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Issue 2 **2015**

PFISTERER

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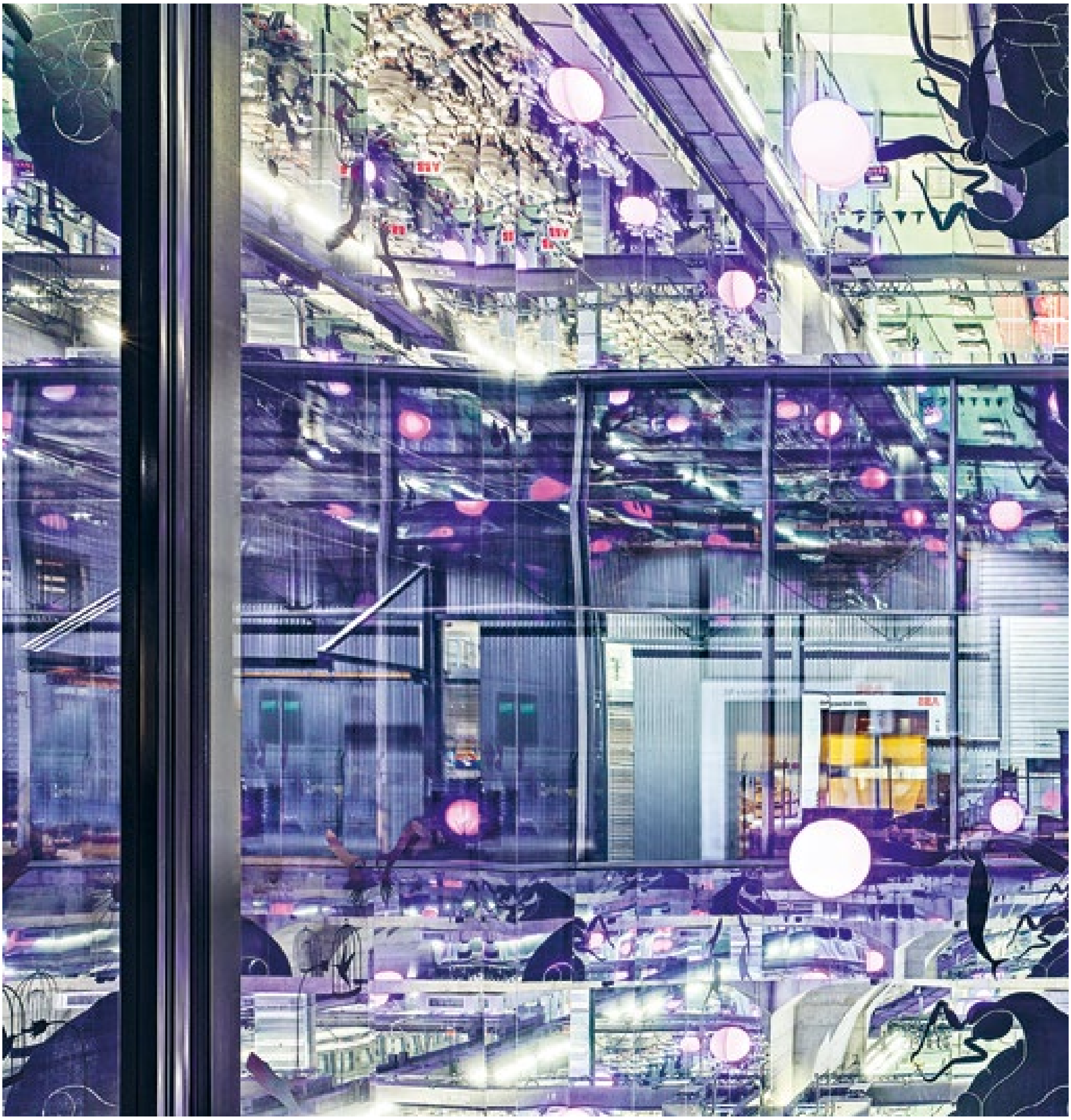

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Editorial

Development with Vision


Jörg Fries

Ideally, innovations provide security of supply for people, the environment, and companies. This is demonstrated by the global debut of new technologies at the ewz Oerlikon substation in Zurich: In reading this issue of CONNECT, you can find out how GIS use eco-efficient insulating gas from ABB and touchproof, plug-in transformers with CONNEX from PFISTERER to promote sustainability and efficiency (page 4). This ties in with our founding principle: The development of technology is at its best when it takes the requirements of users and markets on board. Eduardo Santana, Sales Director for Cable Accessories & Systems at PFISTERER explains how we succeed in doing with CONNEX for power transformers (page 10). We provide further insights into the professional use of voltage detectors for systems over 1 kV in the second part of our series of special reports (page 16).

We hope that reading this issue provides you with informative perspectives on the advanced and reliable solutions we offer. And we are certain that we have the right for your networks, too!

Sincerely,

Jörg Fries

Chief Sales Officer of PFISTERER Holding AG

Power under the City. Plus World Firsts.

In the newly constructed Oerlikon substation, ewz (an electric utility for the city of Zurich) is implementing two technical innovations for the very first time: switchgears with eco-efficient insulating gas from ABB and extremely compact CONNEX transformer connections from PFISTERER. "Both technologies support the sustainable concept of the underground substation," Pascal Müller from ewz can also explain why. As the overall head of the project, he plans aspects such as such as the electromechanical equipment. During a tour of the site, he reveals how the hub of the network brings the aspects of safety, environmental compatibility, and efficiency to an advanced common denominator.

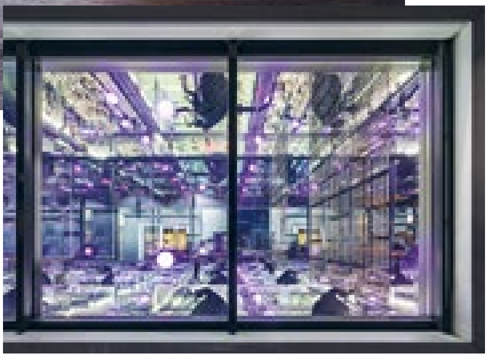
North Zurich, Eduard-Imhof-Straße. The substation would have been virtually invisible, had ewz not decided to erect a network base above its three underground levels. The new buildings, designed by the architecture firm illiz and planned in cooperation with Pöyry Switzerland AG, combine utility with aesthetic appeal. With a warehouse, workshop, and social spaces, the base functions as a station for up to 45 ewz employees for network development and maintenance. Its appealing architecture certainly attracts attention. A large window facade directs people's gaze below ground. There, an illuminated room, artistically staged by Yves Netzhammer with a multimedia mirror installation, reflects one of the new developments: the 170-kV switchgear from ABB and insulated with a unique gas mixture.

New Gas for GIS

ABB has developed the gas as an alternative to sulfur hexafluoride (SF_6). Since the 1960s, SF_6 has been the preferred choice for insulating and extinguishing media in energy equipment technology. Its impressive dielectric strength allows gas-insulated switchgears (GIS) to be built using an exceptionally space-saving design. Unlike air-insulated switchgears, GIS can even be installed in confined interior spaces. The enclosure of the active elements makes for a high level of operational reliability.

Eye-catching presentation: For a fascinating insight into one of the subterranean system rooms at the new Oerlikon substation, the architecture firm illiz designed a generous window facade in the network base. Whoever looks through has a view of the "The Captured Flea" - a multimedia mirror installation by the artist Yves Netzhammer, as well as of the world's first technological innovation: ABB's HV switchgear insulated with an innovative, environmentally friendly gas mixture.

Smart savings: The new ewz Oerlikon substation was built in an urban area of Zurich and is located across three underground levels, directly below an ewz network base (center), which is also new. Together, the buildings take up visibly less space than the old air-insulated substation of the previous substation alone (behind new ewz network base).



Roger Frei, Zurich

These arguments speak strongly in favor of gas-insulated solutions, particularly in metropolitan areas where space is at a premium and comes at great expense.

The downside to SF_6: It is regarded as the most potent known greenhouse gas. Although it is classified as making a very low contribution to global warming, as only a small amount is currently present in the atmosphere, it is said to have an average lifetime of around 3,200 years. Its use in energy technology systems is subject to stringent conditions which demand comprehensive gas management for a system lifetime of between 40 and 60 years and can entail considerable costs for operators.

ABB's new switchgear technology takes all of this into account. The new insulating gas mixture has similar properties to SF_6 – at a carbon dioxide equivalent of well below one. As employed in the pilot plant, it is said to reduce CO_2 emissions by up to 50 % compared with similar SF_6 switchgears – over its entire lifetime and providing a constant level of efficiency and reliability.

Pioneering Spirit and Quality

"The use of this innovation enables us to reconcile the advantage offered by the space-saving design of gas-insulated switchgears with the increasingly important aspect of environmental compatibility in a whole new dimension," explains Pascal Müller. "At the Oerlikon substation, we are therefore able to demonstrate our guiding principle of pioneering spirit and ecological power supply for our customers." ewz is one of the ten largest energy service providers in Switzerland in terms of sales and has been providing the city of Zurich and parts of the Graubünden canton with power since 1892. Introducing an innovative technology is therefore nothing new for this energy supplier which is regulated by public law, and is simply the result of its continuous improvement strategy.

Back in 1967, ewz was responsible for successfully bringing the world's first SF_6-insulated switchgear into operation at its Sempersteig substation. It was produced by BBC (now ABB) and was in use until 2004. Today, the new gas mixture at the Oerlikon substation insulates both the high-voltage and medium-voltage switchgears. Yet from the window facade, these and all the other equipment are nowhere to be seen. They can only be reached following a silent elevator journey into the depths of the entire complex.

«We have been using CONNEX systems and components for over ten years and have found them to be excellent.»

Pascal Müller
General Manager of the Oerlikon substation & ewz network base in Zurich

Groundbreaking innovation: The high-voltage switchgear from ABB connects the space-saving design of gas-insulated switchgears with unparalleled low CO_2 equivalent values – thanks to brand new switchgear technology with a patented GIS gas mixture.

As General Manager, Müller is responsible for the construction of the new substation and network base, and en route explains the reasons behind the consistently high demands that are placed on the technical equipment: "If a component fault occurs, there is a high statistical probability that it will be at a system interface. To minimize this typical operational risk, we place the utmost importance on the quality of the connection technology too." The engineer has investigated the cost effects of component quality. He was part of a team of authors who in 2003 presented a brand new calculation model on the cost-effectiveness of investments in electrical equipment.

The report focuses on incident scenarios whose causes are linked to component quality. Alongside the anticipated expenditure, the model also takes incident-related costs into account. "This includes the management and rectification of faults, but also follow-up costs such as loss of sales and damage to one's reputation," explains Müller. "The calculation for a 170-kV circuit breaker and a substation revealed that their share of the lifecycle costs can increase dramatically for more vulnerable products. Yet if the components are of high quality and are reliable, these costs are virtually negligible."

Partners in security of supply: Pascal Müller, General Manager of the new Oerlikon substation (left), and Reto Aeschbach, Sales Manager at PFISTERER SEFAG AG (right), are delighted with the successful fusion of environmentally friendly technologies: dry-insulated HV-CONNEX cable terminations from PFISTERER in use with an eco-gas-insulated HV switchgear from ABB (to the left of the image).

Extremely Compact System Connection

The CONNEX system from PFISTERER used in the ewz network has already proven itself to be a reliable cable connection technology in a wide range of systems. "We have been using CONNEX systems and components for over ten years and have found them to be excellent. At the new Oerlikon substation, all of the high-voltage and medium-voltage connections in the two switchgears and three transformers use CONNEX," states Müller and opens a signal-red sliding panel. "Here you can see it at work, with a new addition to the product family." A 50-MVA power transformer from ABB, 6.6 m high, 5.5 m long and 4.1 m wide, is the dominating first impression. The new, size 3, straight MV-CONNEX transformer socket (TAT) for 2,200 A or 3,150 A depending on the connection type and 52 kV protrudes over its cover. Inside, three cables equipped with MV-CONNEX separable connectors are inserted right next to each and reach up to the ceiling.

Efficient use of space: 50-MVA power transformer from ABB installed in one of the underground transformer cells at the new Oerlikon substation, connected to heat exchangers for energy-saving use of heat and fitted with compact connection and monitoring solutions from PFISTERER

Extremely compact design from a single source: PFISTERER's new size 3 CONNEX transformer sockets (TAT) for up to 52 kV enable the multiple connection of vertically installed MV cables. The latest addition to the proven CONNEX system makes its debut at the Oerlikon substation – in conjunction with earthing isolator boxes and DSA-i3 continuous voltage indicators.

The extremely compact, vertical cable connection is one of many advantages of the new connection for Müller: "As you can see, its fourth connection point is not in use. Here, we could connect a CONNEX earthing set without having to access the interior of the system and keeping the enclosure intact. We can determine the voltage conveniently via the integrated voltage tap, which is directly connected to a PFISTERER continuous voltage indicator. In addition, the enclosure of every CONNEX cable termination reduces the system's vulnerability to failures and also makes every system interface touchproof. Our maintenance staff can therefore carry out their work in complete safety without barriers – a key aspect with space-saving design."

More Space. Plus Cost-efficiency.

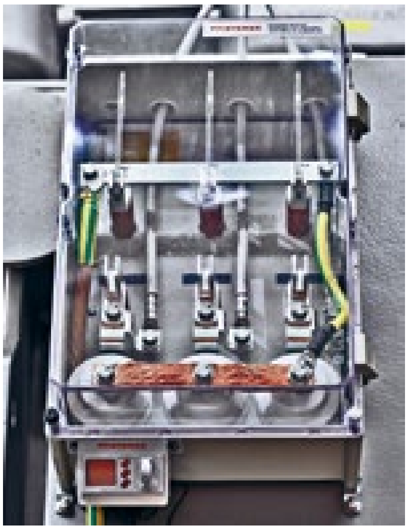
The transformer cell is used to the max. With a room volume of 280 m^3 and covering an area of 35 m^2, it houses more than simply the transformer which weighs a total of 80 t. It is also coupled with heat exchangers on each of its short sides. These cool the transformer oil and use its heat to heat air and water – one of several measures that ewz uses to keep its energy requirements for supplying heat to the building as low as possible. It is possible to hazard a guess at how much installation space the new substation saves in total by taking a look from the balcony of the neighboring building.

«With this radical new technology, we will be able to make a valuable contribution to reducing global CO_2 levels.»

Thomas Diggelmann
Global Product Manager for eco-efficient GIS at ABB Zurich

Behind the new network base, an air-insulated, high-voltage substation stretches across the ewz site. This is part of the old Oerlikon substation, which has been supplying the Zurich districts of Oerlikon, Seebach, and Neu-Affoltern with electricity since 1949, and has now reached the end of its technical service life. It is to be replaced by the new substation, which was put into operation in August 2015. The new system will be integrated into the ewz network in stages, set for completion by 2018. Up to this point, the air-insulated substation will ensure reserve supply, and then finally be decommissioned. The old substation alone is considerably larger than the new construction in its entirety.

Müller expresses the scale in actual figures: "The new substation covers only 30 % of the original space required, including its additional technical equipment." As soon as the old substation has been completely dismantled, valuable land for building will become available. ewz plans to give around 5,200 m^2 over to the city of Zurich. This will cover the additional costs incurred by the subterranean design of the new substation.



Compact all-rounder, smart combination: PFISTERER earthing isolator box to EN 61439 for efficient and reliable screen treatment with integrated cable loss optimization, for use in the Oerlikon substation connected to a PFISTERER DSA-i3 continuous voltage indicator to IEC 61243-5 (VDS test systems) as permanently visible monitoring module for operating personnel (bottom left in image)

Tested quality: Nicolas Meyer, Project Manager for cable systems at ewz (left in the left image), and Pascal Müller, General Manager of the ewz Oerlikon substation (right in the left image), are delighted with the result of the acceptance test for the new CONNEX transformer socket in the PFISTERER high-voltage lab in September 2014 (image top right): The newcomer designed for operating voltages up to 52 kV remains completely free of partial discharges for over one minute at a test voltage of 95 kV (image bottom right).

Maximum flexibility: In addition to medium-voltage cables, further CONNEX components are easy to connect to the new MV-CONNEX transformer socket using plug-in technology. Components could include a surge arrester for optimum protection directly at the system (rear right), a test and connecting unit (front right) or an earthing set (front left), as is shown here.

Touchproof under high voltage: Three cable connections to a 50-MVA transformer designed with encapsulated size 6 HV-CONNEX system for 170 kV as well as earthing isolator box for efficient screen treatment

Focusing on Innovations

The new generation of ABB switchgears with an eco-efficient insulating gas mixture is the result of over twenty years' research. The gas mixture is classified as practically non-toxic on the Hodge and Sterner toxicity scale. Its CO_2 equivalent is 99.995% lower than SF_6 and its ozone depletion potential is zero. "With this radical new technology, we can make a valuable contribution to reducing global CO_2 – what's more, there are advantages for users, as this technology does not require laborious reporting procedures and is not subject to environmental restrictions," explains Thomas Diggelmann, Global Product Manager for eco-efficient GIS at ABB Zurich.

Following intensive investigations with fluoroketones, ABB opted for perfluoroketone (C5 PFK) as the base component for the new gas mixture. In its pure form, it is much more voltage-proof than SF_6, yet has a boiling point of 25°C. By adding dioxygen (O_2) and nitrogen (N_2) or CO_2, ABB succeeded in finding a viable alternative: The properties of the patented gas mixture are similar to SF_6. It is suitable for indoor applications and can be used to provide both insulation and arc interruption. It passed all the type tests for the pilot installation in the Oerlikon substation with the PFISTERER CONNEX systems in sizes 6 and 6-S.

The straight MV-CONNEX transformer socket (TAT) for up to 52 kV is the latest addition to PFISTERER's CONNEX cable termination system. It enables up to four plastic-insulated cables to be connected vertically in a very compact space. This means that even transformers and switchgears installed at different levels can be linked in a touchproof manner. "In the last five decades, substations have become more compact. With the introduction of the CONNEX system and its continuous expansion, we have also helped shape this trend in a solution-oriented manner," states Reto Aeschbach, Sales Manager at PFISTERER SEFAG AG.

The design principles of the TAT were defined by transformer manufacturer ABB (Italy site), the end customer ewz, and PFISTERER Switzerland as the result of exemplary cooperation. Roland Hasler, ABB Market Manager for transformers in Switzerland adds: "The development was completed in a year and a half – from determining the basic requirements to the successfully tested production stage. The new CONNEX TAT components could then be handed over to the fitters on schedule when the transformers were delivered to the ewz substation. The complete package with new and established connector systems, screen treatment via earthing isolator boxes, and earthing sets, really shows what PFISTERER can do."

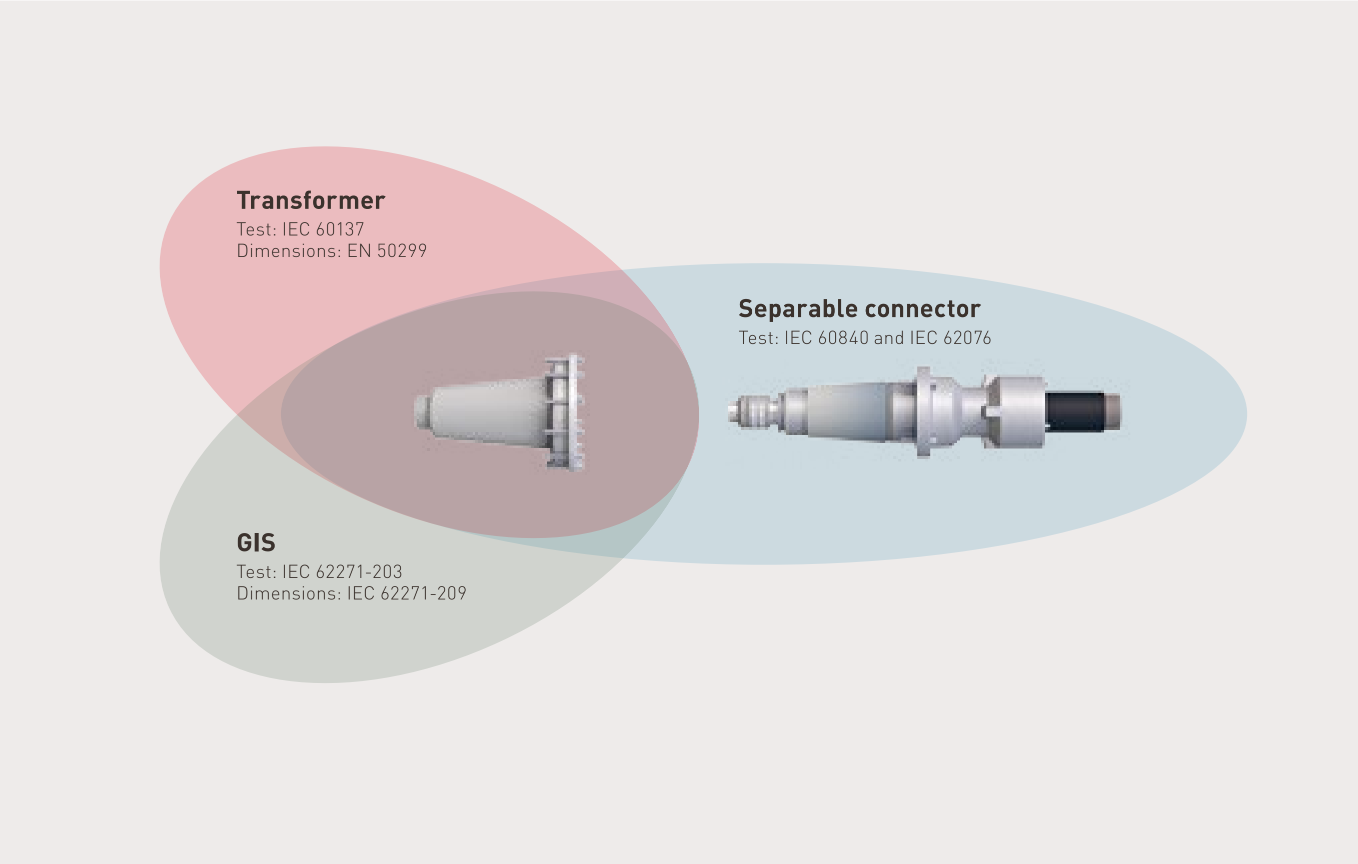
The Universal Power Transformer.

Eduardo Santana, Director Sales Cable Accessories & Systems at PFISTERER, highlights the advantages of using the CONNEX power transformers with the help of the requirements of users and markets.

Maximum flexibility along with optimum safety and efficiency for a service life of at least 40 years. This dream can be realized when you opt for power transformers with the dry-insulated and modular plug-in CONNEX connection system. Eduardo Santana, Sales Director for Cable Accessories & Systems at PFISTERER, explains precisely how in an interview regarding the requirements of users and markets around the globe.

What forms the basis for the high level of flexibility offered by power transformers equipped with CONNEX?
Santana: That would be the plug-in principle of the CONNEX system. The CONNEX socket is permanently mounted in the equipment as a defined interface, forming an enclosed system. This allows various CONNEX components to be easily inserted into the socket without having to access the sensitive interior of the system, such as a bushing, separable connector, or surge arrester.

Components integrated into power transformers have to satisfy specific requirements. How has PFISTERER reliably ensured this with CONNEX?
Santana: Conventional cable accessories are type-tested exclusively to IEC 60840; in being a system, CONNEX, on the other hand, has been type-tested in accordance with every international standard relating to its three system connection areas, i.e., also IEC 62271-203 for gas-insulated switchgears and IEC 60137 for bushings. We take into account the fact that IEC 60137 focuses on conventional solutions by implementing an extended PFISTERER requirements profile. In over one hundred development tests, our sockets alone have proven that they are capable of far more than what is required by IEC 60137 and can be expected in practice with respect to AC voltage, partial discharge, and overload operation. Last but not least, power transformers equipped with CONNEX have been in operation for many years – providing flawless performance and an unparalleled level of user-friendliness.



Extremely versatile thanks to its plug-in principle and certified according to three type tests: the CONNEX system illustrated here features a device-integrated CONNEX socket (component on left) and insertable CONNEX separable connector (component on right)

What does "an unparalleled level of user-friendliness" mean?
Santana: In our experience, system operators give priority to three aspects: operational reliability, efficiency, and flexibility. CONNEX reduces these requirements to a common denominator – economically and without compromise. With CONNEX, a power transformer is optimally equipped for every dynamic situation that arises during normal everyday operations, as well as medium and long-term network developments under a wide range of market and environmental conditions.

Starting with normal everyday operations, how can CONNEX optimize these in practice?
Santana: A transformer with integrated CONNEX sockets is tested at the factory, meaning it can be put to use as soon as it has been delivered. It does not need to be opened for on-site tests or network connection. This prevents areas of liability from becoming blurred at a very early stage. The transformer can then be delivered without protruding components such as pre-installed bushings. Initial installation and any subsequent maintenance measures are also much quicker and easier to implement, as there is no need for oil work. All plug-in CONNEX standard components are also plastic-insulated. This eliminates any environmentally harmful leaks, renders complex monitoring unnecessary, and dramatically reduces the system's vulnerability to failures as a result of external influences.

«With CONNEX, a power transformer is optimally equipped for every dynamic situation that arises during normal everyday operations, as well as medium and long-term network developments under a wide range of market and environmental conditions.»

Eduardo Santana
Sales Director for Cable Accessories & Systems at PFISTERER

How does CONNEX support changes in the network?
Santana: The key advantages of CONNEX in this regard relate to the fact that the bushing and cable termination can be replaced and test or connecting equipment can also be connected. Both of these processes can be carried out quickly and easily. This means that the power transformer is suitable for any practical application, whether desired, required, or dictated.

That sounds like the promise of a "universal transformer".
Santana: And even better, CONNEX actually delivers on this, as has been proven by our countless projects across the globe. Power transformers may initially be connected to an air-insulated substation, then years later to a gas-insulated switchgear, or vice versa. Or they might be operated in a "roaming" manner. Both are relevant if changes are being made to a network. And regardless of how a network infrastructure is set up, forces of nature can disrupt this at any time. For uncertainties such as this, some network operators use transformers equipped with CONNEX as mobile emergency systems.

Even during normal operation, certain environmental conditions can call for the use of power transformers ...
Santana: Most definitely. More and more substations are situated close to populated areas, some in the center of cities. In such cases, space is at a premium and additional protection requirements come into play, meaning that substations are integrated into buildings, often over several stories, and above or below ground. With CONNEX, a transformer is not just able to be designed and connected in a more compact manner, it can also be completely encapsulated and touchproof. It can also be set up in the most confined spaces safely without barriers and is easy to inspect. The ability to save space and costs is also extremely important for underground hydroelectric power plants and offshore platforms. CONNEX was the first

In the network of Austria's largest energy provider, Wiener Netze (formerly Wien Energie), power transformers equipped with HV-CONNEX prove themselves to be all-rounders: The urban infrastructure in and around Vienna is constantly growing. Wiener Netze manages to cope with the resulting load increase in the supply network with the sustainable expansion of its power capacity based on a new network concept. This leads to special requirements being placed on the new 40-MVA transformers: Flexible connection to air-insulated substations or SF6-GIS as well as rapid replacement ensure security of supply based on the (n-1) safety principle. With the CONNEX system from PFISTERER, Wiener Netze was able to achieve both – thanks to CONNEX bushings and cable terminations which can be inserted quickly and easily into the system-integrated CONNEX sockets without having to access the interior of the transformer.

For over 80 years, Alpiq has been building high-voltage networks and switchgears and has installed the size 4 HV-CONNEX surge arrester for up to 72.5 kV for the first time in its Klus substation: The substation has been in operation in the Swiss village of Klus since 2007. It is a joint project between power supply companies Alpiq Versorgungs AG (AVAG), AEK Energie AG (AEK), and onyx Energie Mittelland, and run by Alpiq EnerTrans AG. The transformers and switchgears incorporated into the buildings of the SS are equipped with MV- and HV-CONNEX cable terminations. Four size 3 MV-CONNEX surge arresters and four size 4 HV-CONNEX surge arresters (detailed view in the image at top right) provide the two 40-MVA transformers with optimum protection directly at the equipment. **The project report in CONNECT 2-2013 explains how CONNEX enabled Alpiq to achieve cost advantages for its retrofit project.**

This QR code leads to the project report.

system of its kind to meet the requirements for offshore use; all CONNEX cable terminations are resistant to salt water and UV radiation, and are submersible. All in all, a power transformer with CONNEX is ideally positioned for any potential market.

Which markets do you currently have your sights on?
Santana: Based on the average service life of a power transformer, networks fluctuate to a greater or lesser extent. These underlying dynamics are fueled by various factors. According to the 2015 Global Status Report, just under 28 % of the world's installed generating capacity was made up of renewable energy sources at the end of 2014, with the largest growth recorded by wind power, hydroelectric power, and photovoltaics. At least 164 countries are said to have defined development goals for renewable energies and around 145 countries profess to have introduced incentives for the expansion of such sources. Aside from this, urbanization is set to advance – with the highest growth expected to be in Asia, Latin America, and Africa – although the trend is also continuing in Europe. Energy demand is increasing in the load centers that are more highly populated, yet at the same time, current paths are becoming longer, meaning that cross-country infrastructures also need to be expanded. Where there are transformers, there are also switchgears. With CONNEX, network operators are able to establish an end-to-end connection system with enhanced operational reliability. This is a key factor, particularly in areas that experience extremes in climate or are under threat from sabotage, such as in the USA. Ultimately, security of supply is a way of guaranteeing public order. Even highly conservative markets such as the Middle East are now opening up to CONNEX.

Some parts of the world are moving toward maximum voltage.

Santana: With CONNEX, we already offer the largest product family for 220 kV. And the system is still growing. In 2014, we introduced our first 420-kV cable accessories and new bushings for use up to 420 kV are in development. The medium-term goal we have set ourselves is 550 kV. With PFISTERER, transformer operators are therefore supported by a system partner they can rely on at all times and who is there to ensure that power transformers equipped with CONNEX are and remain enduring all-rounders.

For Global Tech I, one of the first commercial offshore wind farms in Germany, PFISTERER pulled out all the stops in terms of performance: Every single cable connection for the transformers and switchgears on the substation employs offshore-certified MV- and HV-CONNEX connections. Used for the first time in Global Tech I, PFISTERER developed a heavy-duty HV-CONNEX compensation clamp, which provides additional support to the cable retainer under special installation and environmental conditions (shown in the image: compensation clamp used on a power transformer). A 14-strong PFISTERER assembly team laid a total of around 5,800 m of cable in the dry dock, carried out high-voltage testing, and handed over the successfully tested cable system right on schedule. **Take a look at the project report in CONNECT 1-2012 for further details about the wind farm.**

This QR code leads to the project report.

For the expansion of its hydroelectric power plant capacity, Kraftwerke Oberhasli AG (KWO) has chosen to put its trust in the highly compact CONNEX connection system many times over: KWO is one of the leading hydropower companies in Switzerland, operating nine hydroelectric power plants with 26 turbines and outputs of 1,125 MW in the Bernese Alps. To make even more efficient use of the hydroelectric potential that it has already tapped into, KWO has established an investment program stretching into the billions. The project includes upgrading individual power plants: For Innertkirchen 1, new transformers have been purchased and are equipped with size 6 HV-CONNEX cable termination systems for 150 kV. Helping to improve the performance of Grimsel 1 are new switchgears and transformers which have been in operation with size 6-S HV-CONNEX cable termination systems for 245 kV since 2005.

New: Flexible HV-CONNEX Bushing for up to 245 kV

To provide lifelong high efficiency for power transformer operation, PFISTERER is expanding its CONNEX product range: In the same way as its predecessors for 145 kV (size 5) and 170 kV (size 6) did, the new size 6-S HV-CONNEX bushing for up to 245 kV is reducing the wide range of user requirements to a common, economical denominator.

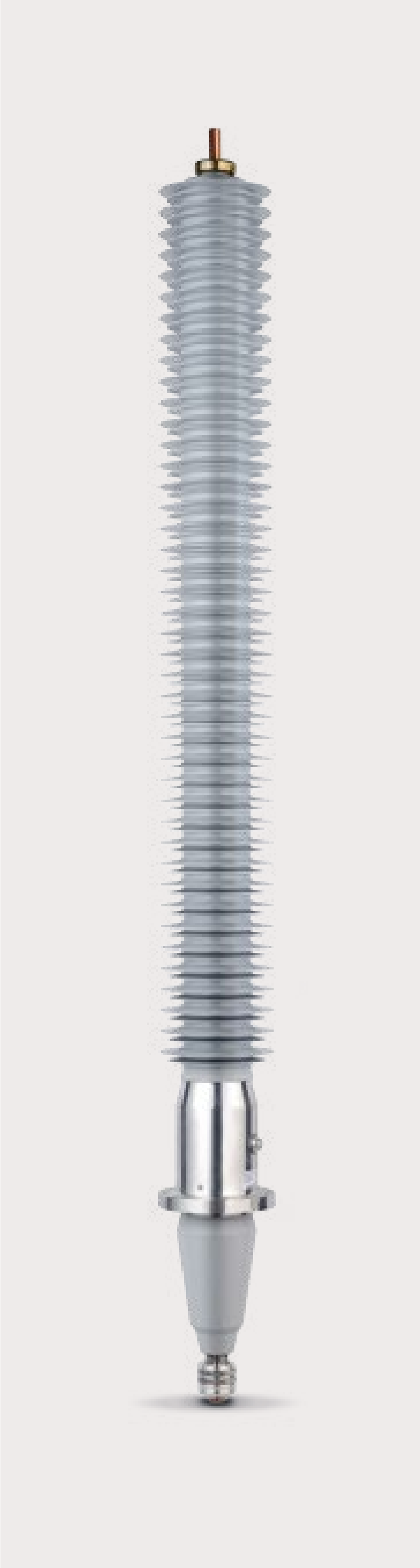
The newcomer can be inserted dry directly into the transformer. The transformer can therefore be tested at the manufacturer's factory exactly as it is to be used in the field: sealed and with an HV-CONNEX connection unit and bushing. Network connection and on-site testing can be carried out quickly and easily without having to access the interior of the transformer and with no laborious oil work. The bushing can be replaced with HV-CONNEX cable terminations at any time, enabling the flexible conversion of the transformer and ensuring investment security over its entire lifetime, even if changes occur in the network. In conjunction with a plug-in CONNEX socket, the bushing can also be used as a temporary bridging solution in the event of network expansions or maintenance to overhead lines. All CONNEX bushings are designed with capacitive field control as standard.

Applications

- Permanent connection of transformers to blank conductors
- Establishing temporary connections
- Transformer tests in factory-sealed condition
- Nominal current I_N = 2,500 A
- Maximum operating voltage U_m = 245 kV

Features & Benefits

- Quick installation with no laborious gas or oil work
- Easy to plug in to device-side pre-installed socket
- Can be used directly after factory testing
- Compact construction for space-saving connections
- Can be installed at any angle
- Maintenance-free and leak-free thanks to solid insulation
- Type-tested in accordance with IEC 60137



Testing Voltage Safely – Part 2: Class Versus Interference Fields

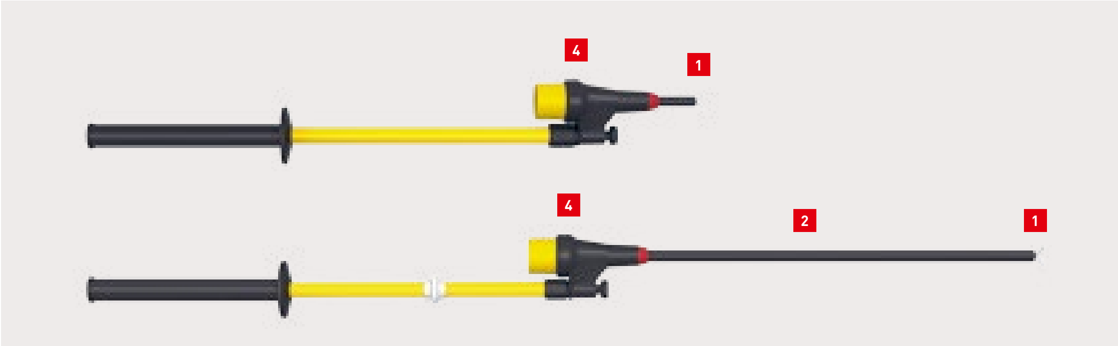


Figure 1: Class S voltage detectors (bottom image) come equipped with a contact electrode extension [2] as standard. This means that, as a general rule, it is possible to immerse them into systems to a deeper level than conventional shorter class L detectors (top image) without running the risk of interference field effects.

Choosing the right voltage detector is one of the most important steps in ensuring that voltage tests are performed reliably and safely. Obvious though the correct option may seem, the only way to be certain is to take account of the testing conditions, which vary from system to system. This much is clear from decades of experience with capacitive voltage detectors for 1 kV and up, which have shown that interference field effects may seriously compromise detector function unless the detector class and system configuration work as one.

Capacitive voltage detectors have asserted their position in a number of energy technology applications throughout the world – and for good reason. Not only do they offer excellent protection from sources of danger, they are more user-friendly and versatile than their resistive counterparts (for more details, see the first part in this series of special reports in CONNECT 1-2015). They are available in classes S and L, and knowing the limitations of and possibilities offered by each variety is essential if the user wants a device that will play to the strengths of capacitive technology.

This QR code leads to Part 1 in CONNECT 1-2015

A. Where the Classes Differ: A Single Component

Figure 1 shows the key difference between the two classes: While class L voltage detectors (top image) have a contact electrode [1] located close to the indicator [4], in the case of class S voltage detectors (bottom image) the contact electrode is on the tip of the contact electrode extension [2], which increases the distance between the contact electrode and the indicator.

The main reason why capacitive voltage detectors need this built-in distance stems from the ability of the evaluation electronics in the indicator to respond to electric interference fields because of the equipment's operating principle (for a more detailed explanation of this, see Part 1 in CONNECT 1-2015).

B. The Significant Impact of Interference Fields

IEC 61243-1, which applies to capacitive voltage detectors on an international basis, defines an interference field as an "interfering electric field, which can influence the indicator. It may arise from the parts of the system under test or other, neighboring parts and have any phase position."

Detailed Information: References to Standards and Terminology Used

- References to IEC 61243, Part 1 relate to the German versions of the standard: EN 61243-1:2005 + A1.2010
- Voltages from 1 to 36 kV are referred to as medium voltage (MV); all voltages above that are high voltage (HV).

We need to interpret this definition in a different way in this case, of course. Every electrically charged body generates an electric field, and this is no less true of the system parts undergoing testing in air-insulated medium and high-voltage systems, whose electric fields extend to the surrounding area. The fields overlap with one another and, to a greater or lesser extent, with those adjacent to the voltage detector. If these conditions were all it took to render capacitive voltage detectors ineffective, they would never have achieved recognition as the state of the art the world over.

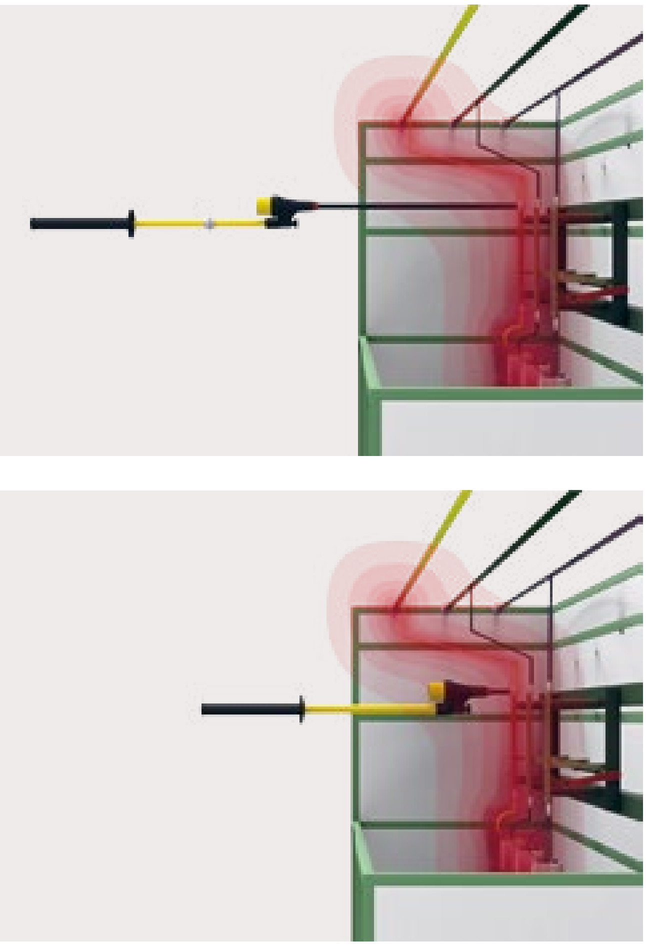


Figure 2: Voltage testing on indoor switchgear: The user must immerse the voltage detector deep inside the switchgear cell in order to make contact with the busbars undergoing testing. If a class S voltage detector is being used, the indicator will remain outside the critical field zones (top image). This is not the case with a class L device (bottom image), which will cause the indicator to move into the in-phase interference field of the first busbar (red zone) and into the interference fields of adjacent busbars (in-antiphase fields; not shown here in the interests of clarity). Additionally, the various interference fields do not cancel each other out and may in fact enhance one another's negative effects.

In the context of the standard, electric fields usually only generate negative effects if the indicator is very close to one or more radiating system parts during the voltage test, as this is the condition required if the field strength is to be high enough to have an effect on the evaluation electronics in the indicator. Specific a condition though this may be, it is still important to watch out for it occurring as its consequences can be disastrous.

We know of two worst-case scenarios that can happen in practice. If the indicator is affected by an interference field in phase, it will signal an absence of voltage even if operating voltage is still present at the system part being tested. If the user then carries out earthing and short-circuiting – like the Five Safety Rules state – the result will be a short-circuit when the phase terminal is connected, not only running the risk of damaging or destroying the system itself, but also putting the user in significant danger as a result of burns from fires or injuries to the eardrums or lungs; and at worst, potentially leading to death.

Conversely, an interference field in antiphase may cause the voltage detector to indicate that operating voltage is present even when there is none. Not only does this prolong the work being carried out on the system, but frequent false indications will cause the user to lose trust in how reliable the safety equipment is.

In principle, both types of interference field can occur on any air-insulated piece of operating equipment or any component designed to handle medium or high voltage – transformers, switchgear, busbars, and even overhead lines, to name a few examples. This second part of the report, however, will focus on MV system configurations that are typically found in substations. Examining these will provide a clear illustration of the kind of test conditions that may encourage a risky distance between the indicator and radiating system parts.

C.I. The System Structure Criterion

Indoor switchgear is a standard MV application found worldwide. Its structure varies from system to system, but the characteristic feature that every example has in common is that the system parts being tested are arranged in a way that requires the tester to immerse the voltage detector deep inside the system in order to reach its inner workings with the contact electrode.

Figure 2 shows a switchgear cell with a straightforward configuration involving parallel busbars. The red zone around the yellow busbar indicates the electric field it is generating; the field strength in this case is high enough to have an effect on the voltage detector's indication behavior.

The top image in this figure demonstrates the use of a class S voltage detector in this kind of configuration. This removes the risk involved in making contact with the busbar, as the contact electrode extension keeps the indicator at a safe distance from the critical field zones.

Not so in the bottom image, where the short design of the class L model puts the user in a dangerous position as he or she is forced to immerse the entire voltage detector much deeper inside the switchgear cell in order to make contact with the busbar. This automatically brings the indicator into the critical zone of the in-phase interference field associated with the system part being tested – and, what is more, into the interference field zones of the adjacent busbars (interference fields in antiphase; not illustrated here for reasons of clarity). If the in-phase and in-antiphase interference fields run into one another in a scenario like this, it is also important to note that they will not cancel each other out and may in fact do quite the reverse; that is, make each other stronger.

Busbars in a diagonal rather than parallel arrangement can make the likelihood of this hazardous scenario arising even higher. Cases like this place two busbars further inside the cell and at a greater distance from the user, and the overall impression given by empirical work with scenarios of this kind to date is that a contact electrode extension is the only way to deal safely with the immersion depth resulting from many such indoor switchgear configurations.

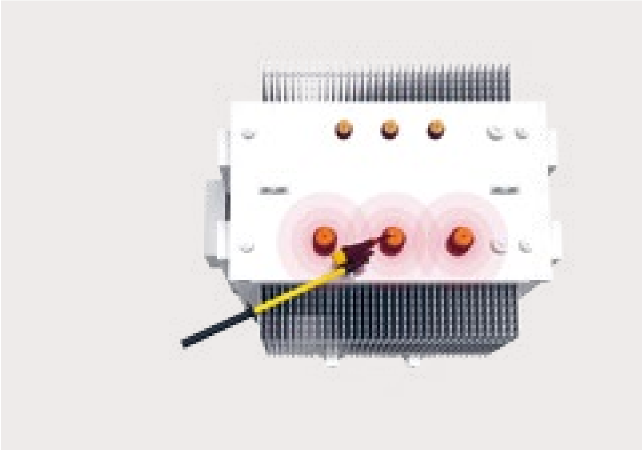
C.II. The Position Criterion

As well as the system's structure, its position within a space affects accessibility to the parts undergoing testing. In local network stations, for instance, there may be oil-insulated distribution transformers that can only be accessed from the transverse side – resulting in the tester having to make contact with the three transformer phases from a side rather than a front position. Figure 3 illustrates this difficult test configuration, showing a view of the transformer from above.

As the top image shows, the tester is indeed able to access all three phases using a class L voltage detector – but contact with the central phase places the indicator in the critical field zones of two phases. This is an issue that also affects the rear phase during testing. Voltage detectors without a contact electrode extension are usually too short for configurations of this kind.

Using a longer class S device, however, averts the risk presented by the interference fields, as the bottom image illustrates. If we imagine the test process shown here continuing right to the end of all the phases, it is clear that the indicator is able to remain entirely outside the red danger zones – even when contact is made with the rear, third phase.

«As well as the system's structure, its position within a space affects accessibility to the parts undergoing testing.»



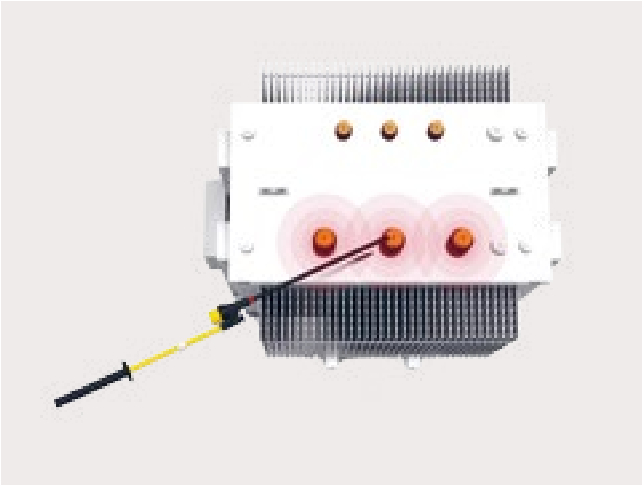


Figure 3: Voltage test on a distribution transformer (viewed from above) that the tester is only able to access from the side: If a class L voltage detector is used, the indicator will be too close to the transformer phases and may therefore feel the effects of interference fields (top image). The only way to achieve a safe distance in this case is to use a class S device with a contact electrode extension (bottom image).

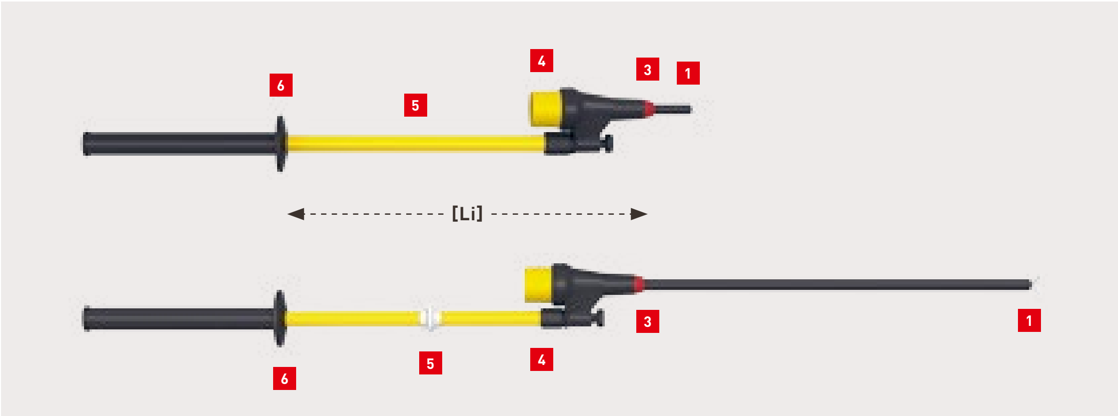


Figure 4: If a voltage detector needs to be immersed deep inside a system, class L models (top image) present another risk in that the red ring [3] gets too close to live system parts. This causes the user to stray beyond the minimum insulation distance [Li] and exposes him or her to another source of accidents.

D. Additional Risk

Another serious risk is apparent if we look at Figures 2 and 3 in more detail. Using a class L model brings the red ring (item [3] in Figure 4) and, therefore, the voltage detector as a whole into territory that is forbidden because, as the 61243-1 standard puts it, the red ring is the "distinctive location or mark to indicate to the user the physical limit to which the voltage detector may be inserted between live parts or may touch them".

The class L detector results in this limit being exceeded – and in fact shortens the minimum insulation distance [Li] that the manufacturer has integrated into the detector as a defined protected zone between the limit mark [3] and the hand guard [6] (i.e., the length of the insulating part). This failure to maintain the required distance from the voltage sources exposes the tester to an increased risk of accident.

A longer insulating pole [5] averts this danger, but not the risk associated with interference fields. No matter how long the pole is, there is no change to the distance between the indicator [4] and the contact electrode [1] – so if class L voltage detectors are used in system configurations of the kind described here, the distance will not be long enough to keep the effects of interference fields in check.

E.I. Solutions: A Happy Medium?

These findings from practice have led to repeated attempts to combine the improved resistance to interference field effects that class S models bring with the benefits of their class L counterparts. Specifically, the shorter design of class L models makes them easier to store and transport, and users find them more convenient to carry and handle – something that is particularly important in overhead line applications.

In MV applications, for instance, this has given rise to a rare hybrid solution whose basic design is a class L model with a short contact electrode element directly on the indicator. Combining it with the appropriate screw-on contact electrode extension effectively converts the device into a class S type. Then there are purely class S models, whose contact electrode extension can also be removed; however, this is for transport and storage purposes, not so that the device can be used like a class L model.

E.II. Solutions: A Questionable Compromise

Inherent in both design concepts, however, are various drawbacks which, taken together, can have significant consequences. All derive from the ability to detach the contact electrode extension from the indicator.

If something can be removed, then it can go missing during the course of a hectic working day – plus, a removable contact electrode extension is easily forgotten if the voltage detector is being submitted for a routine inspection that is only due after six years. Without the contact electrode element, a take-apart class S model cannot be inspected at all; and in the case of a hybrid class L model, the contact electrode extension will not be subject to testing.

As things stand, regular function inspections by means of complete self-testing integrated into the voltage detector (see Part 1 in CONNECT 1-2015) are not potential solutions because the technology needed would be prohibitively complex and expensive. There is only one – laborious – option available as a way of carrying out inspections directly before use, which involves testing the assembled voltage detector on another system part where operating voltage is known to be present.

Even if the voltage detector indicates that it is working properly in this case, however, this may actually be the result of something that is easily overlooked – a contact electrode extension that is screwed on too loosely or a contact point that is damaged or soiled. Both of these factors bring an additional, undefined level of transition resistance into the finely-tuned test current circuit, and as a result may cause the evaluation electronics to receive a weakened signal or no signal at all. If there is a counter-check device located upstream on a live system part, then there is at least the chance of the user identifying this occurrence as an incorrect indication. But if it is not picked up on, it puts both people and the system in the same kind of imminent danger that is presented by an in-phase interference field (see section B).

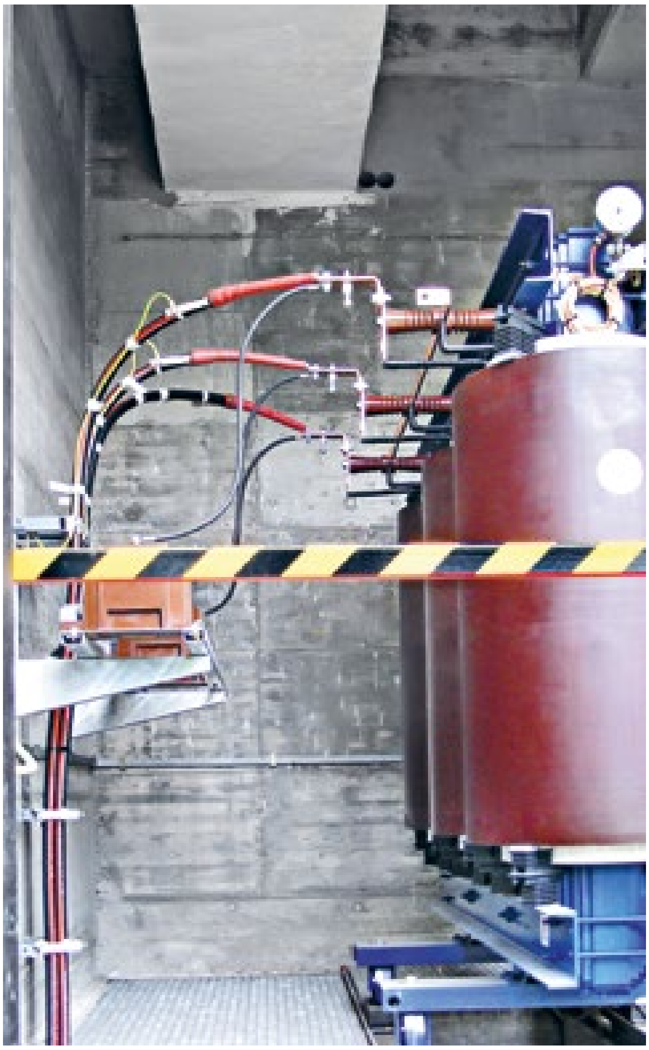


Figure 5: Voltage tests on cast-resin transformers present a very high risk of interference fields – especially if it is only possible to make contact with the busbars being tested from the side, as is the case here.

E.III. Solutions: Safe and Flexible

We can therefore conclude that separate contact electrode extensions can, at worst, inflame the very risk of incorrect indication that they are actually supposed to counteract – and quite apart from this, there is the fact that using a detachable component requires the user to pay more attention to it than they would need to in the case of a fixed one, diminishing any increased convenience that handling the equipment may bring. The bottom line is that class S voltage detectors featuring a non-detachable contact electrode extension and a comprehensive self-test have to date given users the most freedom to work in safety – even on overhead lines.

F. A Special Solution for a Special Case

Screw-on solutions do have their place in specific cases, however. There are applications whose interference field potential cannot be safely overcome without an additional extension – even if class S voltage detectors are used. One example of this from the field of medium-voltage applications is a cast-resin transformer, also known as a dry-type transformer; as both names suggest, materials like epoxy resin are used instead of oil for insulation purposes.

Since cast-resin transformers do not have an earthed metal housing as standard, their entire surface is surrounded by electric fields and their overall field radiation is much higher than in the case of oil-insulated MV transformers.

Being conventional indoor systems, however, both pieces of equipment also share an important common feature in that they are frequently installed in environments where space is limited. Cast-resin transformers are typically found in hospitals, office buildings, industrial facilities, and even ships, to name a few examples. This also means that they may be installed in a way that only allows the system parts requiring testing to be accessed from the transverse side. Figure 5 shows an example of this in practice.

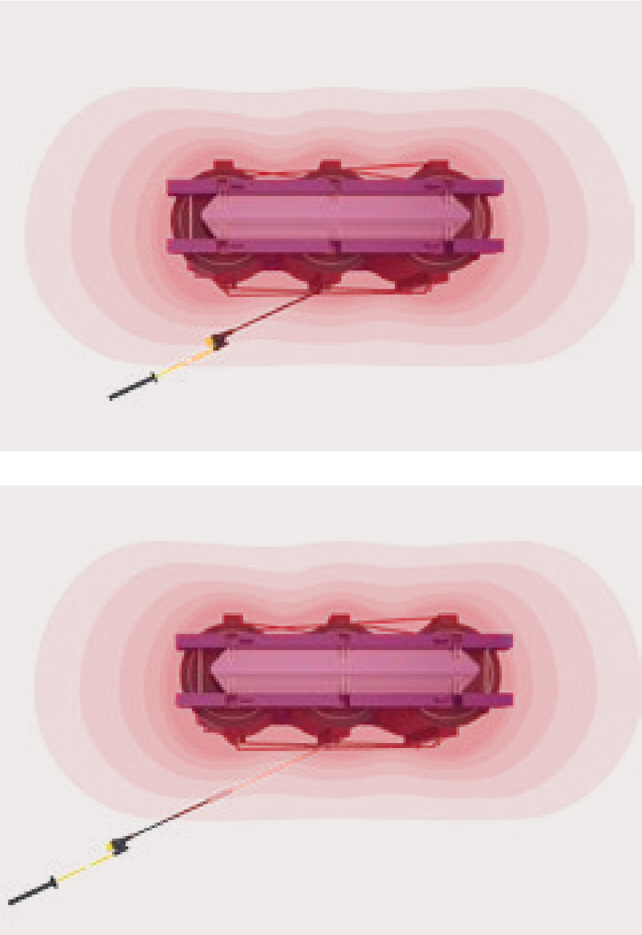


Figure 6: Voltage test on a sideways-installed cast-resin transformer (viewed from above): The significant field radiation and the ability to access system parts from the side only make the test conditions more difficult to work with. As a result, it is not possible to make safe contact with the busbars even if a class S model is being used (top image). The only way to rule out interference field effects with certainty is to combine the class S voltage detector with an additional extension (bottom image).

The impact of combining extreme field conditions with a restricted area in which the user can work is shown as a bird's-eye view in Figure 6. This plainly illustrates the potential for critical field zones at a cast-resin transformer to spread into a wide area.

The top image demonstrates that even a class S voltage detector is too short for a demanding configuration like this: Despite the contact electrode extension, the indicator enters the hazardous interference field zone when contact is made with the busbars.

The only way to create safe conditions in a scenario like this is to screw an additional extension onto the existing standard contact electrode extension. As the bottom image shows, combining these two components gives the voltage detector an adequate reach and keeps the indicator out of the critical field zones.

Figure 7 illustrates the difference in length between a class S voltage detector featuring a standard contact electrode extension (top image, item [2]) and the same model equipped with an additional extension (bottom image, item [7]).

There are many types of additional extensions available, catering to a range of standard system configurations (Figure 8). To apply them safely, users must observe the same requirements as they would for a standard contact electrode extension (referred to previously); that is, ensuring that the additional extension is screwed on correctly and that the contact point is clean and undamaged. It should also be tested before use on a live system part to ensure that it is working properly.

Figure 7: One class, two reach lengths: The top image shows a class S voltage detector with a fixed standard contact electrode extension [2]. In special applications, like the one shown in Figure 6, an additional extension [7] can be screwed onto the same device (bottom image).

Figure 8: To ensure that additional extensions are used safely, voltage detector manufacturers offer solutions that are tested in accordance with the relevant standard and are designed to suit both the voltage detector model in question and the standard designs of widely used systems. This image shows four additional extensions for a range of MV applications.

Last but not least, it is crucial that users do not choose anything other than manufacturer-approved solutions that have been tested in accordance with IEC 61243-1, as only these will satisfy the same requirements as standard contact electrode extensions and prove suitable for the voltage detector model being used. DIY solutions are risky and therefore wholly inadequate, as they can cause severe electric shocks – something that has been shown in practice.

G. Conclusion

Voltage detector manufacturers are unable to provide specific guide values that can be applied in general when determining insufficient distances between indicators and live system parts or their critical field zones. As series-manufactured products, voltage detectors can be designed on the basis of known, predictable values – such as standard system types and their rated voltages – but not on the highly variable factors that may affect them. In borderline cases, only the voltage detector's angle of inclination can determine whether its indicator is crossing the non-constant limit between a negligible field strength zone and a dangerous one.

That said, the combinations of empirical findings and interference fields illustrated in the examples of applications in this article do make it possible to conclude two rules of thumb for tackling this issue. If the test conditions require the voltage detector to be immersed deep into the system, then a model equipped with a contact electrode extension is recommended. In the event of extreme field radiation – as well as other comparably strong influencing factors – an additional extension should also be used to be on the safe side. As well as this, the descriptions of the various manufacturer solutions indicate a basic principle that applies in this case: The fewer potential ways in which a user can mishandle a voltage detector in the course of a demanding working day, the better able the equipment will be to protect the user and the system.

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