Comparing Protective-Relaying Commissioning and Test Philosophies and Methods

Abstract

This paper will discuss the differences in types of testing philosophies, test set units and different automated testing software used across different utilities. These differences typically arise due to legacy procedures, economic and scalability reasons and difference in understanding of industry best practices.

Utilities have their own ways of commissioning and testing protection relays. Some utilities provide logic diagrams along with protection standards and during the commissioning stage the relay testers are expected to test the internal logic and perform dynamic tests, and end to end tests for the protection scheme. Other utilities require the relay techs to only perform static tests and functional tests in order to put the protection in-service. Utilities use different test sets with various capabilities to perform their commissioning and maintenance tests. This paper will present a detailed analysis of some of these differences and discuss their advantages and disadvantages.

In the lifecycle of a relay, a relay will go through 4 different phases of testing.

1) Type test
2) Production test
3) Commissioning test
    - Relay testing
    - Function testing
4) Periodic maintenance test

The first two tests are usually completed by the manufacturer and the last two by a relay tester. There are different types of testing philosophies implemented by utilities to verify the performance of power system protections while commissioning the relay. Function testing usually takes majority of the time and is performed to verify the wiring to the relay, AC system, and the DC control system. When it comes to relay testing, the main objective is to verify the settings issued for that relay in order minimize relay misoperations in the most cost effective manner. Relay testing includes meter test, input/output contact tests, element tests, and dynamic tests. To get the most out of the relay testing, it is essential to understand the benefits and limitations of each type of testing.

Relay testing should begin with a Meter test. Some of the relays such as SEL and GE have automated self tests which verify some of the analog components but not all, so it is pertinent for the relay tester to perform metering tests. It will help verify proper analog-digital converter operation, relay-accuracy, test connection wiring, and gives the relay tester a chance to verify the CTR used as compared to the operating diagram.

Another relay component that is not part of the relay self test and is a reason for a lot of misoperations, is contact input/output circuitry. In order to prevent an inadvertent trip it is important to remember to isolate all external trips while performing this test. Most microprocessor relays have a convenient trip command available in the relay software interface to test the outputs. The most common reason for I/O failure is applying constant or transient voltage/current above the rated value. [1] It is standard industry practice to perform meter test and input/output contact testing. But there are different practices adopted when it comes to element testing and dynamic logic testing. Some utilities encourage just performing element tests, or just dynamic logic tests, or a combination of each to commission a relay. The two types discussed in this paper are Element testing and Dynamic logic testing (also known as system testing).

Element testing is performed to test the operation of particular elements such as overcurrent, timed overcurrent, or differential elements in the relay individually by manipulating the current, voltage or frequency inputs in order to make the element pick up. This type of testing usually requires masking the tested elements' logical output onto a spare output in-order to verify proper operation without activating other relay system components. Automated testing has made this a lot quicker assuming test plans have been correctly developed.

Dynamic logic testing is performed by injecting an expected fault condition to obtain an expected response in logic and output contact state change in order to test the logic. This type of testing simulates actual system fault conditions. This is done typically by initially applying pre-fault voltages and currents for some time to stabilize the relay and allow the memory voltage to come up to nominal. Once steady state conditions are valid, fault current, voltage, and frequency values are applied. The fault values can either be calculated or in most cases can be received from the settings engineer. Monitoring logic states in the relay and output contacts verifies that the correct elements operated, timers worked as expected, and also verifies the logic performed as per design. Relay tester should also monitor breaker status, disconnect status, communication tones, breaker fail and reclose initiates during dynamic testing.

Automated testing software can convert the SS1 or excel file which holds fault values and the sequence of testing into state simulation to perform this test. For example, a dynamic test on a line protection relay would include applying three-phase, phase to phase and phase to ground faults at different steps of Zone1, Zone2 and Zone 3 reach with communication disabled. These tests will then be repeated with communications enabled. The purpose of dynamic testing is to verify that the relay as a whole has operated as expected in fault conditions whereas element testing only verifies that the element under test operates correctly. Dynamic testing is more involved and time consuming but is more efficient in identifying settings and design errors.

Logic diagrams are a great tool to help perform dynamic testing accurately. Utilities should put more effort in producing logic diagrams because by using logic diagrams the relay testers can visualize the relay logic and understand different test scenarios. It will also help the relay tester properly analyze fault records and sequence of events.

Most microprocessor relays have some form of an automatic enhanced self-test and monitoring function. Self-testing verifies correct operation of critical relay components including the memory components housing the relay algorithms. This automated self-diagnostic capability makes element testing a moot effort. Also with element testing there is a high chance of an inadvertent trip. Multiple cases exist where the relay tester forgot to change the setting (such as temporary assignment of an output contact for testing) back to the original setting after testing. On the other hand, electromechanical (EM) relays are still very susceptible to pick-up value drifts due to loosening of spring tension and failure of other mechanical parts. Thus element testing is very relevant test for EM relays as the testing method also serves as a calibration tool.

Automated Testing Software

Many utilities have started using automated testing. Currently most owners use automated testing for element testing using the stock routines provided by automated software developers. But a few owners have started developing their own databases of tests to include dynamic logic and compliance based testing. Some utilities still depend on manual testing. This is great for highly trained relay testers who have extensive knowledge of the power system but it is also very time consuming.

For example, full element testing of an SEL 311L relay could take up to 12 hours to manually test while the same test can take 4 hours by using an automated software. One caveat with automated testing is that because of the process, the test routine shelters the design and relay settings from the relay tester that he/she would have been normally exposed to in the manual set up. Automated testing produces very clear and detailed reporting which is vital for NERC compliance. Most automated testing software also has the ability to prevent relay testers from manipulating the results.

Having a reliable and accurate database of tests requires a lot of front-end effort, standardization, thorough understanding of protection testing, and knowledge on how to manipulate the automated testing software. To successfully use an automated test plan requires highly standardized relay schemes, which drives standardized settings logic. This facilitates efficient and thorough testing of the test plans created. It would be extremely difficult to develop automated test plans for complex logic with multiple variations. Automated testing also has an additional cost of purchasing software licenses or modules.

The three most commonly used automated testing software are discussed below

Test Software 1

This vendor supports almost all the major test sets, thus it is a great tool to use if relay testers have to use different test sets. The stock test routines provided by this vendor only perform element testing by masking the element to a spare relay output contact. The menu-driven software makes it easy for anyone to create simple customized dynamic test routines. But to take full advantage of the capabilities of this software requires basic programming knowledge. The test software gives the user the option of using Steady State (SS1) or an excel file formats to generate state simulation values for dynamic testing.

30 states are available to the user in this company's state sequencer test. The test software also has a COMTRADE playback option.

Three advantages Test software 1 has over other automated software:

1) It supports all the major test sets such as Doble, Manta, Omicron, Megger, ISA, and SMC.
2) It is able to pull settings out directly from Beckwith, SEL, and GE UR series (partially) of IEDs. It is also able to extract and evaluate targets, events, and Sequential Event Records using RS-232 communications from relays that use the ANSI serial communication protocol. This is really helpful if complicated logic and non-standardized settings have been applied in the device.
3) Lastly it stores the test plans and results in a relational database (instead of a flat file database). It means that the files are stored in a hierarchical tree-like structure. A database management product is offered by this manufacturer. It is a more powerful database system that manages the routines, workflow process, provides access control, and easily generates compliance-based reports. The required number of software licenses or 'seats' can be purchased which enables field staff to access the database to download test plans as long as the number of current users with the opened database are within the number of seats purchased. Thus the field relay testers can have access to the database. They can then directly download the test plan and settings approved by the engineering department.

The disadvantage of having this testing software is that like some other testing software options it does not have a great user graphical interface and could look a bit daunting to the relay tester when first using the software. It requires some training to become comfortable in making customized test plans.

Test software 2

This is powerful and convenient test software that works with only the test set sold by this manufacturer. The manufacturer of this software sells pre made advanced test plans in modules. This gives the user the option to limit expense based on their needs. The software has a superior user interface and has graphical display for every element including distance, differential, overcurrent, synchro phasors, etc. In the advanced distance module, the software does all the calculations for the user by just clicking a spot where you want to test or by inputting a relative percentage of the nominal characteristic impedance. It is also able to search for the edges of mho circles to further qualify the settings or search for the mho characteristic boundaries using enough search data if the settings are not available.

The software can import fault values from SS1 or excel files for end to end testing and playback COMTRADE fault files. Users can link test plans into the Extended RIO format and import relay settings to make dynamic test plans that change based on relay settings, such as when multiple settings groups are programmed into the relay. Extended RIO works for almost all the major microprocessor relays that use XML format, but the process is a bit time consuming.

This software uses a flat file database but the user can purchase a database management system from the manufacturer. Their database maintenance management solution produces easy reporting for NERC compliance. The database workflow process is limited as they charge per licensed user. For example, if the settings engineer has access to the test plan he/she will have to develop an alternate way to send that test plan to the field relay tester.

This vendor also sells another software which is worth mentioning. This software allows the user to simulate realistic power system events and verify errors in the settings, logic, or design. It is really useful for end-to-end testing and allows the user to remotely control multiple test units with just one PC.

Test software 3

This software user interface has more bells and whistles then test software 1. It is based on a series of macros to run a test. The user has control to modify the macros to customize the test plan. It is is easier to customize than test software 1 but loses some of the versatility when it comes to evaluating the results from the relay. For example, the user can select test points by manually selecting the points in the mho graphics display. This enables the tester to visually see where the test point will be applied. But the software is not able to communicate with the relay to extract SER records from SEL devices to analyze the outputs. It can import fault values from SS1 or excel files and playback COMTRADE fault files. It can also easily read settings from most of the popular microprocessor relays and update the test plan based on settings.

Relay test sets

Relay testers are very emotionally attached to their test equipment and will swear by the test-set they are most used to. There are several types of relay test sets in the market. Most major test sets can test all available modern microprocessor relays. This paper will briefly discuss the 3 most commonly used test sets in North America; namely Manufacturer 1, Manufacturer 2 and Manufacturer 3. The table in the end of the paper compares the specifications of each test set.

Manufacturer 1

This is a great test set for testing the relays manually. It comes with 6 current channels and 4 voltage channels. It has a much superior front-panel interface and does not require a computer connected to it to perform testing. The controls are easy to understand and are designed around the three most common fault types. The test-set automatically reconfigures the analog voltage and current output amplifiers for those fault types to minimize setting changes due to scaling (not enough current output typically) and increase productivity. The screen can be modified to display watts, impedance, reactance, sequence components, timers, and other operating characteristics while testing.

The intuitive display and positioning of the control buttons used to manipulate test channels make troubleshooting a relay relatively easy. This test set also has different productivity modes which are not as advanced as some other automated programs, but it allows the user to manually enter some relay settings into the test set and helps the tester with some calculations. It is great for users who are working on non-standardized protection schemes, and enjoy the feel of pressing buttons and turning dials to test relays and also have an extensive understanding of the power system.

Manufacturer 2

The comparable model of this manufacturer has 6 voltage channels and 6 current channels which will significantly reduce the need for wiring changes while testing differential protection and voltage imbalance protections. The front panel is not very intuitive or meaningful. It also requires a PC connected to it to operate it. The advantage of having 6 voltage channels is that voltage differential protection can be tested without using two test units. The test unit is more rugged and lighter than the Manufacturer 1.

Manufacturer 3

The comparable model of this manufacturer is a highly durable test set with 6 current and 4 voltage sources. It is the lightest of the test sets discussed in this paper. User can purchase an additional control unit if they prefer to test manually without the use of a PC. [2] This manufacturer also sells test software 3.

	Manufacturer 1	**Manufacturer 2**	**Manufacturer 3**
Size (inches)	18.9W 14.5H 11.7D	15W 9.5H 18D	17.7W 5.7H 15.4D
Weight	49lbs	42lbs	37lbs
4 ph max volts (rms)	250	300	300
1 ph max AC volts (L-L)	750 V	600 V	600 V
1 ph V max VA	250 VA	150 VA	200 VA
1 ph ct max VA (L-N)	2400VA	585VA (transient mode)	1740VA
Max 1 ph current	180A	180A	128A
Max DC voltage	350 Vdc /150 watts	300Vdc/90Watt	300Vdc/ 420Watts
Testing option without a computer	required	No	unit
Current Channels	6	6	6
Voltage Channels	4	6	4
IEC 61850	y	y	y

Table1: Test set specifications collected from test unit manual and manufacturer representative

Function Testing and Zone Test Trip

Almost every utility requires that a function test is performed while commissioning a new protection system. For example, the function test after commissioning a DCB scheme line protection will include at the minimum:

1) D.C. wiring checks and polarity check from different battery sources.
2) CT wiring and A.C. potential wiring by injecting currents and potentials using a test set. This will include phase rotation checks.
3) All relay statuses, breaker statuses, alarms, SCADA values and control functions
4) Breakers operation and reclose test
5) Breaker Failure testing
6) Other logical scheme interfaces that are unique to the utility

For function checking a modified D.C. circuit, some utilities require applying a small source of D.C. to check the integrity of the circuit prior to connecting to station D.C. . In the case where a legacy scheme has been rewired, the D.C. source is applied to an unmodified point that is upstream of the modified point and it is monitored at an unmodified point that is downstream to the modified point. A Zone test trip is performed if such unmodified point does not exist.

A zone test trip will test the whole zone at once and will attempt to simulate a real fault scenario. The following steps are performed in the Zone Test Trip

1) The relay tester will get approval for an outage for all elements included in the zone (Figure 1)

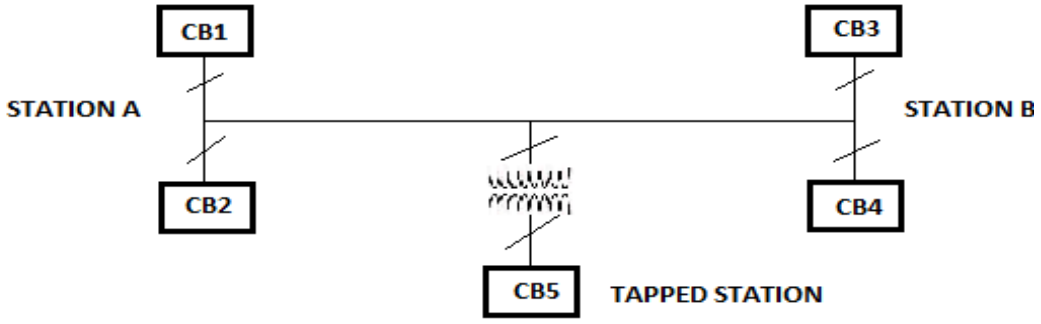

Figure 1: Line Protection Zone

2) Operators will test trip all the breakers in the zone once to ensure breakers don't go into breaker failure during the test.
3) With all breakers and disconnect switches in closed position and reclose enabled, the relay tester in Station A will initiate a trip from the main line protection system. The trip can be initiated by using a fused jumper or by forcing a virtual contact. The relay tester will then verify the following:
   i) All required breakers tripped and reclosed as per design
   ii) Breaker Failure scheme was initiated
   iii) Communication signal was received
   iv) Breaker status changes and interlocks
   v) SCADA and alarms
   vi) Breaker interrupters worked by analyzing fault records
   vii) Scheme testing for "Communications Disabled" or other unique utility-unique options
4) With breakers and disconnect switches closed and reclose blocked, the relay tester in Station B will initiate a second live trip from the second line protection scheme. All the above is verified again. The live zone test trip is the most important test because that test verifies the operation of the interrupting devices with load and all the protection components at the same time. *Note – some utilities may disallow testing with the system carrying primary load.*
5) The rest of the trips are performed with the line out of service and all out of zone trips blocked. The dead zone test trips could include the following
   i) Trip from duplicate line protection in Station A
   ii) Trip from main line protection in Station B
   iii) Transfer trip from tapped station
   iv) Trips from local Breaker fail protections
   v) Transfer trip channels one at a time for "H" configuration style
   vi) End-to-End testing
   vii) "Communications On" and "Communications Off" scheme operation validation where available
   viii) Other utility-unique logic functions
6) All SER records are collected, and protection functions restored after checking for potentials (Zero-0Energy Checks) on the appropriate scheme interface test block switches to verify there is no trip or other scheme-initiating voltage present or voltage present where none is anticipated.

End to End testing

End to end testing is important to test the delays of the communication channels and ensure the protection logic and schemes are working as intended as a system. Sometimes the differential protection setting for each end of the line is created by a different engineer and even though relay may pass the local test, it could fail the end to end test if the two setters are not on the same page. For this reason, many utilities have adopted the use of End to End testing. However, most of them only use this test for differential line protection schemes.

Differential protection works as a single unit. Relays share the current magnitudes with each other through a communications channel, typically fiber optic, which is not the case for other step-distance or power line carrier-assisted line protection schemes. For non-differential schemes, testing the scheme can be accomplished on an element-by-element basis, then functional testing on one end at a time. By performing end to end testing on a differential scheme or other communications-assisted scheme, many misoperation-causing errors can be detected prior to the scheme being placed in serve, including communication delays and not having compatible settings or firmware.

Automated testing has made it easier to perform end to end testing. Most automated test software can convert Steady State Sequences (SS1 files) or Excel files into state sequence tests. Using an Excel sheet to import the states can be a very useful tool for the relay tester in order to troubleshoot issues with the test.

Testing Software 1 provides the option to modify the Excel sheet containing fault testing parameters to fit the format that may have been previously used by the utility and thus provide the relay testers with more information about the test to help troubleshoot. For example the relay setter can add information such as expected time, zone impedance values and even a visual representation of the fault cases. Another format to export the fault states would be COMTRADE. This format helps simulate system distortions such as transient signal, DC offset or CVT distortions. [3] Successfully completing end to end testing requires the relay tester to understand the test cases and expected results. The following steps need to be followed at minimum

1) Isolate the protection relay hard contact I/O interfaces that are not part of the specific test and connect test equipment to the CT/PT circuit of the relay
2) Check synchronization status of test sets on both ends after connecting with a GPS satellite or IRIG-B. If using different test sets on each end, then account for time delay by applying a through fault. In the through-fault test, inject the currents above the

differential pick up values. If the test sets are phase locked, the relay will see the currents as out of zone fault and there will be no trip. Any time delay between the test units will cause a trip. Time delay can be measured by loading the transient recording and measuring the time shift between the zero crossings and preloading the needed time delay compensation to the appropriate end.

3) Perform a meter test to verify the test set connections and zero differential current.
4) Apply the test cases using SS1, COMTRADE or excel file
5) Evaluate results and restore protection, using appropriate Zero Energy Checks and Human Performance methods to avoid misoperations or safety issues.

Conclusion

Thus is it imperative for utilities to move away from element testing and perform for dynamic testing. [4] Dynamic testing is more effective than element testing in the identifying errors in logic and design. End to end testing and zone test trips have the potential to identify a lot of the wiring errors, equipment failures and logic errors that could be missed by just performing local tests.

A cost effective way to approach system protection would be to develop highly standardized logic and design and then extensively test the logic in the lab before implementing the settings in the field. This method will reduce the need to perform complicated dynamic logic testing. The relay testers can then sufficiently test relay operation by performing basic pick up tests (to verify the setting in the relay matches the setting in the database), dynamic test (simulating system faults), end to end testing (where applicable) and finally the Zone Test Trip (function test).

References

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