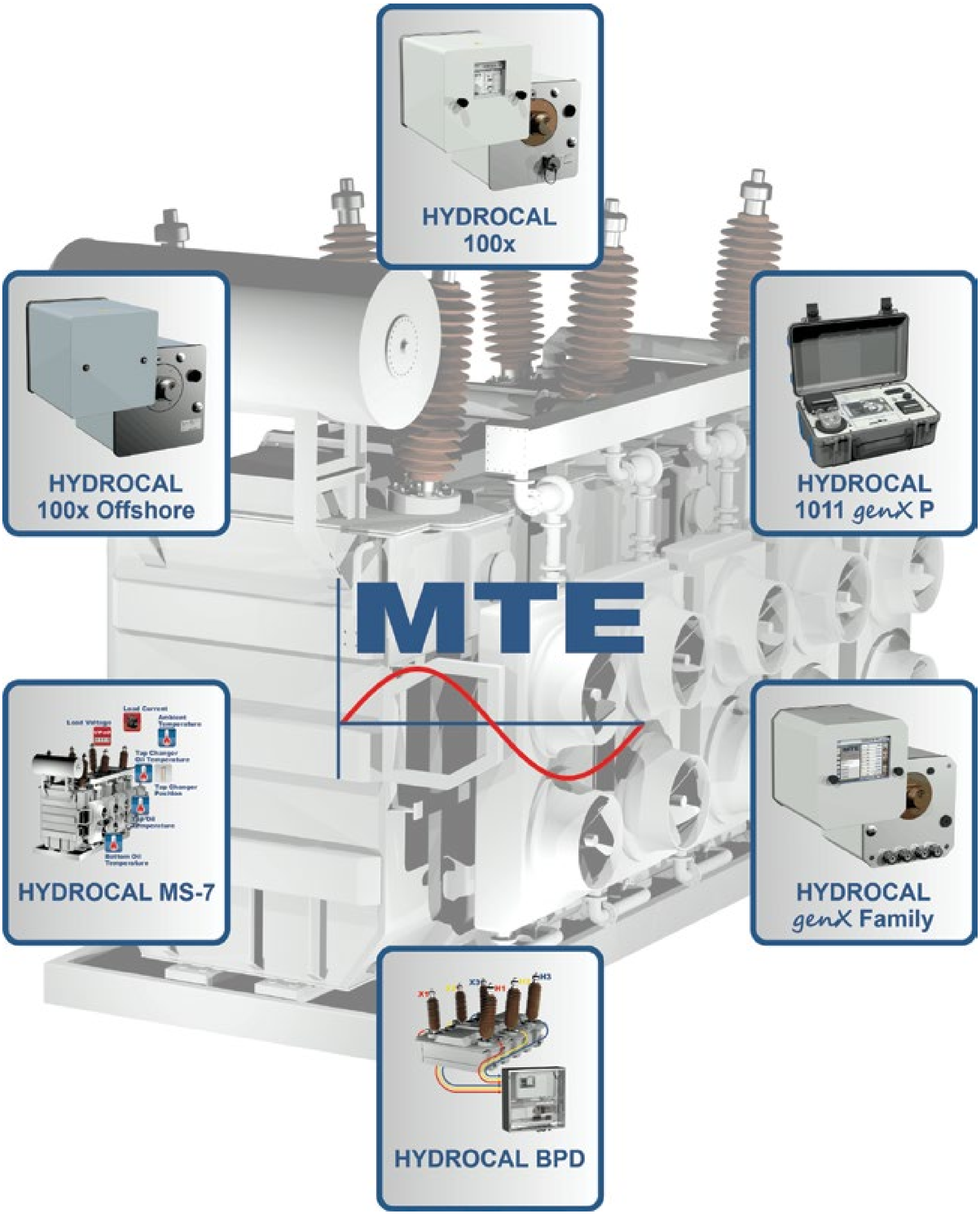


ABSTRACT

Online Dissolved Gas Analysis (DGA) has transformed power transformer monitoring since the 1970s. These sensors, vital for assessing transformer health, initially detected select gases. However, advancements culminated in the 2020s with the HYDROCAL series, allowing multiple gas detection by integrating near-infrared (NIR) spectroscopy, offering a comprehensive and user-friendly solution for detailed gas analysis and enhanced diagnostics.

KEYWORDS:

Online DGA, Near-infrared spectroscopy, Monitoring, Diagnostic, Gas extraction

Online-DGA-Sensor have steadily established their position as a permanent element in the operation of high-voltage grids since the 1970s

New technologies expand the performance range of Online-DGA-Systems

Important stages in the development of Online Gas-in-Oil Analysis

Power transformers are some of the most important and expensive operating equipment in power grids. The reliability of electrical power distribution systems, therefore, depends to a large extent on the condition, proper operation, and maintenance of these components. The most important parameters for evaluating the condition of power transformers are, in the very first instance, the analysis of gases dissolved in transformer oil, the determination of oil quality and the content of furanic compounds.

While many measurements can only be carried out by examining oil samples taken from the transformer in specialized laboratories, Online-DGA-Sensors have steadily established their position as a permanent element in the operation of high-voltage grids since the 1970s. Grid operators around the world use the systems for early warnings about elevated gas concentrations, for detecting trends, and for diagnosing and deriving maintenance and repair measures.

With few exceptions, the process of gas-in-oil analysis always consists of two steps: the extraction of dissolved gases from the insulating oil sample of the power transformer, followed by the analysis of the known free gases. This applies to both laboratory analysis and Online-DGA-Sensors. There are different methods for both process steps, which are also partly described in internationally recognized standards (e.g. IEC 60567) and have specific advantages and disadvantages, e.g. regarding applicability in the laboratory or on-site, accuracy, etc.

The first Online Gas-in-Oil-Sensors came onto the market in the early 1970s on an experimental basis and were then developed continuously until the end of the last millennium. These early variants were primarily used for early detection of an increase in hydrogen (H_2) or a weighted total of various gases, such as carbon monoxide (CO), acetylene (C_2H_2) and ethylene (C_2H_4). The most common gas extraction method used was extraction using gas-permeable membranes or membrane capillaries in combination with gas sensors that work on the principle of fuel cells.

The first commercially successful and proven Online-DGA-Sensor for the precise and individual analysis of hydrogen (H_2) and carbon monoxide (CO) finally came on the market in 2005. For the first time, it was possible to additionally measure the absolute (in ppm) and relative (in %) oil moisture by means of a capacitive moisture sensor. Gas extraction by this sensor was still carried out by means of membrane extraction, but individual and specific electronic gas sensors for hydrogen (H_2) and carbon monoxide (CO) were used in addition.

The dynamics of development continued to increase as more and more grid operators realized the advantages of Online Gas-in-Oil Analysis, and this technology became an increasing standard, especially for the most expensive and most important power transformers.

Very soon, for the first time, a so-called Multigas Online-DGA-Sensor was available on the market in such large quantities that all dissolved hazardous gases important for the assessment of the transformer condition could be detected and, in addition, diagnostic capabilities according to the internationally recognized standards (e.g. IEC 60599) became possible. The basis for this was the industrialization of the so-called headspace principle for gas extraction in combination with a new gas analysis technology, photoacoustic spectroscopy.

Even though further Multigas Online-DGA-Sensor operating according to similar functional principles came onto the market in the following years, and Online Gas-in-Oil Analysis thus became more and more a standard feature of power transformers, all devices had one common disadvantage: relatively high maintenance and repair costs, either due to the technology used (e.g. the replacement of calibration and carrier gas cylinders for sensors that use gas chromatographic principles for gas analysis) or simply due to a large number of necessary and movable mechanical components (e.g. pumps, compressors, valves, so-called

In 2020, a new type of sensor came onto the market, which combined well-known and proven extraction methods (membrane extraction) with NIR spectroscopy for gas analysis

chopper wheels for photoacoustic spectroscopy).

These challenges could only be overcome in 2020 when a new type of sensor came onto the market, which combined well-known and proven extraction methods (membrane extraction) with NIR spectroscopy for gas analysis, which has been commonly used for many years in large numbers. Since then, a sintered metal disc coated with a membrane material has been used instead of an ordinary membrane with the disadvantage of the lack of vacuum resistance.

For the first time, all important gases for diagnosis according to IEC 60599, hydrogen (H_2), acetylene (C_2H_2), ethylene (C_2H_4), methane (CH_4) and carbon monoxide (CO), as well as the absolute (in ppm) and relative (in %) Oil moisture can be determined with minimal maintenance effort and with high availability.

Combination of passive gas extraction and infrared gas measurement

From a mechanical point of view, the principle of membrane extraction of dissolved gases in the oil of power transformers is today considered to be the simplest and most reliable technology since it requires hardly any components, largely has no moving parts and is maintenance-free.

Membrane extraction via the commonly used material Teflon (PTFE), however, was until recently associated with certain limitations in terms of the number of dissolved gases measured. In general, only hydrogen (H_2) and carbon monoxide (CO) could be measured individually. Due to a lack of sufficient permeability and selectivity, Teflon membranes do not allow precise and, above all, individual extraction of Hydrocarbon Compounds (C_xH_x).

Today, the demand for systems that can measure key hydrocarbons is constantly increasing. As hydrogen (H_2) is involved in nearly every fault in the insulation system of power transformers and carbon monoxide (CO) is a sign of involvement of the cellulosic/paper isolation, the presence and increase of acetylene (C_2H_2) further classifies the nature of a fault as overheating, partial discharge, or high energy arcing. The additional measurement of ethylene (C_2H_4) and methane (CH_4) serves for further analysis, e.g., the Duval triangle according to IEC 60599.

Significant development has recently enabled the emergence of a new type of PTFE membrane incorporating another copolymer. These new membranes have the necessary permeability and selectivity to measure not only hydrogen (H_2) and carbon monoxide (CO) but also the main hydrocarbons, i.e. acety-

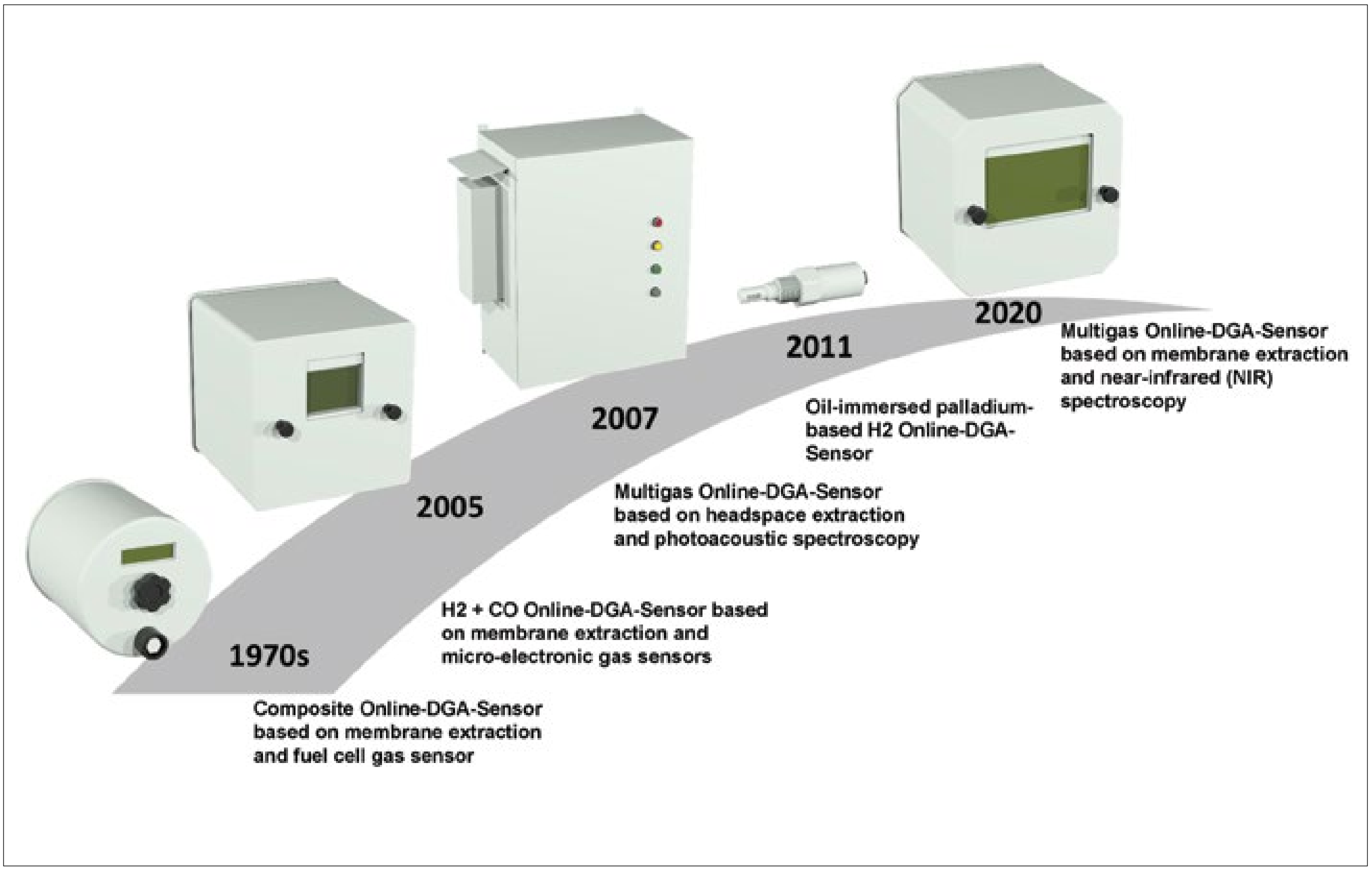


Figure 1. The evolution of Online-DGA-Systems

lene (C_2H_2), ethylene (C_2H_4) and methane (CH_4). In the NIR method, the gas absorbs the energy of infrared radiation of a specific wavelength. The measurement is made via a light-sensitive resistor.

In the latest generation of analyzers from MTE Meter Test Equipment AG (MTE), the HYDROCAL 1004 genX and HYDROCAL 1006 genX, membrane gas extraction technology (PTFE membrane with copolymer) and NIR (near-infrared spectroscopic gas measurement) are combined into a new concept, while the measurement of dissolved hydrogen (H_2) is based on a classic microelectronic SiO_2sensor. In addition, both HYDROCAL systems are equipped with a capacitive oil moisture sensor that determines the absolute (%) and relative (ppm) moisture of transformer oil.

The significant development of near-infrared (NIR) spectroscopic gas measurement has recently enabled the emergence of a new type of PTFE membrane incorporating copolymer

The HYDROCAL 1004 genX performs dissolved gas analysis of hydrogen (H_2), carbon monoxide (CO) and acetylene (C_2H_2) to determine both electrical failures of low intensity, as well as arcing and paper/wood/pressboard decomposition within the power transformer. The HYDROCAL 1006 genX, in addition, measures ethylene (C_2H_4) and methane (CH_4) for further analysis methods (Duval triangle/Rogers' diagram acc. IEC 60599).

Furthermore, the devices are characterized by an intuitive operating concept via a large, capacitive 7-inch TFT color touch screen and an integrated WLAN interface. The integrated genX web server allows the units to be operated from any smartphone, tablet or laptop equipped with an internet browser. The products integrate various communication interfaces: ETHERNET 10/100 Mbit/s (electrical/RJ45 or fiber/SC duplex) and RS485 to support MODBUS (RTU/ASCII

The HYDROCAL 1006 genX performs dissolved gas analysis of hydrogen, carbon monoxide, and acetylene, as well as ethylene and methane, for further analysis and diagnostic methods

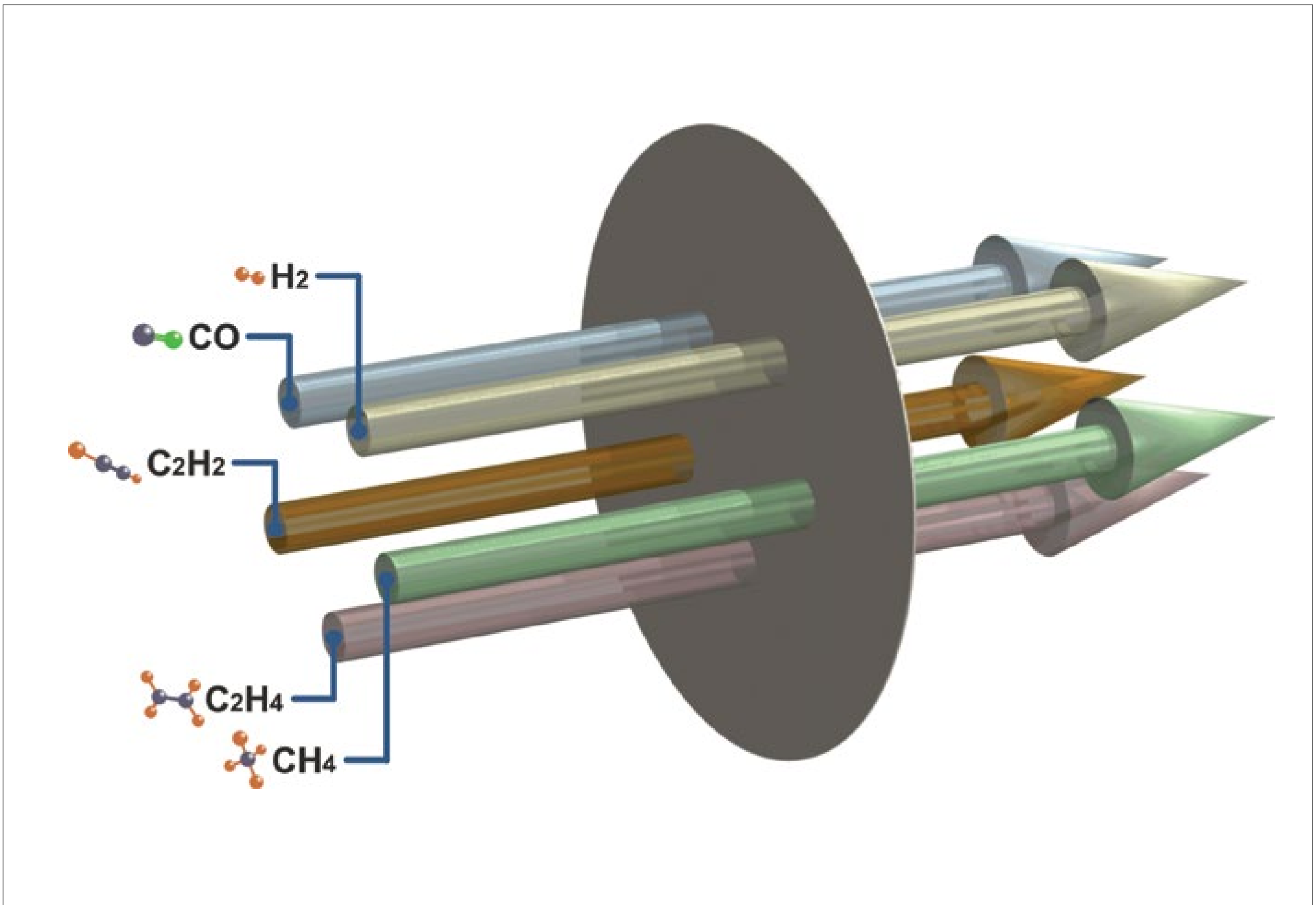


Figure 2. Copolymer membrane in the HYDROCAL 1004 genX and HYDROCAL 1006 genX

The strategic objective of this new concept is the development of Multigas Online-DGA-Sensors for dissolved gases with significantly reduced complexity

and TCP), DNP3 and IEC 61850 protocols.

The strategic objective of this new concept, the development of Multigas Online-DGA-Sensors for dissolved gases with significantly reduced complexity and a minimal number of moving parts to obtain a maintenance-free solution with high reliability, has thus been achieved and has already proven itself in hundreds of devices delivered and installed.

Increasing the reliability of Multigas Online-DGA-Systems using new technologies

All devices of the MTE HYDROCAL family are characterized by a connection to just a single point on the transformer. In the case of transformers that have been in operation for a long time, assembly is usually carried out on the obligatory oil drain valve, a process connection with G 1½" DIN ISO 228-1 or 1½" NPT ANSI B 1.20.1 thread. In the case of more recent transformers, an additional connection point can be provided on the tank or in the cooling circuit during the design phase, which makes the operation and readability of the devices much easier. Unlike units with oil extraction and oil return connections, this connection concept does not require external piping and thus offers the advantage that the filters usually included in the supply lines cannot become clogged because of different flow directions. Furthermore, DGA units of more recent design can, in principle, be mounted and commissioned without switching off the transformer.

To remove a defined volume of oil from the transformer for the analysis process, DGA systems equipped with a process connection usually have integrated level sensors. In the past, capacitive sensors, which are characterized by their small size, insensitivity to vibration and freedom from abrasion, were used for this application. The active principle used in this method is the change in capacitance of a measuring capacitor, which occurs in contact with the medium to be detected. Due to this measuring principle, however, the influence of temperature, type and nature of the respective medium must be considered and compensated accordingly when using capacitive-level sensors. With the latest generation of DGA devices, especially the HYDROCAL 1011 genX, these difficulties have now been eliminated using new-level sensors based on ultrasonic measurement. In addition, further development of these sensors has enabled very small designs. The sensors detect the level in a riser pipe without direct contact with the medium and provide a digital output signal, which can always be evaluated without errors, regardless of the temperature and type of medium.

For the extraction and detection of gases dissolved in oil, Online-DGA-Systems fundamentally use different methods. The headspace principle used in many instruments of the HYDROCAL family is characterized by a very high effective-

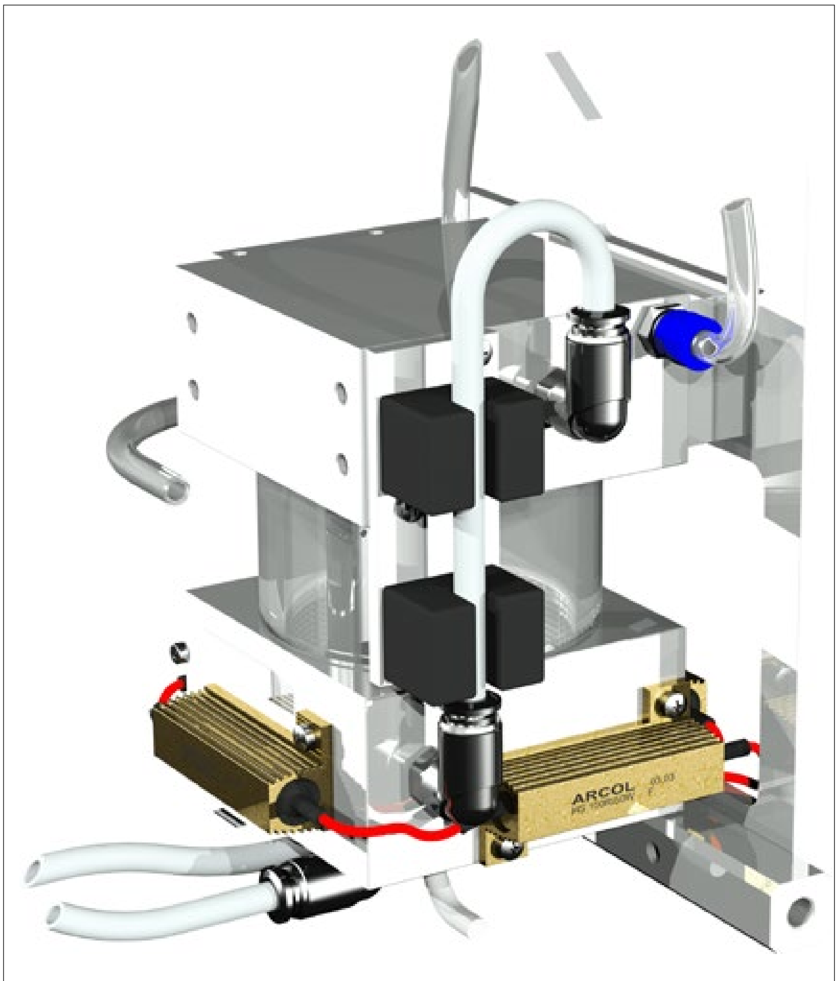


Figure 3. Gas extraction chamber and ultrasonic level sensors in the HYDROCAL 1011 genX

DGA units of more recent design can, in principle, be mounted and commissioned without switching off the transformer

ness and reproducibility compared to other methods. The detection of gases is carried out using various methods such as gas chromatography, which, however, requires the provision of carrier and calibration gases, or via optical methods that do not require any consumables for operation and are based on technologies such as photo acoustics (PAS) or near-infrared spectroscopy (NIR). In this context, NIR technology offers the significant advantage of being completely free of moving parts and thus being able to optimally withstand the diverse loads in the operating environment of a transformer.

NIR-based gas sensors measure different gases by varying the radiation frequency in the infrared (IR) range. For technical reasons, the corresponding components were limited to a few measurement channels in the past, and, as a result, only three or four types of gases could be measured per detector. For this reason, several infrared measuring cells were sometimes used to enable the construction of multigas systems for monitoring up to eight different gases. Thanks to advancing technologies in microsystems engineering, in the production of homogeneous detector surfaces and, above all, in the production of the required optical filters, the integration of the components has now been significantly improved. Today, a single infrared measuring cell is sufficient in the devices of the current MTE HYDROCAL genX family to enable dissolved gas examinations on up to ten channels. This allows a significantly more compact overall design, eliminating the need for previously required electromechanical components such as valves or connecting elements such as hoses. In addition, the number of measured components could be expanded to include hydrogen (H_2), oxygen (O_2), nitrogen (N_2), carbon monoxide (CO), carbon dioxide (CO_2), acetylene (C_2H_2), ethylene (C_2H_4), methane (CH_4), ethane (C_2H_6) and propane (C_3H_8). Furthermore, while maintaining the very compact design of the equipment, important connecting elements

The headspace principle used in many instruments of the HYDROCAL family is characterized by very high effectiveness and reproducibility compared to other methods

Today, a single infrared measuring cell is sufficient in the devices of the current MTE HYDROCAL genX family to enable dissolved gas examinations on up to ten channels

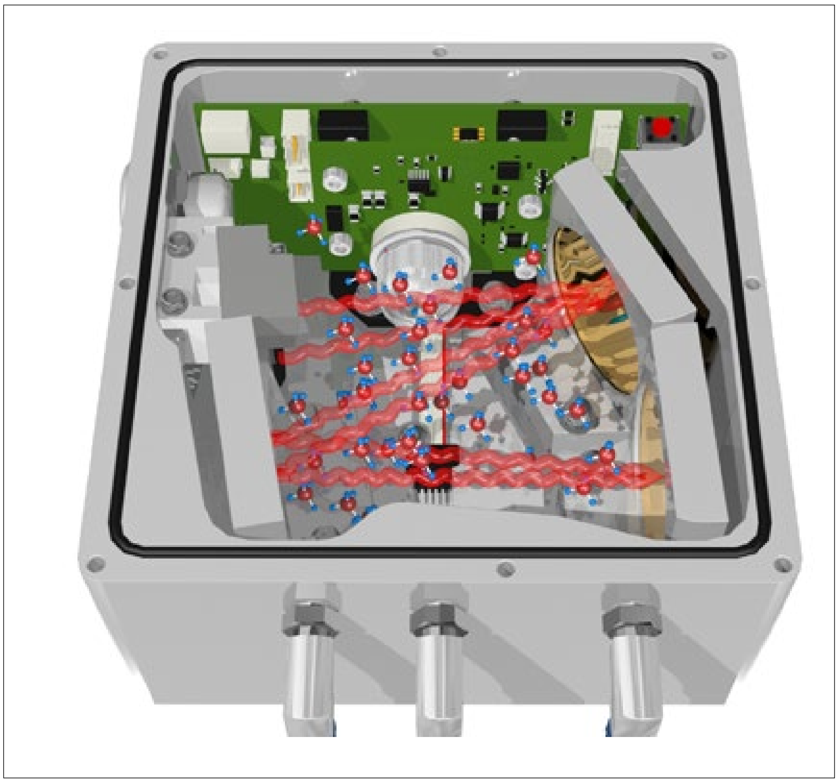


Figure 4. Gas measurement cell

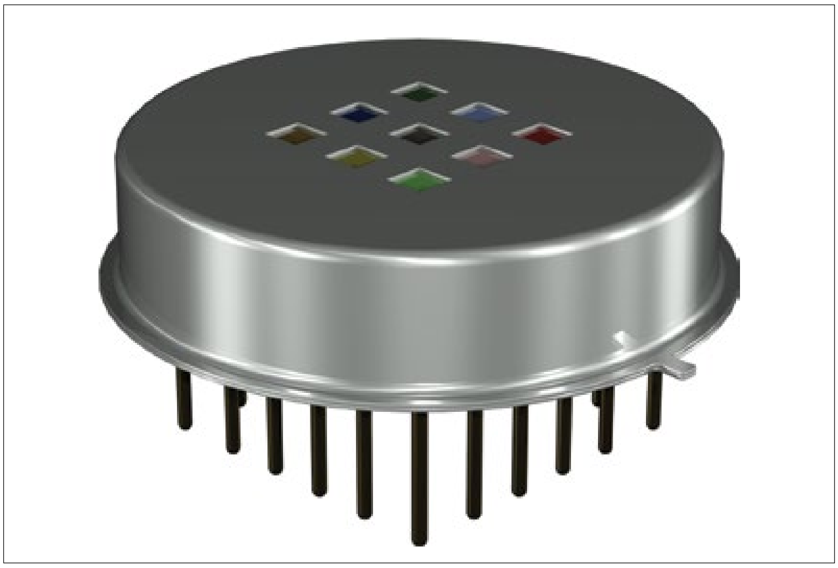


Figure 5. NIR gas detector

The new flagship of the MTE HYDROCAL genX family, the HYDROCAL 1011 genX, is less about minor improvements and adjustments and more about a comprehensive hardware update

made of PTFE tubing were replaced by more resistant metal tubes.

Eliminating different valves and hoses, using metal piping, and using ultrasonic level sensors have significantly reduced the probability of malfunctions (MTBF), which has been successfully proven in the context of initial field experience.

HYDROCAL genX testing under real conditions in the field

Ongoing improvements and modifications of existing and proven technical equipment are not uncommon these days, and software and firmware updates are also part of the optimization process of high-tech equipment. However, the new flagship of the MTE HYDROCAL genX family, the HYDROCAL 1011 genX, is less about minor improvements and adjustments and more about a comprehensive hardware update.

An exciting process is required before a new product reaches market maturity,

Figure 6. HYDROCAL 1011 genX and HYDROCAL BPD installed on a power transformer

Figure 7. Successful commissioning of a HYDROCAL 1011 genX in the field

Many years of experience in the supply of Online-DGA-Systems makes it clear that flexibility regarding voltage supply and interface for communication are becoming increasingly important

beginning with initial field trials through demonstration installations on power transformers and/or shunt reactors. This field experience is essential for future use, as concrete application cases are not only simulated but real measured values are obtained under real conditions. Parallel tests under laboratory conditions complement such deployments and field trials but cannot fully replace them.

In the past, these tests under real conditions proved to be extremely revealing, so this approach will continue to be an important part of the process of developing and introducing new products in the future. The same applies to the findings that can finally be obtained after extensive tests and trials under laboratory conditions at the intended place of use in different parts of the world under changing climatic conditions.

Since nothing has changed in the concept of the compact design of the devices and the use of familiar junctions (either G 1½" DIN ISO 228-1 or 1½" NPT ANSI B 1.20.1), installation and commissioning of the HYDROCAL 1011 genX are carried out in the same simple and familiar manner as for the Online-DGA-Systems already in use on the market. Therefore, both steps can be accomplished as usual by a single person without much effort. The integration of proven operating concepts also makes it easy for the grid operator's personnel to get used to handling the new technology.

Many years of experience in the supply of Online-DGA-Systems makes it clear that flexibility regarding voltage supply and interface for communication are becoming increasingly important. A wide-range power supply in the HYDROCAL 1011 genX ensures that the device can be operated with both DC and AC voltage. A modular communication interface further enables easy adaptation to the IT infrastructure available on-site, regardless of whether it is copper/RJ45 or fiber optic/SC duplex Ethernet.

With the integration of its genX graphical user interface concept into the MTE HYDROCAL range, user-friendliness has been further improved. The intuitive operating concept via a full-color touch

Figure 8. Installation of bushing sensors for the HYDROCAL BPD

display allows, among other things, easy parameterization of the devices as well as the individual input of customer data and alarm limits, which can be carried out easily and conveniently by the operator. The genX user interface also allows configuration via smartphone or tablet using Wi-Fi and web server.

The control concept is also used in the devices of the new HYDROCAL BPD series. As a specific and modular system, MTE HYDROCAL BPD (Bushing and Partial Discharge) focuses on online monitoring of high-voltage bushings and the determination of partial discharges (PD) on high-voltage bushings and the active part of power transformers. HYDROCAL BPD supports both the measurement of voltage and phase angle at the test tap to derive tanδ / PF and the bushing capacitance C, as well as the measurement of the electrical partial discharge according to IEC 60270. UHF (ultra-high frequency) measurement is supported for partial discharge analysis in the active part of power transformers. The devices can be used as stand-alone systems or as a supplement to an Online-DGA-System. The combination of both technologies results in a total solution for comprehensive monitoring of power transformers. The resulting data can be integrated into an existing SCADA system via common protocols such as DNP3.0, MODBUS (RTU/ASCII and TCP) and IEC 61850 or processed with the HYDROCAL Hybrid APP software solution, which has also been developed further and is included in the scope of delivery.

Authors:

Karsten Schröder:
Managing Director at
EMH Energie-Messtechnik GmbH
Area Sales Manager at MTE Meter Test Equipment AG

Bernd Riepenhusen:
Head of Development / Head of R&D at
EMH Energie-Messtechnik GmbH

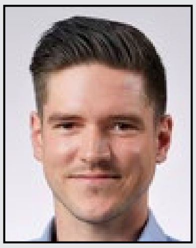
Tobias Pölchen:
Head of After Sales Service at
EMH Energie-Messtechnik GmbH

Stève Belin:
Product and Area Sales Manager for Transformer Monitoring Systems at
MTE Meter Test Equipment AG

Authors

Karsten Schröder is a Senior Sales Manager for MTE Meter Test Equipment AG and Director of MTE's Manufacturing and R&D Center in Germany. Karsten received a master's degree in electrical engineering from the University of Bremen in Germany, where he specialized in Automation Technology. He started MTE's development of Online Dissolved Gas Analysis products in 2001 with first products introduced in 2004.
Karsten's responsibility includes definition of product strategies and R&D project management, besides being responsible for the sales management of some key markets (e.g. India, USA). Karsten's technical experience includes membership in the German DKE UK182 for Fluids and Gases for electrotechnical applications. He holds patents and has authored papers in the field of Online Dissolved Gas Analysis, e.g. within CIGRÉ. He is a member of CIGRE working group JWG D1/A2.77 Liquid Tests for Electrical Equipment and JWG A2/D1.67 Guideline for Online Dissolved Gas Analysis Monitoring

Bernd Riepenhusen is head of MTE's R&D Center in Germany. Bernd received a master's degree in electrical engineering from the Technical University of Hamburg-Harburg (TUHH) in Germany where he specialized in Measurement Technology. Together with Karsten he started MTE's development of Online Dissolved Gas Analysis products in 2001.
Bernd's responsibility includes the R&D project management of all Dissolved Gas Analysis product as well as the related software packages besides being responsible for MTE's ISO 17025 accredited Oil-Laboratory.



Tobias Pölchen is the head of MTE's After-Sales-Service department in Germany. He gained his first experience with Dissolved Gas Analysis products in 2015 as he started his occupation as a field Service Engineer. Since then, Tobias has been responsible for various HYDROCAL and Transformer-Monitoring related Projects, which includes, among others, the installation, commissioning and user trainings, during which he deepened his knowledge and experiences.
Tobias is also responsible for MTE´s training centre in Germany, which provides technical trainings for MTE´s Dissolved Gas Analysis products for various clients, OEMs and key customers.

Stève Belin holds a graduate degree in electrical engineering from the Technical University of Nancy in France and a postgraduate degree in international sales and marketing for electrotechnical products from the Chamber of Commerce and industry of Alsace in France. He worked for 3 years at EMH Energie-Messtechnik GmbH in order to launch the very first HYDROCAL 1002 back in 2004. Since 2007, Steve has worked at MTE Meter Test Equipment AG as Product Manager for the HYDROCAL family. He also acts as Export Sales Manager for several countries in Europe and Africa.