APPLICATION CASE OF THE END-TO-END RELAY TESTING USING GPS-SYNCHRONIZED SECONDARY INJECTION IN COMMUNICATION BASED PROTECTION SCHEMES

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Abstract

This paper reviews the philosophy of the end-to-end relay testing using gps-synchronized secondary injection in communication based protection schemes. The paper describes an application case at a Distribution Division in Jalisco, Mexico, operated by the national utility CFE (Comisión Federal de Electricidad). The line protection scheme is special due to a tap derivation line in the middle of the line which has a normally open switch to feed a sensitive and important customer. In normal condition, the line differential relay (87L) is the main protection and the distance element (21) is an integrated back up protection. Following the discrete back up protection philosophy there is another relay which is used as phase comparison (67N). In maintenance condition the line differential relay (87L) has to be disabled and the settings for the distance element must be changed remotely from the control center. All the above protections are Communication based Protection (Transfer Trip Schemes). The document will describe the purpose of the testing, the actual test scenarios, special tools needed, resources, and criteria for success.

INTRODUCTION

Digital Signal Processors and high-speed operating systems have revolutionized not only protective relays, but protective relay testing as well. Modern microprocessor-based relay test sets, combined with personal computers and GPS satellite receivers have provided the means to dynamically test relay protection schemes end-to-end.

The philosophy for testing and maintenance of protective relays has dramatically changed over the last decade. The proliferation of microprocessor-based relays, down sizing of maintenance and testing personnel and ever increasing time between maintenance intervals has caused many companies to change how relays are tested. System reliability is still a major concern, with increasing load and power wheeling requirements [1].

Development of modern communication technology and the need for selectivity of switched line faults in the shortest time, have inspired Power System Protection Communications Schemes for Line Current Differential, Phase Comparison and Distance Protection communication based protection [2].

Electric utilities may vary in their application of end-to-end testing of relays. At a Distribution Division in Jalisco, Mexico, operated by the national utility CFE (Comisión Federal de Electricidad), a standardized process and equipment set-up for end-to-end relay testing was tested with successful result.

END TO END TESTING

The most common application of GPS-synchronized secondary injection end-to-end relay testing is to verify transmission line protection schemes of newly installed relays. The test is normally performed at the end of commissioning of a new substation or during relay replacement projects. The objective is to perform a complete check of the new system protection scheme, including verification of circuit breaker operation, communication channel time and the effectiveness of relay settings before the relays are placed in service. Other applications have been in verifying relay setting changes, troubleshooting relay malfunctions and evaluating new relay protection schemes [1].

The most important challenge in testing line protection schemes is to provide the test quantities at all the line terminal relays at the same time. A line differential relay acquires the currents from its own terminal only and, based on the method employed, the remote current is provided via various communication channels. A simple and quick test can detect the individual pickup level for each relay by gradually increasing the current(s) at one end. Since no current is provided from the other terminal, the local relay will trip as soon as the threshold is reached. This method is not suitable to determine the operating or restraining characteristic. In order to determine the characteristic all the terminal currents have to be provided synchronously and each of the relays has to send the quantities to the remote ends in real time.

Modern relays are connected between each other by fiber optic system so the processing of the pre-fault and fault quantities and transmitting the trip or block decisions to the remote ends are performed extremely...
fast. In recent years the advancements in the new microprocessor based relay test sets allow you to test the line differential relays in such a way that simulates the real life processes in the Power System. The concept of testing the relays is called “End-To-End” and has become rapidly implemented as a standard technique in the industry. Basically the method requires two three phase test sets equipped with a Global Positioning System (GPS) receiver and an antenna. Fig.1 depicts the standard setup (antenna and the receiver not shown). A Global Positioning System (GPS) consists of a number of satellites orbiting at high altitude (approx. 11000 miles) and ground stations which monitor and control the system. The system consists of 21 active satellites and 3 in-orbit spares each of which orbit the earth twice per day. The design of the system is such that at least four satellites are in view at all times from all places on the earth, thus providing continuous, worldwide, three dimensional navigation capabilities. The satellites transmit encoded signals at either 1575.42 or 1227.6 MHz.

For End-To-End testing it is recommended that a minimum of 3 satellites must be tracked simultaneously. However, a precise time (the only important parameter for this application) can be derived by tracking one satellite only. The GPS receivers are highly accurate with a drift in the nanoseconds range. The satellites send “corrective” signals to GPS receivers which allow the internal clock to be aligned to the high accuracy Cesium atomic clock of the satellites. The programming of the system is simple since the tracking is performed automatically when the unit is powered up initially.

Basically the user has to set the coincidence time (compared to the Universal Time Clock-UTC) when he wants to start the test. The same coincidence time has to be set at both terminals. The time is usually displayed with a resolution within microseconds. [2]

TEST SYSTEM

In the past, relay test sets were manually controlled and were used to evaluate the steady-state response of relays. With advanced microprocessor-based relay test sets, dynamic or multi-state testing of relays became possible. Under dynamic conditions, the relay is tested by applying simulated pre-fault, fault and post-fault condition quantities using a pure sine wave. With modern relay test sets, transient waveforms (which include dc offset and harmonics) can be produced several ways: 1) mathematically using Fourier expansion with exponential offset and decay, 2) using the replay of actual recorded faults from a Digital Fault Recorder (DFR) and 3) using simulation data derived from running the Electromagnetic Transient Program (EMTP), or other Alternative Transient Program (ATP) files converted to the COMTRADE ASCII format, (see IEEE Standard C37.111 – 1999) [5]. The COMTRADE Standard makes it possible to playback digital fault records from different manufacturers fault recorders [1].

Figure 1: End to End testing Set-up

CASE

Power Line 63580 shows in Figure #2 has a special protection scheme due to the tap derivation line in the middle of the line which has a normally open switch to feed a sensitive and important customer called SCI. In normal condition, the line differential relay (87L) is the main protection and the distance element (21 - POTT) is an integrated back up protection. Following the discrete back up protection philosophy there is another relay which is used as phase comparison (67N - DTT). All the above protections are Communication based Protection (Transfer Trip Schemes). Figure #3 shows the protection scheme in one end of the line; the other end has the same scheme.

Figure # 2. Single Line Diagram 69 kV
During the maintenance period at the substation GUD in the Jalisco Distribution Division, CFE has to switch the SCI load from substation GUD to the line 63580 closing the switch 6368C and opening the switch 6368B. Therefore the line differential relay (87L) has to be disabled and the settings for the distance element must be changed. This can be achieved by doing a change of group of setting remotely from the control center. In this condition the distance element is the main protection and the phase comparison is the back up protection.

The objective is testing this line protection scheme providing the test quantities at all the line terminal relays at the same time, in order to verify the main protection, back up protection and the transfer trips for normal and maintenance conditions.

**TEST PREPARATION**

A kick off meeting is held to check the procedures and to define the objectives. The points to be checked were specified as follows:

- Protection Schemes (schematics and relay settings)
- Teams Definition (at least 1 engineer on each side)
- Relay Test Set (Synchronization test)
- Software and test modules for end to end test
- GPS receiver (Synchronization test)
- Test Definition (Internal Fault, External Fault, POTT, DTT etc)
- Sequence Definitions for both sides (Pre fault, Fault and Post fault)
- Teams communication channel definition (i.e radio, phone, cell phone, etc)

**States Playback – Sequence Definition.**

For the line differential relay an internal and external fault are simulated. A pre-fault condition is assumed, which is typically the normal loading condition of the line. Once the pre-fault data are established, an iterative process of running the internal fault and external fault takes place.

For each pre-determined internal and external fault, the pre-selected fault types are simulated.
For the Permissive Overreach Transfer Trip (POTT) simulation, a previous calculation is necessary using the distance setting of the relays. The local relay has to detect a fault in Zone 1 and the remote relay in Zone 2; the local relay trips instantaneously and sends a signal to the remote relay to accelerate the operation of the remote relay, therefore the trip time is faster than the normal time for Zone 2.

<table>
<thead>
<tr>
<th>Local Relay</th>
<th>Pre-Fault</th>
<th>Fault</th>
<th>Post-Fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>la</td>
<td>3...0°</td>
<td>12...0°</td>
<td>3...0°</td>
</tr>
<tr>
<td>lb</td>
<td>3...120°</td>
<td>12...120°</td>
<td>3...120°</td>
</tr>
<tr>
<td>lc</td>
<td>3...240°</td>
<td>12...240°</td>
<td>3...240°</td>
</tr>
<tr>
<td>Time</td>
<td>5000 ms</td>
<td>48 ms</td>
<td>96 ms</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Remote Relay</th>
<th>Pre-Fault</th>
<th>Fault</th>
<th>Post-Fault</th>
</tr>
</thead>
<tbody>
<tr>
<td>la</td>
<td>3...180°</td>
<td>12...0°</td>
<td>3...180°</td>
</tr>
<tr>
<td>lb</td>
<td>3...300°</td>
<td>12...120°</td>
<td>3...300°</td>
</tr>
<tr>
<td>lc</td>
<td>3...0°</td>
<td>12...240°</td>
<td>3...0°</td>
</tr>
<tr>
<td>Time</td>
<td>5000 ms</td>
<td>48 ms</td>
<td>96 ms</td>
</tr>
</tbody>
</table>

The sequences have to simulate a fault at 10% of the line, Zone 1 for the local relay and Zone 2 for the remote relay in order to verify the POTT scheme.

**TEST EXECUTION**

The first phase of end-to-end testing involves setting up test equipment, performing the planned sequence of test events, evaluating test results and taking corrective actions when necessary. A typical step-by-step procedure can be specified as follows:

- Connecting the test equipment to the protecting relays
- Connecting the GPS receiver and look for the appropriate number of satellites
- Preparing the test equipment software for starting the test at both sides
- Coordination between testing teams regarding the first test and starting time.
- Execute the first sequence and waiting for GPS trigger
- Coordination between testing teams regarding the successful start.
- When the first simulation is finished, coordinate with the other side regarding the results of the test and eventually the arrangements about editing of the test sequence (times, phase shift, etc)
- Test results are immediately evaluated and compared to expected values or actions (trip, block, transfer trip, etc)
- Repeat this process for every fault simulation until getting the successful result

Once the line differential relay is tested, the back up protection has to be tested. At this particular scheme the back up protection is a Distance Protection communication based protection (Permissive Overreach Transfer Trip, POTT). The procedure basically is the same as described before, the only difference is changing the group of settings in order to block the differential element (87L) and add voltages channel in the states playback based on the previous calculation for Z1 and Z2.
Two PC's are typically used. The first PC hosts the automation software program for the relay test set and the GPS receiver. The second PC is used primarily to monitor the relay and store relay fault data, see Figure 9.

A GPS antenna with flexible coaxial cable is used for the GPS clock receiver. The antenna is run to the outside of the relay building and can be easily mounted on top of a parked vehicle or on any support structure or platform. Care should be taken in handling and placement of the GPS antenna in EHV yards.

Modern relays have a sequence of event recorder which monitors and records the relay response. It is useful in determining the timing of relay operation and tracking of events. Communication channel times are also readily determined from the sequence of event graphs.

The post-test phase involves more in-depth analysis of test results, which is typically performed when the results do not meet expectations. This is a situation when protection engineers are involved in reviewing the fault study and investigating causes of discrepancies. In this phase, test results are documented and reports are prepared when required.

CONCLUSIONS

In this era of electric utility restructuring, particularly when transmission line providers have to account for line outages, Communication-assisted tripping technology and the end-to-end tests will be applied more often to realistically recreate line events.

End-to-End testing verifies a complete protection scheme, including relays at different locations, plus the communication link between them.

REFERENCES


SEL 311L Instruction Manual. Available online at : www.selinc.com

BIOGRAPHY

James Ariza received his B.S. in Electrical Engineering from Universidad del Valle, Cali, Colombia. He has extensive experience in the testing and commissioning of electrical schemes as well as
performing power system studies and design and electrical system fieldwork supervision. He has previously worked with an electric utility, an R&D technology center and a consulting engineering company for the power industry. He joined Megger in 2005 as an Application Engineer in Technical Support Group and he is in charge with developing custom applications for numerical protection relays using AVTS (Advanced Visual Test Software). He is also in charge with testing and developing auto test modules, which allow the customer to evaluate and diagnose of microprocessor based protective relays. James is currently worked toward a Master Degree in Power Systems. He is a member of the IEEE.

**Gerardo Ibarra** received his B.S in Electrical Engineer from Universidad de Guadalajara, Jalisco Mexico. He joined to CFE in 2001 as a protection engineer. His activities include testing and commissioning of new substations, modernization of protection schemes and relay programming. Prior to his arrival at CFE he worked as subcontractor in the IBM plant in Guadalajara. His activities included corrective and preventive maintenance of PLC’s in the automation system.