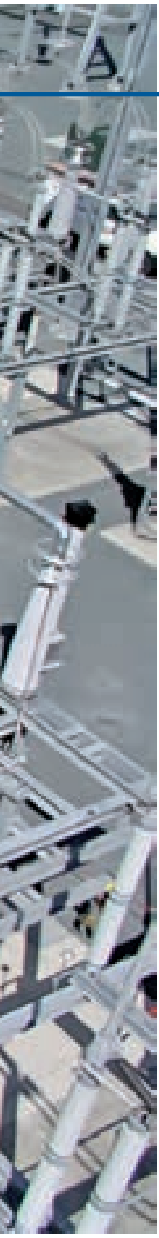
HIGHVOLT testing systems can be connected in parallel with minimal additional effort.



Application

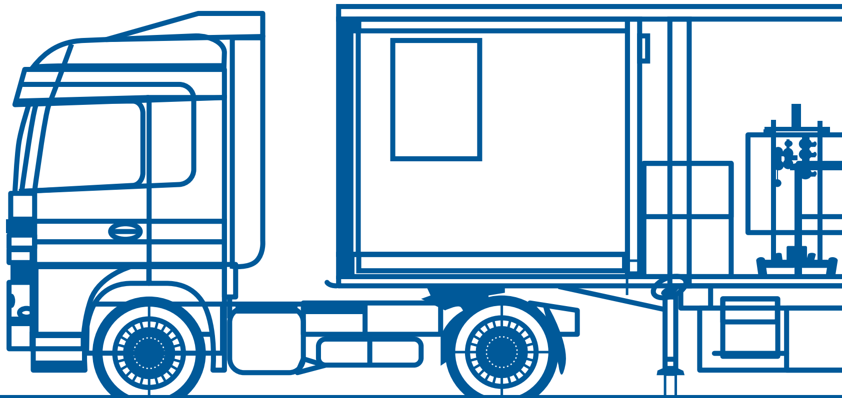
On-site Testing of High-voltage Cable Systems

On-site teamwork: OMICRON – HIGHVOLT – Kinectrics

By Mark Fenger, Dr.-Ing. Martin Hinow, Dipl.-Ing. Thomas Steiner, Wolfgang Pichler, Dr.-Ing. Kay Rethmeier und Dr.-Ing. Alexander Kraetge

Once the comprehensive construction, assembly and installation work of a high-voltage cable system is complete, the test engineer's job begins. These engineers perform start-up tests to ensure that the cables can be connected to the grid and to confirm that there are no obstacles which might prevent trouble-free operation for the next 20 to 30 years. Performing this task properly requires mobile, high-performance test voltage sources and reliable measurement technology for cable testing. These elements are vital.

The Canadian company Kinectrics specializes in on-site testing of a wide variety of cable systems. Formerly known as "Ontario Hydro Research Division", Kinectrics has, since the 1970s, acquired an excellent reputation in the field of partial discharge measurement. The OMICRON MPD 600 is the first choice for the Canadian company when it comes to selecting lightweight, high-precision PD measurement technology for tough "on the road" usage. The test engineers also require mobile high-voltage systems that are capable of providing several hundred thousand volts over the entire length of the cable systems which stretch over tens of kilometers. One of the leading providers of such high-performance systems is the Dresden-based company HIGHVOLT. This manufacturer of mobile resonance systems also relies on OMICRON technology and equips its mobile test benches with the proven MPD measurement system.



HIGHVOLT's WRV resonance testing system allows testing of a 400 kV cable. The testing system has a maximum output voltage of 260 kV and can provide a maximum test current of 83 A. This means, for example, that a 400 kV cable with a length of 8 km (5 miles) or a 110 kV cable with a length of 18 km (11 miles) can be tested. The truck trailer is 11 m (36 feet) long and has a maximum weight of 34 tons.

Cables in power supply networks

High-voltage cables are key components of power supply networks and are increasing in importance. In urban areas particularly, large amounts of energy can be transported or distributed only via cables which are below ground. This is because new overhead lines are subject to lengthy approval procedures and are also increasingly unpopular with the general public. Developments in the field of cable technology now allow the use of underground cables up to the 500 kV level.

Task of on-site testing

Following manufacture individual dielectric tests are performed as standard in the factory in line with IEC or IEEE regulations. To ensure that an underground cable run can withstand the dielectric stresses associated with standard operation, an on-site test is required prior to start-up. The goal here is specifically to ensure that the cable sockets (connection pieces), which are positioned by hand, and the cable end seals are free of faults. Of equal importance is the need to detect any damage to the cables that may have occurred during transport or during the installation of the cables.

In the on-site test, the cable is placed under load for one hour with an AC voltage where the amplitude can be 1.3 to 1.7 times the nominal voltage. If there are any faults in the sensitive parts of the cable insulation, these can be identified via characteristic images in the so-called partial discharge pattern.*

**The testing procedures and the basic conditions to be observed are detailed in IEC Standard 60840 for cables from 30 kV to 150 kV nominal voltage and in IEC Standard 62067 for cables from 150 kV to 500 kV nominal voltage.*

Dr.-Ing. Martin Hinow

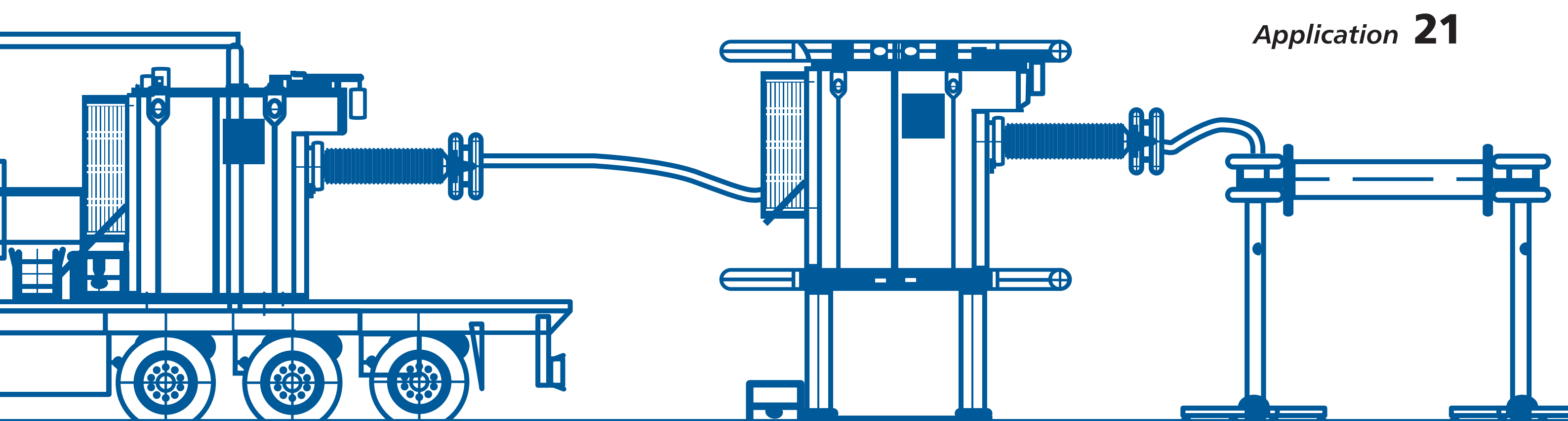
Calculation engineer for system design, HIGHVOLT

- > His doctorate was completed between 2003 and 2008 at the Institute of Electrical Energy Transfer and High Voltage Technology of the ETH University of Science and Technology in Zurich.
- > As a systems engineer, he has been responsible for the surge voltage testing system and for planning high-voltage test laboratories at HIGHVOLT since 2008.
- > He is a member of the CIGRÉ workgroup D1.36 and the IEEE.

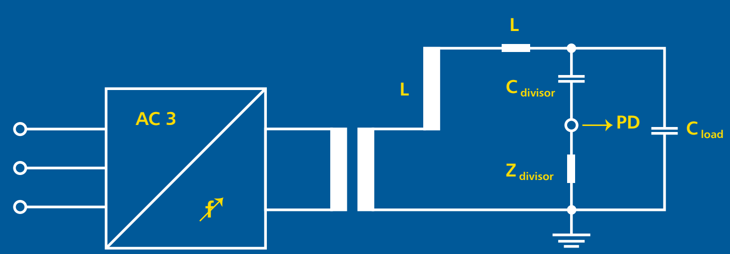
Dipl.-Ing. Thomas Steiner

Technical Director, HIGHVOLT

- > Until 2005 he was head of the DKD calibration laboratory at Dr. STRAUSS GmbH.
- > From 2005 he has worked for HIGHVOLT, taking the post of Technical Director in 2007.
- > He serves as a member on numerous national and international committees, including DKE K124 and workgroups of IEC 61083-1 -2 and -3.
- > He is the German spokesman for the IEC TC 42 and a member of MT 07 and MT 16.



Equivalent circuit diagram of a resonance testing system with variable frequency



Requirements of an on-site testing system

The most important requirement compared to a stationary testing system is portability. This initially involves the entire system fitting on a truck trailer and not exceeding road traffic weight limits. Yet the testing system must also be robust and able to withstand transport to the various places of use without suffering any damage. The sensitive technical equipment must in particular be securely anchored to ensure that the heavy high-voltage reactors do not get shaken and damaged on the journey to the test location. Since the supply energy available for on-site tests is generally limited, a modern testing system must be capable of doing its job with the lowest possible power input.

HIGHVOLT Prüftechnik Dresden GmbH

HIGHVOLT Prüftechnik Dresden GmbH is a mid-sized Dresden-based company and a member of the REINHAUSEN Group. HIGHVOLT plans and manufactures high-voltage and high-current testing systems for the global market to test electrical energy transfer equipment such as transformers, cables and switchgear, and also to equip research and training institutes. A clear customer and service focus together with reliability and innovation have made HIGHVOLT the technical market leader worldwide.

www.highvolt.de

Clever use of the resonance principle

The test voltage is applied to the cable via a high-voltage source. In the HIGHVOLT WRV testing system, the voltage source and the cable form a resonance circuit, consisting of inductance and capacitance. The resonant frequency is set automatically thanks to a special control circuit in the frequency converter. In contrast to testing systems with forced oscillation, with this on-site testing system only a small proportion of energy is required (enough to maintain the resonance procedure). High levels of reactive power are simply not necessary. More than 50 HIGHVOLT on-site testing systems have been delivered to date and are being successfully deployed worldwide.

Weak point analysis using the OMICRON MPD 600

Like factory measurements completed in accordance with IEC 60270, for short high-voltage cable analysis, the partial discharges (PD) are decoupled using a capacitor and then fed to the MPD 600. With long cables, however, the partial discharge signals are too heavily attenuated for sensitive measurement at the cable end. In this case, the partial discharges are decoupled directly at the sensitive points (e.g. cable sockets), recorded using the MPD 600 and then transferred reliably via a fiberoptic cable (no susceptibility to errors) to the measurement computer.

Where possible, all fittings, for example cable sockets and end seals, are continuously monitored for partial discharges throughout the one-hour voltage test. For longer cable runs, this represents something of a challenge due to the distances to be bridged. One approach here is to use a large number of independent PD measuring systems in each individual socket group, although this clearly generates immense personnel costs to operate the measuring systems. Another, more practical approach, is to connect all PD sensors to form a large network which can then be easily controlled by a single operator from the control room in the mobile testing system. The OMICRON MPD 600 offers the option to synchronously connect many measurement stations, a feature which makes the system unrivaled worldwide.

Test results

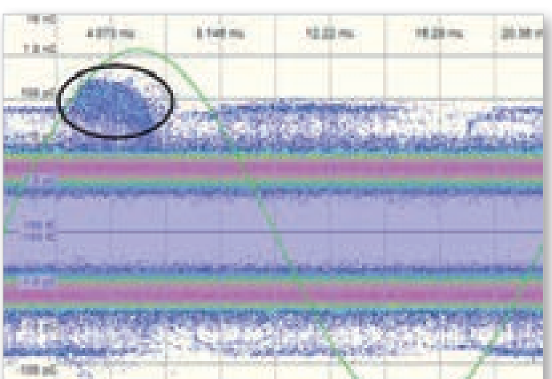
Since 2005, Kinectrics has used OMICRON and HIGHVOLT equipment to test more than 1,700 km (1,050 miles) of plastic-insulated high-voltage cable in the voltage range of 115 kV and above. This corresponds to almost 300 individual cable phases with a total of 2,500 sockets and more than 500 end seals.

Since there is currently no internationally recognized standard for on-site partial discharge measurements with explicit PD limits, the much stricter requirement of zero PD is applied. If any cable-typical partial discharge patterns are detected above the level of standard background interference always present, this is classed as critical and requires more precise analysis. Beside the absolute charge level, the voltages at which PD starts and ends are also of special interest. If the voltage at which PD stops is 20% above the operating voltage, this is considered acceptable.

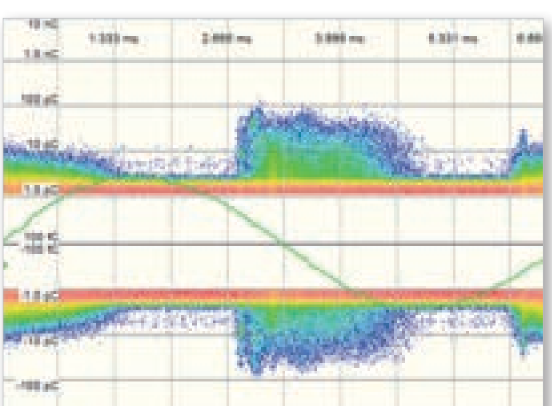
Rated voltage in kV	No. of accessories	Failure rate during AC HiPot	PD occurrence rate (no failure)
66/69/72	156	0.00%	1.28%
115	18	5.56%	0.00%
132/138	254	0.79%	0.91%
220/230	1,239	1.78%	0.84%
345/400	972	0.35%	0.31%

Failure and partial discharge (PD) occurrence rates: Statistical summary of the measurement results from Kinectrics. As a general rule, PD measurements are always taken in parallel to the withstand voltage test.

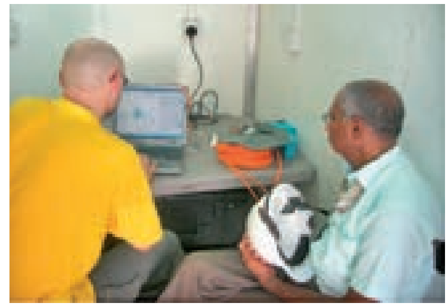
Examples of test results



PD fault, recorded on a 230 kV end seal: According to specifications of the end customer, the test voltage was 250 kV, for example, 184% of the cable run's nominal voltage. A critical PD pattern can be seen with a maximum charge of approximately 300 pC between 45° and 90° of the test voltage, which indicates a discharge between the conductor and a cavity. This PD fault occurred after a test time of around five minutes, which underlines the need for the test engineer to give the test his full attention throughout the entire one-hour PD measurement.



PD fault in a 72 kV GIS end seal: The phase-resolved histogram suggests a surface discharge here, which can occur on the boundary surface between a cable and Gas Insulated Switchgear (GIS) within the end seal unit. A visual inspection of the removed end seal instantly revealed damage to the surface structure, ultimately caused by a defective O-ring in the sealing system of the end seal. The complete end seal was removed and replaced. With this done the repeat measurement no longer displayed any irregularities.



Convenient operation of the MPD 600 via a PC

Mark Fenger

Head of the Kinectrics Cable Group

> Since 1997 Mark has been engaged in fundamental research on the thermal and electrical wear of plastic insulation and the dynamic partial discharge behavior of high-voltage transmission systems.
> He has worked for Kinectrics (formerly Ontario Hydro Research Division) for 9 years.
> Mark is an active member of the IEEE's "Dielectric and Electrical Insulation Society and Power Engineering Society".

Kinectrics Inc.

Kinectrics, formerly known under the name Ontario Hydro Research Division, with HQ in Toronto, Canada has over 250 employees. Kinectrics has more than nine decades of experience in mastering the complex technological challenges of Ontario Hydro and other North American and international energy supply companies.

The name Kinectrics is synonymous with comprehensive customer and engineering services in the energy industry. These include planning, scientific evaluation, development, testing and extensive installation and maintenance solutions for power systems.

www.kinectrics.com

Trends in the field of on-site testing

Two trends in on-site high-voltage cable testing are currently emerging. Firstly, more and more cables are being installed at higher voltage levels and secondly, cable lengths are constantly increasing. This leads to a situation in which multiple testing systems need to be connected in parallel or series to generate the required testing power.

After several years and having tested many kilometers of cable, it is safe to say that the combined withstand voltage test with synchronous PD measurement at all critical fittings is an extremely successful way to prevent premature system failures. The partial discharge measurement's contribution here is the early detection of faults which could reduce the service life of sockets and end seals. The MPD 600 is a measurement system suitable for on-site use and it is even capable of sensitively monitoring and analyzing objects spread far apart, such as high-voltage cable systems.