TEST AND DIAGNOSTIC METHODS
Commissioning tests and condition analyses for transmission and distribution networks
An objective diagnosis can only be made if the possibility of using different types of diagnostic methods is ensured.
Despite the utmost care and high operational reliability, it can never be completely ruled out that damage occurs during laying of cables, mistakes are made in the attachment of cable fittings and age-related damage occurs in cables, cable joints and cable terminations. Moreover, increasing competition and cost pressure put a more intense load on existing electrical installations in the electricity supply industry and force distribution companies to keep them in service for an increasingly longer period. Due to these changed conditions, it is getting more and more difficult to operate transmission and distribution networks in a dependable way.

But you can efficiently prevent failures and problems: With our tests and diagnostics, damages and faults can be detected and rectified at an early stage. Hence, power supply failures and the resulting costs can be avoided easily. Our scope of work contains all the relevant test methods from 0.1 Hz VLF testing, to the effective and variable 50 Hz AC voltage test through to diagnostics and partial discharge measurements up to 400 kV DAC. We are able to carry out the measurements onshore and offshore and provide a reliable basis for further action.

Testing a cable is sensible and advisable before it is put into service for the first time. All components are easy to access at that point, and the quality of the newly built cable system is demonstrated. Later, a permanent or periodic condition analysis can identify impending faults and enable condition-based maintenance to be carried out on the network, which also prevents problems from occurring when the network is in service.
Since the insulation of the cable is still new when the commissioning test is carried out, the installation and assembly quality are the focus of the diagnosis. For example, sheath faults caused by mechanical damage during installation or improper assembly of cable joints and terminations will be detected. The method to be used for commissioning tests depends on the voltage level. Medium voltage cables are tested in most cases using a 0.1 Hz voltage. Practical field experience and numerous scientific studies have proved the effectiveness of this test method for PE/VPE, paper-impregnated cables and their fittings. High-voltage cables are frequently put into service by only using a 24-hours test at $V_0$ in order to save costs. However, testing at damped AC voltages (DAC) and voltages greater than $V_0$ is a lot more conclusive diagnostically.

In order to get information on the installation and assembly quality of your cables and to detect assembly faults which are a problem only in the long run, it is recommended to have your cables checked for partial discharges. In fact, many faults are known to cause partial discharges long before the particular component fails.

Partial discharge is a localised dielectric breakdown of a small portion of an electrical insulation system, i.e. the discharge does not bridge the entire space between two conductors. Inside cables, PD defects typically arise in ionisable gas-filled voids resulting from installation faults, thermal aging in cable joints and terminations or missing impregnation mass in paper cables. Detachment or surface irregularities of the semiconducting layer also cause partial discharges.

Commissioning tests in offshore environments are also no problem for us – for example with our mobile VLF equipment and our OWTS system up to 400 kV.
For this reason, commissioning tests are more and more frequently combined – or completely replaced – with PD diagnostics. Using PD diagnostics on cables, all types of assembly and installation faults can be easily detected and located, which will help you save the avoidable cost of repair maintenance.

Depending on the length of the cable to be tested and its length-dependent capacitance, an oscillating voltage with a frequency of 50 Hz up to some 100 Hz is produced.

In contrast to 0.1 Hz based methods, this frequency is close to the frequency the cable will meet in service and hence enables PD faults to be detected under very realistic conditions. That means, it is also possible to keep in the range of the operating frequency, allowing non-destructive testing, i.e. evaluation of the properties of the cable without causing damage. This ensures the functionality of your network infrastructure from the very first day of operation, and unplanned failures and repairs can be significantly reduced. With test voltages of up to 400 kV, our PD diagnostics cover every application from the lower medium voltage range to high voltage distribution.

The OWTS HV 250 enables commissioning tests up to 400 kV.
The expansion and maintenance of cable networks are significant cost items in the budget planning of a utility company. Hence, the knowledge about the current condition of a network is particularly important, also from the financial planning perspective: The more precisely maintenance tasks, repairs and replacement of equipment can be planned, the more economically the network can be operated.

Continuous condition analysis will provide your company with all relevant information about the current state of your network. It creates a cycle of measurement, analysis and revolving planning. Based on the findings made, a condition-based maintenance strategy is possible. This ensures a methodical and continuous – and therefore economical – use of your resources:

- **Renewal work on cables based on their conditions**
- **Effective scheduling of maintenance jobs**
- **Sustainable reduction of unplanned outages**

With the help of various diagnostic processes, aging-related damage to the insulation of installed cables can be detected reliably. An extensive network condition analysis can moreover answer questions relating to the operational safety as well as the quality and residual strength of the insulation material. In this way, a reliable forecast of the future risk of failure can be made. Of course, the diagnostic processes deployed by us result in no damage or destruction whatsoever of the measurement object.
The condition of the cable insulation is influenced by normal ageing over the years of operation as well as by external impacts. These include, amongst other things, moisture penetration as well as normal and abnormal operating loads such as overloads or surges.

The test methods for determining the dielectric properties of the insulation are adapted to the specific physical properties of the paper and XLPE insulations. Ageing effects, such as water trees in XLPE cables or the cellulose decomposition in paper mass cables, can be identified by means of dielectric diagnosis in the frequency or time range. Therefore, one can assess very accurately the safety and operating reliability of cable lines using our 0.1 Hz loss factor measurement.

In this process, the loss factor $\tan \delta$ is measured at sinusoidal test voltages with a fixed frequency of 0.1 Hz and with varying amplitudes. The angle $\delta$ between the ideal capacitive current and the complex current is mainly determined by the ohmic leakage current of the insulation. The greater the ohmic leakage current, the larger the angle $\delta$ is and the worse the condition of the cable. An analysis is made of the value of $\tan \delta$ for each of the different voltage amplitudes applied and the variation of $\tan \delta$ with voltage.

**THE DIELECTRIC DIAGNOSIS WITH TAN DELTA ($\tan \delta$-ANGLE FUNCTION)**

Tan delta measurement kit installed in a diagnostic test van
A comprehensive condition assessment of the network requires, in addition to dielectric diagnostic procedures, PD measurements. Whereas the primary objective of commissioning tests is to assess the assembly and installation quality of the cable, condition-based maintenance puts the focus on the condition of cable fittings aged in service and the insulation of the cable. For example, offline PD measurement enables diagnosing of the degree of drying of the paper insulation or determination of damage caused by civil works. As a complement to this, online PD monitoring provides monitoring of the cable and allows cables with PD faults to be put on a list for repair or replacement. Subsequently, the offline PD measurement processes are used for pinpointing the faults.

**Monitoring using the online PD measurement method**

Online PD monitoring does not require the cable to be de-energized. This reduces the organisational work to be carried out. In addition to that, load effects on the development of partial discharge inside the cable can be identified. Hence, the method is ideal to monitor trends, for example in industrial power systems.

**Online and offline partial discharge measurement methods for condition-based maintenance**

- Air inclusions between connector and insulation gap
- Surface discharge on field control body inside defective medium voltage cable joint
- Disruptive discharge of the joint box in the connector area
Localizing diagnosis using the offline PD measuring method

Offline PD measurement is suitable for localizing the PD pulses, e.g. after critical PD values have been measured using the online PD measurement method. Unaffected by the interference during online operation, this proven technology provides for a highly sensitive and precise localization of partial discharges. In this process, both the PD inception voltage PDIV and the PD extinction voltage PDEV can be determined. Together with the level of partial discharge, the PDIV is one of the key indicators of whether cable joints or cable lines need to be replaced.

The PD inception voltage $V_i$ (PDIV) is the voltage that leads to recurrent PD signals greater than the basic interference level as the test voltage is increased. Partial discharge will cease once the test voltage is reduced to a certain level. This so called PD extinction voltage $V_i$ (PDEV) can be lower than the PDIV. The effect is dependent upon the type of fault and helpful for diagnostic purposes.
OWTS –
A UNIQUE TECHNOLOGY

One system – many advantages
Age-related flaws as well as damage to the cable can easily be detected and localized using the OWTS technology (OWTS = Oscillating Wave Test System). Moreover the integrated tan delta process allows a very good estimate of the condition of the insulation medium. The OWTS technology also offers advantages for the assessment of high-voltage cables: The majority of the installed HV cables are more than 30 years old and are paper-insulated cables, internal and external gas pressurized or oil pressurized cables. OWTS technology not only enables these cables to be checked for local faults but also to be diagnosed integrally with the tan delta method.

Long cable? No problem!
We use OWTS units from SebaKMT because of their exceptional testing performance. Cables 20 or more kilometres long can be tested in accordance with standards by one system without any problem. As opposed to a simple 24-hours test at $V_0$, the OWTS technology allows testing and diagnosis with higher voltages. That means, also workmanship faults endangering safe operation can be detected and localized with an inception voltage above $V_0$. With our units, we can analyse power supply networks with voltages up to 220 kV. Even commissioning tests on offshore or onshore cables of wind farms do not pose a problem.

OWTS equipment in international mission

Voltage divider
- Embedded computer system with remote control (control unit, TE analyser)
- Digital signal processing card with coupling capacitor (PD detection)

High voltage induction coil

Modern high voltage switch with HS-thyristors triggered via fibre optic cable (LTT)

High voltage power supply (HVPS)
Reliable, simple and non-destructive diagnostics

The manner of operation of the OWTS technology is based on a resonant circuit between the cable capacitance and the coil of the OWTS system. The test object is charged to the desired voltage within a few seconds and is then discharged via a high-voltage switch and an air choke. In this way, an oscillating voltage is generated the resonant frequency of which depends on the inductance of the choke and the capacitance of the test object.

The oscillating voltage (DAC voltage, Damped AC) is an internationally accepted standardised test voltage. Depending on the length of the cable to be tested and the length-dependent capacitance, an oscillating voltage with a frequency close to the operating frequency is produced. As opposed to the 0.1 Hz-based methods, this allows detection of PD faults under realistic network conditions and enables a comparison of PD parameters such as the PD inception voltage (PDIV). Also the test voltage amplitude remains within the range of the operating voltage, which allows non-destructive testing, i.e. evaluation of the properties of the cable without causing damage.

Calibration of the PD measuring circuit is carried out in accordance with IEC 60270. The PDIV is determined by stepwise increase of the test voltage. The PD extinction voltage (PDEV) can be determined unambiguously from the attenuated voltage curve.

The PD faults can be localized with the help of software. In semi or fully automatic mode, the distances of the PD signals recorded and saved are analysed. The result of this analysis is the mapping of partial discharge signals.

During the measurement, the oscillation of the voltage produced by the test equipment is clearly visible.

The analysis shows partial discharges for all 3 phases of the system. Partial discharges occur in several cable joints over a cable length of 6500 m.
TESTING AND DIAGNOSIS OF POWER TRANSFORMERS

State-of-the-art measurement technology allows cost-effective and technically dependable condition assessment of transformers, and is helpful for an uninterrupted power supply and the planning of future investments.

A power transformer is an important component in transmission and distribution networks. Cost-saving measures have lead to a situation where much of this equipment remains in service over decades and is operated at higher load than originally planned. As a consequence, these apparatus are submitted to strong physical stress and a high risk of failure.

Hence testing and diagnosis of power transformers is of enormous importance. Failures and replacements are expensive and cost time. Since power transformers are enclosed systems, it is not possible to assess the interior of a transformer. Especially for used models, it is indispensable to have precise information about their condition.

Possible tests and diagnostic inspections range from the determination of the condition of the insulating oil through the measurement of the resistance of insulations and windings as well as of the voltage transmission ratio, vector group and dielectric strength, to the DFR (Dielectric Frequency Response) and FRA (Frequency Response Analysis) which provide the fingerprint of transformers.

Every year, our specialists carry out tests, overhauls and maintenance on approx. 400 distribution transformers with a power of up to 6 MW. Moreover, 60 to 80 new transformers are integrated in our own projects and commissioned within the framework of a delivery.

Many of the tests and diagnoses can be made on site by our qualified specialists with the help of mobile equipment. Further test units are located in the transformer service centre. Through regular training, our professionals stay current on the latest diagnostic techniques. We have made a standard practice of utilizing the most advanced equipment for years.
FREQUENCY RESPONSE ANALYSIS (FRA)
FOR DETERMINING THE FINGERPRINT

A transformer consists of several capacitors, coils and resistors, i.e. a complex circuit which produces a fingerprint or signature as soon as test signals are supplied at discontinuous frequencies.

The Frequency Response Analysis is performed to evaluate the electrical and mechanical integrity of the active part (core, windings, and clamping structures) within a power transformer.

Measuring apparatus
When the transmission function is determined, the entire electrically effective network including the signal recording device is sensed. Hence, not only the frequency characteristic of the transformer but also the frequency characteristic of the measuring apparatus is recorded. Therefore, the effects caused by the measuring apparatus are to be kept small and, even more important, constant.

Frequency Response Analysis is used in the following cases
- quality checks during production
- before and after short-circuit tests in the factory
- after each transport
- after a short-circuit fault
- after an earthquake or lightning strike
- gas analyses or vibration monitoring experiments show results that give rise to concern
- before and after maintenance

Frequency response of a fault-free transformer

Frequency response of a transformer that shows serious faults
The reliability of transformers is an essential precondition for security of supply. Operating transformers are subjected to electrical, mechanical, thermal and environmental stresses. In the event that a transformer has a defect, delivery periods of several months may have to be taken into account depending on the size and type of the transformer.

In order to assess the condition of the transformer and optimize maintenance job scheduling, we carry out diagnostic measurements to avoid unplanned downtime.

**Insulating oil**
Analysis of the insulating oil can provide information on the chemical and electrical condition of the transformer. In this process, the following points can be checked in the lab: cleanliness, colour number, neutralization number, breakdown voltage, water content, interfacial tension, Furan determination, dissolved gas analysis, dielectric loss factor.

**Insulation resistance**
The conductors inside the transformer must be insulated relative to each other as well as relative to the vessel of the transformer to prevent flashover. These insulation gaps are usually measured with a DC voltage of 5 kV. With the help of the GUARD technology, any leakage current flows through the GUARD connection and hence it is only the leakage current that is measured.

**Winding resistance**
Shorted or open windings as well as connection problems or a defective step switch can be located by measuring the winding resistance of the transformer. In this process, the DC resistance of each of the solenoid windings is measured. For the required magnetization, the Simultaneous Winding Magnetization method (SWM) is used.

**Measurement of the voltage transmission ratio**
The ratio of the transformer input voltage to the output voltage is approximately the same as the “turns ratio”, i.e. the ratio of the number of turns in the primary winding to the number of turns in the secondary winding, of the transformer. In the transmission ratio measurement, a voltage is applied to the primary of the transformer and the voltage induced in the secondary is measured and vice versa. This type of measurement allows identification of defects in the winding (incurrent number of turns, polarity or phase shift angle), insulation faults (destroyed interwinding insulation, large phase-to-phase or phase-to-ground fault) as well as of a defective step switch.

**Testing of the dielectric strength**
This test measures the dielectric strength between the windings as well as between the windings and the vessel of the transformer. The windings must withstand the applied voltage for one minute without flashover.

**Dielectric Frequency Response (DFR)**
Dielectric Frequency Response has become an important part in assessing the condition of insulation systems. In this process, the capacitance as well as the loss factor / power factor are measured as a function of the frequency over the mHz to kHz range. The result is an assessment of the humidity content of the insulating oil and of the solid insulation, which is crucial for the condition and serviceable life expectancy of a transformer.
PARTIAL DISCHARGE MEASUREMENT ON BUSBARS

Partial discharge on solid-insulated components
Practice has shown that, even years after installation or repair, malfunctions due to faulty installation occur. Here, we have to focus our attention on components with a solid dielectric such as cable joints and solid-insulated busbars. In these components, partial discharge can result from tiny inclusions or very minor installation faults and gradually, after months and years of operation, cause further damage to the insulation and finally lead to disruptive discharge. As a consequence, the component will break down prematurely, increasing repair and downtime costs. In order to detect such defects before operation and hence avoid operational malfunctions, partial discharge measuring systems are used.

Compact mobile PD measuring system for busbars
For partial discharge testing of busbars, a modern 100 kV measuring system from H+H High Voltage Technology including an MPD 500 from OMICRON is used. The partial discharge measurement is made according to IEC 60270 (DIN EN 60270 VDE 0434). Our portfolio is complemented by the possibility to carry out a high-voltage test at 50 Hz. Since the connection is made using, amongst other things, T plugs and Pfisterer plugs, it is possible to test a large spectrum of switchgears. Moreover, the compact dimensions of the testing device allow the device to be transported and used even on difficultly accessible switchgears.

With the help of this measuring system, installation work on busbars of medium voltage switchgears from different manufacturers can be tested and signed off. Repeat tests after several years ensure long use and trouble-free operation – and spare the distribution company from unexpected failure of the switchgear due to partial discharge. Hence, the partial discharge measurement technique provides a valuable contribution to the planning of investments.