Conventional Testing in Times of IEC61850

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Abstract

With the advent of IEC61850 standardization, increasingly more power utilities adopt a standardized environment with modern Intelligent Electronic Devices (IEDs) in their substations. As a consequence, conventional test procedures face a future of uncertainty, and established testing routines are called into question. The functionalities and new protection system arrangements of IEDs cause changes in maintenance routines which imply re-thinking of protective panel design. The authors identify existing requirements and how they influence panel design and evaluate to what degree new technologies affect the use of traditional test interfaces for relay testing.

Key words: IEC61850, test interface, secondary injection, dynamic tests, standards, regulations, maintenance tests, relay firmware updates.

Introduction

The basic principle behind power system protection is the perpetuation of system integrity and availability. Reliability is an important requisite for electrical power systems, since both the economy and the development of countries depend on it. To increase reliability in fault detection and isolation, protective equipment in substations needs to be tested for malfunctions. If any malfunction remains undetected during testing, the result may be a miss or a false alarm of a fault event and an incorrect activation of a circuit breaker. Such a deficient fault handling may result in damage to substation equipment which compromises the healthy parts of the system. This in turn affects consumers and may implicate penalties from regulators. Therefore, many regulatory bodies issue rules on proactive practices to ensure reliability of the power systems. In some countries, governments have directly or indirectly established regulations covering this. North America, Germany and Brazil serve as examples to show different approaches.

Individual protection and control devices in substations have become more and more intelligent due to the incorporation of new digital technology into the equipment. Such a development has driven the terminology of Intelligent Electronic Devices (IEDs) which applies likewise to microprocessor-based relays, fault recorders, circuit breakers and reclosers. The technological progress creates some discrepancies between new and old substation hardware components and substation maintenance procedures. On the one hand, modern IEDs come along with more and more advanced control, operating and self-monitoring capabilities. On the other hand, most of the conventional hardware structure is retained with a great portion of analog cabling in today's substations. Hence, the improved functionality of IEDs may cast special doubt on conventional testing procedures used to maintain protective systems with an analog communication structure.

In this paper, it is investigated why conventional test procedures with the use of analog test interfaces are still necessary in substations with a coexistence of both digital and analog communication channels. To this end, the paper discusses implications of the standard IEC61850 in general and of some official regulations in particular, with respect to existing substation technologies and maintenance procedures. The use of test interfaces inside protective relay panels is revisited and it is argued in favor of their continued use in the future.

Conventional Protective Relay Testing

Protective relays play a crucial role in electrical power systems. Relays read out scaled down currents and voltages from the system lines in order to detect condition related faults and actuate circuit breakers. Relays are expected to have almost instantaneous and highly effective detection and signaling. Different types of relays with an inherently different working principle have been developed which satisfy this expectation to a varying degree.

Since the beginning of the electrical energy distribution systems, the need for protection against faults was quickly perceived as essential to save equipment against damage from stress currents, abnormal voltage levels and phase discrepancies. Electromechanical relays, the first type largely available, provide good electrical contacts through a mechanism similar to an AC motor, but their precision tuning typically deteriorates with operation time. The next technological step were solid state relays, which no longer had moving parts, but higher power consumption and were initially affected by some measurement inaccuracies related to early semiconductors. When digital relays came on the market, embedded intelligent logic inside the devices aided in the detection and monitoring of failure or abnormalities.

In the beginning, regular testing of electromagnetic relays was essential to immediately detect any developing drift from the optimal tuning of the mechanical parts. Associated maintenance tests had to be performed every 1 to 6 years. Later, little or no changes were observed for the common maintenance procedures for solid state relays. Finally, gradual changes in relay test routines have been observed for the digital relays. Such relays started to comprise more and more sophisticated self-monitoring functions. Such an automatization took over some of the manual testing sequences and made them obsolete.

Instrument transformers and test interfaces

Conventional Instrument Transformers (CITs), i.e. current transformers (CTs) and voltage transformers (VTs) are used to scale down system currents and voltages to safely make them available for measuring. CITs can be either for outdoor use along with high voltage and current lines, or for indoor use. The secondary circuits (secondaries) are commonly connected to the inputs of relays, meters, fault recorders and merging units (MUs).

The traditional way to interconnect secondaries to any measuring or recording device is through test interfaces or test switches. These interfaces allow a permanent panel wiring and electrical isolation of the device, when they are activated. This is desired for maintenance procedures such as tests, firmware upgrades and device substitution, because it avoids the need to shut down the system. Ostmeier, 2005, [1] discussed the advantages of test interfaces in general and compares different approaches, i.e. rotary switches, knife-blade test switches and test block/test plug combinations, which are prevailing in different regions around the globe.

If applicable test interfaces are used, testing can become both much safer and much more efficient due to the following reasons. Firstly, the IEDs which are scheduled for testing can safely be disconnected from the system while the system remains in operation. Most importantly, the CT secondaries are automatically short circuited with a built-in "make-before-break" functionality, as soon as the disconnection takes place. Secondly, the test set can easily be connected to the secondaries, since most test interfaces have integrated test access points. This way, test interfaces remove the need for any re-wiring before or after testing. Thirdly, test interfaces contribute to a clean panel design. They either may be mounted on a rack panel in the panel itself or they may be surface-mounted on a rail or similar fastener at the bottom of the panel. Figure 1 presents a conceptual wiring scheme for the connection between CITs and the protective relay through the use of a test interface with the features mentioned above.

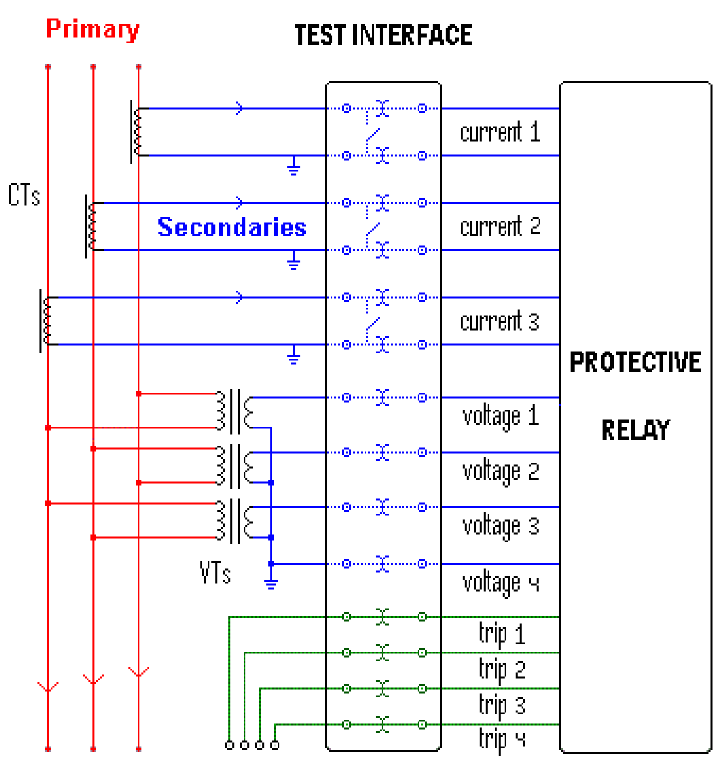

Figure 1 – Conceptual wiring scheme for secondary circuits with integrated test interface

A single test interface is able to accommodate next to each other both relay inputs (CIT secondaries) and relay outputs (trip circuits). Hence, test interfaces allow for full control of both relay inputs and outputs during secondary injection tests (Figure 1). By creating a customized modular composition, test interfaces can be optimized for specific testing routines and protective panel design as demonstrated by Portillo, Woolard & Planert, 2010 [2].

Advent of IEC61850

IEC61850 Communication Networks and Systems for Power Utility Automation has had a worldwide impact on power substation equipment. Development started in the 1990's and the IEC work group is still improving the standard today. The implications on electrical power stations are twofold, since IEC61850 implies both changes in hardware structure and installed software. On the hardware side, the goal of IEC61850 is a multi-vendor interoperability of standardized IEDs with low installation costs and reduced manual installation efforts. On the software side, the goal of IEC61850 is a modern network and communication technology with a standardized configuration language and a reduced setup for self-describing IEDs.

Prior to the IEC standard, microprocessor based relays came on the market since the 1980's as a next generation after solid state approach. With the new relays, intelligent logic could be put inside the device. This had promising benefits in conjunction with novel communication schemes between devices. Overall, a new and defined logic of IED component description and IED communication structure enabled protection, automation and control to enter another level. The details in view of testing are listed in the following:

- IEC61850 standardization allows more flexible choice and management of hardware.
- IEDs allow a mean time between failure (MTBF) far larger than electromechanical and solid state relays, causing the maintenance schedule to adapt.
- IED data integrate with local and remote control devices which allow real-time system monitoring providing ways to quick event troubleshooting.
- Logic programming capabilities of test sets allow for an automated test preparation.
- Test frequency can be lower compared to electromechanical and solid-state relays.

IEC61850 can change dramatically the substation automation and control structure which affects established test practices of protective relays. As a consequence, industry faces the beginning of a transition moment, in which the effects of IEC61850 are being noticed. The standard is intended to integrate into existing installations and to traditional schemes and devices. Current digital relays, which are IEC61850 compliant, keep binary I/O for backwards compatibility and may bring proprietary functionalities as well.

Software is needed

Since today's IEDs run complex firmware which controls many hardware interfaces, such firmware may be prone to bugs. Also, most of the IEDs come along with a comprehensive functionality which e.g. includes a phase measuring of the input signal or some sophisticated control and recording functions. Such functionality may evolve over time and be upgraded by the manufacturer every now and then. Since manufacturers want to offer the most potent firmware to their customers, they issue frequent firmware updates for their IEDs.

The updates are typically announced by the manufacturer in a newsletter. Then, a utility company may decide to download the update from the internet and install it via a serial port at the IED. Depending on the manufacturer and the type of IED, the periodicity of such updates varies from one update every other year to up to 10 updates per year (personal communication with some relay manufacturers).

If a firmware update is about to be installed on an IED, utility companies have to ensure proper operation after the restart of such device. In this context, user guides of utility companies typically instruct their personnel how to handle updated IEDs. For example, the Electric Reliability Council of Texas (ERCOT) stipulates that the owner must test and verify the proper operation of each "modified" protective relay system before placing it back into service. One way of doing it would be to replicate the field settings in the lab and perform a functional test on a specimen IED in the lab. In this case, no tests in the field would be performed and only one lab IED would be tested as a sample for all the field IEDs with the same settings. However, it might not always be given that the same conditions both hold in the field and in the lab. Hence, another and more reliable way of doing it would be to test all the affected IEDs in the field. This would require a lot of testing, but it would also generate the highest reliability with regards to the operation of the tested systems as a whole.

In such a way, firmware updates involve some additional commissioning tests in substations. The system as a whole may have to be commissioned, since an integral part of it has been updated and the system's communication network may need to be verified again. Keeping in mind that the complexity of IEDs and their joint communication currently is increasing, the frequency of firmware updates and related commissioning tests is still expected to grow in the future.

Non-conventional instrument transformers

The use of non-conventional instrument transformers (NCITs) is foreseen by IEC61850-9-2LE. Some of these devices or at least their concepts are not new, but NCITs have only been put into operation in prototype substations and few real-world substations due to high costs and the need to re-organize the substation structure. Nevertheless, advances in digital and optic technology make possible their adoption in the next decades.

NCITs mainly consist of:

- Rogowski Coils and optical Faraday Effect Sensors, both for current measurements
- resistive/capacitive voltage dividers and optical sensors for voltage measurements

The transducers of NCITs typically embed a sensor which converts the measured currents and voltages into sampled values (IEC61850-9-2LE). Clearly, the biggest benefit of NCITs is a better electrical isolation from the high voltage yard to the protective panel, especially with the use of fiber-optic as the intercommunication wiring. Some IEDs allow a mixed configuration with IEC61850-9-2LE and conventional CT and VT secondaries. This is used, for example, in transformer differential protection applications with NCITs on the high-voltage side and CITs on the low-voltage side.

Whenever analog inputs are present, it may be advisable to join up the circuit with a test block/switch with the ability to disconnect the circuit and to provide test access points.

Figure 2 separates the analog and digital side of equipment arrangement which is currently possible. It does not consider circuit breakers and the DC trip circuitry, although most of them in use today would reside on the analog side of Figure 2. IEC61850 defined a System BUS and a Process BUS as separate network levels. The System BUS serves as the main intercommunication between IEDs as well as some extensions of the system. The Process BUS is mainly used to exchange sampled values from MUs to IEDs. Notedly, this enabled a generic separation, i.e. electric isolation, between relays (IEDs) and the IT secondaries.

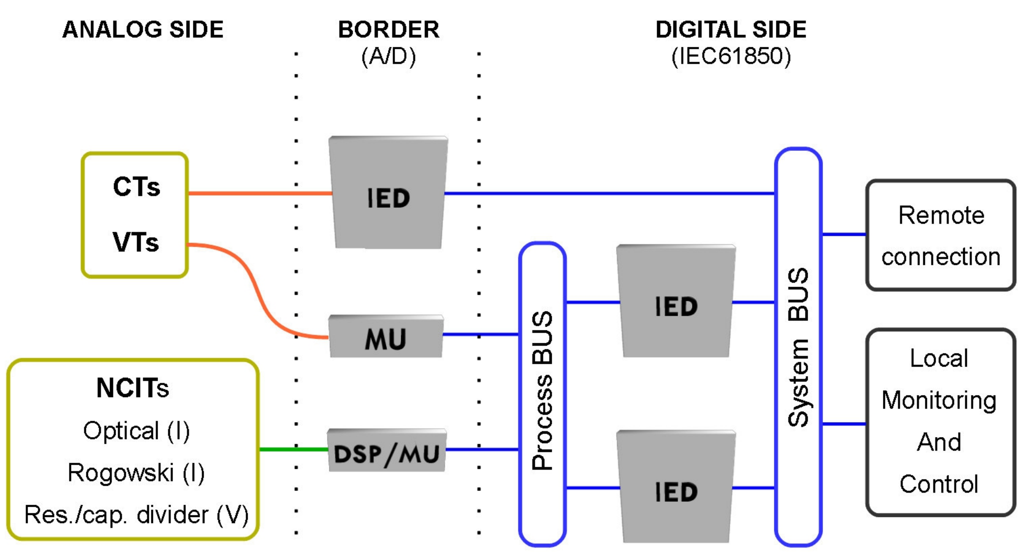

Figure 2 – Analog to digital frontier in IEC61850 installations

All instrument transformers (conventional or non-conventional) are intrinsically analog devices. Notedly, CITs are passive devices that have high-power signals in contrast to NCITs. NCITs in turn require aided signal processing and generate mainly low-power signals.

Practically all approaches on NCITs have some kind of embedded processing unit inside the device so an already digitized signal is passed on.

Regulations, Standards And Recommendations

The work of a protection scheme designer is influenced by various sources. Partially on a voluntary basis, in some cases legally mandatory. Guidelines by well established associations or even governments purposely require a certain protection level to ensure performance reliability of the national transmission and distribution grid. The grid interconnectivity to neighboring countries makes international standards necessary as issued e.g. by IEEE and IEC. This way, some benchmarks are set for the quality of the frontier overlapping electricity transmission.

Looking at North America, Germany and Brazil, some national approaches are compared in the following.

North America

The North American Electric Reliability Corporation (NERC) publishes guidelines for minimum reliability requirements for the bulk power system of the USA, Canada and Baja California (in Mexico). For about 40 years, the adoption of those guidelines was on a voluntary basis. Since the big blackout in 2003, NERC has reacted more to its related federal commissions. Nowadays these guidelines are translated to mandatory regulations and applicable standards which also enforce penalties.

NERC's PRC-005 [3] is an up-to-date example which applies to power plant owners as well as transmission and distribution providers belonging to the Bulk Electric System (BES). The standard requires a Protection System Maintenance Program (PSMP), in which every component of the protection system has a specified maintenance and test method and time table, cf. Table 1 and Table 2. PRC-005 also requires documentation and continuous recording of the implemented PSMP.

On an international level, IEEE and IEC provide guidance on protection of the overall power grid. They are not subject to national regulations and can focus on supporting technological innovations.

Table 1 – Time Based Maintenance Method

COMPONENT ATRIBUTES	MINIMUM INTERVAL
Protective relays	6 to 12 years depending on type
Communication systems	4 months to 12 years depending on self-monitoring characteristics or its absence
Voltage and current sensing devices providing inputs to protective relays	12 years to non-specified depending on system
Protection system station DC supply	4 months for some systems, with a maximum of 6 years to others
Control circuitry associated with protective functions	6 or 12 years or non-specified, according to system
Alarming paths and monitoring	12 years to non specified
Maintenance activities and intervals for distributed UFLS and distributed UVLS systems	6 or 12 years or non-specified, according to system

Table 2 – Performance Based Maintenance Method

TOPICS	CRITERIA
Definition of segment	Consistent group of devices (60 devices minimum)
Countable events in segments	Less than 4% in last year
Immediate maintenance	Components with more than 5% countable events
Establish maximum maintenance intervals	Based on previous year data

Germany

Germany follows a slightly different approach of enforcing quality standards in the power industry. Lacking a comparable organization to the American NERC, the German Law on the Energy Industry (EnWG) defines an energy system which is "safety compliant", if commonly acknowledged "rules of technology" have been respected [EnBW 49]. The law further specifies the acknowledgment by following the guidelines published by the Association for Electrical, Electronic & Information Technologies (VDE). The VDE cooperates closely with members of IEEE, IEC and other technical associations.

Lacking the desired level of detail for time intervals of testing and maintenance routines provided by VDE standards, the EnWG authorizes the German Federal Network Agency to further specify mandatory standards, in which the Network Agency is bound to national standards.

Brazil

The Brazilian Agency of Electrical Energy (ANEEL) is the regulator of the national electrical market. ANEEL oversees power utilities, consumers and the National Operator of SIN (ONS). SIN (Interconnected Grid of Brazil) is the Brazilian equivalent to the BES in the United States. The most important regulations for maintenance of protective systems of the Brazilian power grid are PRODIST, published by ANEEL, and Grid Procedures by ONS.

Grid Procedures defines the procedures and requisites needed to perform the operation planning, transmission administration, programming and real time operation inside SIN. Minimum requisites regarding protective and telecommunication systems are given in sub-module 2.6 [4]: All protective system equipment must have auto-monitoring and auto-diagnostic capabilities; maintenance groups must be able to test devices while the system operates; digital fault recorders (DFRs) must be installed in both new and existing installations, as a completely separate system.

Compared to PRC-005, maintenance and testing requisites require different approaches. Among other topics, the ANEEL and ONS regulations require from the utilities a state of the art protection scheme. Similar to the German energy law, Grid Procedures forces utility companies to comply to the latest official standards. ONS declares the latest revisions of the Brazilian Association of Electrical Standards (ABNT) as the valid ones. If no ABNT standards are available for a specific case, the utilities are expected to follow IEC.

Consequences of the implemented standards

The general purpose of establishing a common ground of minimum safety and reliability requirements in the affected region is fulfilled by all three discussed approaches. Regulative bodies provide standards for utilities to support the decision making process for protection scheme design, utilized equipment and type and frequency of ongoing maintenance procedures. At the same time a higher level of enforced standardization increases time consuming documentation to prove the fulfillment of the regulations.

With the very strict enforcement of the use of monitored microprocessor relays in an IEC61850 communication network, Brazil does not leave much room for still well functioning but outdated installations. The German law enforcement leaves the decision on what kind of aged equipment may still remain in service to the VDE. As long as the VDE standards do not define an outdated technology, utilities are free to keep them in service. NERC in North America is settled in the middle of both extremes. Even though the usage of old equipment does not violate the regulations, NERC sets strong incentives to switch, rebuild or retrofit installations, by allowing significantly smaller test intervals for up to date equipment.

Discussion

Nowadays many requirements must be addressed in order to design protective relay panels and build substation maintenance routines. Intelligent, flexible and functional protective relay panels are essential in order to assure maintenance capabilities, safety requirements, and integration of functions. Today the first substations that have fully adapted the IEC61850 protocol are in service, but most utilities find themselves in a challenging situation of upgrading their systems through retrofits. Protective relay panel design be it in-house or outsourced, has to specify equipment with respect to costs, new technology benefits, worker's safety requirements, technical entities' standards and recommendations and official reliability requirements.

In times of the IEC61850 a minimum of hardwired connections for relays, MUs and meters are retained in present and future panel designs. Although the adoption of NCITs becomes reality, traditional CTs and VTs used to scale down system currents and voltages are far from being put into recess. Proper panel design includes test interfaces in order to adequately deal with the secondaries. Also, the use of test interfaces can achieve economic panel space usage, providing flexibility for most maintenance needs of protective panel devices.

Need for firmware updates are nowadays necessary for micro-processor relays. For these updates, some utility companies choose to take the relays offline just as for testing. In many cases, such a firmware update may require some kind of commissioning testing of the protective system after completion.

Conclusion

Due to advances in technology, less frequent maintenance is allowed for protective systems. However, this decrease in officially scheduled maintenance is partly compensated by frequent firmware updates of IEDs which require some additional testing procedures on demand. The use of conventional instrument transformers requires a certain panel flexibility for tests. The possibility for an exchange of equipment during normal system operation and the provision of test access points in the secondaries still justify the use of permanently installed test interfaces. Modular designed test switches can lead to optimized panel space savings and allow testing and emergency procedures without system shut down. Since conventional instrument transformers are expected to be prevailing in substations around the globe for an incalculable amount of time, test interface will remain an essential component of the protection panel.

Governments, ministries, official agencies and regulators require reliability of electrical power systems, affecting directly protective systems maintenance and its maintenance strategies. Power utilities must observe official regulations regarding reliability and provide workers with sufficient safety conditions. Definition of maintenance plans and personnel training on techniques must follow some guidelines. Those guidelines gradually incorporate new maintenance capabilities introduced by IEC61850, but mostly still tackle safety concerns related to secondaries of conventional instrument transformers.

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Biographies

Roberto Eick received his B.S. in Electrical Engineering (2012) from Santa Maria Federal University, Brazil. Following a three month work experience at SecuBrasil Ltda during 2013, Roberto joined SecuControl Produktions GmbH in Germany. His research interests include test interface applications and protective relay panel design.

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Benno Hornischer received his master level degree (Diplom Ing.) in Industrial Engineering from the Technical University Braunschweig, Germany, in 2012. He joined SecuControl in Germany after his graduation. Benno now works as a sales engineer for SecuControl, Inc., focusing on the US and East Asian markets.

Frank Hergeroeder received a Master of Arts in English Literature from the Free University Berlin, Germany, in 1992. He went on to earn a Master of Business Administration from the Rotterdam School of Management, the Netherlands, in 1998. Since 1992, he has been working in various managerial functions in the protection and automation industry – most recently as CEO for SecuControl, Hettstedt, Germany, and SecuControl, Alexandria, VA, USA. He is a member of the IEEE.