GRIDSCALE X ADVANCED PROTECTION ASSESSMENT

Sensitivity Analysis Module

Evaluate the operational margins of your transmission line protection using automatic sensitivity analysis tests. Assign a quantitative value to the margins of relay operation upon multiple faults and contingency scenarios.

SIEMENS

At a glance

The Sensitivity Analysis module was created to analyze the operational sufficiency of transmission line protection upon faults and contingencies in the protected line. Operational sufficiency refers to assuring there is ample margin for the protection operation upon a set of reasonable fault scenarios.

The Sensitivity Analysis module automatically runs a series of contingencies designed to evaluate the correct operation of the line protection under study, as well as the sufficiency regarding specific requirements of that operation. Most of these studies use a test rule that is evaluated and provides a measure of the correctness of the relay settings for protecting their primary equipment and how ample the margins of that operation are. These rules generally follow recommendations from IEEE Std C37.113-2015, IEEE Guide for Protective Relay Applications to Transmission Lines. The results are presented in a way that protection functions with failed criteria are easy to spot, while obtaining all the necessary data that corroborates that evaluation.

The challenge

Protection engineers are constantly producing, enhancing or modifying protection settings to improve the protection scheme reliability.

Protection sensitivity, defined as the inherent capability of a protection system to operate under conditions of primary equipment fault, represents a fundamental criterion in the formulation of protection schemes. This parameter guarantees that the system will respond to all specified fault scenarios and network contingencies for which it has been designed, while preserving an adequate operational margin to ensure reliability and stability.

The evaluation of protection sensitivity may be performed by simulating a series of faults and contingencies, while determining for each scenario whether the protection asserts, and computing the operative margins in which that operation occurs. However, preparing each one of these fault scenarios is tedious and complicated work. Even when these scenarios are produced, grading the sufficiency of the protection to clear those faulty scenarios is complicated.

There is not an available tool that specifically targets the study of sensitivity and, at the same time, provides a quantifiable measure of such operational margin.

Our solution

The Sensitivity Analysis module executes automatic studies, separately targeting different protection functions. These studies include a combination of faults and equipment outages, while evaluating the operational sufficiency of the targeted protection in a granular and quantifiable manner.

The Sensitivity Analysis module contains tests that target specific protection functions separately. Each one of these focused tests performs a combination of fault types, fault locations and nearby equipment outages. For each of these combinations, pertinent data are gathered, including operating quantities, pickup values, protection reach across the protected line and adjacent lines, among other relevant details.

That collected data is then used to either compute a ratio or calculate the reach of the protection over the primary line. The computed quantities are then compared against user-defined thresholds, depending on the protection function under study. If the protection function settings honor the test thresholds under the presented fault scenario, then the Sensitivity Analysis module deems the protection element as passing (PASS) the sensitivity test; otherwise, the Sensitivity Analysis deems the protection element as failing (FAIL) the sensitivity test.

The use of equations and thresholds provides a quantifiable approach that allows measuring the sensitivity of the protection function under test, giving the protection engineers a factual basis to make decisions about the sensitivity of the relay settings they produce.

Comprehensive protection sensitivity test studies

Together with customers, Siemens has developed a series of sensitivity test criteria for transmission line protection. These tests include:

- Phase, ground and negative-sequence instantaneous overcurrent protection.
- Phase, ground and negative-sequence time overcurrent protection.

- Breaker failure protection.
- Phase and ground zone 1 distance protection.
- Phase and ground zone 2 distance protection.
- Phase and ground zone 3 distance protection.
- Phase and ground zone 2 and reverse zone distance protection for pilot protection.
- Carrier trip ground instantaneous overcurrent protection.
- Carrier start ground and negative-sequence instantaneous overcurrent protection.
- Carrier trip to carrier start overcurrent pickup ratio.

For each sensitivity test, specific aspects of the protection operation are evaluated, according to the objectives of the setting philosophy of this equipment.

For instance, for instantaneous overcurrent protection, its main purpose is to protect the transmission line for internal faults, without overreaching the remote substation. Naturally then, testing the sensitivity of this function involves applying remote bus faults and evaluating the ratio of the pickup current of the protection (I_{pickup}) to the operating current monitored by the function upon the fault condition (I_{fault}). To assure that the overcurrent protection does not assert for faults at the remote bus, this ratio should be larger than 1 by a reasonable safety margin, let's say 1.25, although this margin is configurable by the user.

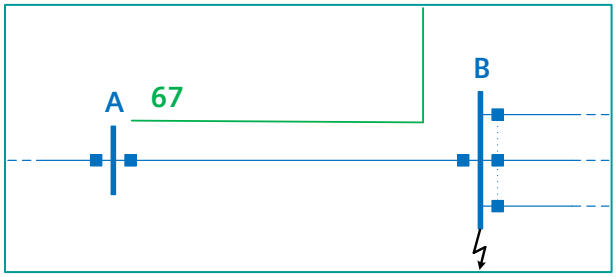

Figure 1: Instantaneous Overcurrent Sensitivity Test.

Removal of short circuit sources connected at the remote substation challenges the fulfillment of the test, as more current contribution flows from the local substation to the fault, decreasing the test ratio value.

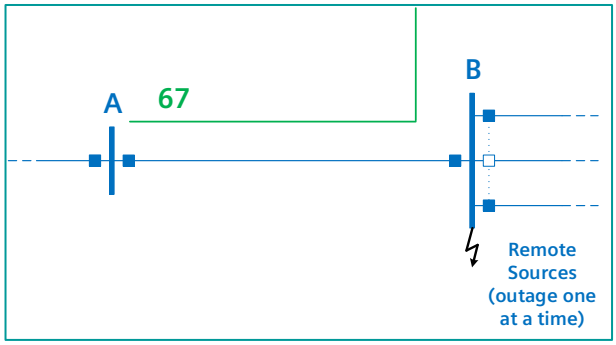

Figure 2: Outaging Remote Sources in the Instantaneous Overcurrent Sensitivity Test.

Complementary, the test includes finding the actual reach of the instantaneous overcurrent protection, under the same fault scenarios, by applying faults in the length of line, until the protection stops operating. The last location where the protection asserts is its actual reach, which is reported as percentage of the transmission line impedance.

Similarly, for zone 1 distance protection, for example, the main protection purpose is to ensure that the distance zone 1 protection does not overreach the remote substation of the protected line. For this, the actual reach of the distance zone 1 element is found by applying a set of sliding faults along the length of the protected line until the point where distance zone 1 element stops operating.

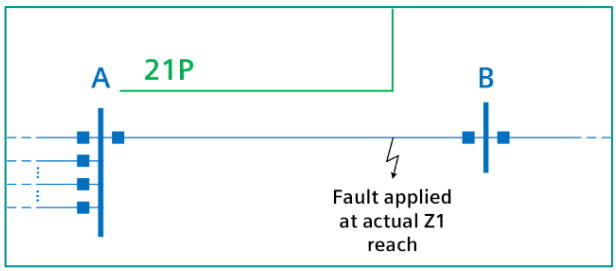

Figure 3: Distance Zone 1 Protection Sensitivity Test.

The actual reach of the element thus found is then compared against a threshold determined by the customer, normally from 85% (also customizable by the user) of the transmission line impedance. If the actual reach of the element does not exceed this threshold, the distance zone 1 element test passes.

The test includes a series of outages that challenge the distance zone 1 protection to pass the test. These network changes include outaging branches converging at the local bus, removing one source at a time. The purpose is to create conditions that might make the distance protection function overreach the remote substation, making it more difficult for the protection to pass the test.

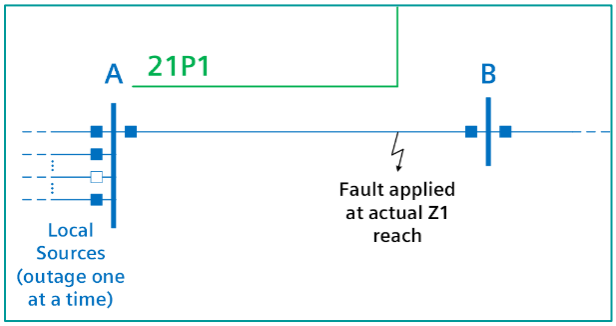

Figure 4: Outaging Local Sources in the Distance Protection Zone 1 Sensitivity Test.

For the testing of ground distance zone 1 elements, lines that are mutually-coupled to the line under study are automatically identified and outaged one at a time as additional test scenarios.

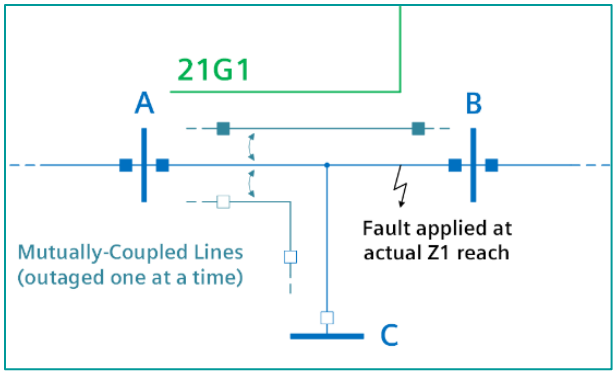

Figure 5: Outaging Mutually-Couple Lines in the Ground Distance Zone 1 Sensitivity Test.

Set up once, study anytime

With the Advanced Protection Assessment Sensitivity Analysis Module, you can set up your sensitivity studies, save the configuration parameters and then rerun these studies with just a few easy clicks. The ability to save and store the settings parameters ensures that your studies are consistent with your protection philosophy.

Easily mapping protection functions and sensitivity tests for automation

The Sensitivity Analysis module has been designed to automatically run sensitivity tests to transmission line protection selected by the user.

This automation is based on a customizable mapping of the protection functions in the relay model with the sensitivity studies the user assigns.

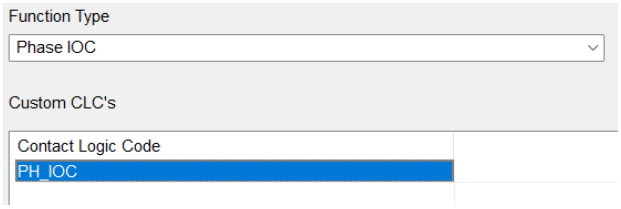

Figure 6: Mapping Protection Functions to Relevant Sensitivity Tests.

Sensitivity Analysis module reviews the relay model instances and automatically runs those studies to the selected protection functions, as desired by the user.

Control of sensitivity study execution

With switches in the Sensitivity Analysis module, the user has complete control over the type of protection functions that are included in the sensitivity study. This programming could be made permanent for each session or only for the current study.

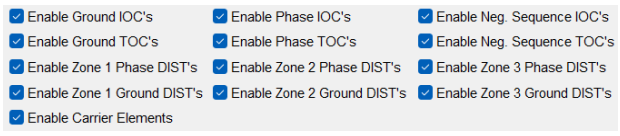

Figure 7: Switches to Control Sensitivity Tests to Run.

Configurable sensitivity study criteria

The operational margins used in the sensitivity tests are completely configurable by the user. The operational margin thresholds and reaches used in the automatic tests may be modified to make these less strict or stricter, according to the user's criteria.

Ratio of pickup setting to operating current for TOC elements (0.2-1)	0.33
Min. multiples of pickup current to operating current for digital and induction cup type IOC elements (1.1-2)	1.25
Min. multiples of pickup current to operating current for solenoid/clapper type IOC elements (1.1-2)	1.50
Ratio of pickup setting to operating current for Breaker Failure IOC element (0.2-1)	0.50
Ratio of pickup setting to operating current for overcurrent fault detectors of DIST elements (0.2-1)	0.33
Actual Zone 1 reach as a multiple of the line impedance (0.5-0.95)	0.85
Desired Zone 2 set-point reach as a multiple of apparent impedance for a remote bus fault (1.02-2)	1.20
Desired Zone 3 set-point reach as a multiple of apparent impedance for a line-end fault at second remote bus	0.50
Actual reach of remote reverse zone as a multiple of the actual reach of the local zone 2 element (1.02-1.5)	1.10
Ratio of pickup setting to operating current for carrier IOC element	0.33
Carrier Trip / Carrier Start Ratio	2.00

Figure 8: Configurable Testing Threshold and Reaches.

Color-based reporting of test results, all computational data in one single place

The sensitivity test report in the Sensitivity Analysis module is color-based, making the distinction between passed and failed tests easy to identify.

Ground Distance Elements Zone: 1; please wait ...

Testing zone 1 reach on path 3671 WALNUT-2369 MAPLE-16 to remote bus 2369 MAPLE(LINE_4926)

Element Details	Fault	Outages Considered (Contingencies)	Line Imp. Ohms	Line Angle Degrees	Set Reach Ohms	Set Reach %	Act. Reach %	Des. Reach %	PASS FAIL
81 DIST ZIG 1 SEL-421_5A	SLG	None	32.21	84.55	28.64	88.93	85.09	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG XFMR	: 3671-3672-2 (TR_3527)	32.21	84.55	28.64	88.93	85.24	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG XFMR	: 3671-3673-3 (TR_3528)	32.21	84.55	28.64	88.93	85.32	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG XFMR	: 3671-3674-4 (TR_3529)	32.21	84.55	28.64	88.93	85.16	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 3671-11-1 (LINE_4961)	32.21	84.55	28.64	88.93	85.09	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 3671-2369-15 (LINE_4898)	32.21	84.55	28.65	88.95	88.91	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 3671-3108-14 (LINE_5694)	32.21	84.55	28.64	88.93	85.09	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 3671-3997-1 (LINE_5498)	32.21	84.55	28.64	88.93	85.16	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 3671-5842-1 (LINE_4952)	32.21	84.55	28.64	88.92	85.40	85.00	FAIL
81 DIST ZIG 1 SEL-421_5A	SLG XFMR	: 2369-2368-1 (TR_3524)	32.21	84.55	28.64	88.92	84.93	85.00	PASS
81 DIST ZIG 1 SEL-421_5A	SLG XFMR	: 2369-2368-3 (TR_3527)	32.21	84.55	28.64	88.93	84.77	85.00	PASS
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 2369-3248-26 (LINE_1800)	32.21	84.55	28.64	88.92	84.62	85.00	PASS
81 DIST ZIG 1 SEL-421_5A	SLG Line	: 2369-3249-8 (LINE_1713)	32.21	84.55	28.64	88.93	85.09	85.00	FAIL

Figure 9: Sensitivity Analysis Module Results of Ground Distance Zone 1.

The protection function under study, the fault scenario details, and the data collected to evaluate the sensitivity operational margin quantity are all presented in one single place, for the convenience of the user.

Exporting results to Microsoft Excel

To facilitate the handling of the sensitivity results for reporting and compliance, the Sensitivity Analysis allows the sensitivity test reports to be exported to Excel.

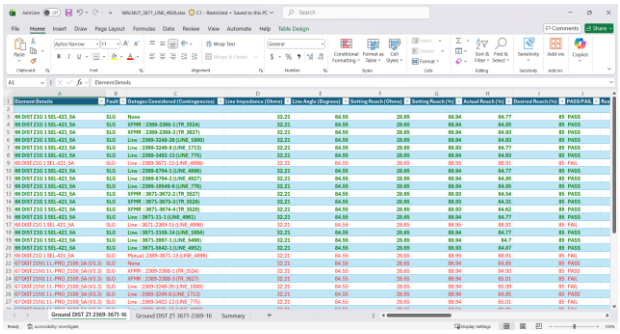

Figure 10: Sensitivity Analysis results exported to Excel.

Advanced Protection Assessment in Action – Features

- Comprehensive set of sensitivity test studies for transmission line protection.
- Automatic topology survey to determine outages to challenge protection to pass the test.
- Set up the study, rerun anytime.
- Flexible configuration to automate the execution of studies.
- Reports in tables where all computational data, results, and evaluation conclusions are in one single place.
- Sensitivity issues are clearly identifiable.
- Apply sensitivity tests consistent with your protection philosophy to improve reliability.

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