G
USE CASE 11 – END TO END TESTING OF PROTECTIVE SCHEME

Use Case Title

End-to-end testing of a protective scheme

Use Case Summary

One of the functions required by utilities is the testing of protection schemes. Some schemes are quite simple and self-contained whereas other schemes involve many parts of this utility. This use case follows from the scheme design concepts through the analysis of the finished scheme.

The objective is to stress the 61850/CIM interface to discover aspects of the “seams” which exist between these two standards.

The CIM and 61850 must both be used at least at both ends of the process for this use case to be of practical use.

Use Case Detailed Narrative

The utility needs to perform satellite synchronized end-to-end testing of the protection of a transmission line based on a steady state or transient network simulation.

End-to-end testing is performed using test devices that apply a sequence of steps representing changing system conditions or replays pre-recorded or simulated waveforms with the devices at all ends of the protected line being synchronized using GPS signals. Refer to Figure G-1.

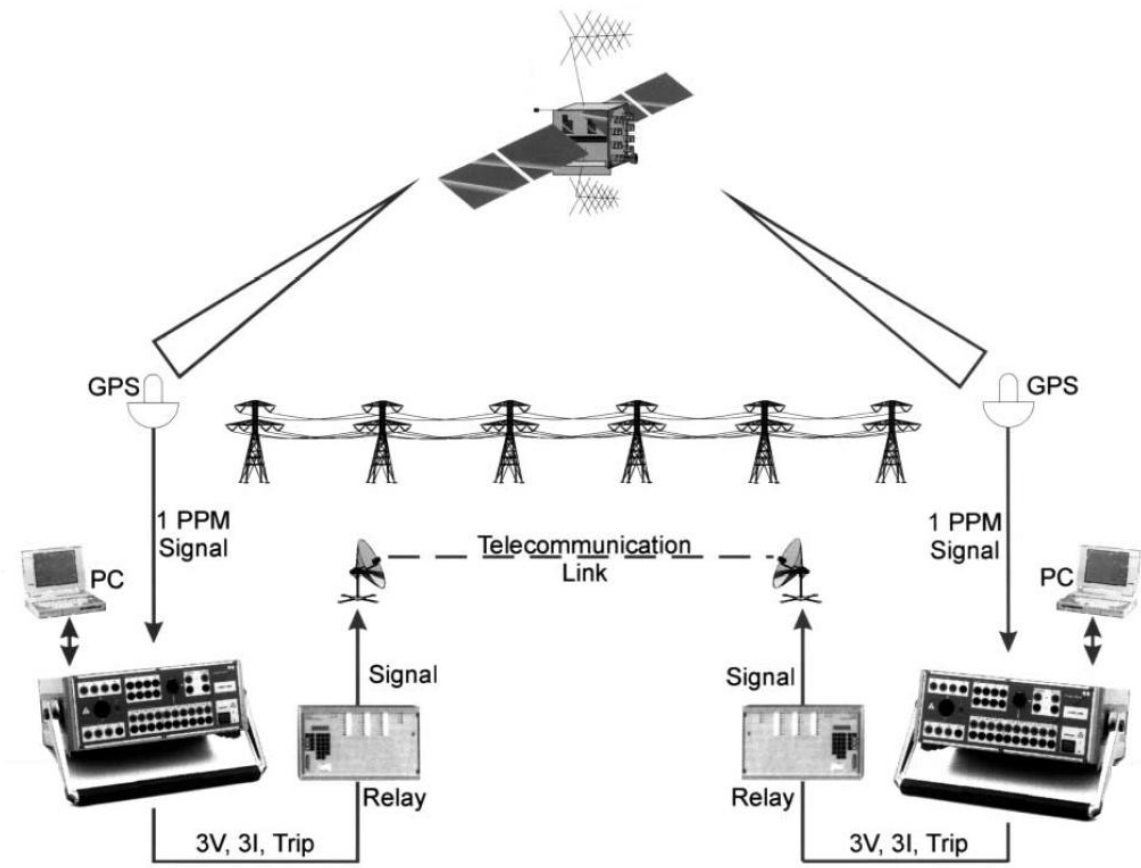


Figure G-1
Overall test setup

The Testing Team needs to run a set of test cases to demonstrate the successful operation of the protection system under different system conditions.

This includes the following steps:

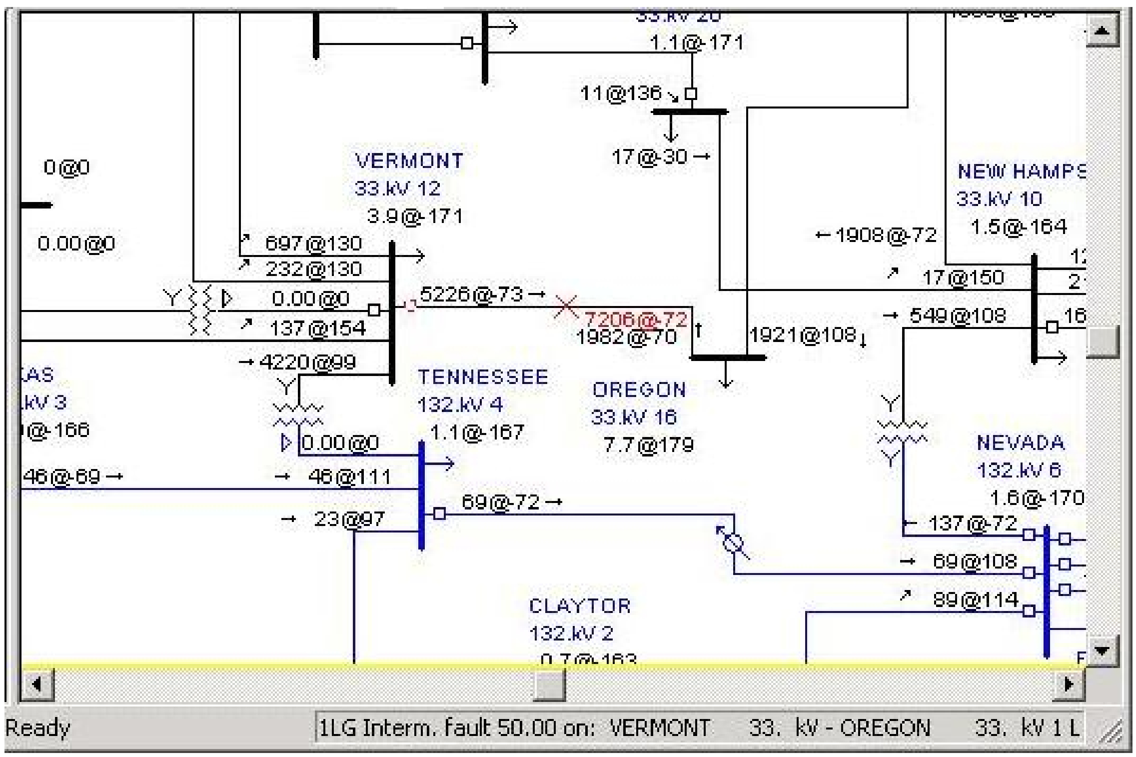
1. Building of a system model used by a simulation program
2. Defining the test cases based on the relay type, settings and configuration
3. Running the test cases calculations
4. Exporting the results from the simulations
5. Importing the results into the testing software
6. Importing the relay settings into the testing software
7. Running the tests
8. Analyzing the test results

Each of the above steps imposes specific requirements for the harmonization between IEC 61850 and CIM.

1. Building of a system model used by a simulation program

The testing can be executed through a pre-configured sequence of steps simulating the test system conditions based on phasors calculation or by replaying a transient simulation file produced by a program such as EMTP, ATP or other similar tool.

The model of the system used for the calculations of the different system conditions depends on the specific tools used and may require the modeling of an area of the power system as shown in the figure below:



Several different steps in the simulation are typically required. These include the calculation of:

- pre-fault voltages and currents
- fault voltages and currents
- post-fault voltages and currents

The simulation program for the steady-state phasor calculations is based on a system model in the sequence domain. It requires the positive, negative and zero sequence models of different system components, such as transmission, sub-transmission and distribution lines, transformers, generators, etc. It is expected that many of these data objects do not exist in either the CIM or IEC 61850 models. The CIM model will need to be extended to cover these requirements.

The transient simulation programs on the other hand require a model of the electric power system in the phase domain.

Both programs also need information on the topology of the system and the substations, due to the fact that the system configuration will change when a breaker in the substation changes state from opened to closed or vise versa. This means that the connectivity model of the system is necessary for the definition of the system one-line diagram for the simulations.

Both types of programs can benefit from a harmonized IEC 61850/CIM model. It will be used to build the model used for simulations.

The models required for the simulations include nameplate data, impedances, admittances and other data for transformers, generators, transmission, sub-transmission and distribution lines, loads and other system components. Performance data for breakers and other devices in the substations might be required as well.

2. Defining the test cases based on the relay type, settings and configuration

The calculations can not be completed without the knowledge of the protection settings and configuration.

Depending on the type of protection and the enabled protection elements, different fault locations, types of faults and sequences of events will need to be configured in the simulation tool.

For example if a Permissive Underreaching Scheme is being used, the tests will include some within Zone 1 of the distance relay and some outside of Zone 1 but inside of Zone 2. The fault location thus will be determined based on the settings of Zone 1 and Zone 2 available in the distance elements model.

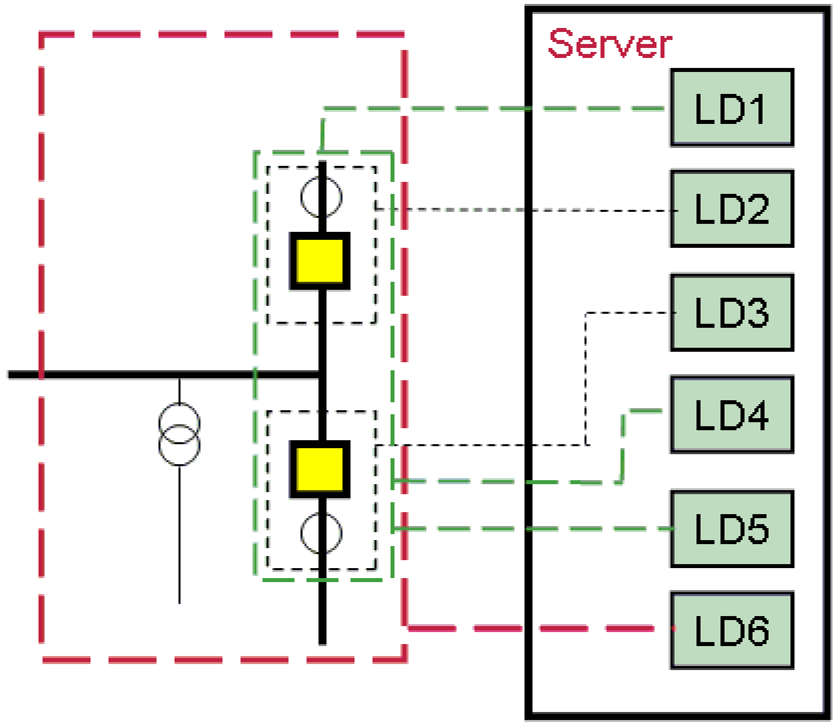
The IEC 61850 protection functions model will be used to determine also the duration of the different steps of the simulation based on the time delay settings of the different protection zones.

3. Running the test cases calculations

The test cases calculations will determine the output of the simulation based on the knowledge of the location of the relay being tested and its connection to the primary system – i.e. bus or line voltages, single or two breakers, etc.

This requires also knowledge of the substation topology and the analog inputs that the protection relay has. For example if a relay on a breaker-and-a-half connected transmission line protection has and single three phase set of current inputs, then the output of the simulation will require the three phase line currents.

However, if the relay has a set of three phase current inputs for each of the breakers, than the output of the calculations will have to provide the three phase currents for each of the breakers.



This is based on the association of the logical nodes with the primary substation equipment and will require probably harmonization.

In the case of multi-step steady state simulation, the model also needs to include the duration of the individual steps and the conditions that result in the transition from one step to the next step.

4. Exporting the results from the simulations

The results from the simulation should be exported as a file of a specific format that can be used by the testing software. Standardized format (such as COMTRADE for transient simulations) is required.

There is no standard format for steady-state simulation results. The event reporting model from IEC 61850 that is being further developed in the IEEE PSRC WG H5-b can be used.

The model needs to provide the magnitude and angle for each step, such as:

- pre-fault voltages and currents
- fault voltages and currents
- post-fault voltages and currents

Information on the duration and transition of the individual steps will also need to be included in the exported file, so they can be applied to each of the tested relays at both all ends of the transmission line.

It is necessary to check if such a model exists in CIM and if Yes, it will have to be harmonized based on the requirements of this use case.

5. Importing the results into the testing software

The results from the simulations than can be imported into the testing software. It has to support both transient simulation results and steady-state simulation results.

6. Importing the relay settings into the testing software

The relay settings in a CID file (extended based on the work done in IEEE PSRC WG H5-a) are imported in the testing software and used to determine the ranges for evaluation of the performance of the end-to-end tested protection system.

In this case the knowledge of the relay expected operating time for the different functional elements (logical nodes) is essential.

7. Running the tests

The tests are executed based on the simulations and the performance of the relay is captured by the testing devices and software. The synchronization is based on specific settings defining usually the test to be performed and time of the test.

The testing software may need to be able to receive the reports from the tested logical nodes to compare the results (for example fault currents or fault location calculation) with the simulated values.

Since the end-to-end testing results analysis is based on the operation of devices at different locations in the electric power system, this data will need to be communicated between the substations involved or to an engineering station at the system level.

8. Analyzing the test results

Based on the test configuration the system evaluates the tested protection system performance and produces a test report.

There is a need for the definition of Testing Logical Nodes that can be used to model the test system components and test results in a standardized form.

The protection model will also be required for the end-to-end test evaluation. The relay settings in this case are used to determine if the operation of the protection system under test is correct. This will require IEC 61850 model support in the testing software.

Test Evaluation Logical Node probably will need to be defined to represent the data required for the analysis of the test. This will include for example the acceptable tolerance ranges for the operating time of the individual protection elements or the end-to-end tested protection scheme.

Harmonization Tasks

Based on the analysis of the above use case, the following harmonization tasks have been identified:

- The existing IEC 61850 and CIM models of the different electric system components – lines, transformers, generators, capacitors need to be compared between themselves and with the modeling requirements for the steady-state short circuit studies or electromagnetic transients analysis programs.
- Positive, negative and zero sequence components of the impedances need to be added to the model.
- A three phase impedance model (3x3 matrix) for single transmission line is needed.
- A three phase impedance model for a double circuit line or a section of lines in parallel (6x6 matrix) is needed.
- Connectivity model for transmission and distribution lines is needed to describe a line with multiple segments. The main issue is that currently a connectivity node belongs to a substation. However, when defining a segment of a transmission line that is mutually coupled with a segment from another line running on the same tower or right-of-way, the connectivity nodes defining the segments typically do not belong to a substation, but to the transmission line. This will need to be addressed in the model.
- The connectivity model needs to be extended to cover mutual coupling on double circuit or parallel lines.
- A multi-step test file format will be required as well.
- An Event reporting model will need to be harmonized between IEC 61850 and CIM (based also on IEEE PSRC WG H5-b)
- Some Test .Evaluation logical nodes will also need to be developed.

Business Rules and Assumptions

ACTORS

Actor Name	*Actor Type (person, device, system etc.)*	*Actor Description*
Relaying test engineer	Person	Designs, tests, and analyses new protection scheme (could be a team)
GPS	System	Provides accurate time synchronization signals used during test (is 1 millisecond sufficient for this test? 100 uSec?
Initiating relay	Device	Causes the tested action to be started based upon stimulator signals
Stimulator	Device	Provides time-stamped stimulus (digital or analog) to initiating relay
Initiating comm. device	Device	Transfers signals from initiating relay to communication channel
Communication channel	System	Transfers signal from initiating relay to receiving comm. Device
Receiving comm. device	Device	Receives signal from communication channel
Receiving relay	Device	Receives and interprets signal from receiving comm. device
Test system	Device	Coordinates configuration of each end, initiates test, create results report
CIM database	System	Contains CIM-level system topology and parameters
Relay database	Device database	Contains configuration information for each relay non in SCL
SCL	File(s)	Contains 61850-level system information for each substation

STEP BY STEP ANALYSIS OF EACH SCENARIO

Scenario Description

Primary Scenario: Successful test

Triggering Event	*Primary Actor*	*Pre-Condition*	*Post-Condition*
(Identify the name of the event that start the scenario)	*(Identify the actor whose point-of-view is primarily used to describe the steps)*	*(Identify any pre-conditions or actor states necessary for the scenario to start)*	*(Identify the post-conditions or significant results required to consider the scenario complete)*
New scheme is to be tested	Relaying test engineer	System-level test case is defined	Scheme result have been analyzed

Steps for this scenario

Step #	Actor	Description of the Step	Additional Notes
#	*What actor, either primary or secondary is responsible for the activity in this step?*	*Describe the actions that take place in this step including the information to be exchanged. The step should be described in active, present tense.*	*Elaborate on any additional description or value of the step to help support the descriptions. Short notes on architecture challenges, etc. may also be noted in this column.*
1	Relaying test engineer	Creates detailed (step-by-step) design of test scenario	Steps do not include parameters
2	Relaying test engineer	Determines parameters needed for the test scenario	Simulation and testing params
3	Relaying test engineer	Partition parameters between CIM and 61850	Need intimate domain knowledge
4	Relaying test engineer	Determines CIM object names for parameters	Need intimate knowledge
5	Relaying test engineer	Requests testing parameters from CIM system	Database inquiry
6	CIM database	Provides requested values from CIM database	Database response
7	Relaying test engineer	Determines SCL object names for parameter	Need intimate knowledge
8	Relaying test engineer	Reads information from appropriate SCL file(s)	Need XML tag name(s)
9	Relaying test engineer	Determines extra information not in SCL information	Any missing information?
10	Relaying test engineer	Requests the parameter information from relay(s)	Query 61850 clients or servers
11	Relay database	Provides parameters which are not available in SCL	
12	Relaying test engineer	Configures simulator with parameters	
13	Relaying test engineer	Executes simulation	
14	Relaying test engineer	Extracts test parameters (ex: individual breaker currents)	Uses CIM/SCL topological info
15	Test system	Configures test system with the testing parameters	
16	Stimulator	Executes pre-test	Sync relays and test system
17	Stimulator	Executes test	Apply stimulus
18	Test system	Execute post-test	Extract relay action with timing
19	Relaying test engineer	Extract useful data from test results	Use to decide if rerun is needed

REQUIREMENTS

Functional Requirements

Functional Requirements	*Associated Scenario # (if applicable)*	*Associated Step # (if applicable)*
All parameters (gens, lines, topology, compensators) are available in CIM/SCL/61850	1	2
Parameter locations are clearly defined between CIM model and SCL file and IED	1	3
CIM location can be determined easily from one-line diagram	1	4
CIM system allows database queries from an engineer desktop system	1	5
SCL location(s) can be determined from one-line diagram	1	7
IED names in SCL files must have deterministic mapping to IED names on one-line	1	7
SCL (SCD) files must be in known location with a sufficient version control system	1	8
61850 information in IED must correlate with CIM information to determine missing info	1	9
61850 servers are online and can be queried	1	10
Simulator input has interface compatible with CIM database (ex:COMTRADE files)	1	12
Simulator output has interface compatible with stimulator (ex:COMTRADE files)	1	15
Test system output has interface compatible with CIM database (for test result archival)	1	18

Non-functional Requirements

Non-Functional Requirements	*Associated Scenario # (if applicable)*	*Associated Step # (if applicable)*
Appropriate security measures are in place to guard against CIM information leakage	1	5
Appropriate security measures are in place to guard against inadvertent CIM changes	1	5
Appropriate security measures are in place to allow engineer to trust CIM values	1	6
Appropriate security measures are in place to guard against inadvertent IEC changes	1	10