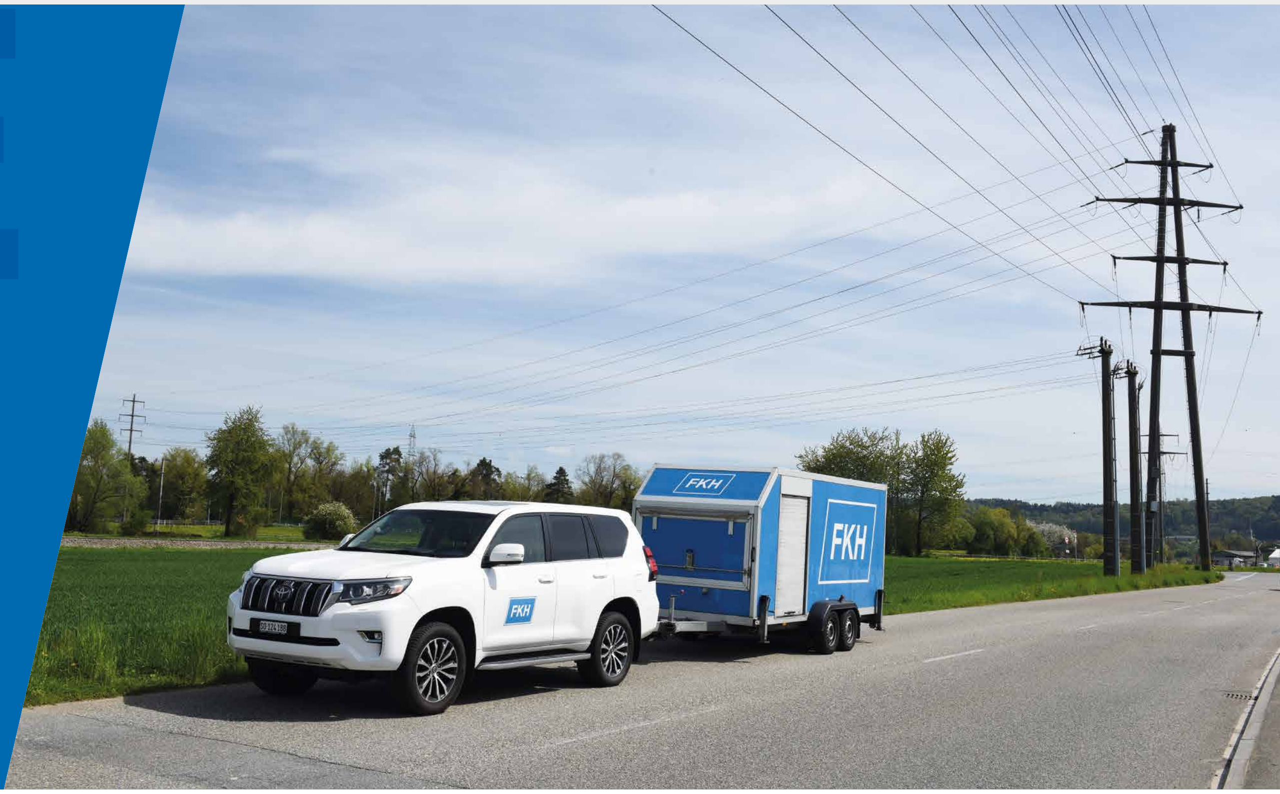
Fachkommission für Hochspannungsfragen
Commission d’étude des questions relatives à la haute tension

Services Offered by FKH




FKH

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What is FKH?

The Technical Commission for High-Voltage Issues (FKH) is a non-profit organisation that offers a wide range of modern testing services for components of the high-voltage grid infrastructure. With its team of technical experts and predominantly mobile test facilities, FKH specialises in on-site testing, flexible test set-ups in our laboratory, and diagnostic measurements and analyses of high-voltage electrical equipment. We also support our members and clients by providing expert consulting and studies on the quality, operational performance and environmental impact of high-voltage grid components.

FKH provides a platform for its members for the exchange of knowledge and supports the next generation of professionals. It addresses key technical issues relating to the electrical power supply infrastructure and, in collaboration with expert bodies, draws up technical recommendations. FKH is committed to the further development and streamlining of testing methods. FKH's primary objective remains, at all times, the promotion of high availability of operating resources within the high-voltage grid.

This brochure is designed to provide you with an overview of our organisation, our objectives and our standard services.

Figure 1: Cable testing using series resonance reactors

Our guiding principles

The neutral and independent FKH pursues non-profit by providing testing and diagnostic services, as well as expert opinions, in the field of electrical power supply and high-voltage technology. The association's activities are intended to promote the continuous availability, long-term reliability and security of the electricity supply in Switzerland.

Since its founding in 1937, FKH's objectives have been exclusively technical in nature. FKH does not pursue any financial goals of its own. The association's funds may only be used for purposes in accordance with the articles of the association. Through in-house development in the field of testing and measurement technology, scientific publications and active participation in international standards and technical committees, FKH contributes to the further development of testing methodology on a global scale. By organising specialist conferences and platforms for the exchange of experience, FKH promotes the transfer of knowledge regarding new scientific findings and practical experience in Switzerland. FKH maintains active links with ETH Zurich and ETH Lausanne, as well as with universities of applied sciences, and participates in research projects. In doing so, it helps to increase the appeal of energy engineering disciplines and acts as a bridge between Swiss universities and companies in the electrical energy sector.

The staff at FKH support you, as the client, with the commissioning and diagnosis of high-voltage equipment, offering testing services both on-site and at the FKH test facility. Where appropriate, they are an effective way of identifying, localising and resolving problems. In addressing the issues that arise, we rely on scientific methodology and specialised, sensitive testing techniques.

FKH is made up of an experienced, well-coordinated team of testing and measurement experts who can respond quickly when needed and carry out even complex testing campaigns.

FKH offers comprehensive services, ranging from consulting on test criteria and planning through to carrying out the tests using its own testing and measuring equipment.

As part of its consulting services, FKH offers theoretical and experimental studies, investigations and tests to clarify all issues and phenomena that arise during the planning, construction and operation of power supply systems, particularly in the fields of high-voltage and high-current technology. In addition, independent, practice-oriented research activities are offered in collaboration with universities, manufacturers and grid operators.

Infrastructure

In addition to mobile and modular systems comprising series resonance test sets, transformer test sources, earth resistance test systems and surge test systems (BIL lightning surge, SIL switching surge and OLI oscillating lightning surge), FKH has testing facilities and laboratories in Niedergösgen, Switzerland. These include an open-air test site, a small laboratory for smaller test set-ups, and a large test laboratory that can be used flexibly for various tests. These facilities and options are complemented by various logistical resources, including vehicles that can be used as mobile measuring offices.
Furthermore, FKH has an accredited laboratory for insulating oil analyses. In addition to dielectric and chemical analyses, spectroscopic methods using GC, HPLC and FTIR are also available.

FKH members

FKH is an association that includes energy suppliers, power station operators, railways, manufacturers, industry associations and universities among its members.

Figure 2: Series resonance system in the large test laboratory

As a member of FKH, you are entitled to a member discount on FKH's in-house services for testing or studies. Moreover, employees of member companies receive a discount when attending the annual conference.

Quality and safety

FKH provides its services in accordance with internationally recognised standards and operates a management system certified to ISO 9001 and ISO 45001.
The insulating oil laboratory is accredited as a Type B testing laboratory for insulating oil and Buchholz gas in accordance with the ISO/IEC 17025 standard.

Figure 3: Oil samples for the analysis of decomposition gases

For additional information, please contact **info@fkh.ch**

Cable testing

The on-site AC testing technology for high-voltage cables, which today is used worldwide, was developed jointly by the ETH Zurich and FKH and introduced by FKH in the 1980s. It is based on the series resonance principle with tunable frequency. In addition to voltage testing, various diagnostic methods are available. Partial discharge measurements are a key example.

High-voltage testing of cable systems

To rule out any errors in the installation of terminations or cable joints, as well as damage to the cable or semiconductor coating, it is advisable to carry out a voltage test before commissioning a new cable system or following the completion of major refurbishment work on an existing one.

Thanks to the series resonance tests on high-voltage cables that FKH has been carrying out since the 1980s, it has by far the most extensive experience in the field of cable testing anywhere in the world. Drawing on this experience, a more rigorous testing procedure has become established in Switzerland. This involves a test duration of 15 minutes and a slightly higher voltage than is recommended in current standards.

Series resonance tests

In the test circuit, a high-quality reactor is connected in series with the test object's capacitance. Under resonant conditions, a voltage builds up across the test specimen that is significantly higher than the voltage of the power supply transformer.

For AC voltage tests on longer sections of XLPE- and EPR-insulated cable, series resonance systems are virtually the only viable option as high-voltage test sources, due to the high charging current and high reactive power involved. Oil-filled cable systems can also be inspected using this principle. Thanks to the modular inductors, the test system can be configured to operate at a sufficiently high test frequency, ensuring that high-voltage instrument transformers integrated into GIS units do not become magnetically saturated and therefore do not need to be removed for testing.

The advantages of the series resonance method lie in the low input power required, even when testing longer cable systems. The voltage across the test specimen is also sinusoidal and free of harmonics. If the test specimen breaks down, the minimal energy dissipation at the point of failure results in less damage than would be caused by a similar incident

	Rated voltage, linked	Maximum linked voltage	Phase voltage for determining test voltage	Factory voltage test			Partial discharge measurement at factory and on site		On site – new cables: in accordance with IEC					On site – new cables: in accordance with CH/FKH			On site – aged cables: in accordance with CH/FKH		
									Table		alternatively								
	U	U_m	U_0	$*U_0$	U_P	Duration	$*U_0$		$*U_0$	U_P	$*U_0$	U	Duration	**$*U_0$**	**U_P**	**t**	**$*U_0$**	**U_P**	**t**
	[kV]	[kV]	[kV]	#	[kV]	min	#	[kV]	#	[kV]	#	[kV]	min	**#**	**[kV]**	**min**	**#**	**[kV]**	**min**
IEC60840	45 - 47	52	26	2.5	65	30	1.5	39	2.0	52			60	**2.2**	**57**	**15**	**2.0**	**52**	**15**
IEC60840	60 - 69	72.5	36	2.5	90	30	1.5	54	2.0	72			60	**2.2**	**80**	**15**	**2.0**	**72**	**15**
IEC60840	110 - 115	123	64	2.5	160	30	1.5	96	2.0	128			60	**2.2**	**140**	**15**	**2.0**	**128**	**15**
IEC60840	132 - 138	145	76	2.5	190	30	1.5	114	1.7	132			60	**2.2**	**167**	**15**	**2.0**	**152**	**15**
IEC60840	150 - 161	170	87	2.5	218	30	1.5	131	1.7	150			60	**2.2**	**190**	**15**	**2.0**	**174**	**15**
IEC62067	220 - 230	245	127	2.5	318	30	1.5	190	1.4	180	1.7	216	60	**2.0**	**254**	**15**	**1.7**[1)]	**216**	**15**
IEC62067	275 - 287	300	160	2.5	400	30	1.5	240	1.3	210	1.7	272	60	**2.0**	**320**	**15**	**1.7**[1)]	**272**	**15**
IEC62067	380 - 400	420	220	2.0	440	60	1.5	330	1.2	260	1.7	374	60	**1.8**	**400**	**15**	**1.7**[1)]	**374**	**15**

Figure 4: FKH testing recommendation for cable installations

1) The insulation margin to be verified should take into account the planned continued operation of the cable system. The required reserve is determined by the required remaining service life of the cable system and the magnitude of the overvoltages expected during operation. The latter can be estimated on the basis of previous operational experience or for the purposes of insulation coordination. If the target remaining service life for cable systems is short and overvoltages are unlikely given the operating conditions of the cable, the test voltage factor for systems rated at 220 kV and above may be reduced to 1.5.

Figure 5: Series resonance system for cable testing without partial discharge measurement

during operation. Several cable connections can be tested simultaneously via a switchgear; this poses no risk to the switchgear being tested.

Partial discharge measurement

Partial discharge measurement is also recommended for critical cable circuits and higher voltage levels. This involves specifically checking the terminators and joints for insulation faults. This makes it possible to identify faults that do not cause an immediate breakdown but do carry the risk of unexpected insulation failure.

The modern partial discharge measuring instruments used by FKH make it possible to take synchronised measurements at different locations. In order to monitor all measurement points simultaneously, fibre-optic connections must first be installed between all sensors.

Figure 6: Resonance testing system for a 220 kV cable system with partial discharge measurement

Cable testing offer	Comments
AC voltage test	Series resonance tests for cable systems at all voltage levels Flexible arrangement of resonance reactors for high voltages and/or long cable systems Used to check the on-site installation and the insulation integrity of the individual components fitted
AC voltage test with partial discharge measurement	Partial discharge measurement during AC voltage testing, with detection of partial discharges at all cable fittings (terminations and joints). This is particularly recommended for voltages of 220 kV and above, or for cable systems critical to the grid
Impedance measurements	Impedance measurement of cable systems, including in combination with overhead lines
Sheath testing	Sheath testing to check the sheath following cable pulling and the installation of cable accessories

Table 1: Offer as part of cable testing

For additional information, please contact **kabel@fkh.ch**

Switchgear testing

Switchgears represent key grid nodes, which must have a very high level of availability. The planned service life is 35–50 years, during which the installations' insulation system must withstand all voltage-related stresses without requiring maintenance. Statistics show that around 50% of dielectric faults in operation were already present at the time of commissioning.
FKH has been carrying out regular inspections of gas-insulated switchgears (GIS) for decades. Switchgears are also inspected regularly in medium-voltage systems. Whether dealing with traditional SF_6-filled systems or systems using alternative insulating gas mixtures from various manufacturers, FKH is able to efficiently identify and localise faults thanks to its extensive experience.

Figure 7: High-voltage test system for a 145 kV GIS test (voltage via Connex test cable, size 6)

Reasons for and benefits of high-voltage testing and diagnostic measurements

A switchgear is typically subjected to a voltage test, including partial discharge measurement, during commissioning. A full inspection is also advisable when expanding a system. In the event of a fault or following an alarm from a partial discharge monitoring system, partial discharge measurements are recommended for a more detailed analysis. Depending on the circumstances, these can also be carried out while the system is in operation.

FKH provides its customers with recommendations on test specifications and procedures for switchgear, thereby supporting them from the tendering stage right through to insulation testing following on-site installation. In the event of breakdowns or damage, it will assist with diagnosis and identifying the causes, and is always on hand to offer its expertise.

Figure 8: High-voltage test system for a 420 kV GIS test (voltage via an outdoor bushing)

Testing and measuring options

FKH has the necessary testing and measuring equipment to test a switchgear, locate the fault, characterise it and narrow down the type of fault. The GIS are subjected to high-voltage testing via a series resonance test set. Partial discharges can be measured either conventionally in accordance with IEC, as required, or – in the case of gas-insulated switchgear – via the integrated UHF sensors. Various tools can be used to locate flashover or partial discharges. A rough location can be done simply by sectioning the system, whereas the more precise position of the partial discharge source can be determined using electrical transit time measurements or acoustic partial discharge localisation methods.

Figure 9: Testing of a medium-voltage switchgear

Figure 10: UHF partial discharge test station with multiplexer, spectrum analyser and oscilloscope

The narrow-band UHF partial discharge measurement method, which utilises the selection of the measurement frequency in conjunction with 50 dB pre-amplifiers, can clearly identify even critical defects with very low partial discharge amplitudes (e.g. particles on insulating material with a typical amplitude of < 0.5 pC). Under transient conditions (e.g. lightning strikes or switching transients), such faults could lead to breakdown during operation.

Switchgear offer	Comments
Voltage test with UHF partial discharge measurement	AC withstand voltage test for 1 minute, with subsequent UHF partial discharge measurement using the built-in UHF sensors to check the dielectric strength after on-site installation Preliminary CIGRE Sensitivity Check Step 2 to verify the sensitivities of the installed sensors (function, number, distribution)
Voltage test with partial discharge measurement	AC withstand voltage test for 1 minute with partial discharge measurement via an external coupling capacitor to check the dielectric strength after on-site installation Particularly in the case of medium-voltage switchgear, or where no UHF sensors are available
Voltage testing	AC withstand voltage test for 1 minute Particularly in the case of medium-voltage switchgear Minimum requirements for testing dielectric strength
Resistance measurements	Resistance measurements carried out phase by phase, bay by bay For checking the contact connections
Online UHF partial discharge measurements	UHF partial discharge measurement using the integrated UHF sensors For condition monitoring in the event of suspected issues or problematic gas analysis readings
Condition assessment	Following incidents or abnormal gas analysis readings

Table 2: Offer as part of switchgear testing

For additional information, please contact **gis@fkh.ch**

Earthing measurements

To check and assess the effectiveness of the earthing systems at substations and other high-voltage installations, FKH carries out earthing measurements using a compact, mobile test system.

Measurement principle

In the current-voltage method, an earth fault current is generated by a mobile 42 kVA frequency converter and fed into a defined earth fault loop, which includes the earthing system. Where possible, a disused overhead or underground cable line is used for this purpose, which is earthed at the remote station. If the power source cannot be installed at the substation under investigation, it is possible to feed in power from the opposite side.

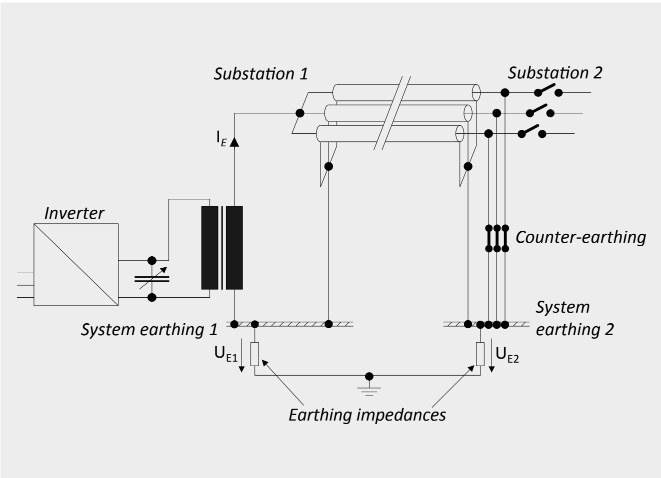

Figure 11: Schematic diagram of the measurement using the current-voltage method

The current flowing between the earthing systems of the substation under investigation and the station with the counter-earthing gives rise to the earthing voltages U_{E1} and U_{E2}, respectively. These enable the measurement of step and touch voltages and the determination of current distribution.
All measuring results are extrapolated to the maximum earth fault current of the substation under investigation.

Figure 12: Mobile source for generating the experimental earth fault current

The frequency converter generates a frequency outside the operating range (e.g. 57 Hz for 50 Hz systems). To adjust the impedance, the source is connected to the test line via a matching transformer and a variable compensation capacitor. The experimental earth fault current, which differs from the operating frequency, allows for a clear distinction to be made between test-induced earth currents and those arising during normal operation.
To determine the effective voltages and the potential gradient, FKH uses measuring instruments fitted with digital filters. These prevent the measurement results from being affected by 50 Hz system operation or by 16.7 Hz railway currents.

Determination of touch and step voltages

Touch, step and differential voltages are measured within the substation and in the surrounding area. The measured values obtained are assessed on the basis of the applicable High-Voltage Current Regulations and Guideline SNG 483755, 2023: “Earthing as a protective measure in high-voltage electrical installations”.

Measurement of the system earthing impedance

The variation in the gradient potential is recorded by measuring one or more radial voltage profiles up to the neutral earth. The potential difference between the neutral earth and the system earth is expressed in relation to the earth fault current fed into

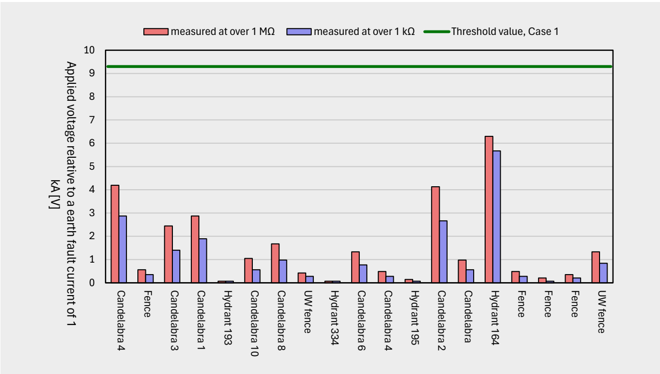

Figure 13: Contact difference and touch voltages relative to a 1 kA earth fault current

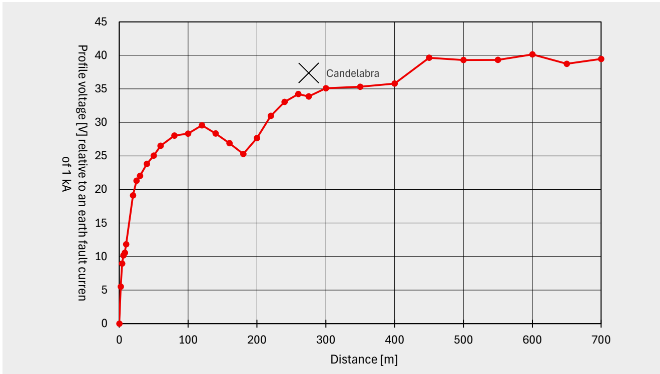

Figure 14: Voltage gradient profile

the substation. This ratio is used to approximately determine the effective earthing impedance of the system. Both the common-mode and zero-impedance are measured on the line used for the earth fault loop.

Measurement of earth fault current distribution

The magnitude and phase of the share of the earth fault current are measured in all cables and metallic connections leaving the substation area. Among other things, these include earthing connections, ground wires for overhead lines, earthed shields of power and signal cables, pressure pipes and railway lines. This test provides information on the distribution of current in the event of an earth fault and enables the effectiveness of the earth connections to be verified. In addition, potential interference issues caused by earth currents can be identified.

Documentation

Once the earthing test has been completed, FKH draws up a report containing an analysis of the measuring results. The effectiveness of the earthing system and the touch, step and differential voltages occurring in the event of an earth fault are assessed and documented. Where touch, step and differential voltages are unacceptably high, appropriate remedial measures are proposed.

Earthing measurements offer	Comments
Earthing measurements of substations	Required every ten years in accordance with SNG 483755, 2023 Earthing trailer with a power source incorporating a compensation unit
Earthing measurements of transmission towers	A portable measuring device for transmission tower impedance measurements is available
Investigation of electromagnetic interference caused by electrical installations or power supplies	Various key parameters are checked using portable measuring instruments

Table 3: Offer as part of earthing measurements

For additional information, please contact **erdungen@fkh.ch**

Transformer testing and diagnostics

On-site testing is carried out on both new and aged transformers. During acceptance measurements carried out as part of the commissioning process, the focus is on checking the assembly and oil impregnation, as well as characterising the transformer for future comparison (a “fingerprint” of its condition when new). Diagnostic tests carried out on transformers that have been in service for some time are used either to assess the condition of the insulation or to decide whether they should continue to be used. This information can be used to determine maintenance measures and plan future inspections. On the other hand, in the event of a fault (e.g. tripping of the Buchholz relay, anomalies in the insulating oil analyses), diagnostic measurements can be used to determine its cause and to plan the necessary inspection and repair work.

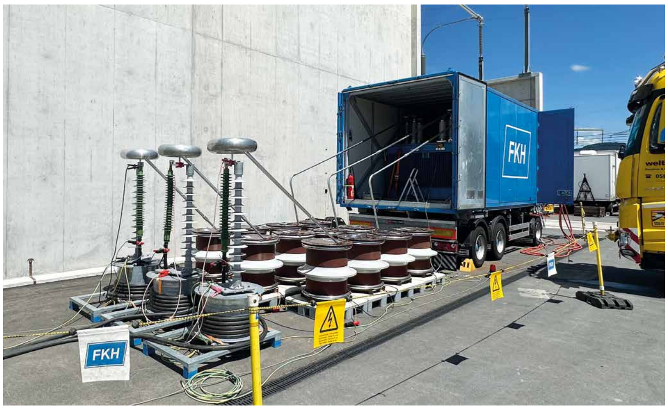

Figure 15: High-voltage test system, including compensation reactors and cables, for testing a large power transformer bank

High-voltage test with partial discharge measurement with electric and acoustic detection

Offline partial discharge measurement on a transformer is the most reliable test for detecting localised insulation weaknesses and is used to identify faults. It is usually carried out at 120% of the rated voltage for 60 minutes. Wherever possible, partial discharges are electrically decoupled and recorded at all existing connections. A modern partial discharge measurement system is available for this purpose, which can be used to test even large power transformers comprehensively (at all terminals). In addition, it is possible to detect partial discharges using the UHF measurement method, provided that UHF sensors are installed.

Figure 16: Partial discharge measurement using a mobile measurement unit (in a van) and a test trailer

Diagnostic and fingerprint measurements

In addition, FKH has extensive knowledge and many years of experience in the diagnosis of transformers. There are various diagnostic procedures that can be used both for regular checks and for troubleshooting.

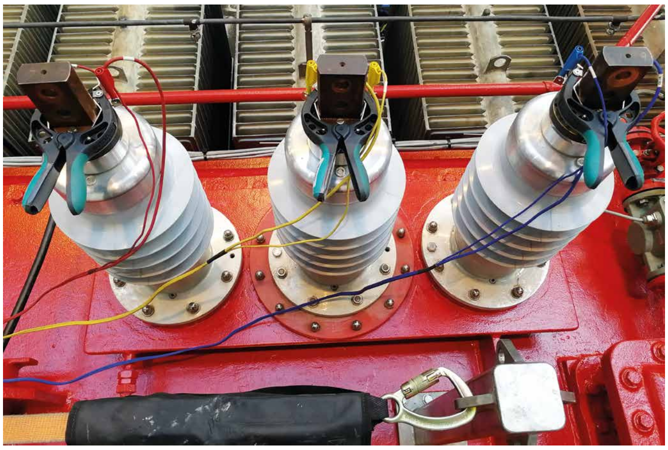

Figure 17: US bushings with cabling for DC resistance and ratio measurements

Transformer offer	Comments
AC voltage test with partial discharge measurement	Three-phase AC voltage test at 1.2 U_r for 60 minutes with partial discharge measurement UHF measurement is possible if sensors are installed Voltage distribution as in normal operation (no-load operation)
Static winding resistance measurement	4-wire resistance measurement Checking the functionality of tap changers and tap selectors
Dynamic winding resistance measurement (OLTC scan)	4-wire resistance measurement Diagnosis of tap changers by measuring the commutation characteristics during the switching operation
Ratio measurements	Comparison of the voltage applied to the HV terminals with the resulting voltage at the LV/MV terminals
Magnetisation current measurement	Recording of the magnetisation-current characteristic Detection of damage to the iron core
FRA measurement (Frequency Response Analysis)	Applying an AC voltage with a variable frequency and a fixed amplitude to a terminal Measuring the frequency response at a different terminal Diagnosis by comparing frequency responses with measurements taken during commissioning or at the factory Detection of changes in geometry (e.g. deformed winding)
PDC/FDS measurement (Polarisation/Depolarisation Current/ Frequency Domain Spectroscopy)	Determination of the moisture content of cellulose Applying a DC voltage to one winding and performing a sensitive current measurement on the second winding PDC: Time domain measurement FDS: Frequency domain measurement
Insulation resistance measurement	Measurement for 1 minute using a DC voltage Insulation inspection
C-tan(δ) measurement on bushings and windings	Measurement of capacitance and loss factors Measurements at various voltages (up to 12 kV) and frequencies Checking the insulation of the winding and the bushings

Table 4: Offer as part of transformer testing and measurements

For additional information, please contact **trafo@fkh.ch**

Insulating oil analyses

Analyses of insulating fluid are key to assessing the condition of electrical grid equipment. The FKH's insulating oil laboratory offers a wide range of services, including highly accurate analyses and reliable interpretations by experts. Thanks to our central location in Switzerland, we are able to serve our customers locally. The insulating oil laboratory operates in accordance with international standards and is accredited to ISO 17025 (Swiss Testing STS 581) and certified to ISO 9001 and 45001. The oil laboratory carries out its own sampling at transformers throughout Switzerland. In the event of critical findings, FKH can provide expert support for further diagnostic tests, as it has many years of experience in testing high-voltage equipment.

Dielectric-chemical analysis

In dielectric-chemical analysis in accordance with IEC 60422, the state of ageing of the oil-paper insulation system is determined from the key figures of the insulating oil. The breakdown voltage provides an indication of the oil's current insulating capacity. The neutralisation number (acid number) and the interfacial tension are highly sensitive indicators of the oxidation state of the insulating oil and the ageing of the entire oil-paper insulation system. They are early indicators of sludge formation. An increased water content drastically impairs the oil's insulating properties and accelerates the ageing of paper and pressboard. The loss factor, tangent delta, is a sensitive measure of the formation of conductive ageing products and of contamination in the oil. The colour number and appearance are simple yet meaningful indicators of oil ageing. The ageing dynamics can be estimated from the inhibitor content, enabling timely re-inhibition to be initiated.

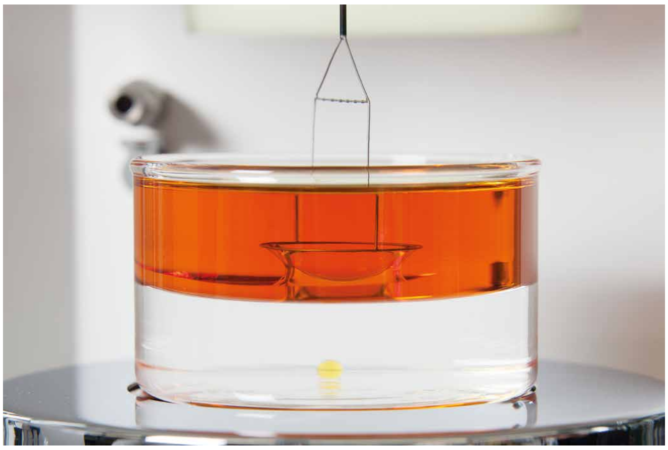

Figure 18: Measurement of interfacial tension

Furan analysis

During the thermal ageing of the solid insulation (cellulose), various furan derivatives are formed. By analysing the furans dissolved in the oil, it is possible to assess the mechanical strength of the solid insulation (paper, pressboard).

Figure 19: Vials containing oil for the analysis of dissolved gases in GC

Dissolved gas analysis (DGA)

The determination of gases dissolved in oil (IEC 60567 and 60599) provides an indication of impending faults, in particular localised thermal overheating of the insulation system or electrical discharges.

Oxidation stability

During the oxidation stability test in accordance with IEC 61125, the oil is tested for quality in an accelerated ageing test and its expected behaviour over its service life is assessed.

Special testing

Our laboratory can be contacted regarding special testing. The various options are discussed in consultation with the client.

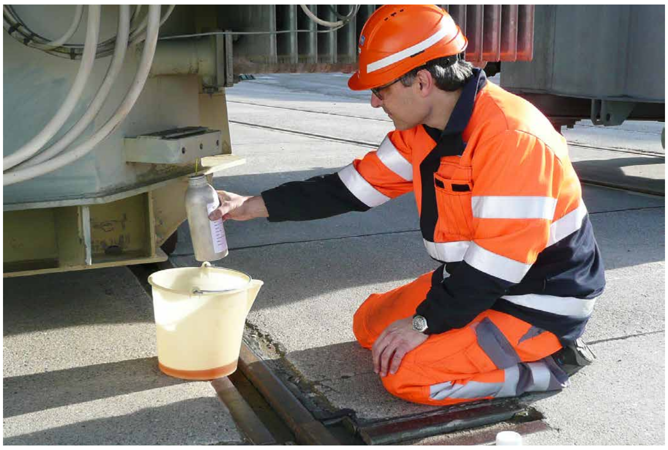

Figure 20: Oil sampling from a transformer

Emergency service

In the event of an incident, such as a Buchholz warning, an FKH employee will usually take a sample within a few hours and analyse it either on site or in the laboratory.

Analysis report

Our analysis report includes a comparison with previous measuring results, an individual assessment and practical recommendations for action regarding the equipment tested. The report is drawn up by experts. In the event of critical findings, the client will be notified immediately and advised.

Insulating oil analyses offer	Comments
Dielectric-chemical analysis	Colour number, appearance, water content, acid number, interfacial tension, loss factor and breakdown voltage in accordance with IEC 60422 Individual measurements from dielectric-chemical analysis
Dissolved gas analysis (DGA)	Gas chromatographic analysis using the headspace method in accordance with IEC 60567 and 60599
Furan analysis	HPLC analysis with separation of individual furan derivatives in accordance with IEC 61198
Determination of inhibitor content	Analysis of the infrared spectrum using FTIR in accordance with IEC 60666
Oxidation stability testing	Accelerated ageing in accordance with IEC 61125
Buchholz gas analysis	Gas chromatographic analysis
PCB analysis	Colour reaction test (colourimetry)
Test for corrosive sulphur	Ageing test in accordance with IEC 62535

Table 5: Insulating oil laboratory offer

For additional information, please contact **oellabor@fkh.ch**

Studies and consultancy

Accurate calculations are crucial for the design, selection and safe operation of electrical installations. FKH uses a wide range of technical calculation methods and specialised software to analyse electrical systems and optimise them where necessary.

E- and B-field calculations

Electric and magnetic fields play an important role both in the design of insulation systems and in environmental impact assessments. FKH uses simulation tools to analyse electromagnetic systems and processes in the static, low-frequency and high-frequency ranges.
Furthermore, calculations are carried out to assess the effects of electromagnetic interference from high-voltage and high-current installations on communication cables and pipelines, both during normal operation and in the event of a fault.

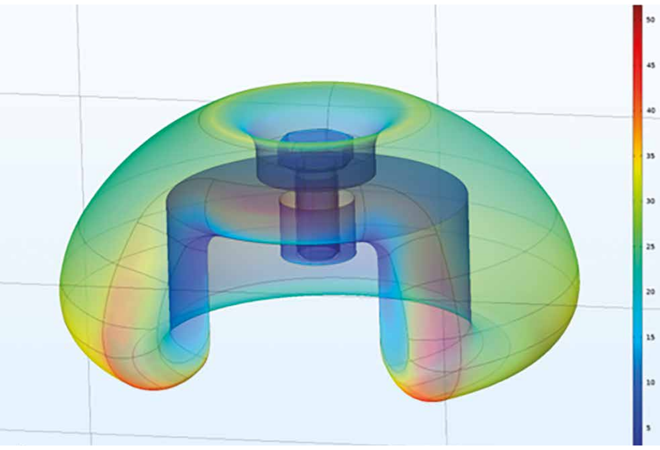

Figure 21: Illustration of the results of a 3D electrical field calculation on a shielding electrode

Transient grid calculations

FKH uses numerical calculations to analyse transient processes in electrical power systems. The research focuses primarily on time-dependent phenomena such as switching operations, lightning surges and fault conditions in high-voltage grids.
By taking frequency-dependent models into account, these simulations can reproduce the actual behaviour of electrical grids more accurately. Surge voltages and transient currents can also be calculated more accurately, and the design of protection systems and equipment can be improved.

Typically, questions regarding insulation coordination in accordance with SN EN 60071 may relate to switching overvoltages (e.g. in the case of cables, transformers or compensation systems) or questions regarding lightning surges and the propagation of the associated travelling waves are also addressed. Fault transients (short-circuit and earth-fault events) as well as in-rush currents and saturation effects in transformers can be determined using the models.

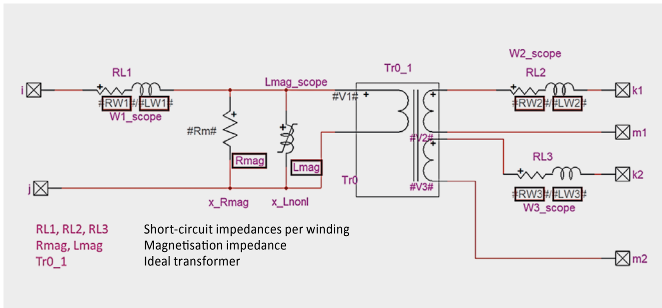

Figure 22: Single-phase equivalent circuit diagram of a three-winding transformer, as shown in a transient grid calculation programme

Calculation of earthing systems

The design of earthing systems is a key component of electrical power systems, as they safely divert fault currents into the ground and limit dangerous touch and step voltages. To verify the effectiveness of the earthing systems at substations and other electrical installations, FKH offers earthing calculations and their analysis, which it can support with measurements such as specific soil resistance or a comprehensive earthing survey. This enables earthing systems to be analysed realistically and designed safely. An earthing calculation involves modelling the earthing system (including taking into account any measured specific soil resistances), calculating the earthing resistance and the associated potential gradient.

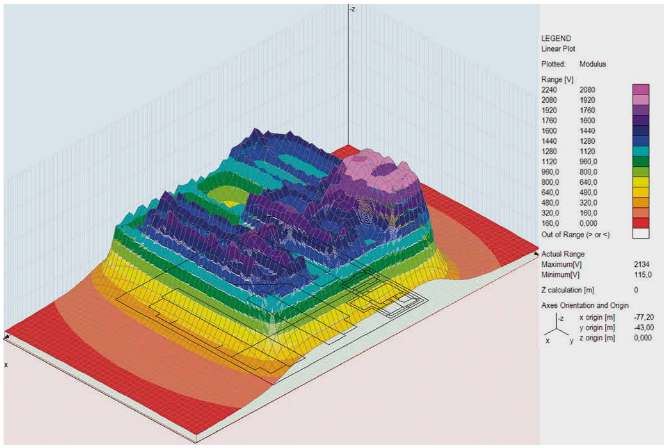

Figure 23: Result of an earthing calculation: Ground potential in the form of a three-dimensional, colour-coded surface

Corona-induced noise calculations

When constructing new overhead lines or replacing their conductors, expert reports calculating noise emissions are often required. At FKH, the HVLBuzz programme is used for such studies. The programme was developed by the High-Voltage Laboratory at ETH Zurich and has been maintained and further developed by FKH for several years. HVLBuzz allows sound emissions in the overhead line cross-section (2D) to be calculated quickly and easily. Different calculation formulas have become established in different countries; these can be applied as required. Depending on the specific application, the results can be presented graphically or provided to the customer as numerical values.

Studies and consultancy offer	Comments
E- and B-field calculations	Simulation and analysis of electric and magnetic fields for insulation systems and environmental issues Assessment of the environmental impact and electromagnetic interference caused by cables and pipelines
Transient grid calculations	Network simulations using EMTP Investigation of time-dependent processes (switching operations, lightning surges, fault conditions)
Calculation of earthing systems	Modelling of earth systems Calculation of earth resistances and potential gradients A combination of modelling and on-site measurements
Corona-induced noise calculations	Preparation of noise assessments for the construction or refurbishment of overhead power lines Use of the specialist software HVLBuzz for 2D noise emissions Use of different international calculation formulas as required

Table 6: Studies and consultancy topics offer

For additional information, please contact **studien@fkh.ch**

Infrastructure in Niedergösgen

Large testing laboratory

The dimensions of the FKH's large test hall in Niedergösgen allow tests to be carried out using a rated lightning impulse voltage of 1050 kV peak and a rated short-time withstand voltage of 460 kV_{eff}/1 minute on components of the 245 kV series (IEC 60071-1).

For the generation of alternating voltages up to 600 kV_{eff}, series resonance systems are primarily used, in line with standard on-site practice. The test frequency can be adjusted using adding additional capacitors within the frequency range of 45 Hz to 65 Hz, in accordance with IEC 60060-1. All components of the series resonance system are free from RF interference. In our fully shielded test hall, a background noise level of <1 pC can therefore be achieved at the test voltage.

Fifteen stages of the modular 1.8 MV Haefely surge generator (with 180 kJ) can be set up in the test laboratory, enabling lightning surge voltages of up to 1,350 kV to be achieved.

Figure 24: Series resonance system (from left: tower with three 80-H reactors in series, capacitive voltage divider, auxiliary and coupling capacitors) for an internal test in the large test hall

Figure 25: Modular pulse generator (shown here with 12 stages). In the foreground is the charging unit; to the left is the 1600 kV voltage divider

Small laboratory

In the small laboratory, system components operating at voltages ranging from lower voltage levels up to 72.5 kV can be tested. The laboratory is equipped with high-voltage transformers and series resonance systems. Thanks to the existing infrastructure, a small-scale test can be prepared and carried out quickly and with minimal effort.

Figure 26: Testing a test cable using a series resonance system in the small laboratory (from left: test cable, coupling capacitor, resonance reactor, voltage divider and additional load capacitor)

Open-air test site

FKH also has conventional test transformers. In addition to static AC voltage tests (dry and wet) on outdoor components, the 1 MV test transformer manufactured by Moser Glaser AG is used primarily for step tests on medium-voltage cables, either on the forecourt of the test hall or inside the test hall itself, with the voltage being fed in through the main gate. Outdoors, surge tests can be carried out using standard surges of up to 1600 kV. The gas-insulated 400 kV test transformer manufactured by Trench GmbH is mounted on a trailer and can also be used in the test hall as required.

Figure 27: 1 MV test transformer manufactured by Moser Glaser AG

Figure 28: The gas-insulated 400 kV test transformer manufactured by Trench GmbH

Figure 29: Magnetic field measurement on a 3.15 MVA distribution transformer

In front of the large test hall there is a covered forecourt, which can also be used for tests such as rain tests. There are other areas on the site that can be used for long-term testing. For example, magnetic field measurements (B-field) can also be carried out on large distribution transformers to confirm compliance with the NISV.

Figure 30: Covered forecourt of the test hall with a test rig for step tests, powered by the 1 MV test transformer (in the background)

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