How to test digital relays

by Javier Palomino and Eduardo Marchesi, EuroSMC, Spain

Modern, so-called digital relays are no longer relays, as understood in the traditional meaning. Instead, these sophisticated, compact and versatile microprocessor-based devices are actually complete protection and control sub-systems.

They feature the electronics, control and computing resources needed to implement a full protection scheme rather than a few more or less coupled protection functions.

Former, now obsolete - though still ubiquitous - electromechanical and solid state relays have long time conditioned the way in which every elementary protective function is accomplished and implemented. This heritage is still evident in the name we continue to give to (and the way we still handle) substantial relay dynamics like reset time and maximum torque. The resulting transitional stage will persist in old power grids, because the tight dependencies existing between the scheme's design and the working characteristics of traditional relays make direct, one-to-one replacement an almost impossible task.

Testing

In its most comprehensive conception, relay testing involves complete, realistic fault simulation. Simulators combine powerful computer and signal generation resources for accurate real-time synthetic production of, and data acquisition from, an electrical fault in order to fully check a modern protective IED for correct operation.

How to test digital relays

by Javier Palomino and Eduardo Marchesi, EuroSMC, Spain

Modern, so-called digital relays are no longer relays, as understood in the traditional meaning. Instead, these sophisticated, compact and versatile microprocessor-based devices are actually complete protection and control sub-systems.

They feature the electronics, control and computing resources needed to implement a full protection scheme rather than a few more or less coupled protection functions.

Former, now obsolete - though still ubiquitous - electromechanical and solid state relays have long time conditioned the way in which every elementary protective function is accomplished and implemented. This heritage is still evident in the name we continue to give to (and the way we still handle) substantial relay dynamics like reset time and maximum torque. The resulting transitional stage will persist in old power grids, because the tight dependencies existing between the scheme's design and the working characteristics of traditional relays make direct, one-to-one replacement an almost impossible task.

However, the advantages of using digital relays greatly compensate the cost of replacement and, naturally, determine the obvious choice for any new installation. Reliability, versatility, accuracy and manageability are just a few and, for the sake of this discussion, convenience in testing and maintenance ultimately define digital relays as the best pieces of technology at the core of any modern protective system.

Table I illustrates the main differences between traditional and digital relays in the context of testing activities, required tools and necessary skills.

Table 1: Differences between traditional and digital relays.

<table>
<thead>
<tr>
<th></th>
<th>Traditional relay</th>
<th>Digital relay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difficulty of type testing</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Difficulty of commissioning</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Frequency of routine testing</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Frequency of specific testing</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>Computer-based test functions required</td>
<td>Recommended</td>
<td>Yes</td>
</tr>
<tr>
<td>Required operator skills</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

Fig. 1: Functional diagram of a traditional relay

Though the use of simulators is mandatory in some of the implementation design stages, most testing is conducted using simpler equipment, typically portable devices, and sometimes fixed test appliances that are installed in automation racks and panels along with the relays themselves.

Traditional relays differ from IEDs in the way they can - and should - be tested, and different test levels and goals must be distinguished, too, according to different test scenarios: type (application) testing, commissioning, specific (diagnostic, corrective) testing and routine maintenance.

energize - November 2007 - Page 41
**Type Testing**

Type Testing is called before a new relay model enters the protection system, and basically consists of assessing the intended protective application(s) and the relay’s capacity of interaction with other components in a scheme. The primary goal of type testing is to validate a product’s suitability to a given protective function in the context of a scheme. Closed-loop test procedures typically associated to type testing may involve the use of complex, specific methodology and highly specialized equipment like fault simulators, as mentioned above. Simulators are dedicated, expensive equipment, usually rack-mounted and engineered to stress the design characteristics of protective IEDs in a laboratory environment, to where IEDs are brought for testing. A brief look at the IEEE’s recommendation for fault simulators’ characteristics (see Table 2) will give a good idea of what closed-loop test execution is all about. Type test execution goes well beyond just applying a discrete series of static CT and VT secondary magnitudes across the protective terminal’s inputs. The need for high power values, awesome I/O capabilities, complex modeling, intensive parametric calculations, real-time generation of, and data acquisition from line-level faults and logical events precludes the use of commonplace portable test sets for this job.

**Commissioning testing**

Commissioning tests are conducted on the installed equipment right before the electrical facility or any of its sections comes into service for the first time. This definition leads to two important considerations that determine the characteristics of needed methods and tools:

- Portable equipment is required for on-site testing
- Relays are tested as an integral part of a multi-function protective assembly that includes interconnection cables, auxiliary devices and other relays, among other components.

The following is tested during commissioning:

- The IED as such a device (measurement accuracy of analogue inputs, proper initiation and reset of I/O features, relay’s settings and overall observed operation compared to theoretical response, etc.), when it is assumed to be in its final location and setup. Computer-originated mistakes in settings (like ‘32’ instead of ‘3.2’), faulty trip logic and other last-minute errors are targeted by a factor of 100 with regards to that of a traditional relay. This dramatically simplifies and reduces the frequency of routine testing with communications, management and reporting capabilities, The self-test feature available in many digital relays, combined with communications, management and reporting capabilities, dramatically simplifies and reduces the frequency of routine testing by a factor of 100 with regards to that of a traditional relay. This is true to the surprising conclusion that the more you extend your experience and appropriate tools is the key to safely reducing protective commissioning time period to a minimum.

**Specific testing**

Specific or diagnosing, corrective testing is conducted after a protective component failed to operate as expected during a real fault.

Accurate fault playback is one of the most efficient techniques to isolate the causes of relay failure in these cases. Digitized fault information recorded in a quantization file at a high sample rate is streamed into the test equipment to be played back on the suspicious relay’s analogue and digital I/Os. Relay’s recognition of the fault parameters and its consequent response in terms of operation time and I/O actuation are then compared against expected operation characteristics for a fast, conclusive location and correction of the erroneous setting(s).

**Routine maintenance testing**

The self-test feature available in many digital relays, combined with communications, management and reporting capabilities, dramatically simplifies and reduces the frequency of routine testing by a factor of 100 with regards to that of a traditional relay. This is true to the surprising conclusion that the more you extend your routine test intervals, the less subject to failure your digital relays will be.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak output voltage</td>
<td>± 300 V</td>
<td>± 50 V</td>
</tr>
<tr>
<td>Peak output current</td>
<td>± 1 A</td>
<td>± 100 A</td>
</tr>
<tr>
<td>Continuous output power</td>
<td>150 VA</td>
<td>2500 VA</td>
</tr>
<tr>
<td>Frequency response</td>
<td>0 – 10 kHz</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>&lt; 1% (0 – 1 kHz), &lt; 3% (1 – 3 kHz), &lt; 5% (above 3 kHz)</td>
<td></td>
</tr>
<tr>
<td>Power bandwidth</td>
<td>0 – 10 kHz</td>
<td></td>
</tr>
<tr>
<td>Slew rate</td>
<td>&gt; 10 V/μs</td>
<td>&gt; 2.5 V/μs</td>
</tr>
<tr>
<td>Output impedance (0 – 3 kHz)</td>
<td>&lt; 0.5 Ω</td>
<td>&gt; 250 Ω</td>
</tr>
<tr>
<td>Worst case load impedance</td>
<td>70 Ω (S/C protected)</td>
<td>5 kΩ (stable in open-circuit)</td>
</tr>
<tr>
<td>Number of digital inputs</td>
<td>16 (per terminal)</td>
<td></td>
</tr>
<tr>
<td>Digital input specs</td>
<td>Optically coupled, 50 – 100 V dc / 10 mA</td>
<td></td>
</tr>
<tr>
<td>Number of digital outputs</td>
<td>16 (per terminal)</td>
<td></td>
</tr>
<tr>
<td>Digital output rating</td>
<td>Optically coupled, 50 – 150 V dc / 200 mA</td>
<td></td>
</tr>
<tr>
<td>Number of analogue outputs</td>
<td>8 (per terminal)</td>
<td></td>
</tr>
</tbody>
</table>

Table 2: Fault simulator characteristics (subset of IEEE recommendation).
Self-test routine checks the IED’s hardware integrity at fixed intervals by examining its core functional components: power supply, microprocessor, a/d elements and information (settings) storage. When any of these critical parts fail to the self-test program, a cybernetic sentinel will trigger a pre-programmed procedure that typically includes an alarm signaling action – to the control center and, where required, a preventive contact operation that triggers other relay’s action or the opening of a breaker.

This great technological step has virtually removed the need of periodic testing of IEDs from the planned maintenance boards. Instead, shutdown times and/or other human-assisted maintenance activities are used to perform very quick (usually just checking the correct measurement of voltage, current and phase angle) tests in selected, mission-critical relays, using basic, straightforward steady state functions in the test equipment.

**Design guidelines of test equipment**

Increasing specialization of the technical staff in charge of testing, added to increased sophistication of protective devices, demand the use of computer-based technology and human-oriented interfaces that streamline the process from the lowest element-by-element test capabilities to the highest possible degree of automation. The tools must be able to adapt themselves to different test situations and requirements, including

---

**Fig. 3: Automated testing process.**
unexpected device behavior, less-than-optimal test conditions or limited operator’s skills. The reason for this is very simple: Situations cannot be adapted to the available tool’s capacity.

Physical characteristics and capacity for adequate fault simulation are evident aspects of available test equipment, which should be viewed as an ‘interface’ between the method and the device under test.

As a result of this consideration, the methodology is the actual target for good design, which in terms of technology means good software design. The test equipment must eventually be examined in terms of human interface, i.e. its ability to match the user’s capacity and the test scenario to the biggest possible degree.

When erroneous behavior results from commissioning tests, for example, fast, accurate targeting and isolation of the failing component(s) is needed. The available tools must then be able to provide the operator with specific raw functions and resources that let her/him suspend momentarily the automated procedure and proceed manually without disrupting the whole process. To achieve this, the test equipment must be designed with this casuistry in mind. Minor changes in connections, as well as immediate use of basic test and measurement features must be possible until the faulty component is located and corrected, and any pending automatic steps resumed if necessary.

In fewer words, sophistication should be a hidden, underlying design characteristic of modern test equipment which visible result is a set of powerful, fast and friendly functions that are easy to understand and can be readily located and used for each test situation.

These considerations, together with the main practical aspects that differentiate the testing scenarios described above, lead to the following as key guidelines when designing latest-generation relay test equipment:

- **Portability.** Equipment’s size, weight and shape must be a main concern. Designers must provide the best possible compromise between ergonomics and performance. A self-contained design is faster to move and is less prone to accidents with connections or missing external components.

- **Integral control provisions.** The test equipment must be fully operable as it is, without mandatory dependencies to external, not always ready to use components or personal computers. This does not exclude the possibility even the must of connection to a PC for remote control when the application cannot reside inside the test set.

- **Intuitive user interface.** Basic functional components must be obvious for non-trained operators, and graphical paradigms should be extensively used throughout the built-in test intelligence, so that the user can concentrate in the test object’s characteristics rather than in the test equipment’s operation.

The procedure as part of the test equipment: an adaptive approach

Let’s discuss here what could be a practical implementation of the above statements and conclusions.

Physical characteristics of the test equipment are comprehensive in terms of system fault simulation, measurement and logic simulation. A built-in computing platform is in charge of human interface, simulation control, data management and communications. The human interface, i.e. the part of the software that determines the testing experience, is intuitive at any stage of testing, and adapts itself to different levels of control in order to maintain a perfect compromise between automation and capacity to solve unexpected situations. Intelligent simulation control frees the operator from complicated, error-prone changes in cabling and manipulation of the test platform, as they are performed automatically according to the test type and conditions. Other important functions like data management and communications should also be observed under the same innovation path.

Once the test equipment is provided with integral computing power, an enormous range of new capabilities and innovative approaches comes at hand.

The electrical and logical features, including measurement functions, are the ‘physical’ layer in this design. A second layer contains peripheral functionality like communications, storage and external interfaces, as well as general control of the hardware platform and interface to the computing resources.

The computing platform implements a hardware abstraction layer that enumerates and determines the working rules of hardware resources, seeing these as test services and providing a consistent API. The visible computing functions live here. A raw-level human interface displays an organized representation of the test resources which the user quickly recognizes and associates to his needs. These resources include direct control of available voltage and current channels, adjustment of signal characteristics like frequency and phase angle, use of timing resources and access to storage and retrieval of repetitive setups and test results.

By mixing and linking these elemental functions into automated tasks, it is easy to create a comprehensive range of pre-programmed smart tools for instant testing of protective functions in one level and for automation, planning and reporting in a superior level. The goal is completing the test in a three-step procedure:

- Relay type selection and connection
- Test procedure selection and execution
- Results storage, management and reporting

Any of these to intermediate steps can be broken down at any time into lower-level or elementary functions like, for example, definition of a new protective function and programming and applying a voltage ramp.

Final conclusions

Digital relays, or IEDs, impose an obvious change in the way we look at protective device testing. This change impacts our traditional thinking and practices in many aspects:

- Scheme design, control features, practical implementation, planning and testing of relays
- Required personnel skills
- Design of suitable test equipment
- Training

The approach and ideas proposed in this document try to synthesize these changes in a brief overview of the impact of latest digital technologies present in modern protective devices.

Bibliography


