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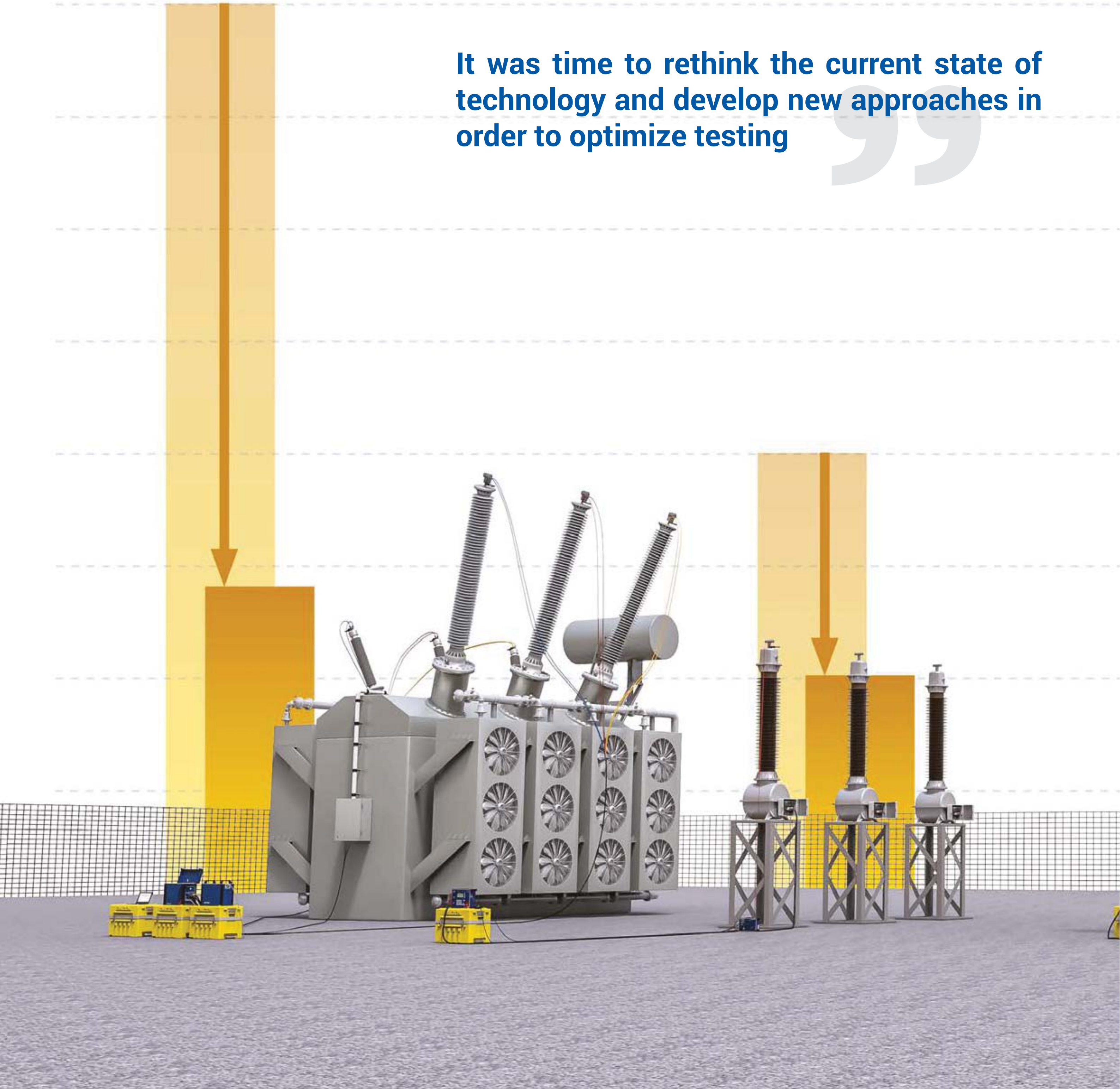

ABSTRACT

The article describes the increasing challenges faced during substation asset testing. It further shows the changing requirements for state-of-the-art test solutions to allow the most efficient way of testing in order to counteract these challenges. Thereby, state-of-the-art test solutions not only require optimized hardware, but also tailored software which does not just cover the pure test execution on site. It can also make the entire testing process, including preparation, and follow-up tasks such as assessment and reporting, as efficient as possible.

KEYWORDS

substation asset testing, efficiency, optimized test solutions

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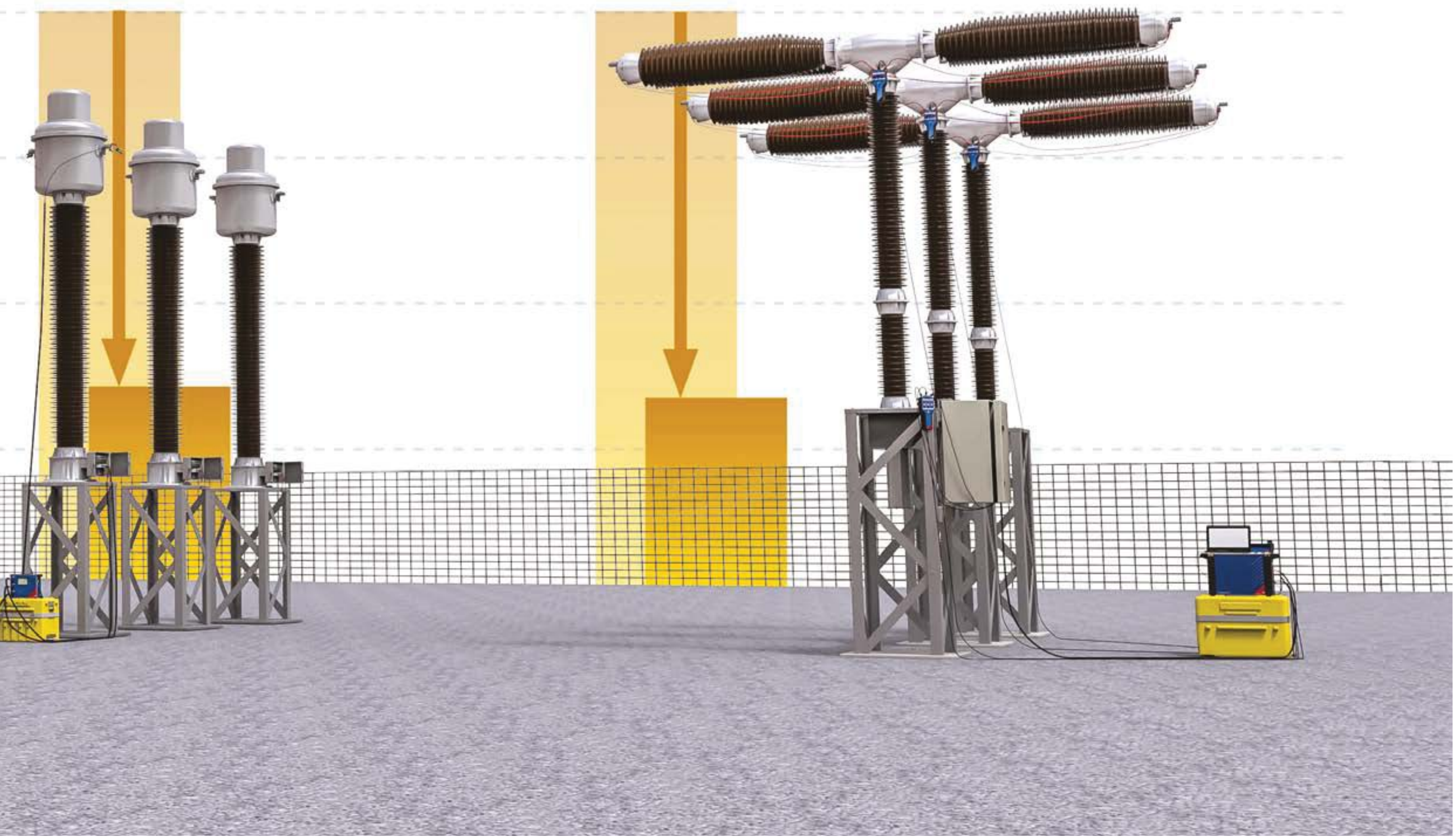
Achieving maximum efficiency during testing



1. Introduction

When it comes to testing assets in substations and performing comprehensive condition assessments, efficiency is king. To be able to come to informed conclusions about the correct operation and condition of the asset, whilst also keeping outage time to a minimum, all relevant test data must be collected within the shortest possible time and with the least amount of effort. The safety of the test engineer, the equipment, and the immediate surroundings must be guaranteed at all times.

The actual testing does not begin and end when entering and leaving the substation. To save time on site, the asset that is to be tested and all tests required should ideally be specified in advance. Afterwards, the collected data must be managed and evaluated, and test reports created.

Conventional testing solutions are increasingly reaching their technical limits

A true three-phase, multifunctional power transformer test system can offer numerous advantages, which all lead to reduced effort and shorter testing times

and are only fulfilling growing requirements in terms of effort and test duration. Thus, it was time to rethink the current state of technology and develop new approaches in order to optimize testing.

The greatest added value comes into effect as follows: If you use testing solutions that are optimized in terms of effort and time, and if several test teams test different substation assets simultaneously, the total time in which the assets must be disconnected from the network is minimized. The advantages of this approach can be used as a part of the general maintenance strategy, for example in case of a planned or unplanned outage of the substation. Figure 1 shows the average test duration and time-savings per asset using optimized test solutions.

This article describes the individual challenges during testing of power and instrument transformers, as well as circuit breakers, and points out the requirements for optimized testing solutions derived from them. The given data in terms of time-saving is based on our experiences using a selection of modern test solutions. It does not include a detailed comparison between conventional and the used test solutions due to the variety of available test solutions and asset types.

2. Challenges during power transformer testing

Power transformers are one of the key components in electrical transmission and distribution networks. Due to the increasing age of the transformers and changed load conditions in the network, regular diagnostic testing and condition assessments are becoming increasingly important in order to be able to make the right maintenance decisions.

The design of power transformers is complex, and accordingly, testing the wide range of transformer parameters is a time-consuming and costly task. In order to perform different diagnostic tests, several test devices and considerable rewiring are often required. Testing individual phases and tap changer positions further increases the work involved, as well as the required outage time.

On average, an entire working day needs to be scheduled for the full range of routine tests. Power transformer testing is, therefore, the most time-consuming type of asset testing in the entire substation.

3. Three-phase testing makes the difference

A true three-phase, multifunctional test system can offer numerous advantages, which all lead to reduced effort and shorter testing times. Due to the multifunctionality of the system, the most common standard electrical tests can be carried out using more or less the same test set-up, such as measuring transformer turns ratio, winding resistance, dynamic resistance, short-circuit impedance, as well as frequency response of stray losses. Intelligent algorithms further ensure fully automated, simultaneous test execution across all three phases. This reduces the testing time to less than a third of the time required when compared to using conventional single-phase testing solu-

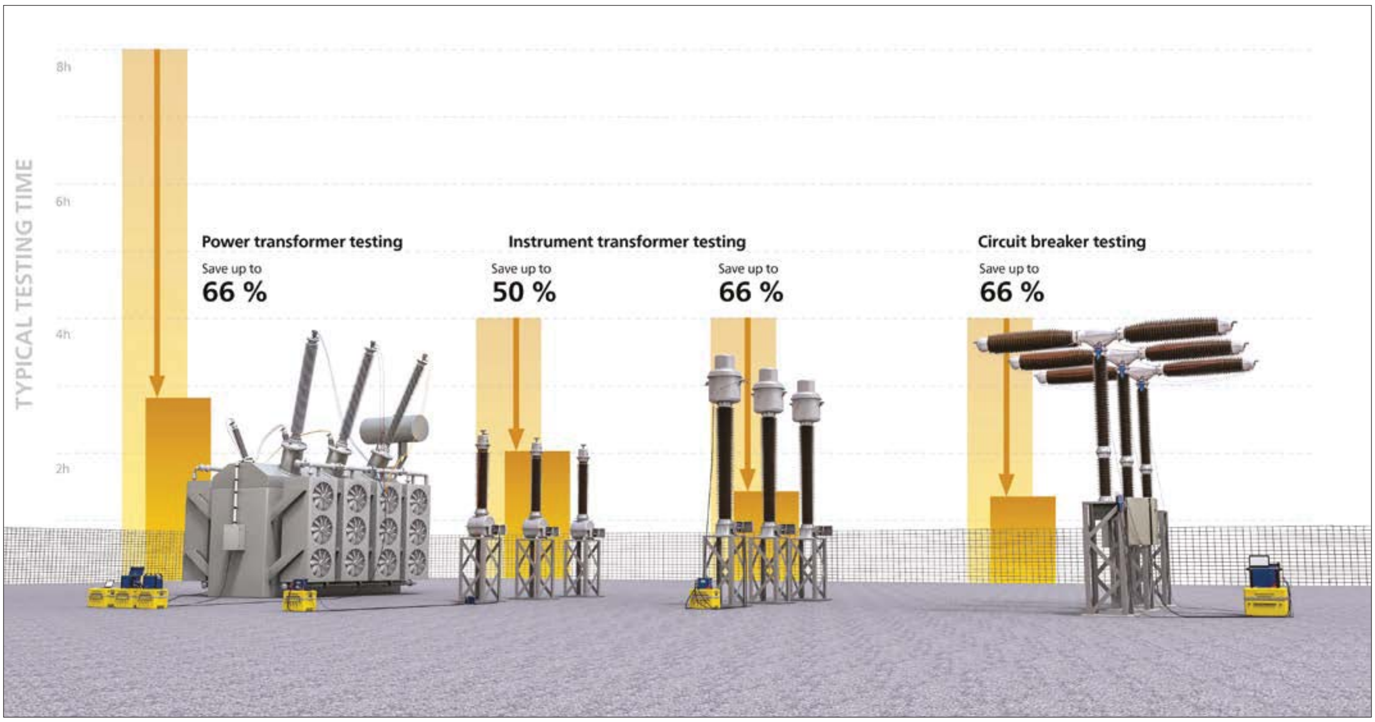


Figure 1. Using optimized test solutions reduces the individual test duration and in consequence, the total outage time in the substation

Table 1. Example for common electrical tests on a 132 kV / 12 kV power transformer, the given time does not include the required time for setting up the tests or rewiring between tests

Test	Required Time (minutes)	Required Re-Connection
Transformer turns ratio (TTR) (per tap position)	7 min.	Same connection
Primary DC winding resistance (per tap position)	30 min.	Same connection
Tap changer / OLTC analysis (DRM) (per tap position)	Included with winding resistance test	Same connection
Secondary DC winding resistance	2 min.	Same connection
Demagnetization of transformer core	2 min.	Same connection
Magnetic core balance	5 min.	Same connection
Short-circuit impedance / leakage reactance measurement (@ 3 tap positions)	5 min.	Short secondary terminals
Winding insulation capacitance and tan delta (DF/PF)	7 min.	Re-connection required
Bushing insulation capacitance and tan delta (DF/PF)	7 min.	Re-connection required
Report generation	1 min.	–
Total Time for Tests	**66 min.**	**–**

tions involving multiple rewiring (see Figure 2).

Modern test systems reduce the number of required leads and offer a simple and intuitive approach for setting up the test, which minimizes the likelihood of errors. Specially developed 4-wire cables serve both signal injection and measurement and have to be connected to the high-voltage and the low-voltage side of the power transformer. All inputs and outputs can be automatically controlled without rewiring. To switch automatically between the individual taps of the tap changer, an additional third cable can be connected. This can also be used to record the motor current and voltage of the tap changer.

Table 1 shows an example of a typical power transformer test procedure using an optimized three-phase test system and describes the required time and rewiring effort. The test object was a 132 kV / 12 kV two-winding power transformer with 25 on-load tap changer positions on the primary winding. The individual and total testing times only represent the time required to run the tests and do not include any time required to remove bus-bar connections, or set-up and change connections between tests.

Model-based solutions for instrument transformers testing can be used to determine all parameters within minutes, including the accuracy and class assessment under different load, current, and voltage conditions

4. Challenges during instrument transformer testing

Instrument transformers, such as current and voltage transformers, connect the primary and secondary system and play an important role in the reliability of the energy supply. Regular testing and calibration of these assets guarantee correct operation in normal conditions and in the event of a malfunction of an instrument transformer for protection purposes.

Conventional solutions require complex on-site testing or the complete dismantling and transport of the instrument transformer to a test laboratory. Depending on the testing method and the scope of required tests, high test currents and voltages are needed. These require bulky equipment or make dedicated applications, such as on-site testing of the transient behavior of protection current transformers (types TP, TPX, TPY, TPZ), impossible.

In order to meet the relevant standards, all of the cores, windings, and specified operating points, must be checked. The amount of different instrument transformer types and designs requires considerable work in terms of test prepara-

Figure 2. Using a three-phase test system can significantly reduce the effort for rewiring between the individual power transformer tests

This new approach and modular connection technology simplifies circuit breaker testing and reduces the testing time to a third of that which needs to be scheduled for conventional solutions

tion and execution, e.g. for specifying the asset or rewiring. The test duration itself can take up to several hours if, for example, different measuring points have to be tested at different currents, respective voltages and burden ranges.

5. Model-based testing as a guarantee of precision and mobility

In order to master these challenges as efficiently as possible, and to reduce the weight of the test equipment required, an indirect, model-based testing method has been developed. Based mostly on the secondary side measurements, the internal parameters of the instrument transformers are determined. Then, based on these specific parameters, all performance characteristics of the instrument transformer are calculated with very high accuracy.

This approach has been implemented in the form of dedicated test systems for both current and voltage transformers. Both testing solutions can be used to determine all parameters within minutes, including the accuracy and class assessment under different load, current, and voltage conditions (see Figure 3).

A switching matrix reduces the required wiring effort to a minimum and makes testing of tapped current transformers and multi-winding voltage transformers efficient.

Table 2 shows a case study for the accuracy assessment of a metering current transformer while Table 3, in turn, details the accuracy assessment of an inductive voltage transformer - both using a model-based test system. Here too, the individual and total testing times only represent the time required to run the tests.

6. Challenges during circuit breaker testing

Circuit breakers protect the transmission and distribution systems against damages through reliable separation of the electrical circuits in the event of a malfunction, e.g. stopping a high fault current flow during the event of a line-to-ground short circuit in the transmission line.

Any malfunction of a circuit breaker can lead to failures with far-reaching material losses and economic consequences. Due to their design, a broad spectrum of mechanical and electrical faults can occur in circuit breakers. For this reason, a number of diagnostic tests must be carried out, which, until now, required mul-

Table 2. Example of accuracy assessment of a metering current transformer, the given time does not include the required time for setting up the system, respective leads, or rewiring between tests

Test	Required Time (minutes)	Required Re-Connection
Ratio and phase accuracy of CT (including polarity check, winding resistance, ratio, phase, and excitation curve)	Typically < 1 min.	Connect to CT, automatic sequence with same connection
Class assessment	< 10 s. (directly after measurement available)	–
Report generation	Automatically, directly after measurement	–
Total Time for Tests	**1 min.**	**–**

Table 3. Example of accuracy assessment of an inductive voltage transformer, the given time does not include the required time for setting up the system, respective leads, or rewiring between tests

Test	Required Time (minutes)	Required Re-Connection
Ratio and phase accuracy of VT (including polarity check, winding resistance, ratio, phase, and excitation curve)	Typically < 15 min.	Connect to VT, automatic sequence including 1 x rewiring
Class assessment	< 10 s. (directly after measurement available)	–
Report generation	Automatically, directly after measurement	–
Total Time for Tests	**15 min.**	

tiple test devices and led to time-consuming wiring and testing effort.

Another important aspect is the power supply during testing. Normally, the substation battery is used to supply power for this test. However, this can lead to volatile test voltage and, thus, to reduced reliability of the test results.

A 3-in-1 test system makes a crucial difference through combining a micro-ohmmeter, timing analyzer, and a coil and motor supply in a single device

7. A 3-in-1 solution instead of 3 individual devices

A 3-in-1 test system makes a crucial difference through combining a micro-ohmmeter, timing analyzer, and a coil and motor supply in a single device (see Figure 4).

It follows the same principle as the devices for the previously mentioned applications. A number of parameters such as switching times, static and dynamic contact resistance, sequence of operations, coil and motor current, and testing of the under-voltage and response time can all be recorded using just one test set-up. This new approach and modular connection technology simplifies circuit breaker testing and reduces the testing time to a third of that which needs to be scheduled for conventional solutions.

The integrated power supply also guarantees safe and independent operation, as well as reliable and reproducible measurement results. The ability to test circuit breakers while they are grounded on both sides also means increased safety for all on-site personnel.

Table 4 shows an exemplary test procedure for a 132 kV gas-insulated switchgear (GIS) on all three phases. The test procedure comprises of testing of open coil, closed coil and of the two auxiliary contacts. The given testing times only represent the time required to run the tests.

Figure 3. The model-based approach enables automatic assessment of the instrument transformer within seconds

8. Challenges during test and asset data management

As mentioned earlier, the comprehensive management of substation assets also requires reliable handling of the data which is to be managed. In particular, merging the mass of data, as well as the further analysis and evaluation, is an extremely complex manual task, with an increased margin for errors. This also applies when summarizing the results obtained and during the creation of the test report.

The use of different testing solutions from various manufacturers entails further challenges relating to data exchange and data integration. Users are often confronted with incompatibilities in terms of file formats, or interface problems with proprietary ERP systems, or

Table 4. Example of a typical test sequence on a 132 kV gas-insulated switchgear; the given time does not include the required time for setting up the tests or rewiring between tests

Test	Required Time (minutes)	Required Re-Connection
Static contact resistance Dynamic contact resistance (all 3-phases)	10 min.	Circuit breaker (CB) closed, one side grounded
Timing tests including coil analysis, motion analysis (sequence C, O, CO, OC, O–CO, synchronism)	5 min.	Change voltage sensing, CB both sides grounded
Minimum pickup test (for trip and closed coil)	2 min.	Same connection, both sides grounded
Undervoltage condition test (Timing at for example 80 % of nominal voltage)	2 min.	Same connection, both sides grounded
Motor current analysis	1 min.	Same connection, both sides grounded
Report generation	1 min.	–
Total Time for Tests	**21 min.**	**One Test Setup Only!**

systems for maintenance planning and asset management.

Software-based testing has additional benefits, as a clever mix of automation and user guidance can offer a high degree of support, security, high-quality measurement results, and time savings

9. Combined software for test execution, condition assessment, and data management

A comprehensive software solution can master many of these challenges. Users only need to train themselves on one type of testing software, which can be used to operate several test systems and perform diagnostic tests on various substation assets. As well as the reduced effort for induction and training, the effort for maintenance measures, such as regular software updates, is also significantly reduced – a step in the right direction for greater efficiency.

The use of combined software further ensures the compatibility of the data obtained. Integrated import functions enable the import of measurement data which has been created with test devices from third parties or by oil laboratories, e.g. during dissolved gas analysis.

Therefore, all asset and measurement data can be collected and managed in a central location or shared database. The data can also be recorded throughout the entire lifecycle of an asset, which enables trending analysis. All of this also has a positive impact on test reporting, as the desired information can be selected from the data in a targeted manner and compiled thorough. Flexible import and export interfaces ensure simple data exchange with other software systems and integration into a larger software eco-system.

Software-based testing also has additional benefits, as a clever mix of automation and user guidance can offer a high degree of support, security, high-quality measurement results, and time savings. Corresponding automatic functions can accelerate complex steps such as specifying assets or making test execution as efficient as possible through automatic test algorithms. The validity of the obtained test results can be checked directly on site or evaluated automatically in accordance to applicable standards. Tailored user guidance also ensures quality and reliability when performing tests and of the data obtained.

Conclusion

This article describes the various challenges involved in the testing of installation equipment. It also examines what requirements testing solutions should ideally fulfil according to the current state-of-the-art, in order to enable a process that is as efficient as possible. Furthermore, it demonstrates that the suitable software support can make not only the performance of tests on equipment, but also the entire testing process including preparation and follow-up as efficient as possible.

However, operators only experience the greatest added value through intelligent use of these new opportunities. If, for ex-

Figure 4. The 3-in-1 solution offers all functions of simple circuit breaker test set, source and micro-ohmmeter in one device

ample, several test teams with optimized testing solutions are working on equipment at the same time, the maximum amount of data can be recorded in the shortest possible time, making the most efficient use of the time the installation equipment is out of operation.

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Authors

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After graduating from polytechnical college, where he studied Electrical Engineering, **Martin Pfanner** worked in the telecommunications technology sector for seven years. Since 1990, Martin has occupied a number of positions at OMICRON and is helping to shape the future of the company. Since 2016, he has been working as a Product Manager in the software-based testing and data management department.