



by Boris Bastigkeit, Thomas Schossig and Dr. Fred Steinhauser,
OMICRON electronics, Austria

Efficient Testing of Modern Protection IEDs

The reliability of electricity generation, transmission and distribution is directly related to the reliability and quality of the protection system. Regardless of which generation of protection equipment is protecting the elements of the system, it is always necessary to prove its proper functioning during commissioning, and after certain duration of service. Complex technical devices and protection equipment can fail for any reason therefore 100% security is impossible. While electromechanical relays have problems with ageing mechanisms and coils, static relays deal with drifting analog circuits and digital relays struggle with software bugs and firmware updates. Due to the inactive nature of relays during proper network conditions, a possible relay malfunction can only be detected at the instant of a power system fault.

THUS, DUE TO THE VITAL ROLE protection relays play to achieve high power system stability and also in preventing the power system owner from high financial losses due to damaged power system elements, the risk of malfunctioning relays should be minimized. Thorough commissioning and routine testing of relays should be undertaken to minimize this risk. On the other hand, trends like liberalization of the electricity market and privatization of utilities put the relay

commissioning, routine testing and protection engineering departments under pressure to save costs.

How can the quality of the protection system and as a direct result, the power system, be sustained or even improved when the staff for relay evaluation, commissioning and routine testing is generally reducing? One way to escape this dilemma is to increase the productivity of the remaining experts through automation. Automation can save the relay experts' time, allowing them to concentrate on solving and analyzing actual failures during power system operation, or relay commissioning and maintenance. Furthermore automation can even increase the depth of testing in a shorter time, raising not only the efficiency but also the quality. This article describes testing of modern relays and the impact of IEC 61850 on protection testing in a practical manner.

Challenges for today's protection engineers

One of the biggest current challenges today's protection engineers have to deal with is to master the high complexity of modern protection systems. Further challenges which are faced by

engineers (e.g. operating the systems closer to the limit, distributed generation, rising time and cost pressure etc.) will not be discussed here in detail.

Reasons for the risen complexity of modern protection devices: In order to master the field of protection engineering, one needs solid expertise and broad theoretical basics on electrical power systems. Thus the field per se is complex. The following points will show where the additional complexity of modern protection devices originates:

Multifunctional protection relays: Whereas formerly there was mostly one protection function implemented per device, nowadays prevail multifunctional protection devices. Even though the multifunctionality is not used to the full extent most of the time, it is still there and thus increases complexity.

Integration of additional functions: Transient recorder, SCADA functions, interfaces, process bus, fault locator, control functions, plc functionality, phasor measurements functions and many further functions are integrated into protection devices nowadays. The standard IEC 61850 stays abreast of this development and emphasises it

Boris Bastigkeit (IEEE, OVE) was born in 1969 in Kempton Park, South Africa. He received his MS in Electrical Engineering at the Technical University of Graz (Austria) in 1998. He joined OMICRON electronics in 1997 where he held various positions before he was appointed to his current position as head of product management in the field of testing solutions for protection and measurement systems. He is member of the working group IEC TC 95 MT4.

Thomas Schossig (IEEE) was born in 1970. He received his MS in Electrical Engineering at the Technical University of Ilmenau (Germany) in 1998. He worked as a project engineer for control systems and as a team leader for protective relaying at VA TECH SAT in Germany from 1998 until 2005. He has been working as a product manager for substation communication and protection testing products at OMICRON electronics in Austria since 2006.



by using the term "IED" (Intelligent Electronic Device) instead of calling them protection devices.

Algorithms are handled in the software (firmware): This fact results in a higher complexity, because of requirements for frequent firmware updates.

PC-Software: Modern protection devices are parametrized and read out by PC-software. Therefore one faces not only the advantages but also the problems resulting from PC usage. Only some of them are: short life cycle of the PC hardware and pc operating systems, error proneness, networking problems with the corresponding security, firewalls, driver, interface and updates issues, the classic SW bugs, different SW concepts of different vendors, etc..

Life cycle of protection devices becomes shorter: New ideas and concepts as well as rapidly developing fundamental technologies are the basis for innovations, which enter the products within increasingly shorter cycles. As a result the knowledge gained about such devices with short life cycle will also pay off for a short time.

Greater variety of interfaces: Formally one could do everything with the classical 1A/5A and 100V/110V interfaces and some contacts. Nowadays this has

changed completely. In addition to the "classical" interfaces there are interfaces to the SCADA system e.g. IEC 60870-103, Modbus, DNP, IEC 61850. For the process bus we use IEC 61850 GOOSE, non conventional VTs and CTs with low level or data interfaces like IEC 61850 Sampled Values are available. Time synchronization, communication between the protection devices (e.g. line differential protection), proprietary communication interfaces to the PC, or station computer etc. are further interfaces that have to be dealt with.

As a central result of all of these points we can see a very high amount of parameters available in modern protection devices. Finding strategies to manage all these parameters becomes more and more important.

Ways to manage the big amount of parameters

In most cases only a very small amount of parameters is actually set to configure the relay to protect certain equipment. Therefore utilities for a common application such as line protection often define a standard setting for a standard application. This standard setting often is defined in connection with the acceptance test by the standardization group of the utility.

During the evolution from single - to multifunctional relays, the challenges for protection testing have evolved on at least the same scale.

This standardization work is usually done in the laboratory of the utility. The field engineers who then apply the relays to the local conditions do not touch the standardized parameters anymore. Only a very limited amount of relevant parameters is varied, thus reducing the complexity.

Often the standardization process inside the utility does not stop there. Many utilities have started to create standard test plans in connection with the settings´ standardization process. These standard test plans are handed over to the field engineers together with the standard settings.

Relay Test Automation

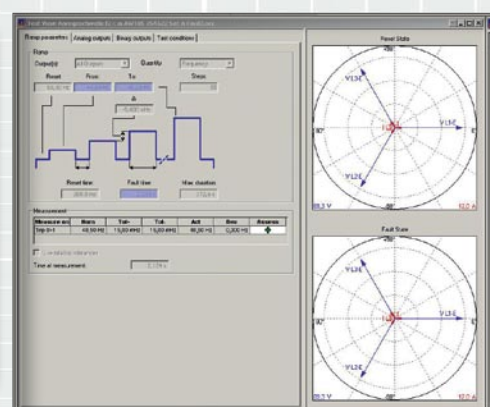
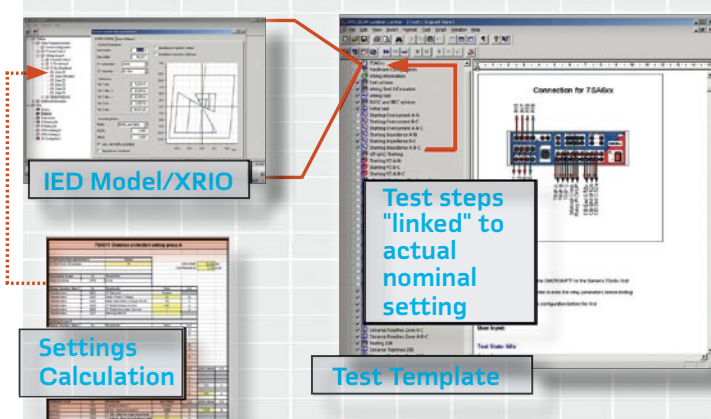
The last section of this article highlights that standardization is the key strategy to dealing with the challenges protection engineers

Finding strategies to handle the complexity.

Many utilities have started to create standard test plans in connection with the settings´ standardization process. These standard test plans are handed over to the field engineers together with the standard settings.

1 IED test plans ideally adapt to: the nominal data derived from the settings calculation source

2 Pulse ramp functions Test the pick up of overlapping elements



We are not perfect and errors do happen. Therefore we try to minimize errors by testing. Focus should be on errors in setting and configuring the IED as well as checking the plausibility of the settings calculation.

in today's utilities are facing. Once the utility has standardized on a few relay types and its basic parameterization, a next natural step is to create standardized test plans that help the engineer to verify the IEDs functionality in a standardized manner. "Test automation" in this regard does not mean to create a fully automated procedure that runs through after a single button click. Well, it can be. However, the focus is more on creating a standardized procedure that verifies in predefined and standardized comprehensible test portions - step by step - all the important functionalities of the IED under test.

Testing an IED shall assure that its designated (protective) function is fulfilled. Before putting together test strategies, possible reasons for relay malfunctions should be considered:

- The firmware of modern digital relays is complex software and like all software it is not free of bugs.

- Although the influence of hardware component drift or error could be reduced in digital protection equipment (self monitoring), there is still hardware which is not monitored and which may fail.

- Human errors. We are not perfect and mistakes do happen. Therefore we try to minimize errors by testing. Focus should be on errors in setting and configuring the IED as

well as checking the plausibility of the settings calculation. Dozens of parameters have to be set correctly. Only 1 wrong setting may lead to a maloperation when correct operation would be important.

- Frequent firmware updates of modern relays are on the one hand eliminating errors, but may also be a source for new errors.

- Changes in network topology become more frequent due to trends such as distributed generation and network liberalization. Changes in relay settings are an error source and correct operation after changed settings should be verified.

- If the IEC61850 functionality of IEDs is utilized, the question arises what happens if the SCD file has to be changed/updated. For example when a new feeder is added to an existing substation. The SCD file will be changed because it describes the entire substations. Now, changing the SCD file means changing the configuration and parameterization data for all IEDs in the substation. To be on the safe side after the IEDs have been updated, retesting the IEDs after each SCD file update is recommended.

- Wiring errors and errors in the protection system including CTs, VTs, Breakers, etc.

Modern IEDs present many hurdles for test automation:

The challenges for protection testing have evolved significantly.

- Many, often overlapping functions, are active in parallel.

- Not every function has a dedicated contact routed for easy checking of its proper functioning.

- The parallel operation and interaction of those functions should especially be tested.

- Free programmable logic functions may differ from relay to relay and make it impossible to create standardized test plans.

General rules for successful test automation programs:

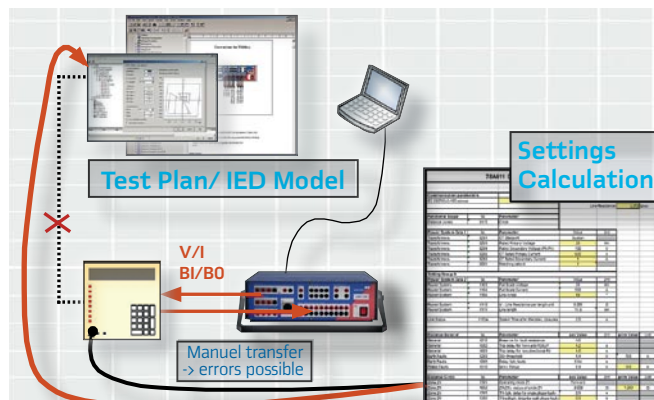
- Standardization of relays and their parameterization is the key to successful test automation.

- 100% Standardization is impossible therefore a test automation system has to provide the tools to quickly and easily adapt standard test plans to fit non standard applications.

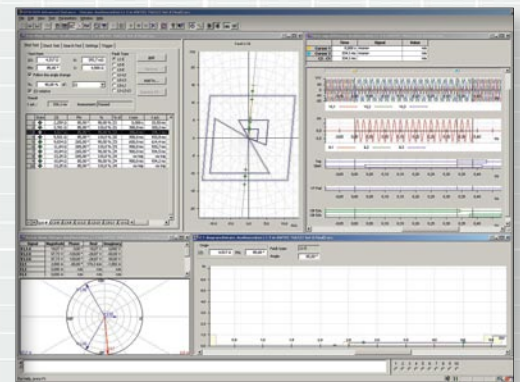
The listed aspects lead to the creation of guidelines which should be observed when creating standardized test templates:

1. A relay has to be tested to its actual settings. Testing a relay to factory default settings or other

3 Errors in setting the IED: remain undetected by deriving the nominal data from the IED



4 Test results assessment Visualization of the test steps is important





changed settings does not guarantee a proper function with actual settings. -> Automatic test plans (Fig.1) have a possibility to adapt to fit the actual relay settings. E.g. by linking the test steps to the relay settings.

2. The person in charge should understand all aspects of the test plan and should be able to adapt the test plan if necessary -> Tools for creating a test plan should be easy to use in such a way that no programming is required to build or change it. Ideally the test plan is built by adding/adapting standard test functions (test modules) that can easily be linked to the actual settings of the protection.

3. Blocking/disabling of overlapping functions for testing purposes should not be done, because the unblocking/enabling can be forgotten after the test. Secondly the influence the parallel functions may have on each other (e.g. limited processing power) is not tested. -> The test software must support test algorithms that allow stimulation of exactly the function under test although the other functions are active in parallel (Fig. 2).

4. GOOSE possibilities: The GOOSE can be used for transmission of any kind of data (startup, trip, measuring values, counters). This offers new possibilities for protection itself and its testing. Due to GOOSE's multicast mechanism

distribution every information is available everywhere- in every feeder for instance. Distributed functionalities can be realized without additional effort for wiring etc. -> Utilizing GOOSE messages for testing purposes allows reducing the complexity of test plans. The complexity of test plans can be reduced if efficient testing is considered in the engineering phase for the protection IEDs already.

5. Testing of relays should be done against the settings calculated in the relay setting sheet. Reading the settings file directly from the relay and testing against those settings introduces the danger of (human) errors when setting the relay or unwanted re-parameterizations, for whatever reasons, are not discovered. -> Testing against the settings read directly from the relay is not covering an important error source (Fig. 3).

6. As it is possible to freely program the logic of modern digital relays, it is required that the tester can easily add new tests to a standard test plan for those "non standard" functions. -> Adaptation of standard test plans has to be easily possible.

7. Automatic assessment of test results, according to given relay tolerances, is a must. However, the automatic assessment can never fully replace the plausibility check of

The GOOSE message can be used for transmission of any kind of data.

the results by the testing relay expert. -> Visualization and straight forward graphical representation of the results is necessary to allow the expert a quick and easy plausibility check of the test results (Fig. 4).

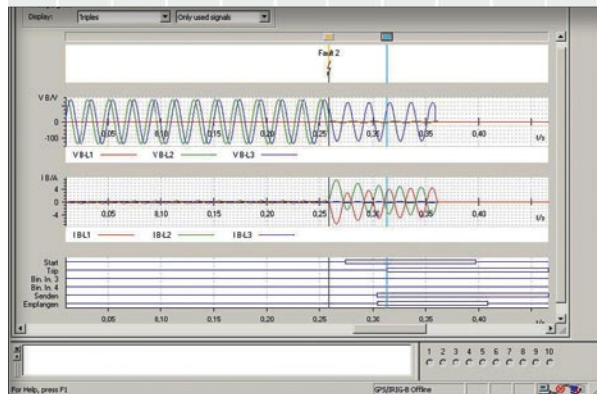
8. Utilization of easy to use network simulation tools helps to do a plausibility check if the protection IEDs basic settings are correct. This way errors in calculating the IED parameters or setting errors can be discovered. -> Ideally the test plan contains test steps that simulate faults in a network model that is based on the primary data of the protected network components (Fig. 5).

9. Once a failure is found in a relay, be it the relay itself, a wrong setting or even a wrong test plan, it is important to have the appropriate analysis tools and support to quickly locate and eliminate the error source. -> Automated testing requires very good documentation and visualization with event recordings and graphics of all the test steps. The test set should provide troubleshooting

Dr. Fred Steinhauser was born in Feldkirch, Austria, in 1960. He studied Electrical Engineering at the Technical University of Vienna, where he obtained his diploma in 1986 and received a Dr. of Technical Sciences in 1991. In 1998 he joined OMICRON, where he worked on several aspects of testing power system protection. Since 2000 he works as a product manager with a focus on substation communication issues. Fred Steinhauser is a representative of OMICRON in the UCA International Users Group. He is member of WG10 and WG17 in the TC57 of the IEC working on the standard IEC 61850, and a member of CIGRÉ SC B5.

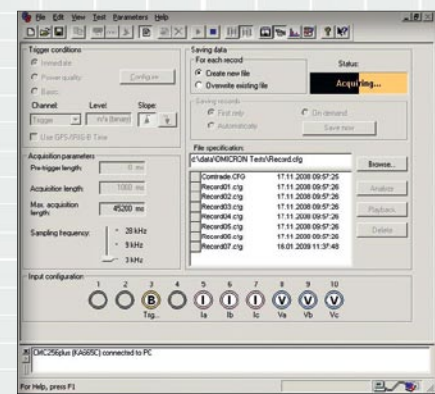
5 Transient network simulation

It can be used for plausibility testing of the IED parameterization



6 Troubleshooting tool

Transient recorder function in a test set



The test set should provide trouble - shooting tools like transient recording, wiring checking, etc.

tools like transient recording, wiring checking tools and measurement functions (Fig. 6).

Generating Fault Quantities

It is the task of an IED (especially for protection purposes) to detect faults on assets. To do this the IED receives information regarding the developing of values as current, voltage, phase shift... For testing these values can be provided in different manners.

Conventional measuring transformers: As mentioned the 1A/5A and 100V/110V is a well established interface for a long time already. Due to that test sets are available and approved. Combined with powerful software a test even of complicated protection functions is possible.

Distributed functions (as busbar protection) especially with different nominal values of the CTs, require test sets with high power and high amplitudes of currents.

Non-Conventional Measuring Transformers: Non conventional transformers such as Rogowski coils and optical CTs, solve some known problems of conventional transformers - for example CT saturation. A disadvantage might be non standardized interfaces and protocols used, that can make them difficult to test. Sampled Values as described in the next paragraph might accelerate the use of this technology. In the cases when non-conventional instrument

transformers are used, Sampled Values primary injection is accepted as a trustworthy test.

Sampled Values: IEC 61850-9-2 describes a special mapping to transmit measuring values as primary values on Ethernet, they are called "Sampled Measured Values" or "Sampled Values" (SV). A special guideline ("9-2LE" defines a certain profile of this standard with dataset (what are the values to be transmitted-voltages and currents) and sample rate (80 samples per cycle for protection and measurement, 256 for Power Quality purposes) and enables an easy implementation for vendors and users. So called Merging Units (MUs) produce the SV streams. If the standard does not describe a special technology to make sampled values out of "real" values these MUs can be utilized for output of non-conventional transformers or conventional transformers and can even be a part of the transformer itself.

Primary Injection: For a plausibility check and even for "real" protection testing, primary injection will become more and more important. If in case of SV the measuring values are "just a stream of primary values" the proper functionality of an MU can be easily tested in that case. For testing the verisimilitude a powerful "secondary injection test set" is sufficient.

8 GOOSE performance calculation summary

Average value \bar{t} and standard deviation σ

Calculating DUT performance:

$$\bar{t}_{DUT} = \bar{t}_{RT}/2 + \sigma_{TS}, \quad \sigma_{DUT} = \sqrt{\sigma_{RT}^2/2 + \sigma_{TS}^2}$$

Calibrating the test set:

$$\bar{t}_{TS} = \bar{t}_{RT}/4, \quad \sigma_{TS} = \sigma_{RT}/2$$

Confidence interval: $[\bar{t} - k\sigma, \bar{t} + k\sigma]$

$k \approx 4$ for 99.99% confidence

$k \approx 2.6$ for 99% confidence

Maximum rating: $\bar{t} + k\sigma$

Advanced Testing

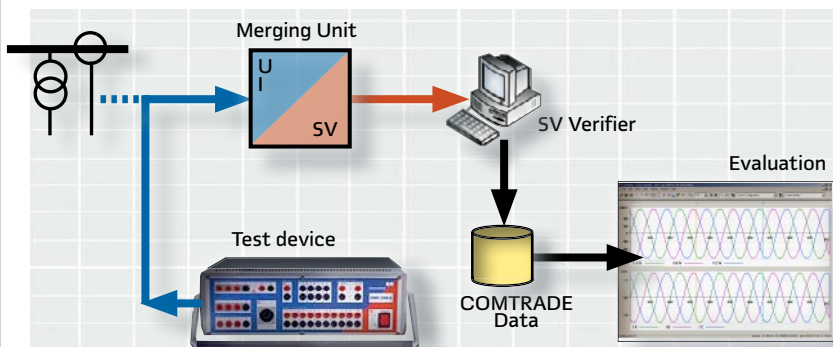
Background: IEC 61850 utilizes different possibilities of communication. For client/server communication and exchange of non time critical information between a substation HMI (client) and an IED (server) services such as reporting, logging and control are used. On the other hand the standard describes a set of "real time services" for fast exchange of data such as the mentioned GOOSE and Sampled Values. For this "real time data" a conventional client-server communication is not sufficient and an unconfirmed mechanism is used - a multicast that spreads out information over a network.

Protection Testing in that case involves the measurement of the performance of the overall transfer time as described in IEC 61850-5.

The standard describes several performance classes. For important information as "trip" the overall transmission time shall be less than 3 ms This requires the testing of the overall system.

GOOSE Performance: Occasionally there are reports about failed GOOSE applications due to insufficient GOOSE performance. In some places this has even raised doubts about the usability of GOOSE in general. Most of these problems emerge from non-recommended usage

7 Secondary Injection for Testing of MUs



Primary injection will become more important for testing of MU with non-conventional sensors.

