THINK BIG! VACUTAP® VRL®

The new VACUTAP® VRL® is the world's most powerful on-load tap-changer in vacuum design. With this model, Maschinenfabrik Reinhausen (MR) sets new standards for the most challenging applications with maximum performance and reliability in the energy supply industry.

The departure from fossil fuels and the massive expansion of wind and solar plants is just one side of the coin when it comes to the future of the grids. The other is that the demand for electricity is rapidly rising at the same time. Not only are the mobility and heat sectors going electric, but a growing number of people also depend on electricity in

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Sustainability

Regenerative energies

HVDC transmission is a key component of the energy transition which requires ever-larger HVDC transformers and more powerful tap changers

DC transmission with HVDC transformers

High-voltage direct current transmission (HVDC) is a key component of the energy transition. This is because climate-friendly electricity is usually generated far away from urban centres and large industrial consumers – such as on the high seas or in desert regions. Using DC technology, the energy can be transported over long distances with low losses and even exchanged between countries with different grid frequencies. Increasingly greater transmission capacities are needed to transport more and more solar and wind power. Therefore, ever-larger HVDC transformers and more powerful tap changers are needed.

Stabilizers in the grid: phase-shifter transformers

With the growth of renewable feeders, volatility in transmission grids is also increasing. Without further grid expansion, individual lines can be overloaded depending on the weather conditions. To keep the grid stable, the generated electricity cannot be used, and expensive re-dispatch measures are required. Power flow management is therefore becoming increasingly important. Phase-shifter transformers help to increase the transmission capacity of the existing infrastructure by shifting the overload from a line in such a way that the network is better utilized. Here, too, applies the equation: *If the solar and wind power increases, the phase-shifter transformers must also become larger.*

An example of this is the largest and most powerful phase-shifter transformer used to date by the German grid operator Amprion. It already features three VACUTAP® VRL® units.

High-performance applications: Transformers for industry

Furnace transformers in steel mills must handle enormous amounts of energy. They ensure that the temperature curve required for the smelting process in electric arc furnaces is maintained. The central actuator for controlling this is the tap changer, which regulates the voltage around the clock. In a just few weeks, it performs tap-change operations more frequently than it would in a normal grid transformer in 20 years.

With up to 300,000 switching operations maintenance-free, the new VACUTAP® VRL® is equipped to meet such enormous demands. And this high-performance tap changer is not only

The largest and most powerful phase-shifter transformer, used by the German grid operator Amprion, already have installed three VACUTAP® VRL® units

their daily lives. According to forecasts from the UN, the world population will grow to around 10 billion by 2060. But if more electricity is to flow, we need more lines and larger transformers to manage the energy flows of increasingly volatile markets so that we can provide renewable energies where they are needed and ensure a reliable supply for high-end industrial applications.

The new VACUTAP® VRL® is optimally equipped for the future challenges of the energy supply industry, with a maximum rated current of up to 3,200 amperes, a step voltage of up to 6,000 volts and a switching capacity of up to 10,000 kilovolt-amperes.

The following areas illustrate the demand for on-load tap-changers of the highest power rating classes:

With up to 300,000 switching operations maintenance-free, the new VACUTAP® VRL® is ready to meet the most challenging demands that can be found in the industry

of interest to the steel industry. Other energy-intensive applications where large transformers are needed include cement plants, copper and aluminium production facilities, or electrolysis applications, such as hydrogen production.

Maximum availability and reliability are the focus

With this model, MR is pushing the limits of physics and testing what is technically feasible for use in high-end applications. Reliability and maximum availability have top priority, as these features illustrate:

The greatest challenge in the development of this diverter switch was in implementing the ultra-high switching capacity, which had never been done before. Even with the same oil compartment diameter as for previous VACUTAP® diverter switches, MR achieved an increase of the switching capacity by approx. 66 % from 6,000 kVA to 10,000 kVA. This could only be accomplished thanks to the extensive design expertise and detailed knowledge of vacuum interrupters, the core of the diverter switch. An optimal combination of system simulation and thorough system tests was also required to achieve an ideal setup with maximum reliability that meets all common standards.

Advantages of VACUTAP® VRL®

The advantages of the VACUTAP® VRL® can be seen in both the transformer design as well as in operation.

Advantages for the design of high-performance transformers:

- No forced current splitting required, allowing a simplified winding design
- More compact design with less material and oil, lower weight and smaller dimensions

Advantages for operation:

- Low maintenance thanks to vacuum technology

In the same oil compartment diameter as for previous VACUTAP® models of diverter switches, MR achieved an increase of the switching capacity by approx. 66 % from 6,000 kVA to 10,000 kVA

- Improved transmission system resilience as well as high security and reliability of transmission grids
- Higher transmission capacities

VACUTAP® VRL® in what is probably the largest phase shifter transformer in the world

Amprion, one of four transmission grid operators in Germany, is combating the overload of grid nodes by using high-end phase shifters. This is necessary if energy from offshore wind parks has to be transmitted over long distances, for example. These high-end phase shifters prevent individual electric circuits from being overloaded and increase the transmission capacity of the entire transmission system, thereby reducing high re-dispatch costs.

Based on the performance data and advantages of the VACUTAP® VRL®, Amprion decided to use it in what is likely the largest phase shifter transformer in the world. The data: 400 kilovolts of the rated voltage, 2,000 megavolt ampere throughput capacity and 2,992 amperes of the rated current. Since the new VACUTAP® does not require forced current splitting, it can carry the entire load current in one sector. This enables transformer manufacturers to avoid complicated winding designs. In addition, the phase shifter is considerably smaller than versions with forced current splitting due to this VACUTAP® feature alone. Smaller means it has less material, lower weight, less insulating oil and is thus substantially more affordable.

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Comprehensive consulting is crucial in projects of this magnitude. At MR, every order for a VACUTAP® VRL® is checked and assessed by experts. The customer gets full support, from the design phase to commissioning.

Another six VACUTAP® VRL® units are at work at Hydro One – the excerpt from the Cigre Canada paper illustrates this demanding application.

Cigre Canada Paper

Power flow control of carbon-neutral energy to industrialized urban areas

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Hydro One Inc. Canada

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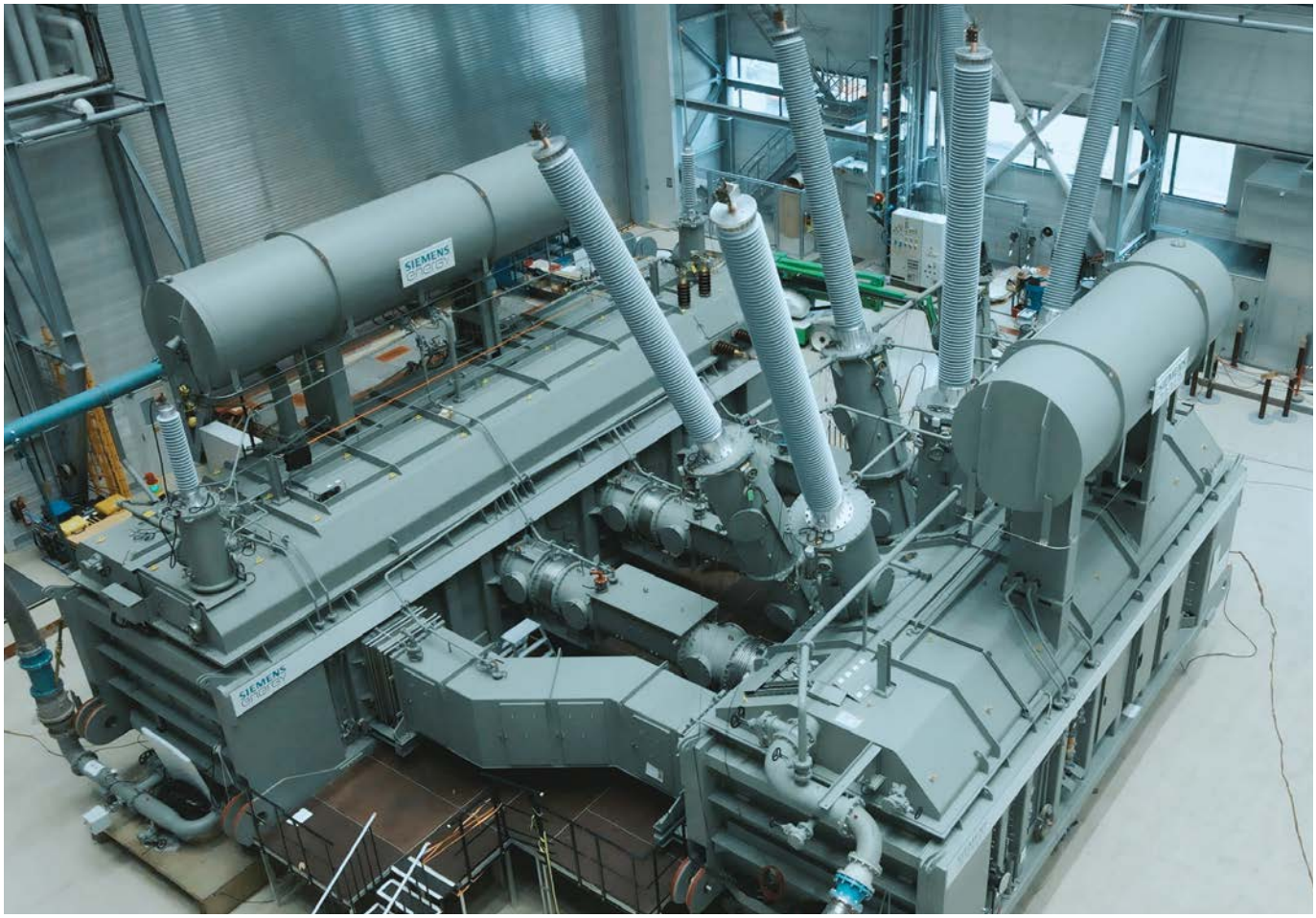


MR developed a new tap-changer with significantly increased step capacity, which does not require forced current splitting - VACUTAP® VRL I 3000

"Two independent sets of phase-shifting transformers combined with voltage regulators (PSRTs) will be installed at Hydro One St Lawrence TS to regulate the power flow continuously in either direction through the system interconnection between the Ontario Hydro and Power Authority of the State of New York. The phase-shifters will be used for the control of MVAr and MW interchange in either direction regulating the renewable energy sources between Canada and USA.

The selection and development of the on-load tap-changer (OLTC), which is the most critical and limiting component of a PSRT, and meets all the requirements above, will be explained in detail. To foster an efficient selection and development process of the OLTC, a detailed design of the PSRT is necessary in the bid phase of such a project.

The latest generation of VACUTAP® allows the realization of phase shifting transformers with significantly increased phase angle and rating. The reason is that the step capacity has been almost doubled compared to the standard oil tap changer with the highest step capacity of 6000 kVA with single-phase OILTAP® R or the older VACUTAP® generation, respectively. However, the previous generation of VACUTAP® requires a design with enforced current splitting for step capacities higher than 6000 kVA, which is not feasible all the time. The latest developed on - load tap-changer – the VACUTAP® VRL3001 with a step capacity of 10,000 kVA, overcomes this problem.

For this special application of a PSRT, with a very high phase angle of +/- 60 ° and additional in-line voltage regulation, it was determined that the best arrangement would be to have all tap changers at the neutral end.

The phase shifters are used to:

- Manage loop flows following schedule changes on the Ontario – Quebec and Ontario – New York interfaces.
- Alleviate post-contingency loadings on the Ontario – New York and the Ontario – Michigan interfaces

Importance to power flow CAN – US (carbon neutral energy)

The New York State Climate Leadership and Community Protection Act (CLCPA) establishes targets for the reduction of greenhouse gas emissions, most notably requiring 70 % of electricity to come from renewable resources by 2030. Consequently, there is a move to develop wind and solar production state-wide. The Phase-Shifter controlled lines will provide the operational flexibility needed to optimize the renewable resources in Northern NY and Ontario.

The main advantage of the quadrature booster concept is the location of the tap changer in the neutral end of the Exciter unit, where required BIL withstand levels are reduced. This translates itself to a more reliable and better dielectrically controlled solution.

This requires forced current splitting for the tap-changer, which already results in a sophisticated design. With additional tap-changers inside the delta of the exciter transformer, the concept of forced current splitting via the winding arrangement in the series unit was not possible anymore.

Fortunately, MR had a new tap-changer with significantly increased step capacity under development, which does not require forced current splitting - VACUTAP® VRL I 3000. Very detailed discussions with MR were required, in the offer stage, especially because not all the limits of this new tap changer were known. In order to avoid problems at the order stage, besides the load phase angles and voltages under load, Siemens Energy submitted an inductance matrix of the active parts to MR for additional calculations. In addition, the magnetic stray field nearby the tap-changers was calculated and provided to MR, in order to check possible influence on the tap changer operation.

- None of the tap-changer is located at the line end-high voltage
- Only Vacutaps are used to lower maintenance cost
- Small footprint. An additional autotransformer would have had a footprint of 9 x 4 m
- Low losses in comparison with the alternative solution with autotransformer appr. -35 %
- The no-load phase angle does not change with the in-phase regulation (LR).
- The newest OLTC needs no forced current splitting

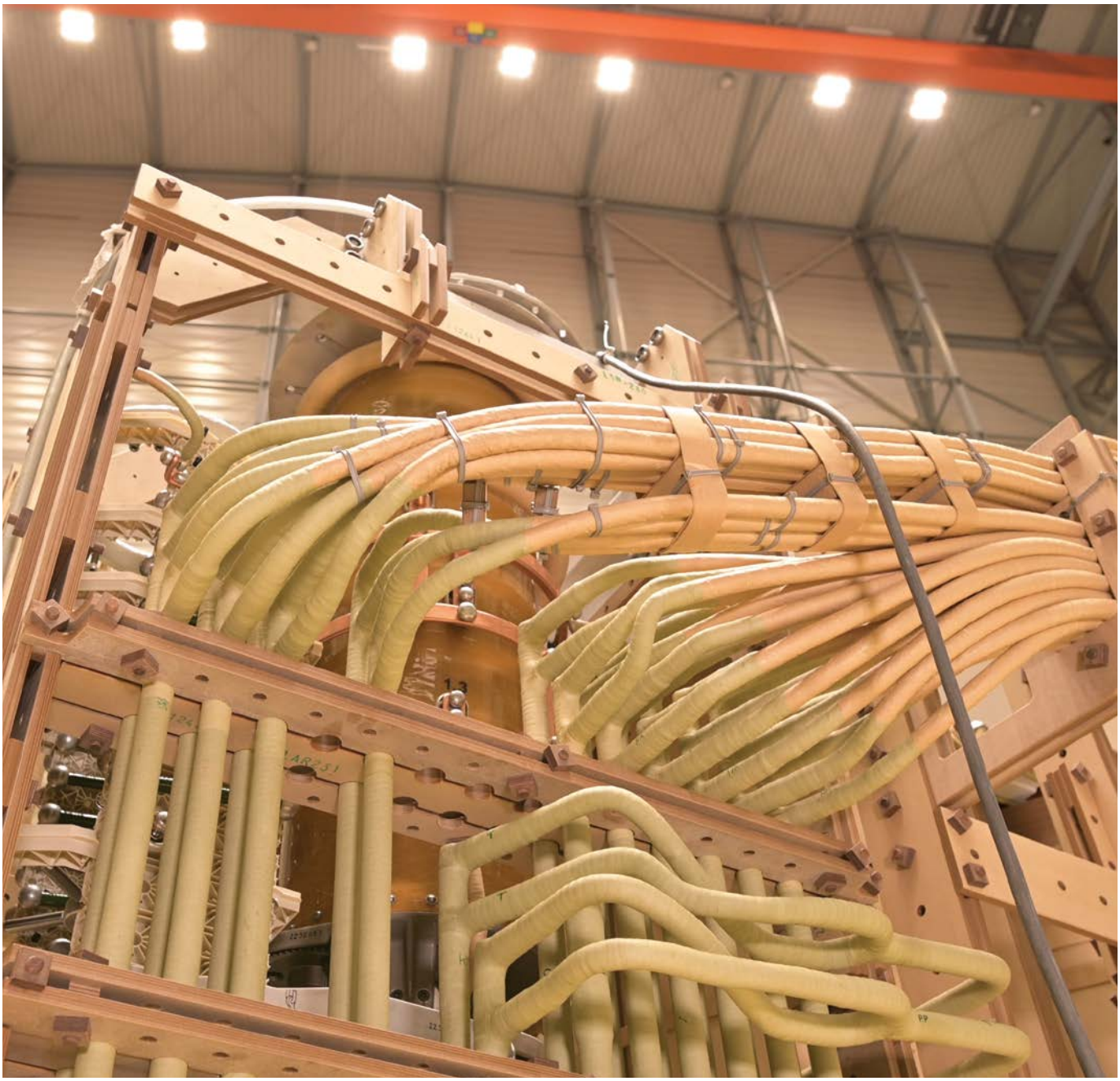
To enable efficient operation and maintenance of systems and prevent critical faults in power transformers, MR offers ETOS®, an open system solution for power transformer automation

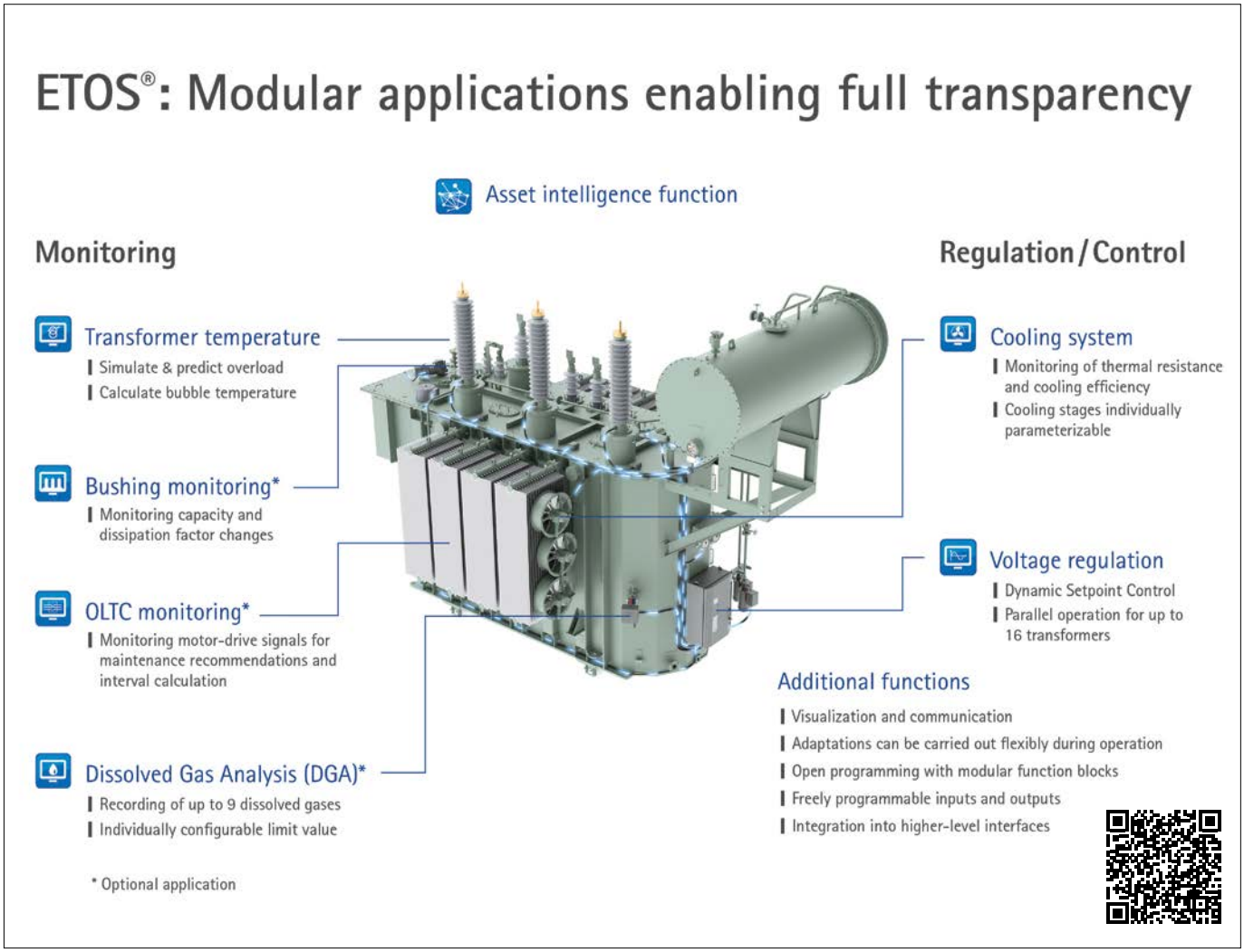
With the brand new VACUTAP® VRL I 3000, a step capacity PStN of 10MVA has been achieved. Furthermore, in comparison with the old OILTAP® R I 3000, the maximum rated step voltage Uim is increased by 50 %, and step capacity PStN is increased by 66 %."

Maximum availability through complete consideration of the power transformer with ETOS®

For high-end transformers, availability and safe operation are especially important.

To enable efficient operation and maintenance of systems and prevent critical faults in power transformers, MR offers ETOS®, an open system solution for power transformer automation – combining decades of experience in the control and monitoring of power transformers. It is comprised of monitoring and protective devices, conventional and intelligent sensors, field devices for control, regulation and monitoring, superordinate fleet monitoring, and all attachment accessories for communication. The special feature is the simple connection of components to ETOS®. This allows for an individualized design and the easy expansion or upgrade of existing power transformers. As a





result, transformers can be controlled and monitored more effectively – for maximum availability and reliability.

ETOS® is the world's first solution for the automation and digitalization of power transformers, allowing new approaches in asset management. ETOS® intelligently links existing actuators, state-of-the-art sensors, communication and algorithms. This results in self-learning digital twins of grid nodes, for example, for which not even real-time data was previously available. New insights about the dynamic overload capacity or technical remaining service life of equipment are also obtained, which supports the best possible use and maintenance of the existing energy infrastructure.

ETOS® integrates all data on the transformer into one system, regardless of manufacturer, and enables multiple uses of existing sensor information. The collected data is evaluated and assessed directly on the transformer with the aid of algorithms developed by MR. Thanks to the open, standardized ETOS® interfaces, custom algorithms can also be implemented.

A new standard function is Asset Intelligence – a virtual "transformer doctor". It evaluates the sensor data and reports faults before they become critical. The combination of a technical understanding of power transformers, the available sensor information and data analyses with state-of-the-art algorithms enables ETOS® to create a condition assessment for power transformers and their subsystems.

In the past, there were only fault messages from individual systems when limit values were exceeded. Now, a **complete consideration of the transformer** is possible based on artificial intelligence. The more information that is available, the more precisely the likelihood of certain faults can be calculated. If a fault exists with a certain likelihood, this is described in detail, the criticality is assessed, and remedial measures are suggested. In this way, Asset Intelligence leads to simpler condition diagnostics, lower repair costs, improved reliability and fewer unforeseen downtimes.

ETOS® – The automation solution for power transformers

ETOS® is a digital operating system for power transformers. It organizes the exchange of information between system components (on-load tap-changer, cooling system, bushings, etc.), consumers and higher-level systems; assumes the control of all actuators; and regulates the relevant physical variables (voltage, temperature, etc.). ETOS® also provides a variety of monitoring functions with self-learning algorithms.