Off-grid electrification systems can be the best option to provide electricity access in areas where the central grid is too expensive or the incumbent distributor is unable to extend the grid, for whatever reason. Researchers supported by the MIT Energy Initiative's Tata Center for Technology and Design in collaboration with IIT-Comillas in Madrid have built a computational tool called the Reference Electrification Model (REM) that can improve electrification planning in developing countries with low electricity access and help increase the success rate of off-grid projects.

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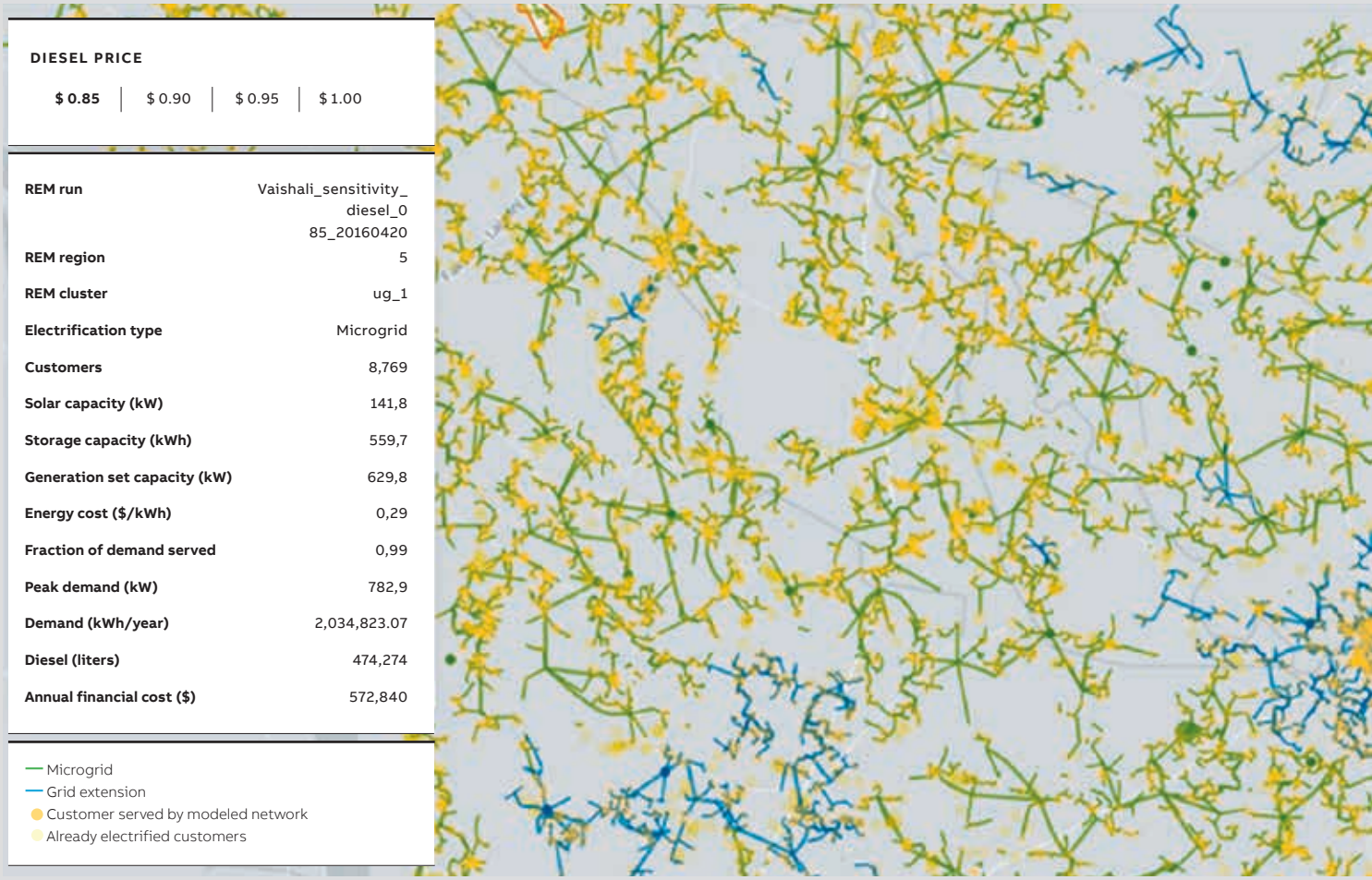
Over half a billion people in sub-Saharan Africa live without electricity, mostly in rural areas that may be years away from receiving reliable, centralized electricity (if it happens at all, considering the potential expense). A substantial portion of the rural population in the developing world could be served by off-grid systems – 70%, according to the International Energy Agency. But determining where off-grid systems such as microgrids would be the best solution (let alone building and operating those systems) is easier said than done, and it is here where the REM model can help. REM can also estimate the costs of electrification and potentially illuminate solutions to a serious financial viability problem: the cost of supplying scarce and disperse demand is more than what many of the customers that lack service can afford.

Developing low-cost, standalone systems to provide a small amount of lighting and phone charging has been the recent trend, but those solutions tend to do little to enable families to rise up the income ladder and realize the additional benefits that electricity can provide. The lack of "anchor loads" in rural areas – industrial or commercial – which could increase the total level of consumption, makes it challenging to design economically viable systems. The diversity of contexts in which microgrids hold promise create scalability challenges that tend to drive up engineering costs.

EDITOR'S NOTE:

With three decades experience in numerous projects around the world, ABB is a leader in off-grid and microgrid solutions. Whether powering whole islands, remote villages, or isolated industrial sites, ABB knows how to customize and right-size systems, agnostic to the generation source, and with the aim to drive maximum reliability with low cost. Most recently, the group introduced a new set of "plug and play" modules based on a number of pre-designed variants, which are scalable, expandable, and easy to install.

This guest essay from MIT's Tata Center for Technology and Design, which is part of the university's Energy Initiative, is an example of how such projects can be identified and scoped. MIT is a participant in ABB's Technology Forum.



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Among other uncertainties, the possibility that the grid could eventually arrive makes investments in off-grid systems seem risky.

These obstacles – along with the regulatory challenges associated with upsetting the electricity sector status quo – mean that the decision about where to extend the grid, deploy microgrids, or use standalone systems is worthy of serious consideration. Existing approaches to this sort of hybridized electrification planning in developing countries range from politically motivated decisions to extend the grid, to other software tools, like Columbia University's electrification planning software, Network Planner.

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REM provides the maximum degree of granularity in decision-making that until now has been unattainable in such data-constrained environments.

REM provides the maximum degree of granularity in electrification decision-making (i.e., individual building level) that until now has been unattainable in such data-constrained environments.

REM is a robust optimization tool designed to process data about any size region, be it a village, a county, or an entire country, in order to make cost comparisons between different combinations of electrification modes (grid extensions, microgrids, or standalone systems) and identify areas better suited to on- or off-grid electrification →6. The tool also produces first-pass technical designs for recommended grid extensions and is capable of doing detailed system designs for grid extensions or microgrids that contractors, governments, and investors can rely upon for scenario planning and budgeting.

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01 A mock-up of how REM output might be presented to the end user.

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02 A topographical map of Rwanda used as an input to REM.

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03 View of the mountainous terrain in Rwanda as seen from the village of Karambe (Photo by Ignacio Pérez-Arriaga).

How It Works

In order to assess these tradeoffs and determine least-cost plans, REM requires two categories of inputs:

- Geospatial and resource information — Location of buildings, existing electricity distribution grid (if any), administrative or other context-relevant boundaries (including topography and geological features that the network cannot cross or at higher cost) →2, and the availability and prices of different energy resources.
- Electricity demand and costs – Classification of building types, characterization of the electricity demand for each building type (based on data such as hourly demand profile of similar buildings in similar contexts, census data about appliance ownership, or existing demand targets) →4, electrification status of buildings, reliability of the existing grid, cost of non-served energy (CNSE), generation and network equipment/technical requirements, and a discount rate to determine the net present value of a project.

The foundational input is the location of the buildings in the study region, since the ability to make decisions at such a granular level is what enables REM to do both large- and small-scale

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REM uses a series of processing steps to organize the buildings into clusters, design systems for those clusters, and compare the costs of the viable options.

planning. This information is still rarely available from governments or local utilities (although significant progress has been recently observed), so REM employs an algorithm capable of extracting building locations from satellite imagery →5. With this data, REM uses a series of processing steps to organize the buildings into clusters, design systems for those clusters, and compare the costs of the viable options.

REM outputs information about the set of least-cost options for all consumers in a region in two formats: One, a table of information about each cluster or isolated building, including the type of system assigned to it, the estimated cost of the system, the type of generation and a detailed cost breakdown; two, a set of files that can be visualized using GIS software so that a full map of the study area can be evaluated →1.

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Project planners (public or private) can use these results to ask a wide variety of “what if” planning questions, and study possible outcomes of various policy or regulatory interventions. At the individual system level, the goal is that REM can provide a reliable basis from which to conduct follow-on feasibility studies and community engagement.

Status & Availability

REM’s development process has been facilitated through early stage on-the-ground projects that have enabled improvements to various capabilities of the model as well as highlighted some key lessons. In Rwanda, for example, where the REM team has been interacting with the Ministries of Infrastructure and Education, it has become clear that the country’s mountainous geography lends itself particularly well to microgrids →3, since it is costly to extend the grid to these villages or to link them electrically. These communities place a high value on electricity since it alleviates the need to travel frequently down the mountain to the capital to purchase batteries or services, such as phone charging.

In addition to running REM, extensive community surveys have been employed to obtain reliable load estimates, reducing the risk of over-sizing systems and incurring unnecessary costs.

In Vaishali, a district in Bihar (one of India’s poorest states) REM has been used to model a wide range of electrification scenarios that have led to other robust conclusions. Most interestingly, REM analyses here suggest that areas in which there is already grid distribution infrastructure may still be good candidates for microgrids if grid reliability is poor and grid extension is not progressing quickly.

Project planners (public or private) can use these results to ask a wide variety of “what if” planning questions.

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04 An example of how loads were characterized in Karambe, Rwanda.

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05 Two examples of early results obtained using an object extraction algorithm designed to locate buildings in satellite imagery.

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06 A graphical example of how costs change under different assumptions about demand and generation mix.

Additionally, the lack of load diversity gives rise to a demand curve that peaks in the evening and requires substantial battery storage, driving up microgrid costs. REM uses rigorous system optimization to minimize the costs of investment plus operation for a prescribed reliability target, while taking into account the expected demand profiles as well as historical weather and insolation patterns.

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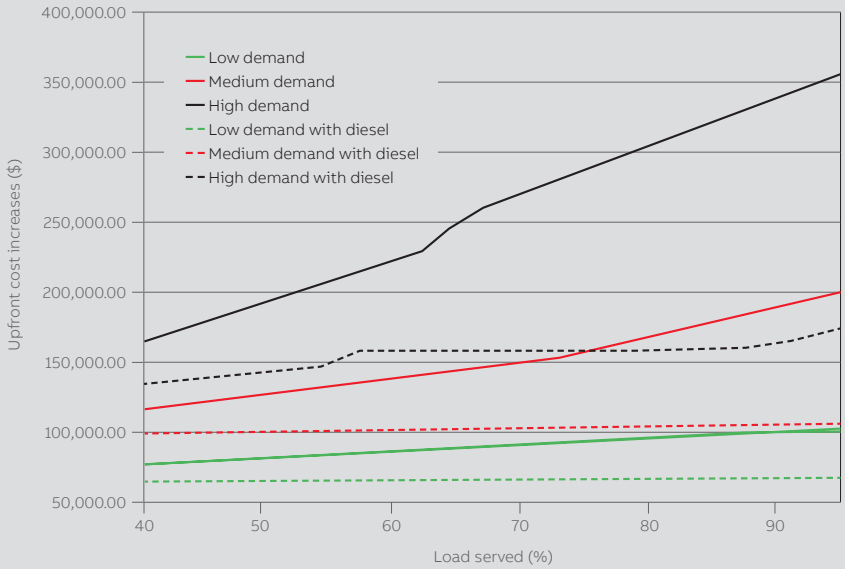
REM will be critical to studying and producing insights about the best mix of solutions in countries considering hybrid electric power systems.

REM is already helping users better understand the enormous role for both private and public dollars in closing the so-called “viability gap” between what people who lack access to electricity can pay and what it costs to improve their electricity access. As it is necessary to consider a diversity of large-and small-scale projects, REM will be critical to studying and producing insights about the best mix of solutions in countries considering hybrid electric power systems. ●



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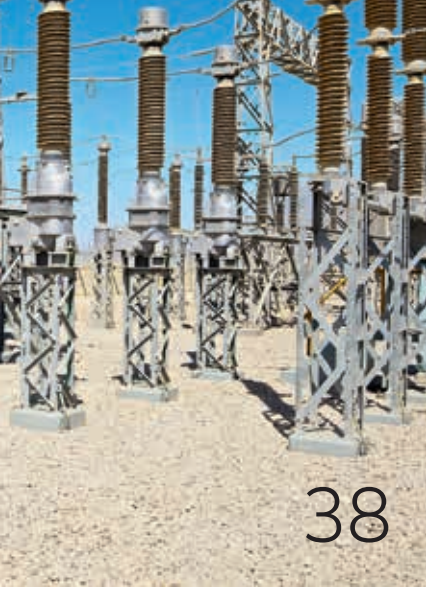
Designed for safety



In the century and more that ABB has spent bringing the latest technology to its customers, it has proven that usability, and reliability when it comes to the operation of mission-critical systems, is not only a functional requirement, but a key component of security as well as safety. That operational expertise flows into the design of equipment and the control systems on which it relies, both to lower the risk of disruptions, and to minimize their effect and duration if and when they occur.

DESIGNED FOR SAFETY

Human factors and their impact on plant safety

Operators in modern plants are tasked with numerous activities, making it difficult for them to handle abnormal process conditions. Research has demonstrated how an intelligent and ergonomic workspace can both mitigate risk and increase productivity.

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The introduction of mission-critical computing systems and automated tasks in manufacturing processes has resulted in increased safety and productivity during normal operation. But what happens when abnormal situations arise? The answer is, of course, that a human must step in →1.

Human factors and safety culture

The human factor need to be at the center of any safety discussion for many reasons, one of which is that human error is often the cause of incidents and accidents in the first place – despite the strict safety culture prevalent in most firms. The consequences of such incidents range from minor injury to headline-making catastrophe. If an organization wants to ensure a successful safety culture, it must have a clear and explicit risk management strategy.

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Understanding and managing risk

To understand and manage risk, plant operators should first carry out a hazard and risk assessment to identify the overall safety requirements. After that, they should focus on proactive measures to ensure, if possible, that a failure does not occur and that negative consequences are minimized if one does. Learning from experience can be an ideal starting point:

- What should be done differently after a certain experience to prevent reoccurrence?
- What can be done to learn more from this experience?
- What should be done differently after a reoccurrence of this experience?

It is important that, rather than be a chore, the company safety culture should provide an opportunity for individuals and organizations to learn from and be motivated by positive change. Employees can thus aspire to a safer and more productive way of working →2.

Technology as part of the solution

Anticipating failure, engineering best practice allocates risk reduction across different and independent protection layers in the form of multiple independent functions or systems. One such system is a safety instrumented system (SIS), which is based on a concept involving different layers of protection.

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01 Ultimately, human operators must step in to rectify many abnormal situations.

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02 Safety and productivity should be part of company culture.

Layers of protection

A process control system provides a “layer” that not only assists in the productivity of the process but also helps plant operators keep the process within safe operational boundaries. Today, most process control systems will alert the operator to abnormal conditions and support him by providing real-time access to critical information.

When events develop too rapidly for effective operator intervention, other protection layers, such as an automatic SIS, spring into action to return process conditions to normal.

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Anticipating failure, engineering best practice allocates risk reduction across different and independent protection layers.

Design-for-safety is supported by a series of standards – such as IEC 61508 and IEC 61511 – that aim to establish, and in some cases mandate, the best practices for design, documentation reviews, validation and verification of a safety project.

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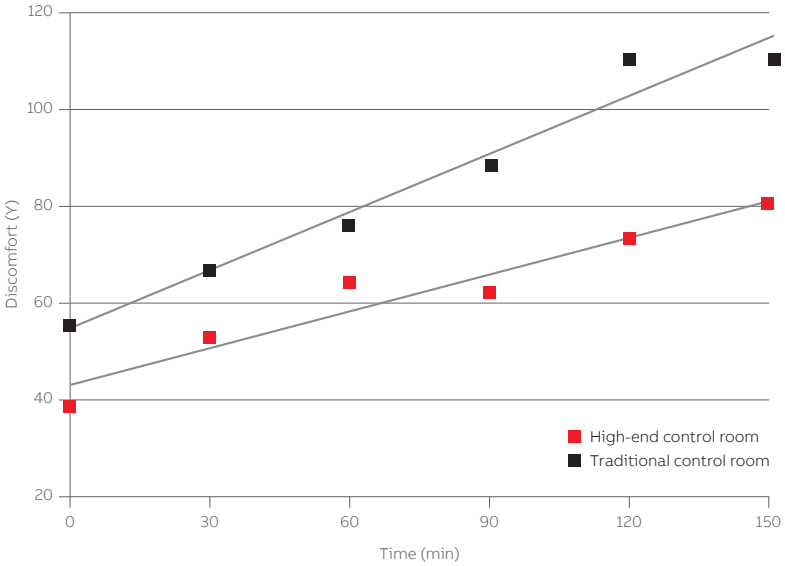

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If any of these layers (technology or human) fail to prevent the hazard, there are other layers intended to mitigate consequences, such as fire and gas systems or emergency response procedures, which are not discussed here.

However, the reality is that all these technologies are designed and implemented by human beings and, as a result, will not be perfect or 100 percent safe.

Integration of control and safety systems delivers consistency for the operator

Integrated control and safety systems provide the enabling technology to drive effective operations and minimize some of the sources of human error. Some benefits of this approach are:

- Common failure modes can be designed out before the product is released.
- The standard product can be made secure to prevent unauthorized access to critical facilities.
- Integrated testing occurs in the product test lab and can be carried out by experts with in-depth domain knowledge of the multiple technologies involved.

Human-centered design

Various sources indicate that around 70 percent of reported incidents in the oil and gas industry worldwide are attributable to human error and account for over 90 percent of the financial loss to the industry. This human error challenge can be addressed by matching the control room operator's psycho-social working environment (WE) with his physical WE. This type of human factor engineering and the use of ergonomic solutions can reduce financial losses.

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Human error can be addressed by matching the control room operator's psycho-social working environment with his physical working environment.

Designing a control room or control center working environment for humans is challenging yet fundamental. One of the most important quests to reduce human error by matching physical and psycho-social elements in the design. The UK Health and Safety Executive (HSE) formulates the problem thus, "physical match includes the design of the whole workplace and working environment. Mental match involves the individual's information and decision-making requirements, as well as their perception of the tasks and risks. Mismatches between job requirements and people's capabilities provide the potential for human error [1]."

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03 Perceived discomfort in the traditional control room and the high-end control room.

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04 The flexibility of the Extended Operator Workplace allows a human-centric approach and thus increases efficiency.

There are plenty of guidelines and standards that tackle the design process of a control center or control room – the offshore industry has established ISO 11064 as the main standard worldwide, for example.

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Health-improvement awareness among operators is one of the main factors driving ABB to develop solutions for the early recognition of adverse stress levels and deteriorating health.

Developing the control center and control room working environment

Despite the prevalence and cost of human error, control center and control room design has tended to focus on physical aspects and the process itself, to the detriment of the human angle. Further, with the increasing trend for operators to move from local control rooms to control centers, comes a higher operator workload and attendant increased stress level. Increased stress can lead to depression, anxiety and burnout.

Poor ergonomics, poor lighting and high noise levels that directly cause physical ill health can exacerbate this fundamentally bad situation.

The alignment of psycho-social and physical elements automatically improve health and wellbeing in the control room or center. Organizations should develop stress management and counseling policies to identify and eradicate work practices that cause the most job dissatisfaction. Of course, humans differ very much in cognitive processes and ability to solve problems – for instance, some operators can be skilled in multitasking, some in understanding the complexity of a workload, others in data analysis and yet others in effective leadership. Nevertheless, there is one main value they share: health. Health-improvement awareness among operators is one of the main factors driving ABB to develop further solutions for the early recognition of adverse stress levels and early warnings of deteriorating health status.

Human-centered design is made all the more imperative by the demographic pressure exerted by an aging workforce in the northern hemisphere. To prevent knowledge being lost, young people must be attracted to a career in the industrial world. This can only be done by offering them a workplace in which they are content.

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05 A Best-in-class control room environment reduces the chance of human error.

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Reference
[1] "Reducing error and influencing behavior," Health and Safety Executive, 1999. Available: http://www.hse.gov.uk/pUbns/priced/hsg48.pdf

A holistic approach
Improving only the physical part or the psycho-social part of the control room environment is not a holistic approach – both aspects must be improved in a mutually compatible way. This effect was illustrated by research conducted by ABB and Chalmers University, Sweden in which a traditional control room was compared with a high-end control room. The perceived discomfort increased over time in both, but the increase was lower in the high-end control room. Thus, a more holistic physical and psycho-social environment was provided →3.

Ways to increase efficiency
One way to influence performance is through varying lighting levels – a high level of illumination increases motivation and reduces errors and accidents. Lighting also has a direct impact on health and well-being since the human circadian rhythm is directly related to ambient light levels. ABB has cooperated with Lund University and others to provide a human-centered lighting platform for operators in a control room. One application of the research so far has been to allow the operator to freely adjust their task area lighting by using cold or warm light →4. The range of illuminance is between 900 to 1800 lux, which exceeds the minimum 500 lux recommended by ISO 11064.

Another way to increase operator efficiency is to simplify the variety of communications possibilities (an operator does not become more efficient by using many different communication tools at the same time.) Instead of a clutter of equipment for VHF/UHF radio, telephony, cell phone, intercom, public address system, etc., all communication can be moved to just one device.

Finally, controlling noise levels by working with directed sound is another way to improve the operator's workplace experience. Sound showers are especially beneficial as they allow telecommunication, alarms, etc. to take place without disturbing others.

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Integrated control and safety systems provide the enabling technology to drive effective operations and minimize some of the sources of human error.

Putting people first
Planning for human error is a critical part of control room design. Designers of systems have to be very careful as they can induce human error if they have not identified all operational eventualities and provided a suitable control process or system response to them. These latent failures can lurk unseen until a specific operational constellation appears and an incident occurs. In such situations, the operator is often unprepared and unable to respond appropriately.

As industries continue to invest in new facilities or modernize existing ones, they could profit from directing some of the investments toward reducing the propensity for human error. This can be done by the adoption of human-centered design best practices →5. Consideration of the human elements of the control room will lead to additional benefits and a safer and more productive environment. "Putting people first" is a sound business strategy. ●

DESIGNED FOR SAFETY

Adaptive operator workspaces improve the mobility of control room operators

Operators occasionally have to leave their workplace temporarily. ABB has created a prototype workspace that aims to improve operator mobility by removing the necessity for them to be near their workstation while still enabling them to perform their work effectively.

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Today's control room operators are often faced with workstations of a much greater complexity than those of even just a decade ago. Even though automatic process control solutions can handle many process events, the constant presence of a human operator at a workstation is, in many cases, imperative. However, the operator may have to leave his station at various times during his shift. What can be done to maintain his vigilance over the processes for which he is responsible during such absences?

> The main goal of the prototype was to increase operator flexibility regarding how and where they interacted with the control system.

The first step to be taken in designing a solution that allows more operator mobility is to gain an in-depth understanding of how control room operators perform their work. To achieve this, interviews and observational approaches were used to gain valuable insights into real work practices, goals, needs and concerns:

- Operators interact with several complex graphical user interfaces (GUIs) on several different monitors and navigate between many different views of the control process.
- It was a challenge for operators to find the correct mouse for the correct screen and to navigate to a particular view or object. Navigation is usually implemented through complex multilevel drop-down menus and sometimes navigation menus span the entire screen.
- When operators need to leave their workstation and, for instance, go to a colleague's workstation, it is difficult for them to stay informed about what is happening on their workstation (eg, what alarms are being triggered).
- Operators sometimes need to engage in work outside the control room, eg, on the factory floor. When returning to the control room, they may need additional time to remove safety equipment or clothing or wash their hands before once again interacting with the control process.

The information gathered provided key design considerations for the new solution.

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Design concepts

Based on the needs identified during interviews and observation sessions, a prototype was built. The main goal of the prototype was to increase operator flexibility regarding how and where they interacted with the control system by providing:

- the ability for the operator to work even when not in front of the displays
- flexibility in the way the operator works
- fast navigation between different views in the system
- fast navigation to a specific process object in a view
- better situational awareness for quickly detecting alarms, types of alarms and state of the current process view.

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When there is at least one urgent alarm, the lamp switches to bright red. When there are only warnings, the color switches to orange.

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Features of the prototype included:

- an adaptable GUI that adjusted the size of text and graphics on the screen based on the operator's location within or outside the control room →1–2
- an interactive light that projects white ambient light when no alarms are present. When there is at least one urgent alarm, the lamp switches to bright red. When there are only warnings, the color switches to orange
  In addition to colors, the intensity of the light may also be altered to indicate the alarm priority →3

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01 A smaller GUI used for the prototype, shown when the operator is close to the screens.

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02 Larger prototype GUI, shown when the operator moves away from the screens.

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03 Light display connected to alarms triggered in control room.

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04 Speech and gaze can trigger the display of information relating to a specific process graphic.

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05 Using Leap Motion to point and select a graphic in the control process.

- different sound tones to indicate which object is the cause of the alarm signal and the degree of alarm seriousness eg, a boiler alarm triggers the sound of boiling water
- the capability for eye-tracking, speech recognition and gesture interaction with the control system. Using Microsoft Kinect, a Tobii eye-tracker (Tobii is a world leader in eye tracking), speech recognition and Leap Motion (a motion-control software produced by the eponymous American company), operators can interact with the system by fixating on a process graphic while using verbal commands such as “open faceplate” →4. This example interaction triggers information about the object in focus to be displayed to the operator. Also, the operator can gesture up or down to navigate up or down in the hierarchy of system views.

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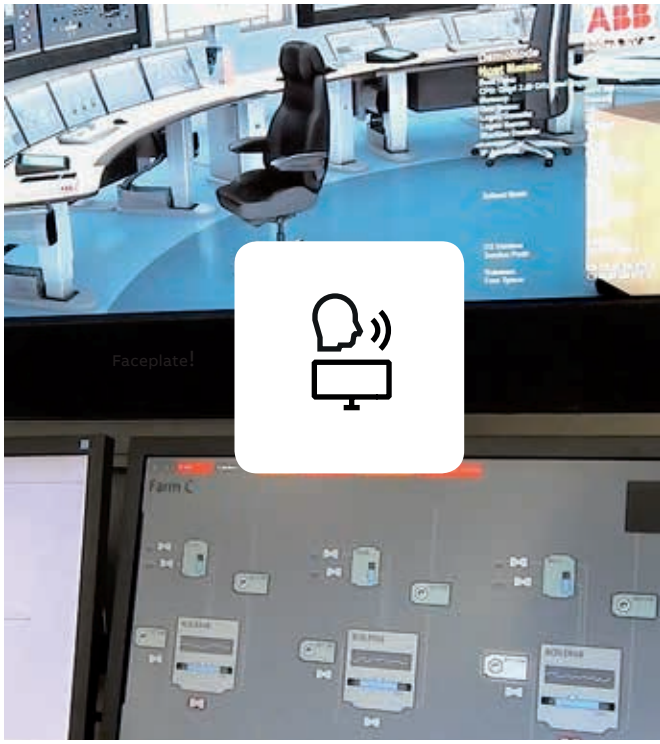
The first step to be taken in designing a solution that allows more operator mobility is to gain an in-depth understanding of how control room operators perform their work.

Furthermore, the operator can use their index finger as a mouse pointer to select objects and to perform click operations →5.

These modes of interaction free the operator from mouse- and keyboard-only interaction with the process and enable them to work in a more mobile, flexible and unrestricted way. They also eliminate the difficulty of finding the correct mouse on a



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desk containing several mice, allowing operators to focus fully on their tasks. Providing operators with the ability to access the information they need while being able to move freely in and out of the control room ensures situation awareness is continuously maintained.

This type of solution can be used in a wide range of industrial processes, giving operators more flexibility of movement while maintaining operational standards. ●

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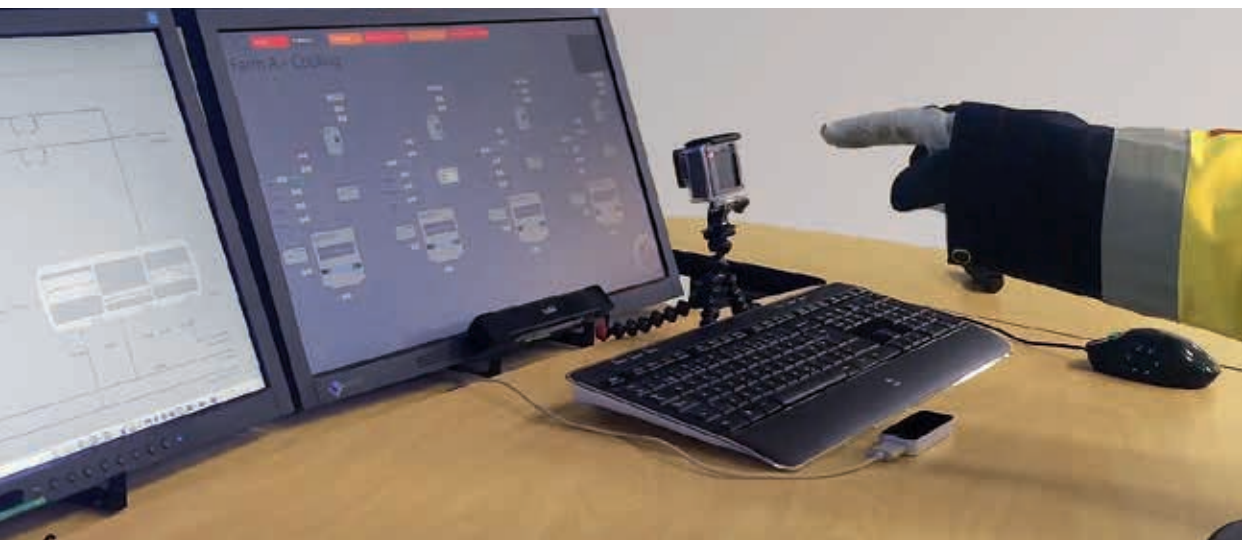

DESIGNED FOR SAFETY

Modeling insulation in high-voltage substations

The goal of insulation coordination is to determine the dielectric strength of transformers and other substation equipment in relation to overvoltages that can appear on the system. Once insulation characteristics have been assessed, the designer can choose an appropriate protection scheme that reduces or eliminates the chances of surge-induced failure.

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Overvoltages in power systems can be caused by a variety of events. These events can be represented in the frequency domain, in line with international standards for insulation coordination (IEC 60071 series), and are mainly characterized by their magnitude, rise time and frequency.

The main topic of this article is high-frequency phenomena. These are classified as fast-front transients. Such transients are usually caused by lightning surges and can result in overvoltages with values five times or more the rated operating voltage.

Fast-front transients are usually caused by lightning surges and can result in overvoltages with values five times or more the rated operating voltage.

Properly rated and well-located surge arresters (such as the ABB Polim series) are very effective at limiting excessive overvoltages. Although their application is straightforward, there are several aspects that must be addressed during the surge arrester selection process.

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01 What steps must be taken to ensure that equipment in substations can handle overvoltages caused by events such as a lightning strike? (Shown is a 132 kV substation.)

Of these aspects, the evaluation of overvoltage protection during transient conditions is the most complex.

In the past, it was impossible for engineers to perform the complex studies that would provide a better understanding of transient phenomena. Nowadays, electromagnetic transient (EMT) simulation software comes to the aid of designers and is even considered as indispensable for the investigation of certain cases.

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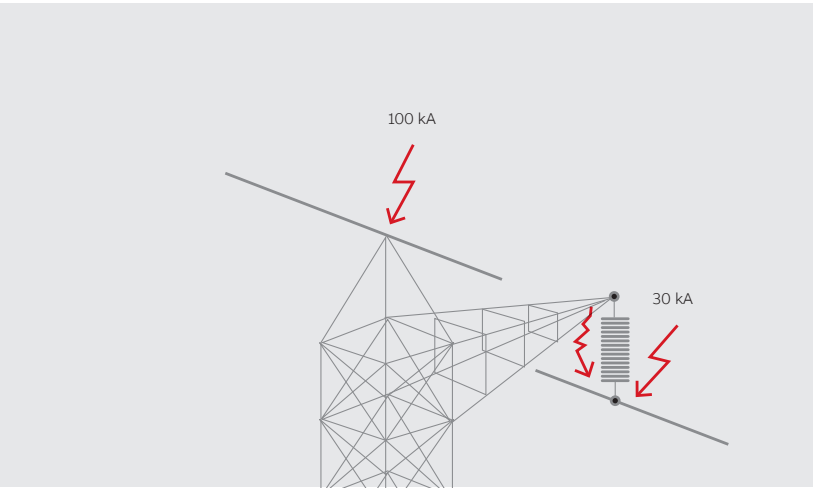
Properly rated and well-located surge arresters are very effective at limiting excessive overvoltages.

Modeling lightning strike effects
Lightning strikes are inevitable when an high voltge (HV) substation is supplied by overhead transmission lines →1. The lightning can hit either the phase wire (direct stroke) or the shield wire, causing backflash over the insulator string. Voltage magnitudes can reach values as high as several megavolts at frequencies in the range of 50 kHz to 10 MHz.

The lightning-generated current magnitudes and waveshapes that are used for EMT studies are selected according to international standardization committee guidelines (IEC, CIGRE) that have been established over many years of measurements. Despite the unpredictable nature of lightning phenomena, such an approach ensures a satisfactory level of lightning current approximation →2.

Protect your substation
When a direct strike or backflash occurs, an overvoltage wave is generated that propagates along the phase conductor to the substation. Limitation of such overvoltages is crucial for the safe and reliable operation of substation equipment, especially transformers, which are the most expensive components of the power system. Overvoltage mitigation can be achieved thanks to the nonlinear characteristics of surge arresters based on zinc oxide. These surge arresters consume negligible current in the steady state and very high current (kA range) when faced with surges due to events such as lightning discharges.



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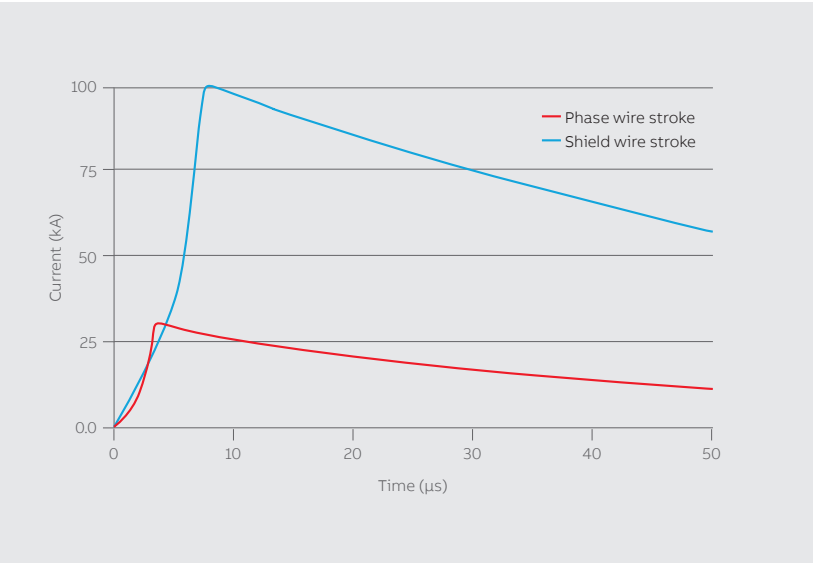

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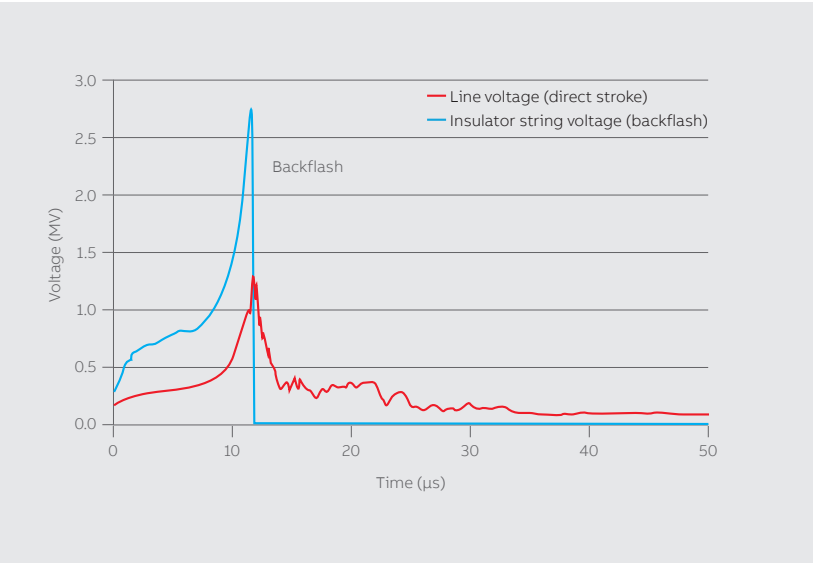

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Thanks to this characteristic, overvoltages are clipped below the maximum permissible levels.

→3 shows the voltage behavior during a so-called 8/20 µs lightning surge, with respect to Uc, the maximum continuous operating voltage (MCOV).

The general rule is to keep the surge arrester as close as possible to the equipment that it is meant to protect.

The 8 and 20 refer to the rise time of the current crest and current tail off time, respectively, in µs, of the impulse curve. The 8/20 is one of several standard discharge current waveshapes that have been in use for many years. It is often used, even though it does not accurately represent all lightning surges.

Simulating lightning overvoltages

Insulation coordination studies must assume that the worst possible conditions will arise and all at the same time. Planning for this eventuality necessitates the verification of several critical aspects of the application – such as lightning current crest and steepness, substation topology, overhead line layout, presence of HV cables, tower structure and the ratings and location of surge arresters. These aspects can be deliberated upon using a typical HV network modelled in EMTP-ATP (Electromagnetic Transients Program – Alternative Transients Program) software. The network studied here consists of a 380 kV overhead line, an HV cable that supplies the gas-insulated switchgear in the substation and a power transformer →4.

Examples of simulation results for lightning strikes on the phase conductor (direct stroke) and shield wire (backflash) are presented in →5–6. It can be seen that the application of surge arresters results in a decrease of the maximum overvoltage peak value to below the permissible limits of the basic insulation level (BIL), which, according to the IEC 60071 standard, is 1,425 kV (peak value) for 400 kV networks. This standard also proposes a so-called safety factor, k_s, of 1.15. Some customers have their own standards, where the k_s factor is set at 1.20 or even 1.25. This higher margin of error implies stricter requirements in the surge arresters' specifications.

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02 EMT simulation of a lightning strike on a tower structure according to CIGRE WG 33.0.

02a Tower structure and lightning strike locations.

02b Typical lightning current surges.

02c Typical voltages generated by a lightning strike.

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03 Nonlinear characteristic of ABB's PEXLIM surge arrester.

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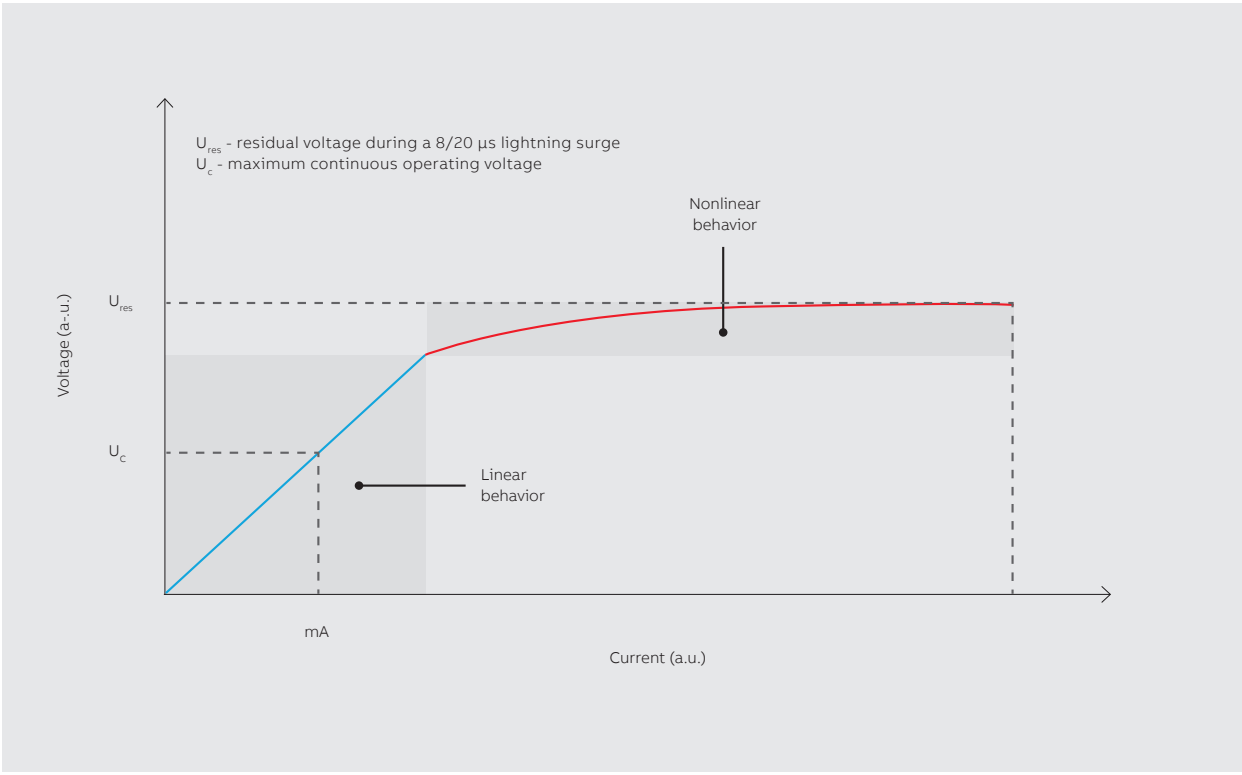
04 Simplified diagram of the 380 kV system under study.



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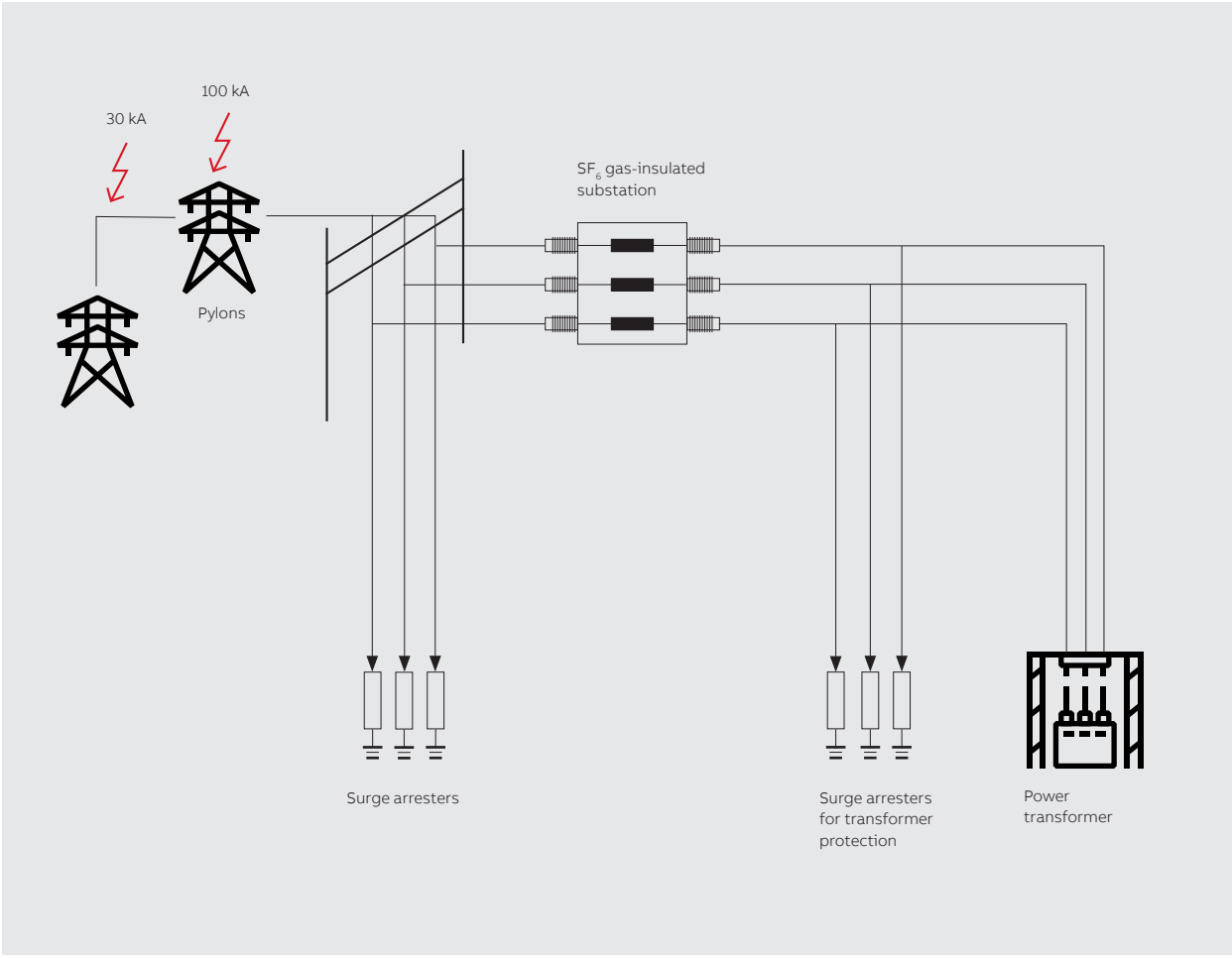


04

Do not forget about…
Besides the surge arresters themselves, there are also other factors that have to be considered – eg, the lengths of the leads that interconnect the surge arresters. Here, the general rule is to keep the surge arrester as close as possible to the equipment that it is meant to protect (transformer, cable or switchgear). Overlong connections lead to a decrease of the surge arrester's overvoltage damping capabilities, especially at higher frequencies. This effect is due to the inductive reactance of the connections playing a more significant role during high-frequency transients than during 50 Hz or 60 Hz steady-state conditions →7–8.

ABB also provides an insulation coordination simulation service in other relevant domains – for example, analyses related to circuit breaker or disconnector switching.

In other words, an additional voltage drop occurs during the lightning event, which may increase overvoltage values and cause BIL levels to be exceeded.

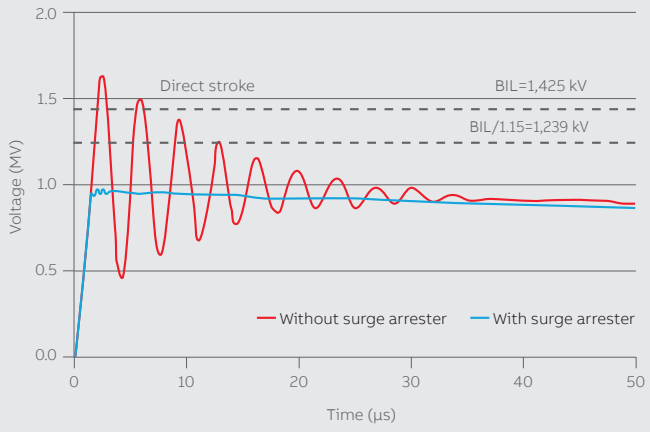
Therefore design engineers should keep surge arrester leads as short as possible. This is especially important on HV and ultra-HV systems, where leads are usually long.

Another factor that must be considered is the ability of the surge arrester to handle the large amounts of energy generated by surges. Surge arresters are assigned a line discharge rating from class 1 (lowest) to 5 (highest) that reflects their energy handling ability.

Class 2 devices may be selected for less hazardous areas where lightning activity is infrequent and switching operations are occasional. Class 5 has to be delivered for high lightning activity areas or for installations where switching operations are frequent (daily) →9. Sometimes designers use a device of a class higher than is strictly necessary to provide an additional safety margin.

Customer-oriented approach
In every project in which ABB carries out engineering, installation and commissioning of HV gas-insulated switchgear, the suitability of the proposed surge arresters, must be verified. Most customers are keen on having studies made based on the latest relevant international standards, such as:
- The IEC-60071 series
- IEEE standard C62.82.1 (revision of IEEE 1313.1 and 1313.2).

The customer expects ABB to comply with these standards in its high-frequency transient studies.



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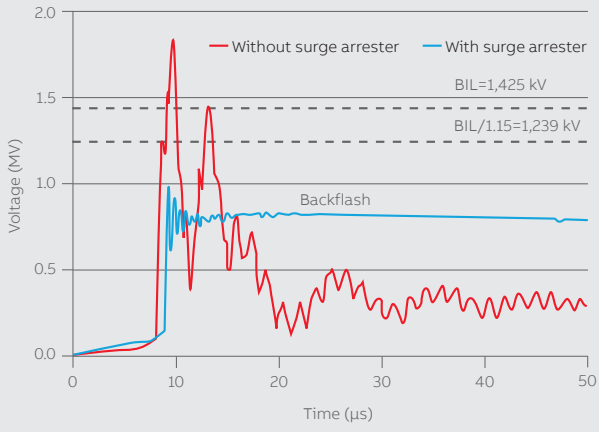

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05 Simulation results: overvoltages simulated at the transformer HV terminals – direct stroke.

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06 Simulated overvoltage for backflash.

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07 Residual voltage contributions for a surge arrester with top and bottom lead connections.

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08 Overvoltage as a function of total lead length.

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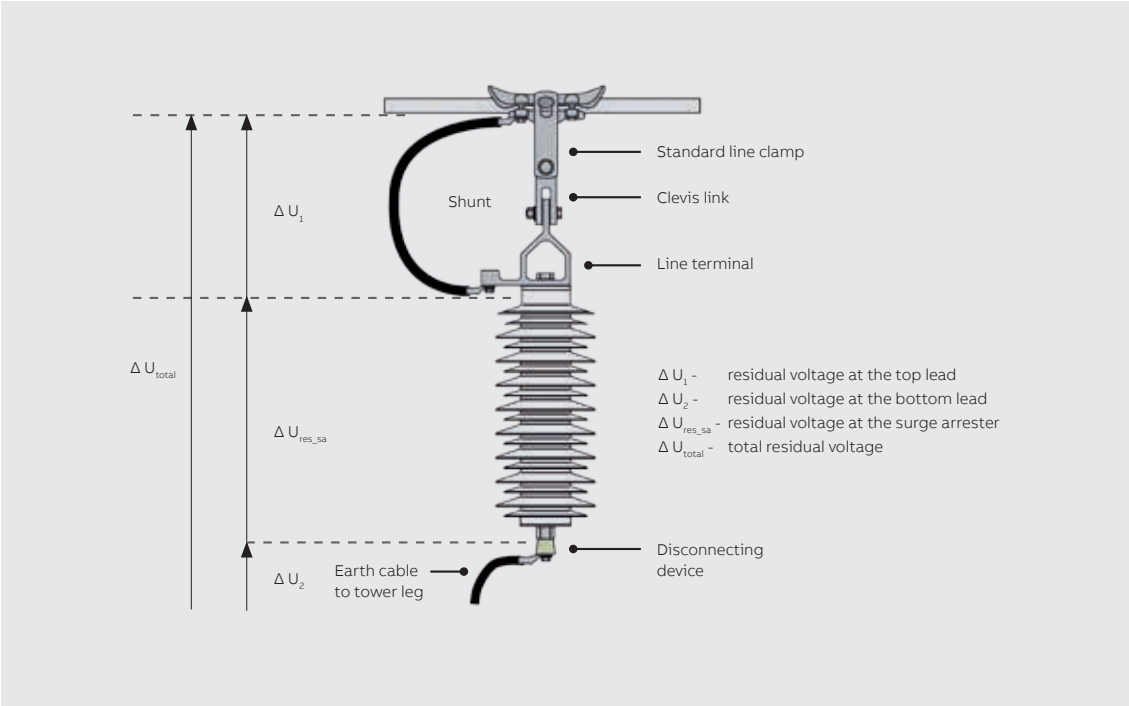
09 Comparison of residual voltages for different discharge classes of surge arrester during lightning current surge (8/20 µs).



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Moreover, some customers have their own project technical specification (PTS) that must be considered and referenced in the final report. It is of extreme importance to be able to find agreement if

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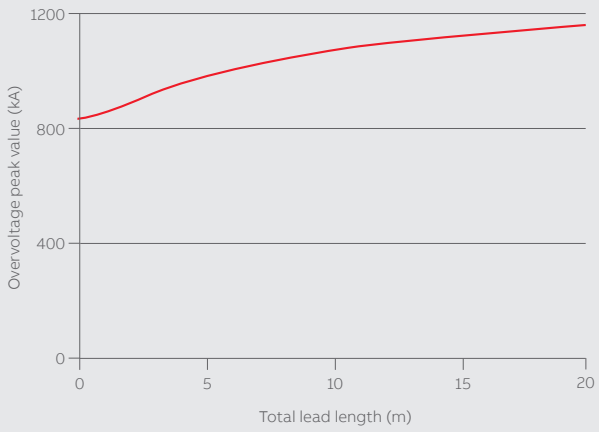
Voltage magnitudes can reach values as high as several MV at frequencies in the range of 50 kHz to 10 MHz.

there are deviations from the end client's requirements. In certain cases, it is necessary to consider a special approach that is not fully specified by the international standards.

The customer always has the right to review the insulation coordination study report to clarify any uncertainty. Such full transparency and openness to discussion ensure that the results delivered are correct and comply with all the customer requirements.

Of course, a lightning overvoltage study is only one aspect of substation design. It is worth adding that ABB also provides an insulation coordination simulation service in other relevant domains – for example, analyses related to switching events when circuit breakers or disconnectors are operated, at all voltage levels. ●



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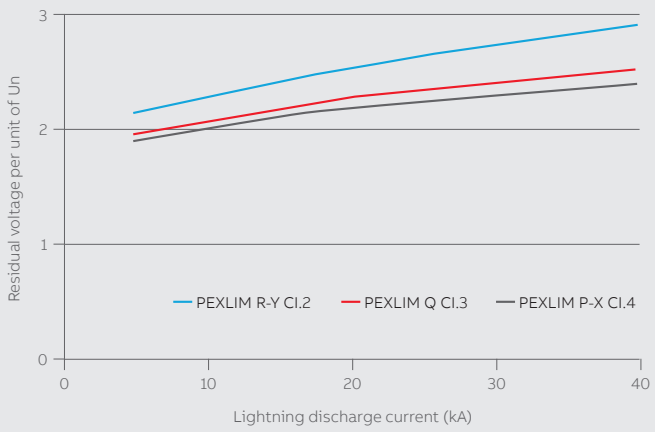

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Digital and analy

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The “cloud” is an approximate term describing the distributed collection, aggregation, analysis, and application of data, often at speeds that are too fast to rely on human intervention. It often applies to situations in which significant safety and/or financial issues depend on quick action.
ABB continues its leadership in harnessing these tools to the technologies on which industrial, mission-critical applications rely. Its new ABB Ability™ platform gives customers the ability to collaborate, optimize, automate, and assess data.
It brings clarity to the cloud.

DIGITAL AND ANALYTICS

Monitor, optimize and control power networks with ABB Ability™

The ABB Ability Electrical Distribution Control System can leverage the connectivity of Emax 2 circuit breakers to provide a powerful ABB Ability cloud-based solution designed to monitor, optimize and control low-voltage power distribution systems.

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The world of electric power was once ruled by massive, state-owned utilities that generated electricity in large, centralized power stations. The transmission and distribution networks that carried the power all the way down to the end user were owned by the same bodies. Deregulation changed this picture completely. Now, a host of enterprises is involved in the generation, transmission and distribution of power.

A further catalyst for change came with the rise of the renewable energy sources that now supply a significant portion of the national energy budget in many countries.

In this new landscape, cost and complexity have become critical issues: Any additional expense involved in installing system control, monitoring or management hardware and software quickly gets out of proportion compared to the overall expenditure. Increased system complexity also gives rise to added costs. The drive to reduce these outlays has given rise to many innovative hardware and software solutions. But with a plethora of digital systems on offer and a multitude of vendors, a fully integrated approach is required.

ABB Ability

In late 2016, ABB unveiled its new centralized software platform – ABB Ability. The aim of ABB Ability is to bring together all of ABB's digital products and services – each of which is built from a unique combination of sector knowledge, technology leadership and digital expertise – to create business value for ABB customers. As well as housing ABB's digital offering, ABB Ability will enhance ABB's Industrial Internet of Things (IIoT) capabilities across a scalable, horizontal plane throughout its business divisions.

ABB Ability falls on fertile ground: With one of the largest installed bases in industry, more than 70,000 digital control systems and over 70 million devices already out in the field – the potential ABB Ability has for ABB customers is huge.

In order to enhance performance and guarantee the highest reliability and security, ABB Ability has been based on Microsoft Azure. ABB and Microsoft Corporation have entered into a strategic partnership to enable customers to benefit from the unique combination of Azure and ABB's deep domain knowledge and extensive portfolio of industrial solutions.

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01 Emax 2 is the data node of the LV micro-grid or other electrical network.

The digital transformation that will be brought about by the partnership extends far beyond the electrical infrastructure mentioned above: Industry segments such as robotics, marine and ports, buildings, electric vehicles and renewable energy will also benefit from the cloud-based integrated connectivity platform hosted by Microsoft Azure.

Emax 2 and the ABB Ability Electrical Distribution Control System

In the arena of electrical systems, ABB's low-voltage equipment and ABB Ability Electrical Distribution Control System combine to take full advantage of ABB Ability's power to allow the user to deploy an innovative energy and asset management solution.

By equipping a product that is already there – eg, the Emax 2 circuit breaker – with intelligence and by exploiting a communications infrastructure that is already there (the Internet), sophisticated protection, optimization, connectivity and logic as well as load, generation and storage management can be provided without the need for expensive additional devices. With the addition of the ABB Ability Electrical Distribution Control System, the door is opened to the extra functionality that allows the user to monitor, optimize and control electrical systems with a cloud-based Azure system that is an inherent part of the ABB Ability concept.

The Emax 2 air circuit breaker, can become the smart hub of the low-voltage power distribution systems by managing both power and data flows →1.

The ABB Ability Electrical Distribution Control System is a cloud-based platform for electrical systems that is designed to:

- Monitor: Determine plant performance, supervise the electrical system and immediately get access to the most important information
- Optimize: Collect data from each device, analyze it and use the output to inform business decisions
- Control: Set up reports and alerts; remotely implement an effective power management strategy.

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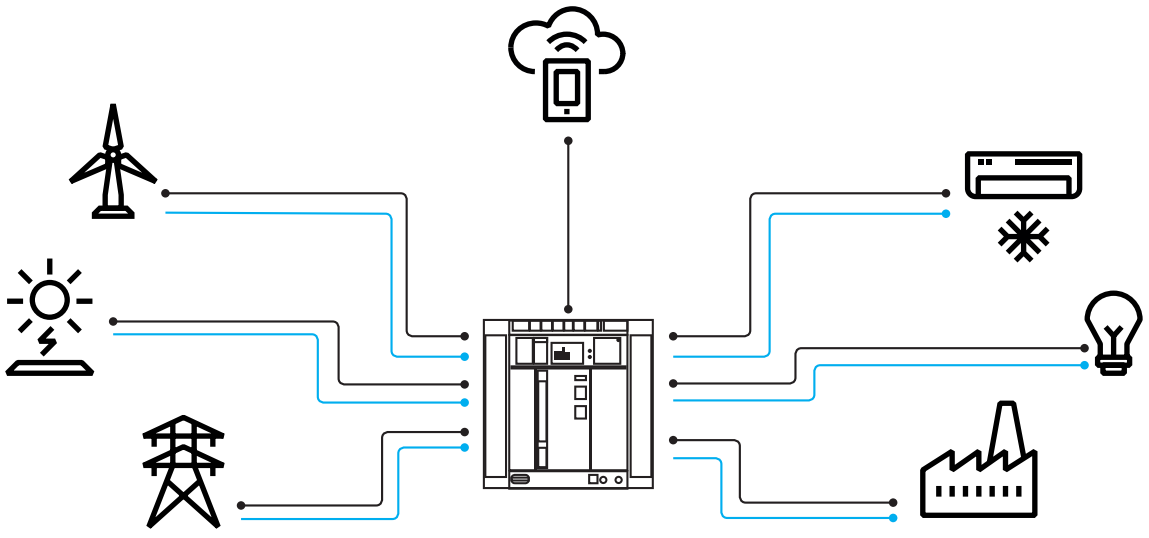
The ABB Ability Electrical Distribution Control System is a cloud-based platform for electrical systems that is designed to monitor, optimize and control.

Featuring high scalability of services and great flexibility of application, the ABB Ability Electrical Distribution Control System is suitable for small-to-medium industries and commercial and public buildings applications. It has been designed for end users, facility managers, consultants and panel builders.

The ABB Ability Electrical Distribution Control System also provides access on a multi-site level; it can monitor and compare the performances of different facilities at the same time. In addition, it allows profiling of the users' experience according to the level of access they require.



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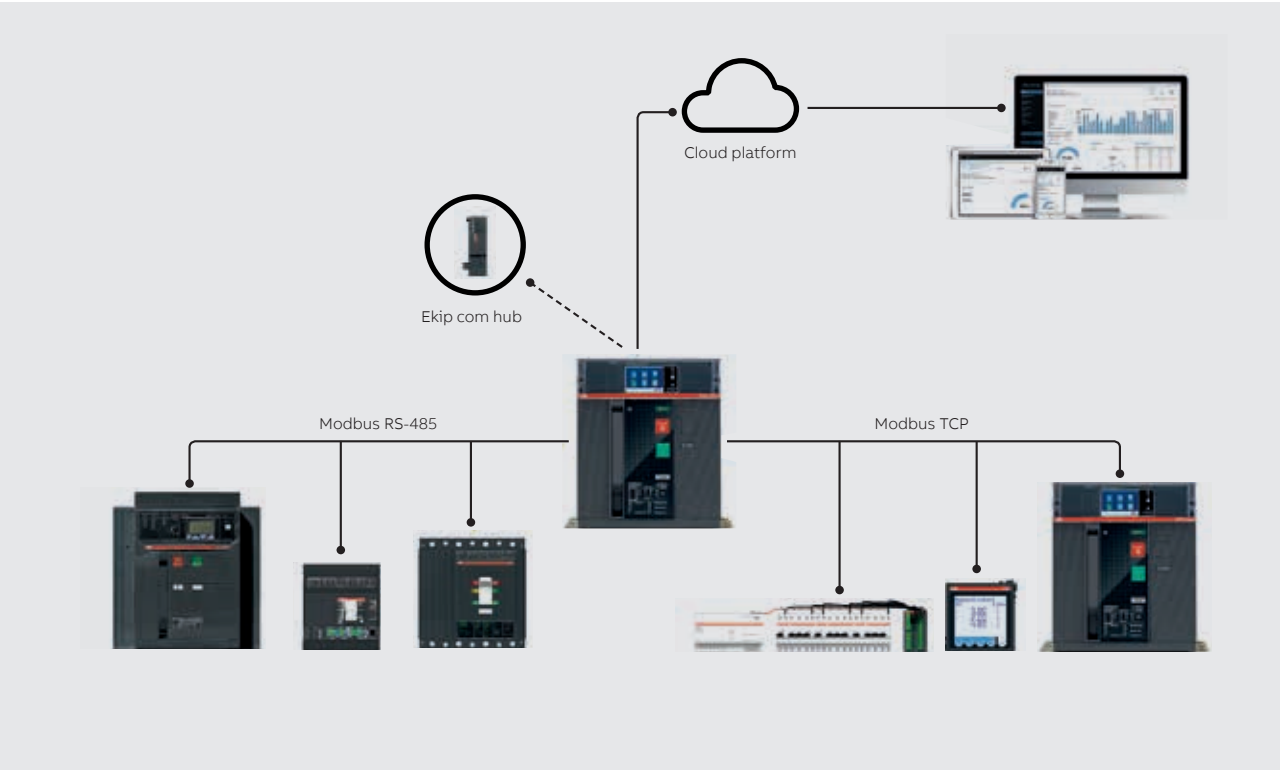

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These features allow the user to keep up to date with actual system performance and execute efficiency analysis and audits without on-site assessments. Real-time data and historical trends can be accessed – on a single- and multi-site level – so that performances can be compared and benchmarks created. One maintenance technician can manage several sites and because the ABB Ability Electrical Distribution Control System continuously performs diagnosis on the devices in the electrical system, maintenance action need only be taken when actually needed. This higher level of predictive maintenance enhances operations and cuts costs.

The ABB Ability Electrical Distribution Control System is suitable for small-to-medium industries and commercial and public buildings applications.

Also, the ABB Ability Electrical Distribution Control System can be integrated into more complex supervision and automation systems while driving simplification of operations and cost reduction. By having the ABB Ability Electrical Distribution Control System manage power distribution, it is possible to reduce the overall cost and buildup time of a building management system by 15 percent.

Perhaps the greatest value of the ABB Ability Electrical Distribution Control System is that users can simplify the energy and asset management processes and activities in their facilities. The ABB Ability Electrical Distribution Control System is designed specifically to make it easy to do this.

ABB Ability Electrical Distribution Control System architecture

The ABB Ability Electrical Distribution Control System operates through a Web app interface, so can be used anytime and anywhere via smartphone, tablet or personal computer. It provides multiuser access and immediately connects to the low-voltage power distribution system.

The ABB Ability Electrical Distribution Control System's cloud services are also available for retrofitting the installed base and previous versions of ABB circuit breakers.

The electrical system can be connected, plug and play, to the cloud-computing platform by sharing data either with Emax 2 or with Ekip E-Hub. The solution can be embedded or external:

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02 Embedded solution with the ABB Ability Electrical Ekip Com Hub.

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03 External solution with the Ekip E-Hub.

Embedded solution
An Emax 2 equipped with the new Ekip Com Hub module establishes the cloud connection →2. This dedicated cartridge-type communication module just needs to be inserted into the terminal box and connected to the Internet. Other devices can also share measurements and data with Ekip Com Hub and the cloud if the Emax 2 is equipped with one of the following communication modules:

- Ekip Com Modbus RS-485
- Ekip Com Modbus TCP
- Ekip Link.

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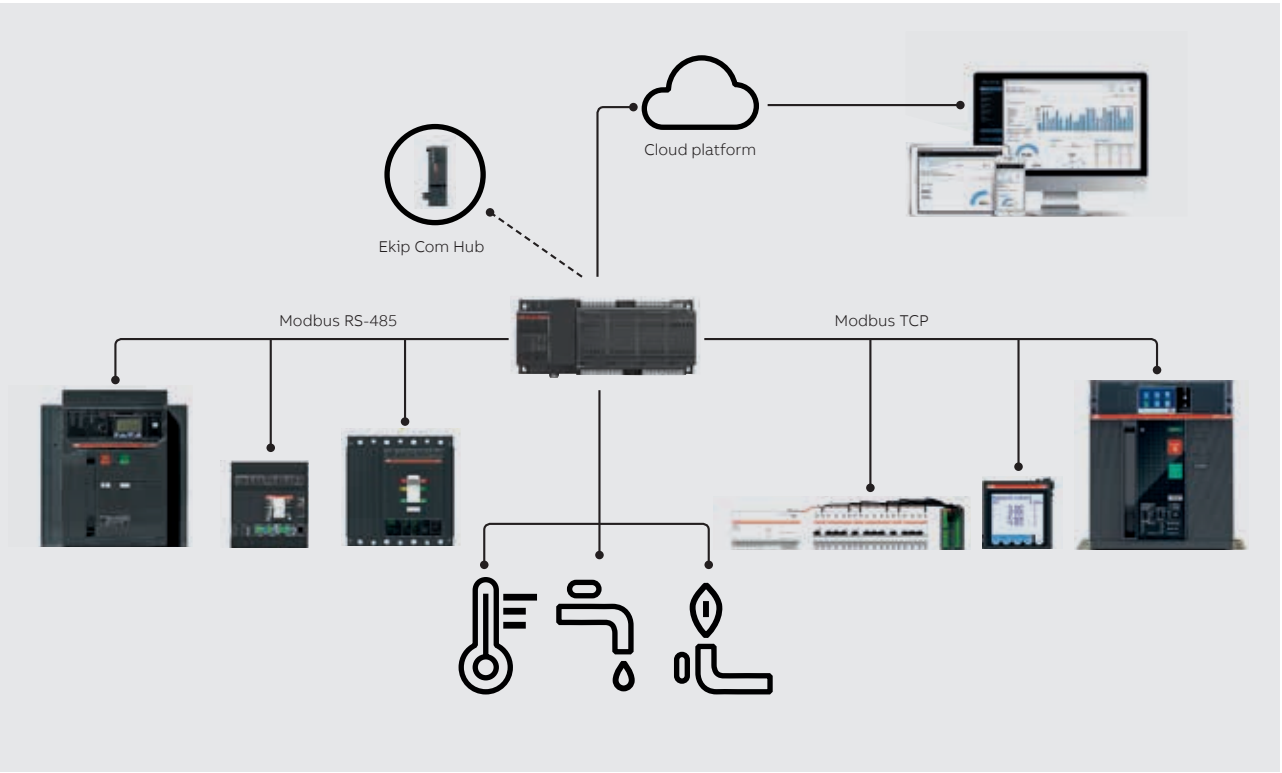
The ABB Ability Electrical Distribution Control System also provides access on a multi-site level.

The ABB Ability Electrical Distribution Control System is designed to make things as simple as possible: By accessing the Ekip Com Hub module via Ekip Connect software, it is possible to achieve guided commissioning in just a few minutes thanks to self-configuring connections.

External solution
Extraneous hardware can be mounted on a DIN rail to permit data collection throughout the electrical system →3. Moreover, it is possible to connect sensors for data such as temperature; humidity and water consumption via analog and digital I/O. Optional modules for Wi-Fi or GPRS extend the possible applications.

Monitoring
Monitoring functions are made easy by the preconfigured widgets in the ABB Ability Electrical Distribution Control System Dashboard →4. Single or multiplant data can be processed to display energy consumption and generation trends. In addition, users can obtain insight into the electrical system through real-time demand information, peak trends, and power factor and power quality information →5. The ABB Ability Electrical Distribution Control System's tools simplify information exchange and deliver higher efficiency on a daily basis, with a lower risk of downtime and maintenance cost reduction of up to 30 percent.



— 04 The ABB Ability Electrical Distribution Control System Dashboard.

— 05 The ABB Ability Electrical Distribution Control System Dashboard allows access to single or multiplant data.

— 06 The ABB Ability Electrical Distribution Control System's powerful Assets management feature.

— 07 Timely alerts can further increase operational efficiency.

The ABB Ability Electrical Distribution Control System's powerful Assets management feature makes it possible to arrange a familiar overview of the plant. In fact, users can upload custom diagrams, photos, switchboard technical drawings and images of plant synoptic panels →6. These images can be made interactive through tags, and drag-and-drop tools. Users can access, at any time, all the asset information they need, for example:

- State of devices.
- General parameters, such as device type, serial numbers and rated parameters.
- Maintenance data – eg, latest maintenance operations, contact wear, number of trips, etc.
- Electronic data, such as software versions and relay information.

The user is also provided with direct links to related ABB documentation and manuals.

Optimization

Access to all the relevant data enables the user to maximize reliability and efficiency. The ABB Ability Electrical Distribution Control System allows digital collection and export of data, compilation of reports and access to historical trends. Users can obtain full knowledge of the electrical systems to set effective benchmarks and compare them with best practice. Furthermore, users can digitally file maintenance activities and download them via reports.

The ABB Ability Electrical Distribution Control System Analytics feature simplifies and enhances the analyses of power factor compensation, energy management and costs allocation. By leveraging a comprehensive collection of data, at the single or multiplant level, decision-making can be fully informed.

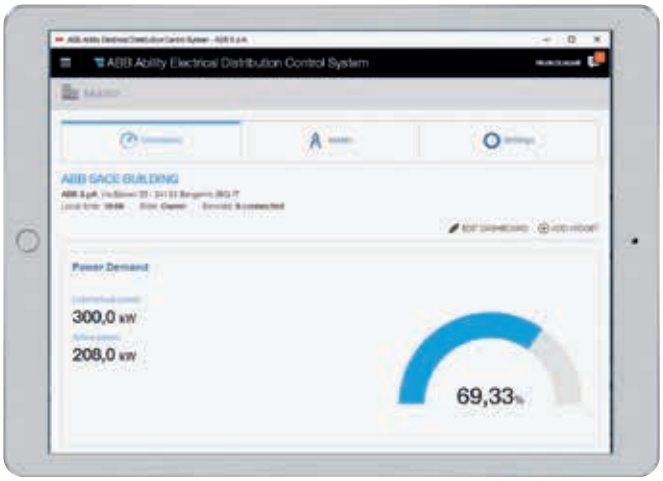
Control

The ABB Ability Electrical Distribution Control System provides support not only in identifying need for improvement but also in remotely implementing an effective strategy for power peak control and energy management.

Perhaps the greatest value of the ABB Ability Electrical Distribution Control System is that users can simplify the energy and asset management processes and activities in their facilities.

The Controls feature makes load management simple and bases actions on accurate measurements, thanks to the ABB Ability Electrical Distribution Control System and Emax 2 Power Controller function. Cutting down on power demand through a shedding/inserting routine for non-priority loads facilitates energy savings.

The ABB Ability Electrical Distribution Control System Alerts feature provides users with a plant watchdog →7. Users can customize alerts settings to suit their needs and intervention plan, and to notify key personnel at any time via text messages and email.



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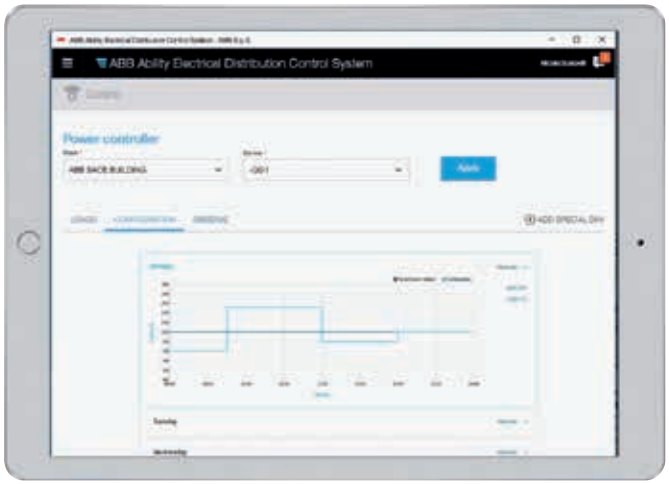

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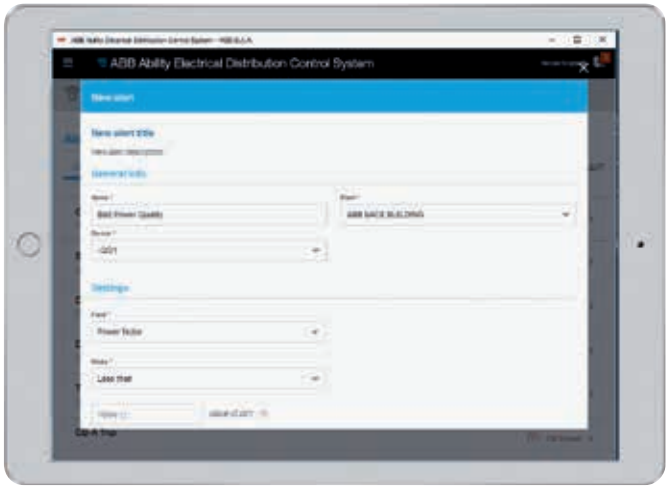

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Simplicity
The ABB Ability Electrical Distribution Control System solution obviates the high cost and complex setup of a traditional energy monitoring and management system: Just a cartridge-type communication module, the new Ekip Com Hub, has to be installed on the terminal box to establish the cloud connection. By commissioning the system via the Ekip Connect wizard with self-configuring connections, the ABB Ability Electrical Distribution Control System provides unmatched advantages, like the capability to connect a panel to the cloud in around 10 minutes →8.

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The ABB Ability Electrical Distribution Control System operates through a Web app interface, so can be used anytime and anywhere via smartphone, tablet or personal computer.

Once the connection is set up, it is possible to extend platform access to further users – such as partners and staff – in a few clicks. Each user is entrusted with tasks and authorizations according to their appointed role in the specific plant.

No complex configurations, multiple DIN-rail adapters or gateways have to be installed. Compared to similar solutions, the ABB Ability Electrical Distribution Control System allows the number of hardware components required to be reduced by 60 percent. the ABB Ability Electrical Distribution Control System's integrated architecture also enables reduction of wiring and connection time, while simplifying the integration of devices in the system.

The ABB Ability Electrical Distribution Control System in the field
The first pilot installation of the ABB Ability Electrical Distribution Control System was carried out with an Italian public water company, Consorzio di Bonifica Veronese. The ABB Ability Electrical Distribution Control System provided the customer with remote supervision and alerting, which enabled a reduction in the time and costs spent on travelling between the different sites. It also allowed proactive and rapid intervention to restore normal working conditions, avoid faults, perform maintenance and reduce downtime. These measures helped the customer achieve a 40 percent savings on maintenance time and a 30 percent savings on operational costs. The likelihood of incurring penalties for poor power quality – an ever-present risk in an industry with variable-load water pumps – was also greatly diminished.

In addition, the availability of this data made the customer eligible for energy efficiency certificates worth $25,000, without requiring the time and expense of independent external auditors. The customer will now deploy this solution across dozens of further water distribution facilities.

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08 Simple setup.

08a Start Ekip Connect 3.0 and select function

08b Scan the network

08c Configure device and plant

08d Publish to cloud

ABB powers one of largest regional solar rooftops in Dubai

Another field implementation of the ABB Ability Electrical Distribution Control System is found in one of the largest privately owned solar rooftops in the Gulf region, in Dubai, United Arab Emirates. The 315 kW solar rooftop is at ABB's Al Quoz facility. The electricity generated from the solar rooftop will be used for powering the ABB office while any surplus power will be fed to the state utility provider.

The ABB Ability Electrical Distribution Control System connects the ABB solar rooftop to the IIoT, creating a digital profile of the photovoltaic installation, continuously analyzing the power quality, as well as tracking trends in the site's energy production and demand. Continuous diagnosis of the solar rooftop helps maximize the asset's productivity and makes maintenance more effective and intelligent.

IIoT and the ABB Ability Electrical Distribution Control System

ABB has been advancing technologies for the IIoT for more than a decade via its control systems, communication solutions, sensors and software.

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The ABB Ability Electrical Distribution Control System allows digital collection and export of data, compilation of reports and access to historical trends.

Now, with ABB Ability, IIoT technologies have the even greater potential to use data intelligently to optimize operations, increase productivity and maximize flexibility. Emax 2 and the ABB Ability Electrical Distribution Control System are natural occupants of this space and will fundamentally change the face of electrical systems monitoring, optimization and control. ●

DIGITAL AND ANALYTICS

Addressing transformer physical security with sensors and edge analytics

New ABB technology improves the physical security of power infrastructure, especially that of large power transformers (LPTs), by leveraging vibroacoustic sensors, real-time impact detection and edge analytics

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According to a recent USA TODAY report, the power infrastructure of the United States (US) is subject to a cyber or physical attack about once every four days [1]. A 2013 substation sabotage incident marked the first major intentional attack on the power infrastructure and underscored the changing physical security requirements. The increasing number of physical and cyber-attacks on power infrastructure is a major concern. When such attacks occur, LPTs are often the center of attention – and for a good reason: While LPTs make up less than 3 percent of all infrastructure transformers in the US, between 60 and 70 percent of the US's electricity flows through them in high-voltage substations [2] →1.

01

Additionally, it may take between 5 to 16 months to replace a damaged LPT and restore service. Power transformers in general are among the most critical assets on the power grid due to the lack of availability of spares, customization of design, long manufacturing lead times, transportation difficulties, and installation requirements.

New technology from ABB improves physical security for power infrastructure by leveraging vibroacoustic sensors and real-time analytics.

Recognizing the security importance of the power grid infrastructure, NERC (North American Electric Reliability Corporation) developed reliability standard CIP-014-1 according to a FERC (Federal Energy Regulatory Commission) order that went into effect in October 2015. This standard required certain transmission owners to assess the vulnerability of critical substations and implement security plans by August 2016.

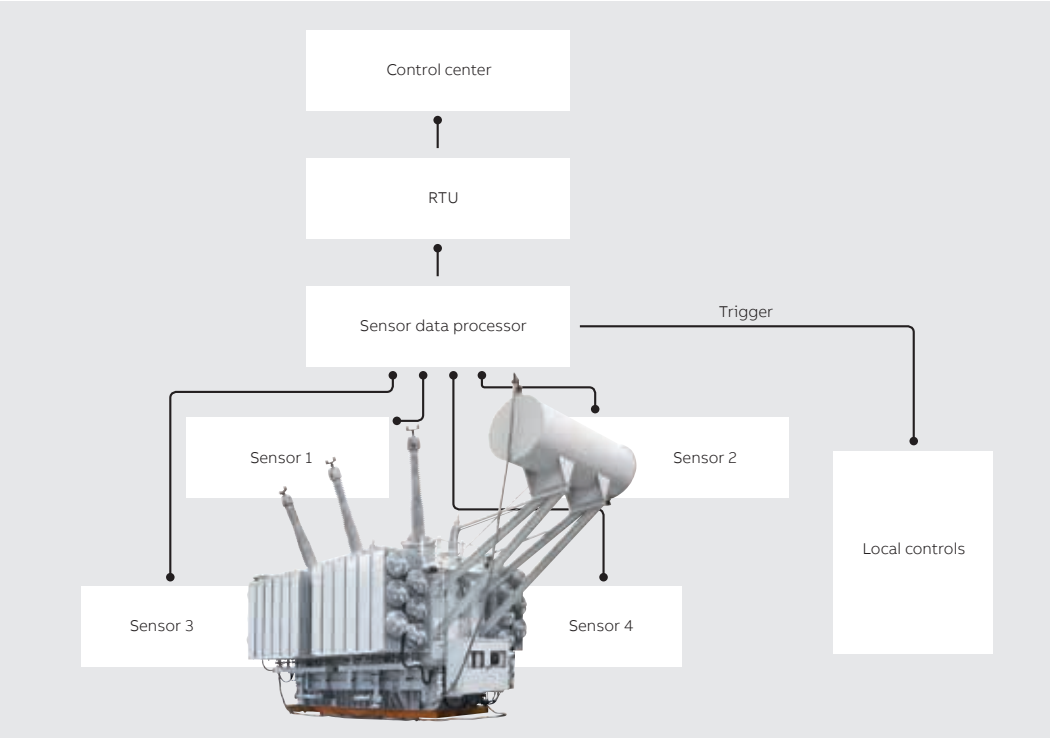
New, patent-pending technology from ABB – commercially known as CoreStrike™ – improves physical security for power infrastructure by leveraging vibroacoustic sensors, real-time impact detection and edge analytics.

Motivation

According to a recent survey conducted by Utility Dive, 80 percent of utility executives surveyed considered planned sabotage a potential threat to their substations [3]. The same survey revealed that utilities reported over 300 intentional physical attacks on power infrastructure between 2011 and 2014 that resulted in power disturbances. Enhancing the physical security of substations and power transformers using sensors and automation addresses this critical vulnerability which impacts grid reliability.

If transformer physical integrity is compromised, the situation needs to be dealt with immediately – at least operationally – to contain the magnitude of the damage and avoid the substantial consequential and collateral losses that could result from a catastrophic failure. Despite having a high impact, attack incidents are not expected to be frequent and therefore deployment cost is always a constraint that has to be kept in mind.

To address the vulnerability of power infrastructure, ABB developed CoreStrike – a cost-effective, real-time impact detection and assessment system and applied it to power transformers. While various technologies address the physical security requirements of critical substation assets, absolute physical security is practically unachievable. There is no relief in this statement for bulk power asset owners and operators. However, the prudent use of the technology described in this article as an integral element of a security plan can mitigate the impact of an incident and, in some cases, deter it.



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01 A significant fraction of a nation's power flows through a relatively small number of power transformers. ABB technology helps improve the security of these vulnerable nodes on the power grid. Shown is a polytransformer.

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02 Solution concept and architecture.

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03 Low-end hardware prototype.

Solution concept and overview

ABB's concept for sensor-based impact detection and assessment is composed of specialty sensors, a sensor data processor (SDP), a remote terminal unit (RTU) for remote communications, and an interface to the control center →2. Data from sensors is gathered and time-stamped by the SDP. The SDP also performs preliminary data processing tasks on the raw data such as filtering and averaging.

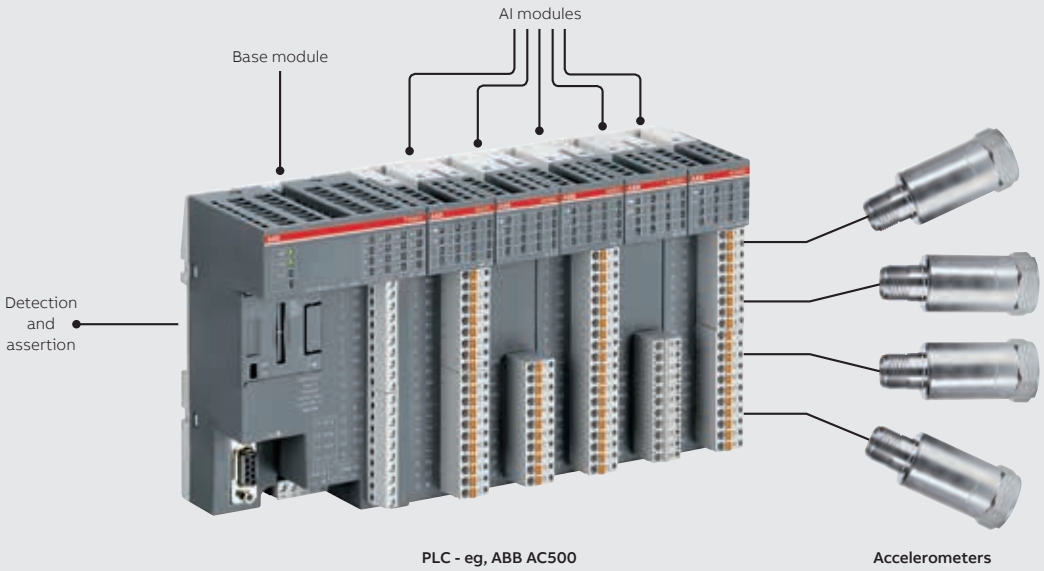
The sensor output can be used to close cooling system valves should an oil loss be detected by other sensors or to open valves to engage a redundant transformer cooling system.

The SDP runs detection algorithms that lead to local alarming and annunciation. This is conventionally known as edge analytics. The output from the SDP unit is received by the RTU and communicated over a preferred communications medium to the utility control center where more sophisticated algorithms may be run to assess infrastructure damage or check asset integrity (cloud analytics).

The outcome is displayed on the operator dashboard in real-time. In certain implementations, and while observing operational and cyber security requirements, the output from these sensors can be used for local control such as closing cooling valves on a transformer should an oil loss be detected. The sensor output can also be used to open valves to engage a redundant transformer cooling system, if one is installed.

The sensor-based system is also used as a trigger for activating other security measures. For example, it can be used to instruct substation cameras to take or preserve specific shots of the transformer or substation perimeter. Such evidence may be used for forensic analysis and in court proceedings. Conventional monitoring schemes are either fixed at particular angles or on particular assets – or move slowly and are thus likely to miss the onset of the attack.

A low-cost hardware embodiment of the concept was developed and demonstrated in a field test. The basic setup consists of a minimum of four RMS (root mean square) accelerometers with detection and assessment logic embedded in a PLC (programmable logic controller) that acts as the RTU and SDP combined →3.



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The accelerometers are strategically placed on the transformer tank wall to cover any impact on all vulnerable areas →4. The system monitors the transformer tank for any impact excursions beyond set limits, in which case it lights up an LED and/or raises a digital flag that can be mapped over into a supervisory control and data acquisition (SCADA) system for automated or semi-automated initiation of control actions. The number of assertions activated as a result of the impact denotes the severity of the impact – ie, an attack that is registered by all accelerometers is considered to be more severe in nature than an attack that triggers an assertion by only one accelerometer.

Proving feasibility through field trials

Three sets of tests were conducted, each at a different location and with a different objective,

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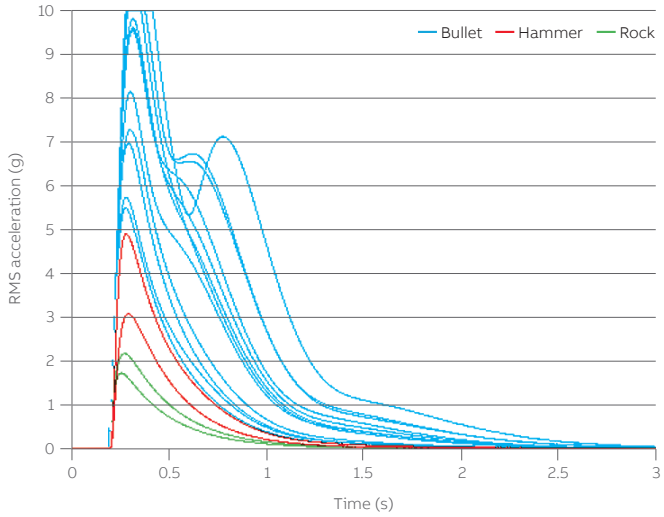
A low-cost hardware embodiment of the concept was developed and demonstrated in a field test.

to evaluate the technical feasibility of the solution, and to address various research and design questions.

The first set of tests was conducted at a ballistics laboratory according to UL 752 Ballistic Standards at selected levels. The data and images gathered from these trials helped specify sensor and data acquisition requirements for the subsequent field trials.

The second set of tests, conducted at a gun club, subjected a water-filled network transformer tank to shots fired from a variety of guns from a distance of 55 m. Vibration and acoustic measurements allowed a thorough analysis and characterization of impact signatures arising from various bullets as well as from hammer and rock strikes →5. The clear differences in the RMS waveforms can be exploited to distinguish a bullet impact from a rock thrown at the transformer tank. Interestingly, some hammer strikes resemble the bullet impact signatures. This is a desired outcome as it indicates that all blunt attacks can be detected and asserted by the same setup.

→6 shows a high-resolution acoustic signal captured during one of the trials. The shockwave and muzzle blast arrival times agree with theoretical calculations and the pressure changes along the way signify the caliber and location of the bullet.



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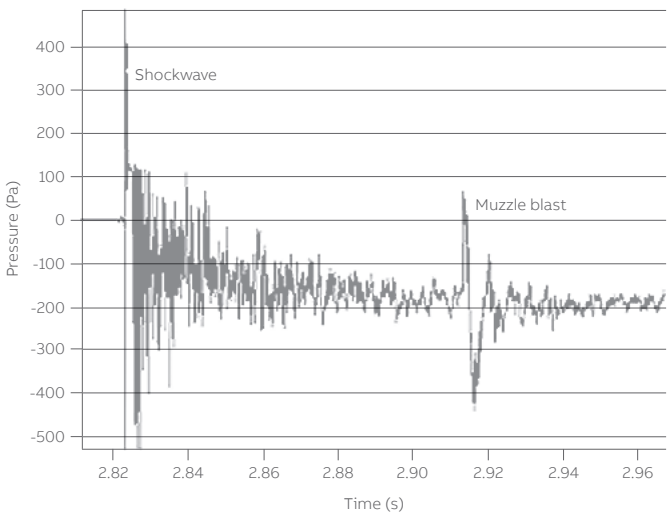

06

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04 Example of accelerometer placement.

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05 RMS acceleration measurements for bullet trials.

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06 Acoustic signature during a field trial.

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07 RMS acceleration for natural events.

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[1] [Online]. Last accessed Feb 25, 2016. Available: http://www.usatoday.com/story/news/2015/09/09/cyber-attacks-doe-energy/71929786/

[2] P. W. Parfomak, "Physical Security of the U.S. Power Grid: High-Voltage Transformer Substations," Congressional Research Service, June 2014.

[3] [Online]. Last accessed Feb 25, 2016. Available: https://www.utilitydive.com/library/the-state-of-physical-grid-security-2015-report/

A detailed analysis of a number of such records can reveal a great deal of information regarding the shot's direction, location, trajectory, and bullet type and caliber.

The third set of tests was performed on a live transformer to establish baseline vibration and acoustic figures and signatures using high-fidelity sensors and data acquisition devices. The proximity of the subject transformer to a railroad (immediately behind the transformer) and an airport allowed the research team to measure and observe realistic environmental effects and design the detection methodology around robustness against false alarms. Example RMS acceleration profiles for five cases appear in →7. As can be seen, hammer strikes are far more dominant than the vibrations caused by routine events such as the energization impact of the transformer, pumps, and fans.

Solution benefits
Enhanced physical security measures using sensors and data analytics bring a number of advantages, for example:

- Detection is virtually simultaneous with the impact event. This gives the operators valuable extra time to decide how to mitigate the impact effects. The main benefit of a quick response is the possibility of saving the active parts of the transformer from severe damage and a subsequent prolonged outage.
- The system is also beneficial in cases where the transformer survives the attack. In this case, knowledge of the attempted assault can trigger on-site inspections or justify other investments for hardening the transformer or the substation.
- The detection is specific to the transformer and therefore more actionable than general-purpose substation security measures such as video monitoring.
- The detection is automatic, so no active, permanent monitoring by an operator is required.
- Other security measures, such as surveillance cameras, can be triggered.

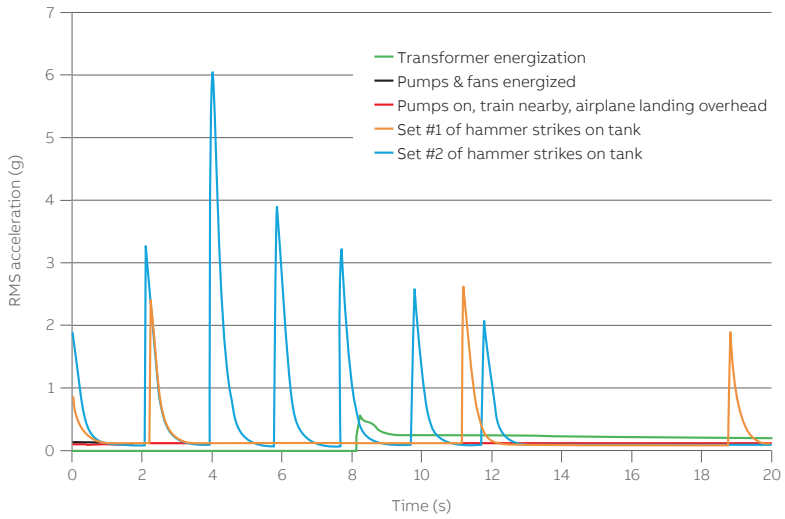
Future impact
The real-time impact detection and notification solution is another digital innovation from ABB to help utility customers achieve and exceed their physical security goals with respect to power transformers and other high-value assets. CoreStrike addresses a key area of physical security for timely detection and assessment of potential or actual impact. The information from the system can be used in automation and control schemes to alarm

—
Clear differences in the RMS waveforms can be exploited to distinguish a bullet impact from a benign impact such as a rock thrown at the transformer tank.

or alert the operators upon impact and/or prevent further damage, eg, by initiating redundant cooling systems. It is noted that for control applications, certain operational and cyber security requirements must be considered and addressed.

The prototype technology has been installed on an actual substation transformer to observe long-term stability and robustness against false positives. Hailstorm activity has already been logged and recorded by the system. Future versions of this technology may integrate additional sensors and include prescriptive mitigation actions in line with the ABB Ability portfolio of solutions for the digital grid.

Acknowledgments
The authors gratefully acknowledge Andrew Bleich, Randy Joyce, Randy Colvin, Ning Kang, Poorvi Patel and Don Puder for their assistance during the field experiments. We also thank Craig Stiegemeier, Thomas Buijs and Petter A. Fiskerud for motivating the business case and championing product development, respectively. ●



07

66

Energy

Energy has always been a resource, but harnessing it requires a system of tools and processes that is informed by experienced expertise, and an appreciation for the where, when, how, and why it is used. One project provides technology that supports vehicles operating under 3,000 meters of ocean while another delivers a new climate-friendly insulation gas that has widespread applications.
In every instance, ABB is an energy leader that does much more than energy.

ENERGY

Rock-solid electrics for ROVs 3,000 m down

Supplying electrical power 3,000 m under the sea to the remotely operated vehicles (ROVs) of Total Marine Technology is a challenging task. ABB's softstarter and AF contactor technology proved to be ideal technologies for the job.

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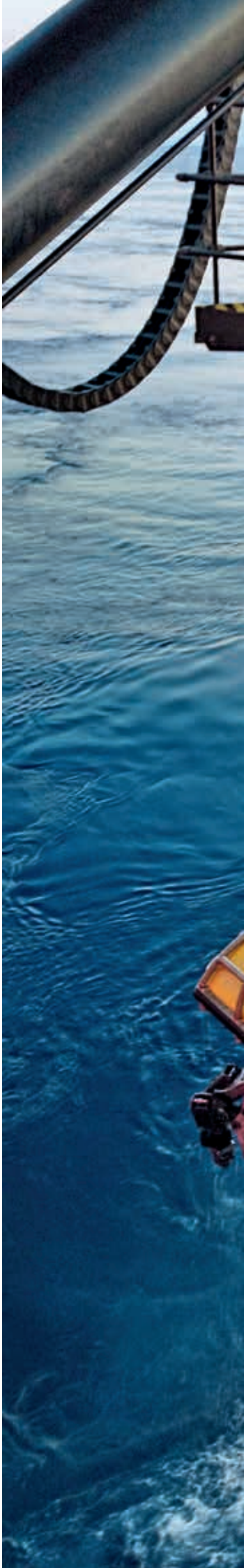
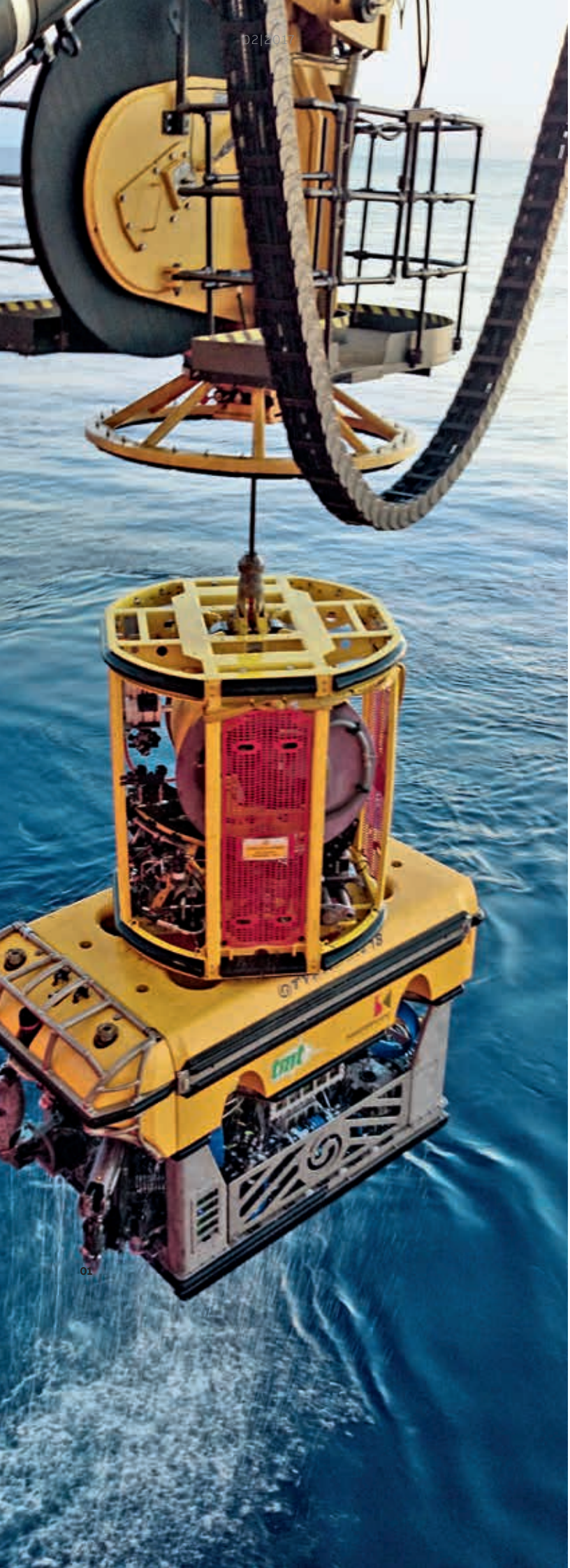
Unsurprisingly, most of the easy-to-get-at subsea oil and gas has already been found and extracted or is in the process of being extracted. New oil and gas plays are now usually found in more remote, deeper locations where operators have to work in water depths of several kilometers and combat strong currents and freezing water temperatures.

It is for this deep sea world that Total Marine Technology (TMT) supplies a complete range of ROVs, some of which regularly operate at depths of 1,500 m →1–2. However, TMT won a contract in 2010 with another Australian company that required them to design and build an ROV that could go twice as deep.

Making sure that everything works well with ROVs deployed at depths of 3,000 is demanding.

In contrast to an autonomous underwater vehicle (AUV), which has no connectors joining it to the topside ship or facility, an ROV will usually be connected by cables that carry hydraulics, power, video, or command and control signals →3–4.





01

The power – hydraulic and electric – provided to the ROV may be used for onboard systems, for propulsion or to drive the hydraulic manipulator arms and grabbers that enable the ROV to carry out its work underwater. In the case of the TMT Typhoon MK2 ROV, the hydraulic power is generated by a hydraulic power unit (HPU) on the ROV. The

A softstarter ramps up the voltage over a predetermined period, which means that the peak current drawn from the system is reduced and the output voltage is more stable.

440 V AC power available topside is stepped up to 3,250 V AC (60 Hz) and sent to the ROV to start it. The HPU uses 3,000 V AC to operate the hydraulic pumps subsea.

For the ROV to perform its work successfully, correct operation of its manipulators and other systems must be guaranteed. Any failure or glitch in the power supply topside, for example, could lead to hydraulic malfunction, which could damage equipment or introduce mission delays or even abandonment and the consequent loss of a clear weather window. Making sure that everything works well with ROVs deployed at depths of 1,500 m is difficult enough; deploying at 3,000 is even more demanding.

To guarantee a smooth and constant supply of electrical power to the hydraulic generators that power the ROV 3,000 m down, TMT chose ABB's softstarter and AF contactor technology.

Softstarter

Although some marine facilities, even hundreds of miles offshore, are powered from the shore, the majority rely on local power generators. On a ship, power generation is, of course, always local. These local generators are dimensioned to deliver the power the ship or platform and its ancillary systems need, and not a lot more. Therefore, when a large piece of equipment such as a pump starts, there can be large dips and peaks, which can disropt the power supplying the ROV hydraulics.

01

Fluctuations in the surface power supply are not the only challenge. For the ROV hydraulic system to function, it needs to maintain a certain pressure. If one of the ROV arms for the vehicle is moved by the operator (located topside) for example, the hydraulic system pressure will drop and the topside generator will have to supply the sudden increase in power demanded by the pump supplying the hydraulics. When the pump starts direct-on-line without any starting assistance in the form of a temporarily reduced voltage (as would be supplied by a softstarter), there is a major risk of a voltage sag as the generator usually cannot provide enough instantaneous power. This could cause the HPU to malfunction.

—

The circuit board coating ensures that the moist and aggressive marine environment poses no threat to the electronics.

This is where the softstarter comes in →6. A softstarter ramps up the voltage over a predetermined period, which means that the peak current drawn from the system is reduced and the output voltage is more stable, making the whole system more reliable. Typical starting current is about 60 percent that of a direct-on-line start.

02

—
01 ABB's softstarter and AF contactor technology proved to be ideal for the electrical system powering the hydraulics for an ROV at depths down to 3,000 m.

—
02 A TMT Typhoon 20 ROV.

—
03 ROVs are connected to the surface facility by hydraulic, power, data and control cables. The unit on top of the ROV is the tether management system.

ABB's softstarters have a number of other features that make them very reliable:

- The softstarter has torque control. This helps avoid pressure instabilities in the fluid that would be otherwise caused by the rapid closure of valves. The resultant lower stress extends system lifetime. This feature is very useful in eliminating water hammer in pump systems. ABB's softstarters have, in the past, shown a 40 percent saving on pump maintenance costs when using ABB's torque control.
- Built-in protection against electronic overload ensures the motor does not overheat. ABB's PSTX softstarter, for example, has over 10 protection schemes against different load conditions as well as against different network irregularities, eg, undervoltage and overvoltage. PSTX is known for its extensive number of functions and features that help customers to reduce the number of components in their panels by 80 percent and slash installation time by 60 percent.
- Reliability is further enhanced by the use of coated circuit boards. The coating ensures that the moist and aggressive marine environment poses no threat to the electronics.

—

Fewer spares are needed when using AF contactors as they can support both AC and DC, and only four coils are required to cover large AC and DC ranges.

ABB's softstarters are also compact and easy to install and use:

- A built-in bypass allows the device to be smaller than one that has a separate bypass installed on the side of the softstarter. The built-in bypass shortens installation time and increases reliability as the integrated softstarter/bypass is assembled and tested in the factory.
- A clear and simple HMI (human-machine interface) makes the device easy to operate. Setup and diagnosis are performed via intuitive menus. The ABB softstarter uses an external keypad – a feature seldom found on other softstarters – so the operator can monitor or change settings without opening the panel door. It is included in the PSTX together with a 3 m cable to connect it.

It is these advantages that convinced TMT to replace their existing softstarters with ABB's PSTB softstarter range.

03

AF contactors

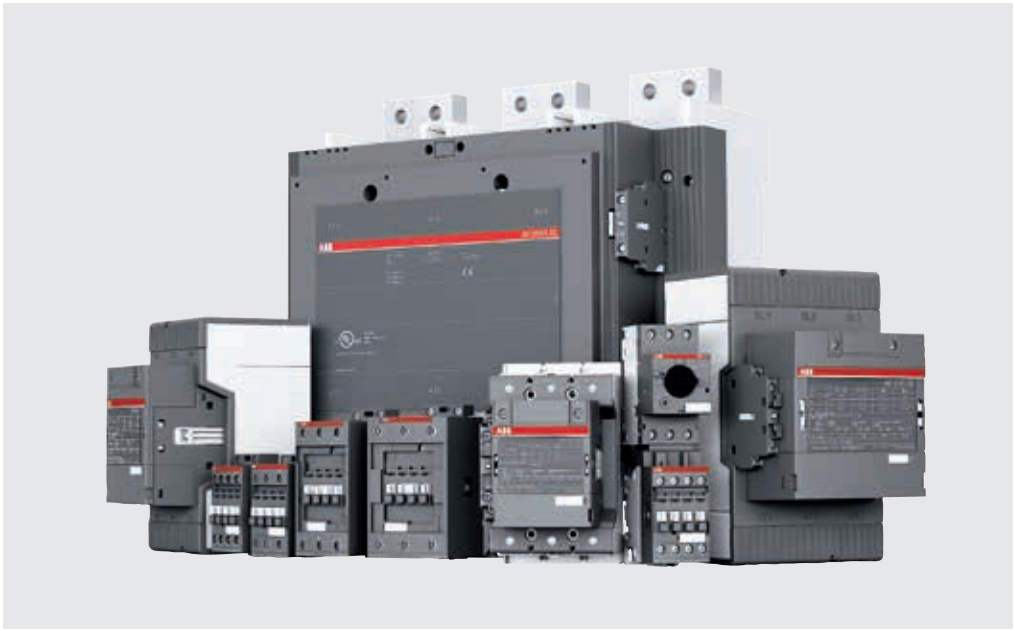
Both ABB softstarters and contactors handle the electrical network challenges relating to the motors and pumps that drive the ROV hydraulic system.

A contactor is an electrically controlled switch that operates an electrical power circuit in order to distribute power or start motors. It is similar to a relay but works at higher current ratings. Unlike relays, contactors can be directly connected to high-current loads and they are fitted with features to control and suppress arcing when high motor currents are interrupted.

04

The electronics in ABB's AF contactors rectify AC or DC control circuit voltage to a DC control voltage that is applied to the coil which closes the contacts and the main circuit →5. Combined with a wide control voltage range, this type of control enables the contactor to operate normally in unstable network conditions. The electronics in the AF contactor ensure that the energy consumption of the contactor is always optimized. They also remove traditional contactor problems such as humming and chattering, thus extending the contactor's life and making it virtually noise free.

The voltage fluctuations that can occur in an unstable network and cause trouble for conventional contactors, pose no threat to an AF contactor. Surges are handled by the contactor itself (conventional contactors require external surge suppressors) and the surge never reaches the control circuit.



05

— 04 The tether management system before it is lifted onto the ROV.

— 05 ABB's AF contactor series.

— 06 ABB's Softstarter product family.

Logistics at sea can be a tricky business, with limited space available to store spare parts and a long and risk-prone supply chain facing replacements ordered in a hurry. Fewer spares are needed when using AF contactors as the same coil can support

— The electronics in the AF contactor ensure that the energy consumption of the contactor is always optimized.

both AC and DC control voltages, and only four coils are required to cover from 24 V to 500 V in the AC range or 20 V to 500 V in the DC range. This represents a reduction of some 90 percent in part numbers as compared with a conventional contactor range. AF contactors are compact, too (up to 30 percent smaller than conventional items), which saves further valuable space on a ship.

Additional control products for improved reliability

In a second step, TMT decided to replace their existing competitor control products with ABB's low-voltage products. The benefits of this move are more than just a reduction in the number of suppliers. For example, ABB's easy-to-install three-phase monitoring relays offer an overvoltage and undervoltage monitoring capability with exactly the functions needed, such as phase failure detection, while the thermistor motor protection relays guarantee a longer motor lifetime due to their direct measurement of the temperature in the motor windings. Further, control panel elements have been replaced by ABB's pilot device range (buttons, switches, lamps, etc.) that include robust products that tolerate the tough environments expected to be found where TMT operate their ROVs. Moreover, and very relevant for TMT ROVs that are operated far from home, ABB's global orientation, as well as a strong local presence all around the world, guarantees worldwide support.

Simple, compact and reliable

Deploying an ROV at depths of 3,000 m requires a well thought-through and professionally executed technical approach. One major element of this is a first-class electrical power system that can ensure the ROV performs exactly as it should. TMT chose

— In a second step, TMT decided to replace their existing competitor control products with ABB's low-voltage products.

ABB's softstarters and AF contactors to help ensure that this is the case because of the simplicity, reliability, compactness and logistical convenience of these products. ●

ENERGY

ABB is the first to offer MV GIS with a climate-friendly alternative to SF_6

Gas-insulated switchgear (GIS) technology with sulfur hexafluoride (SF_6) gas provides the most compact dimensions, highest reliability and maximum safety. However, SF_6 is a potent greenhouse gas. ABB is the first company to offer MV GIS with a climate-friendly insulation gas based on a new molecule.

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Lighting residential and commercial areas, and powering energy-intensive industries, sports stadiums and metro lines, the medium-voltage grid sits between the high-voltage (HV) long-distance transport grid and low-voltage household consumer grids.

Switchgear forms the central nodes in the electricity grid where all connections come together. It is designed to switch currents on and off under all expected conditions. Under normal conditions, it gives the operators flexibility and control over their networks and under failure conditions it automatically breaks high fault currents and protects the rest of the grid – thus saving people from serious injury.

GIS technology for demanding applications
Cities and their energy demands are growing while real estate is becoming scarce and expensive – sometimes making it necessary for switchgear dimensions to be compact. This is where SF_6 GIS comes into play: Instead of using ambient air as an insulation medium, SF_6 is used as it insulates three times better than air and thus allows more compact switchgear designs →1. SF_6 GIS offers not only a smaller footprint but also higher reliability: The sealed SF_6 gas tanks keep the gas in place and separate electrically live components from the environment – thus preventing contamination from dust, humidity and animals. This reduces the probability of an unplanned outage to virtually zero – a major benefit for industries where a production stop can easily cost over $100,000 daily. Additionally, GIS technology is practically maintenance-free and helps to reduce operational costs over the complete life cycle (typically 30 years or more).

SF_6 under discussion
ABB built the world's first GIS in 1967 and pioneered the technology, which is now state-of-the-art for demanding applications. The outstanding electrical performance of SF_6 has made the technology a global success story – in MV as in HV. However, despite all its advantages, SF_6 has a downside: It is a potent greenhouse gas if released into the atmosphere.

GIS offers not only a smaller footprint but also higher reliability.

—
01 ABB's SafeRing AirPlus.

—
02 The C5 fluoroketone molecule.

The impact of greenhouse gases is expressed by their global warming potential (GWP). GWP is a calculated value that takes two main factors into consideration:

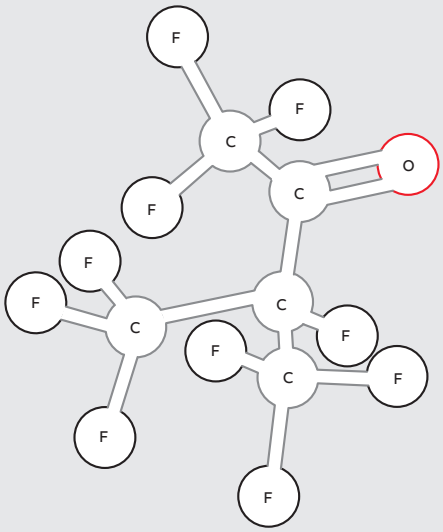
- Radiative forcing capacity: How well does a gas absorb warmth (in the form of infrared rays) instead of letting it reradiate to outer space?
- Decay time: How long does the gas exist in the atmosphere before it decomposes?

—

Despite all its advantages, SF_6 has a downside: It is a potent greenhouse gas if released into the atmosphere.

The GWP of carbon dioxide (CO_2) is defined as a reference value of 1; SF_6 has a GWP of 22,800.

Since the 1990s, in the light of growing awareness of climate change, the search for climate-friendly alternatives to SF_6 has received growing attention. Until now, results have always been disappointing as promising candidate gases turned out to be unstable or toxic.



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A further downside to SF_6 is that because of its high global warming potential and the lack of a suitable alternative for electrical applications, SF_6 users in many countries are now bound by regulatory and inventory procedures, which increase administrative overheads.

AirPlus – A low-GWP alternative to SF_6

Fifty years after pioneering the world's first GIS, ABB is again making GIS history. Together with partner 3M, ABB has developed a promising alternative to SF_6: ABB's AirPlus insulation gas. While coming close to the technical performance of SF_6, the new gas – with a GWP of around 0.5 – has virtually no impact on global warming.

—

ABB is again making GIS history. Together with partner 3M, ABB has or identified a promising alternative to SF_6: ABB's AirPlus insulation gas.

Compared to SF_6 with a GWP of 22,800, the GWP of the new gas represents a reduction of more than 99.99 percent. After an average of 16 days exposed to solar radiation in the atmosphere, AirPlus's new molecule decomposes – compared to over 3,000 years for SF_6. Of course, these figures only apply if the gas were to be released to the environment, which is why ABB has a closed gas life cycle in its GIS products that avoids emissions wherever possible, irrespective of whether AirPlus or SF_6 is used. Unlike SF_6, AirPlus is not a pure gas but a gas mixture. More than 80 percent by volume is made up of dry air and the remaining part is NOVEC 5110 dielectric fluid, a C5 fluoroketone (C5 FK or $C_5F_{10}O$) molecule provided by 3M →2. This molecule combines remarkable dielectric performance with a very low carbon footprint.

With regard to gas handling, AirPlus does not require more safety measures than SF_6. It is classified as practically nontoxic with a permissible exposure limit comparable to SF_6. And AirPlus comes with additional safety benefits for underground applications like tunnels or mining: While large amounts of SF_6 take time to mix with air – leading to oxygen deficiency – the AirPlus mixture is already more than 80 percent air and quickly dilutes even further.

—

After an average of 16 days exposed to solar radiation in the atmosphere, AirPlus's new molecule decomposes – compared to over 3,000 years for SF_6.

Apart from the environmental and safety aspects, users of AirPlus will benefit from streamlined processes and reduced operational costs. The use of SF_6 is regulated in many countries, which involves inventory keeping and regulatory procedures, and even SF_6 taxes in a few cases. These regulations do not apply to AirPlus, nor is regulation expected in the future.

Pilot project with Netze BW

Netze BW is one of the biggest distribution system operators (DSOs) in Germany, operating their network in the southwestern part of the country. As part of the EnBW group, they are among Germany's top four power utility companies.

In a 10 million EUR project, Netze BW is modernizing the 110 kV/20 kV Trochtelfingen substation. The old 20 kV MV switchgear was replaced by ABB's ZX2 GIS in a double busbar configuration – saving 40 percent of space compared to air-insulated switchgear (AIS) technology →3–5. This allowed Netze BW to install additional feeders and to remain flexible, as renewable power sources like wind or solar are growing in popularity in this region.

"When ABB mentioned their ongoing developments in SF_6 alternatives, we were interested from the very beginning," said Chief Technology Officer Martin Konermann from Netze BW, "as AirPlus fulfills two of our mission goals at the same time: being innovative and preserving the environment."

Netze BW and ABB agreed to change a part of the lineup from SF_6 to AirPlus, demonstrating that panels of both technologies can be mixed even within the same switchgear lineup. This is the first AirPlus GIS to the installed in Germany and the second worldwide.

—
03 AirPlus GIS arrives at the Trochtelfingen substation.

—
04 AirPlus GIS installation work in the Trochtelfingen substation.

04

05

Of course, the pilot switchgear has passed all type tests and routine tests according to IEC standards. After installation and on-site testing, the new switchgear was energized in June 2016 and is now in service. This is a successful pilot project for Netze BW and ABB, and an important milestone in bringing the new technology closer to a standard product.

ABB's product offering

At the Hannover Fair in April 2016, ABB announced the launch of two switchgear products that use the climate-friendly alternative insulation gas AirPlus. These products are the first step toward a broader AirPlus portfolio and the opening of a new era for GIS technology in the MV market.

ZX2 AirPlus

ZX2 AirPlus is ABB's primary distribution switchgear with the new AirPlus insulation gas. It is based on the known ZX2 high-end SF_6 GIS in single and double busbar configurations. In a first step, the AirPlus version is available in an IEC rating of up to 36 kV with 31.5 kA short-circuit and 2,000 A nominal current, including most panel types and variants.

While the inner parts have been adapted for the use of AirPlus, the exterior remains unchanged so that users can rely on the known compact dimensions and proven ZX2 design.

As primary switchgear is a long-term investment with lifetimes of over 40 years, ABB can optionally offer ZX2 Ready-for-AirPlus – ideal for the user who may want to switch to AirPlus later. ZX2 Ready-for-AirPlus comes factory-filled with SF_6 but with all necessary preparations to use AirPlus whenever the user wishes to switch.

—

AirPlus requires no more safety measures than SF_6 does, it is classified as practically nontoxic and has a permissible exposure limit comparable to SF_6.

05 ABB's ZX2 GIS is much more compact than its predecessors.

SafeRing AirPlus

SafeRing AirPlus is ABB's secondary distribution ring main unit (RMU) featuring the new AirPlus insulation gas. It has the same compact dimensions as the well-known SafeRing/SafePlus products with SF_6 insulation and initially covers IEC ratings up to 24 kV with 16 kA short-circuit and 630 A nominal current. The most important load-break switch and circuit breaker units will be available in different configurations in block design, covering the most typical applications.

At the Hannover Fair in April 2016, ABB announced the launch of two products that use the climate-friendly alternative insulation gas AirPlus.

As AirPlus requires a broader redesign of the existing RMU, both circuit breakers as well as load-break switches are based on vacuum technology. In this way, switching is done with reliable vacuum interrupter technology, and the AirPlus gas is used exclusively as an insulation medium.

AirPlus technology for everyone

ABB is convinced that AirPlus helps to reduce the global warming impact of the power grid and wants as many users as possible to benefit from this innovative technology. This is why ABB decided to disclose its patents, inviting other manufacturers to join the AirPlus journey.

AirPlus is ABB's eco-efficient alternative to SF_6 for MV switchgear with a GWP below 1. It helps to reduce further the carbon footprint of the electricity grid by taking GIS technology to the next level. ABB has launched the first products with the climate-friendly insulation gas and will extend the AirPlus portfolio over the coming years. As SF_6 will still be needed for the highest ratings and special applications, ABB will also continue to reduce GIS gas emissions even further. This two-pronged strategy will pave the way to a greener future and power for a better world. ●

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ABB Ability™

Having produced 70 million connected devices operating around the world, ABB has been a pioneer in bringing the benefits of digitization to industrial applications. Yet this transformation has only just begun, and the next issue of ABB Review will high-light some of the latest examples of its work with customers to use the cloud to aggregate, analyze, and then apply it to operations.