Look at a sales brochure, or even an instruction manual, for many relays available today and you’ll find only a small portion of it dedicated to protection. Much of what you’ll find is dedicated to the integration of the device into the power system so it can replace what was previously performed by a myriad of devices. Metering, monitoring, and control features allow for significantly more functions than the predecessor to the modern digital relay. These additional features are part of the digital relay and can be used to remotely control and monitor portions of a system. To implement these remote features, the relay must be incorporated into a communications system, which requires the selection of appropriate network architecture. In addition to the remote control and monitoring, one incredibly powerful feature of the digital relay is its ability to record and evaluate system events. Recorded data can also be used to aid in operations. Many of these devices require a significant number of settings to take advantage of these features and often times these ancillary elements may be overlooked.

The ANSI/NETA Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems, 2013 edition, identifies various methods to inspect and test microprocessor-based relays. These procedures identify the recommended methods for testing the protective functions, inputs, and outputs associated with digital relays; however, many of the functions available in the digital relay requiring testing are not included in these specifications. Testing of metering and the relay logic are indicated in this standard, although no specific methods are identified. Perhaps the accuracy of additional features such as fault recording and display data does not seem apparent; however, when properly used, these features are extremely helpful in evaluating events.

As with any product class, the functions and features of digital relays will vary between manufacturers and even within the varying
product lines of the same manufacturer. Some digital relays have built-in features, which cannot be altered by the end-user; other digital relays allow the user to create an incredibly complex scheme to meet the user’s specific requirements. A relay will require settings for each protection element, and its output must be identified. Some schemes will require additional elements or logic (Figure 1) to implement the complete function of the relay, so either the manufacturer’s logic is enabled or the user must create their own logic to implement the required functions. In addition to the protective settings, many modern digital relays require settings to drive the relay target, initiate event reports and fault recordings, and transmit data to report the event (Figure 2). There is no consensus on whether and how these additional features should be tested. When the digital relay is used as a remote control and monitoring unit, these features must also be incorporated into the test plan.

Testing a digital relay is performed to determine whether its desired functions will operate when required. Since there are typically multiple functions used in a digital relay, multiple tests are typically performed. These tests are generally approached as if the various elements were discrete components and the individual elements are evaluated; however, it is not always possible to isolate the elements in a digital relay. A simple example is a three-phase overcurrent relay having a neutral element. When testing the phase element for pickup or time, the neutral element will typically operate because the simulation of a single-phase fault causes zero sequence current to flow and the neutral element will respond. In many test environments, the neutral element is turned off for the phase testing and turned back on for the neutral testing. When testing multiple functions includes changing settings throughout the testing, it is possible to inadvertently leave the element in the off position. A different approach may be to test the element using analog quantities that don’t produce the pickup of other elements. In this example, a three-phase test set can be used to generate a pickup on the phase under test and the return current split between the remaining two phases. This sort of strategy may save the time of changing a setting and will avoid the risk of not returning a setting to its proper value.

An alternate method used to test multifunction relays is to map the element under test to a spare output and test it in isolation. When isolated, the element can be tested without being affected by other elements in the relay. This type of testing may allow for testing of every aspect of the element to ensure the relay performs as expected; however, it does not prove the relay is working properly at the correct output. At a minimum, a time overcurrent relay will require a setting for its pickup, its time delay, and its characteristic curve. It would be extremely unusual for a properly functioning digital relay to not operate correctly given a proper setting, so the only purpose achieved by isolating a protective element to a spare output is to test the relay algorithm. Unless there are multiple analog-to-digital converters in the relay (for example, one for low levels of current [load] and one for high levels of current [fault]), the conversion will remain within the accuracy of the specification.

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**Figure 1:** Logic Diagram for Programmable Functions
Depending on the purpose of the test, acceptance testing may have different meanings to different people. To some, acceptance testing is to run a rigorous set of tests to ensure all functions of a relay will perform at extremes — testing the operation of the algorithms. To others, acceptance testing may simply imply testing to verify the relay operation at defined points. When field testing digital relays, it should be sufficient to verify the settings without testing the various relay algorithms. For example, a three-phase overcurrent relay should not have to be tested for every type of fault (i.e., A-B-C, A-B, B-C, C-A, A-N, B-N, and C-N). All of these faults will respond to the same settings; testing any type of these faults will determine if the pickup, time delay, and characteristic curve are correct. The only remaining function would be to determine whether the individual input filtering and the analog-to-digital converters are operating correctly. Testing specifications of an overcurrent relay require a test for the pickup and two test points of the overcurrent relay. It does not indicate the extent to which testing should be done. Can testing be limited to two points on one phase and one point on the remaining phases? The two points verify pickup, time delay, and characteristic curve. The other phases test the analog input — the input filtering and the analog-to-digital converter. However, although not clearly indicated in the specification, testing should not only verify the proper relay output operates, it should also verify that the target information and event recordings operate properly for the individual tests.

Is it necessary to test the protection algorithm of a standard product or should an acceptance test simply verify the proper setting was applied? Without question, it is necessary to test user-created logic. Some manufacturers have protection algorithms that prevent simple test methods from being used because the algorithm expects to see a condition to occur over time — a real-world condition — which cannot be generated using simple test methods. Some relays, for example, can evaluate a loss of voltage as a fuse or PT failure. This feature can be used to block certain voltage-based protection functions. If this is an internal feature provided by the manufacturer, should it be tested? If it can be switched off to effect protection, it should be tested with the elements. For example, if an electro-mechanical loss of excitation relay were used to protect a generator and its operation was supervised by an electro-mechanical voltage balance relay, the two relays would be tested individually and the complete trip path would be tested separately. In a digital relay, a supervising feature similar to a voltage balance relay may have to be switched off because it will make testing difficult, if not impossible, without sophisticated test methods. Since the purpose of testing the relay is to evaluate its performance, oscillographic recordings could capture the simulation of the element and its block by the supervising component, which can be used to prove the relay performed correctly.

Since a feature of the digital relay is its ability to capture the event, specifications should exist to identify that it is tested and working properly. Many digital relays require the user to identify the various conditions that should be used to...
trigger events or waveform capture (Figure 3). Where user modifications are required as part of the relay settings, anything affected by these settings should be tested. Some may consider these settings part of the relay logic. Even though the relay logic is to be tested, I have yet to see a test report indicating that the event record or waveform capture operate properly.

Tests performed on protective elements are performed on a per-phase basis but, unless the event is triggered on a per-phase basis, there is no reason to test these event records on a per-phase basis. There is good reason to verify individual elements are recorded in the various records. When evaluating a fault, all conditions associated with the event should be included, or the evaluation of the event may be misleading.

Protective elements, analog signals, inputs and outputs, and other intermediate logic are extremely useful in evaluating events, so proper operation of these recordings must be validated. Other functions, such as when the digital relay is being used as a remote control and monitoring device, also require testing to ensure these functions are proper and should be integrated into the testing plan.

Does a coordination study really provide the information required to set a digital relay? Studies may identify the protection elements and the required outputs; however, most do not indicate the target and event record data. Upon review of most digital relay manuals, the testing section is sparse. For the most part, it seems the manufacturer’s position is clear: The relay will function properly if it is set properly, given no internal alarms have been detected, and the analog conversion is functioning properly. It is often difficult to determine how to properly set a digital relay without testing it based on the lack of data provided in some of the instruction manuals. A coordination study often does not convey the finer points required in the setting of the relay, such as the minimum trip time or the unlatch settings.

Often, the test technician is deemed responsible to determine the appropriateness of the settings, as the default settings will not always be an appropriate choice. ANSI/NETA ATS calls for downloading the setting file and comparing it to the coordination study. With so many required settings not included in the study, it is strongly recommended that this review be completed not by the technician, but by the person responsible for issuing the relay settings. Review by additional personnel will typically be more exhaustive. At the extreme end, if a complete setting file is provided without significant direction, it is difficult to determine the desired functions of the digital relay.

So what should be included in an acceptance test of a relay? If the relay is treated as a
collection of individual items in a singular device and the acceptance test includes the testing of these, individual testing should include the following items:

- Verification of all metering functions
- Verification of required protection elements
- Verification of required inputs
- Verification of required outputs
- Verification of device targets
- Verification of event records
- Verification of protection logic (including its interaction with internal and external elements)

Generally, acceptance testing exists in a vacuum, and it is not until systems are commissioned that the device integration into a larger system is evaluated. A digital relay is truly a small system and must be tested as such. ANSI/NETA ATS calls for testing of pilot schemes and in-service monitoring. These are tests that can only be performed when other components are in service. Instrument transformers, external contacts, coils, and other devices must be tested with the digital relay as part of its system, and its testing should be as detailed as the acceptance testing. The digital relay should be tested using a method that closely represents the system that it is intended to protect and the conditions it will be expected to withstand. It should also be tested for all functions and features it is expected to perform. The ANSI/NETA, Standard for Electrical Commissioning Specifications for Electrical Power Equipment and Systems, 2015 edition, provides good direction on developing complete testing protocols to ensure the digital relay system will provide its intended function.

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