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Making sense of adaptive techniques to improve the stability of generator differential protection and its testing methods

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Introduction

Protective relays have evolved from a single phase, single function protection only devices to multifunction protection, control and communication devices. With the advancement in relay technologies, power system industry has gained a lot in terms of monitoring, diagnostics and adaptivity of protection and control. Standard schemes based on single contingency have evolved to adaptive systems based on specific conditions of the system at a given time.

Advanced microprocessor generator differential protection relays have incorporated Adaptive techniques to enhance the stability of the differential protection.

The challenge is How to test them?

What is an Adaptive Protection?

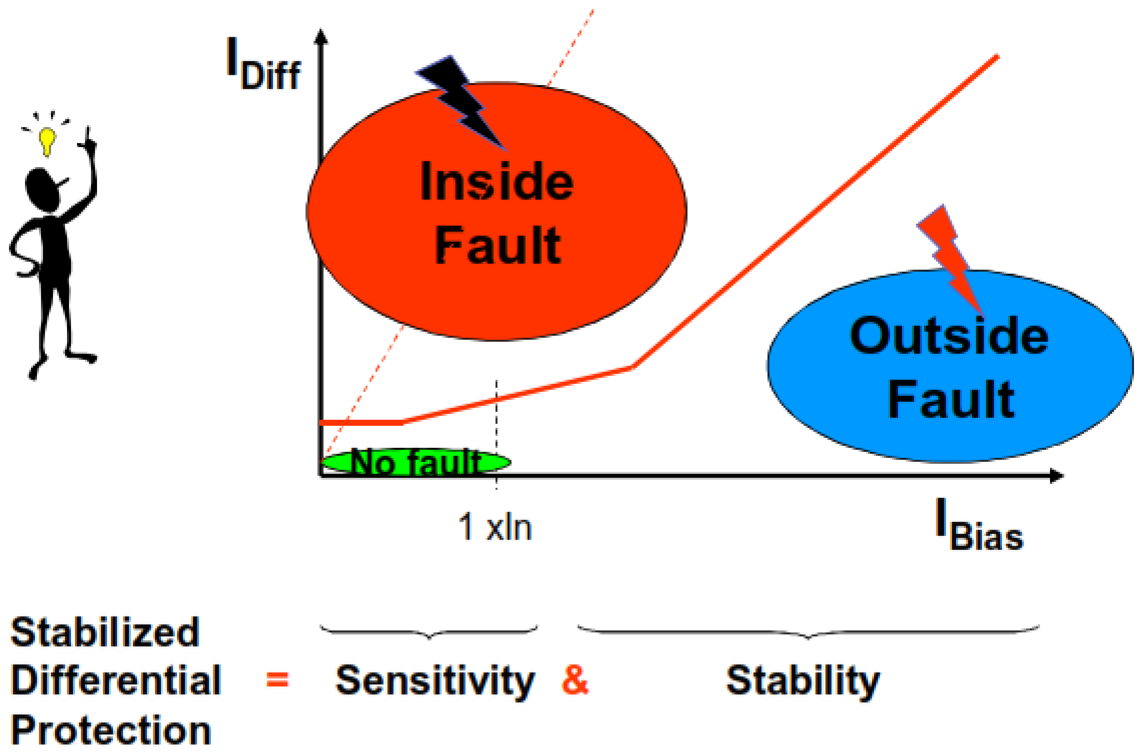
- An adaptive system is a system that changes its behavior in response to its environment.
- Adapting the behavior of the protection system to any change in their environment has become a necessity.
- Adaptive relaying utilizes the continuously changing status of the power system as the basis for online adjustment of the power system relay settings. Consequently, it provides the required flexibility for obtaining very high levels of power system reliability.

What is an Adaptive Protection?

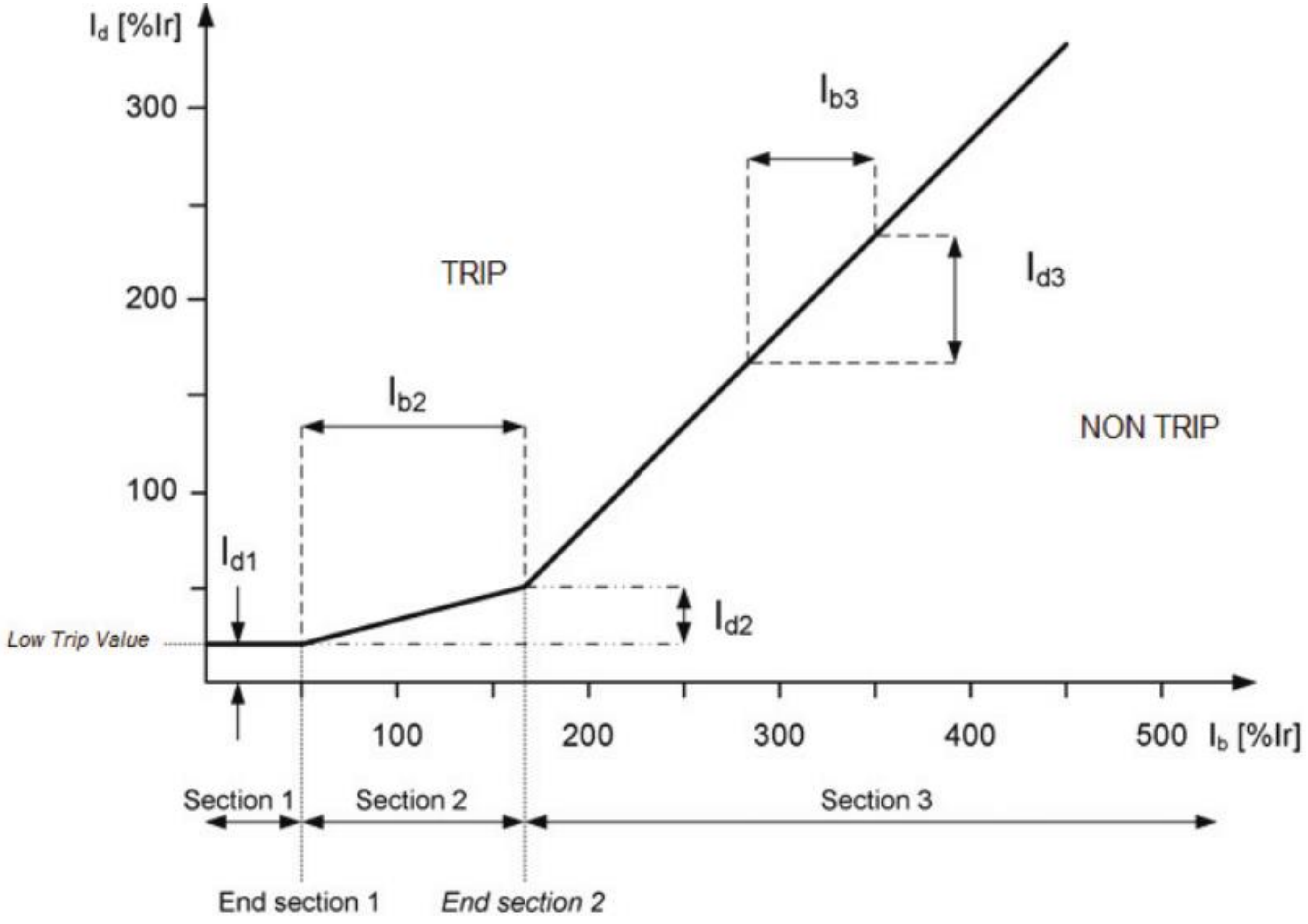
Some of the relay features that allowed the relays to adapt to changes are:

- Frequency tracking
- Multiple setting groups
- Programmable logic
- Adaptive restrained differential characteristic
- Voltage transformer supervision
- Circuit transformer supervision
- Changes in Substation configuration
- Adapting to loss of protection relays.

87G Operating Characteristic



87G Operating Characteristic

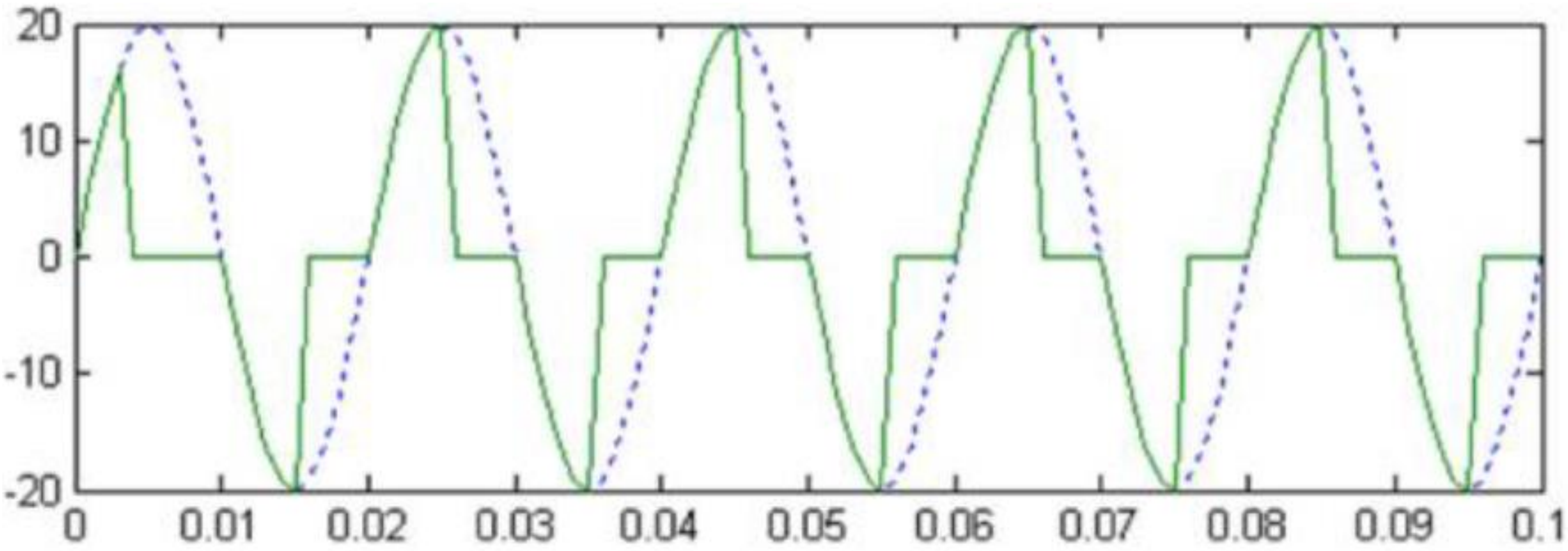


87G OPERATION CHALLENGES

- External short circuits result in the generator delivering large current to the fault. It is very important that the differential protection does not operate in case of such external short circuits. However, there is a risk of generator differential protection misoperation if a CT saturates.
- There are basically two types of saturation phenomena that must be detected:
  - AC saturation
  - DC saturation.

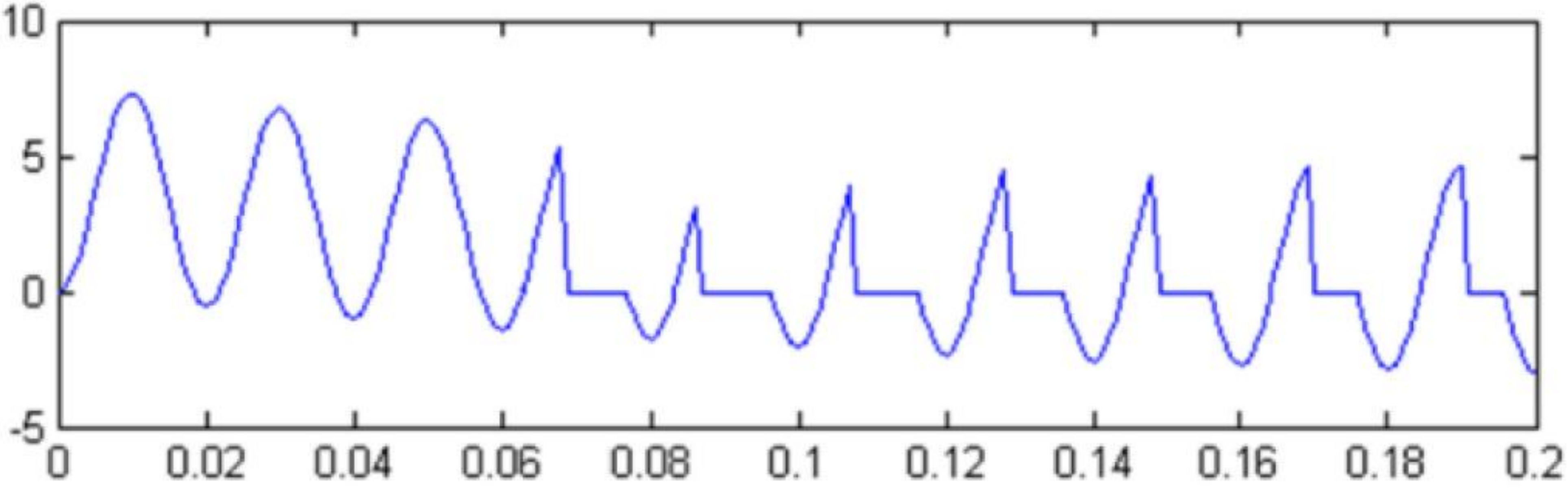
87G OPERATION CHALLENGES

- The AC saturation is caused by a high fault current where the CT magnetic flux exceeds its maximum value. As a result, the secondary current is distorted.

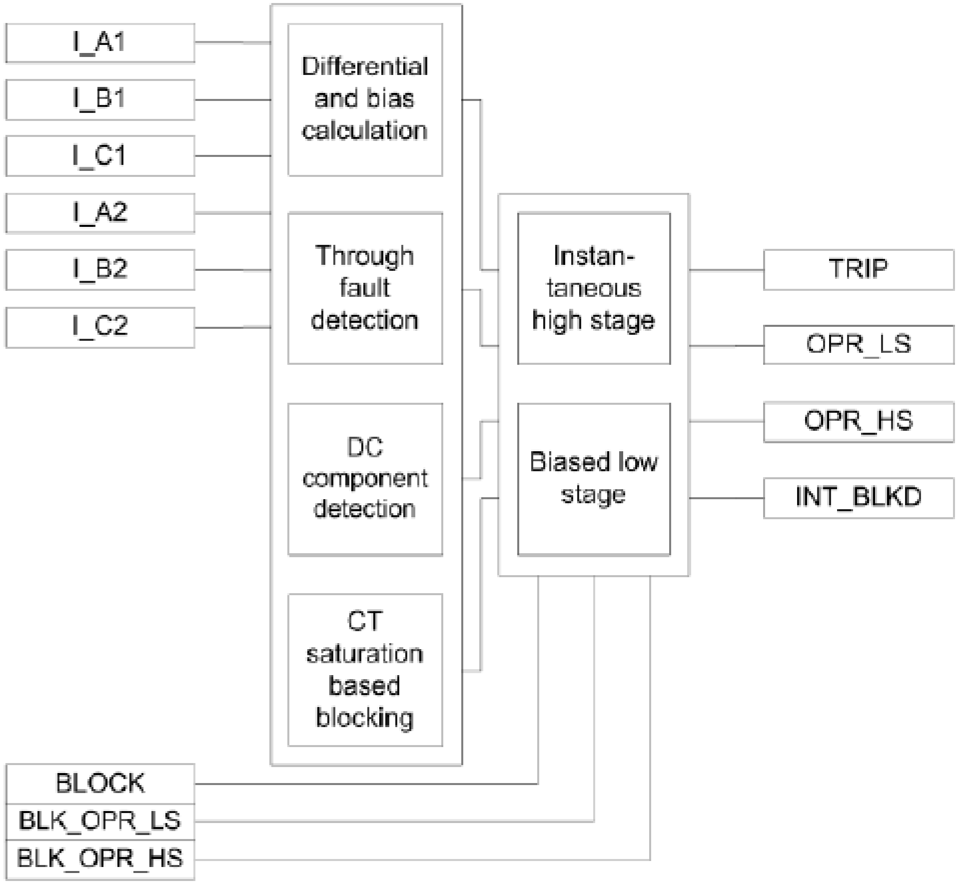


87G OPERATION CHALLENGES

- During a short circuit fault in the power line, the short circuit current contains a DC component. A DC component in the current also causes the flux to increase until the CT saturates.

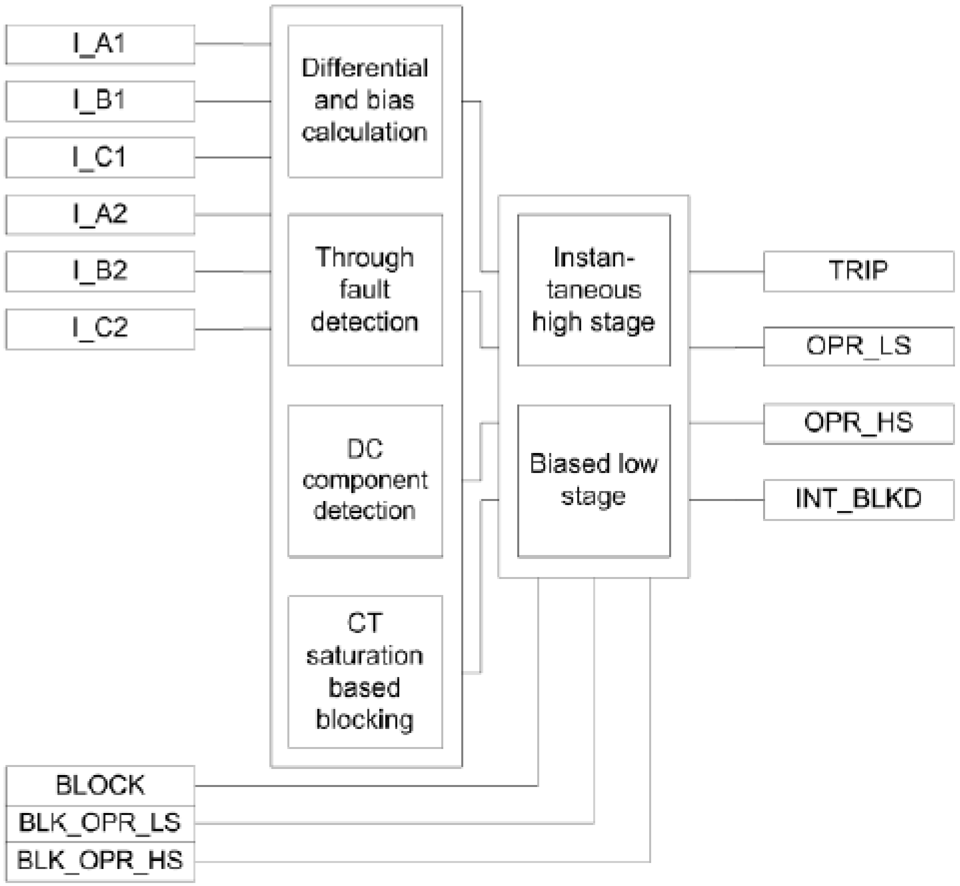


ADAPTIVE TECHNIQUES TO ENHANCE STABILITY & SECURITY OF 87G OPERATION



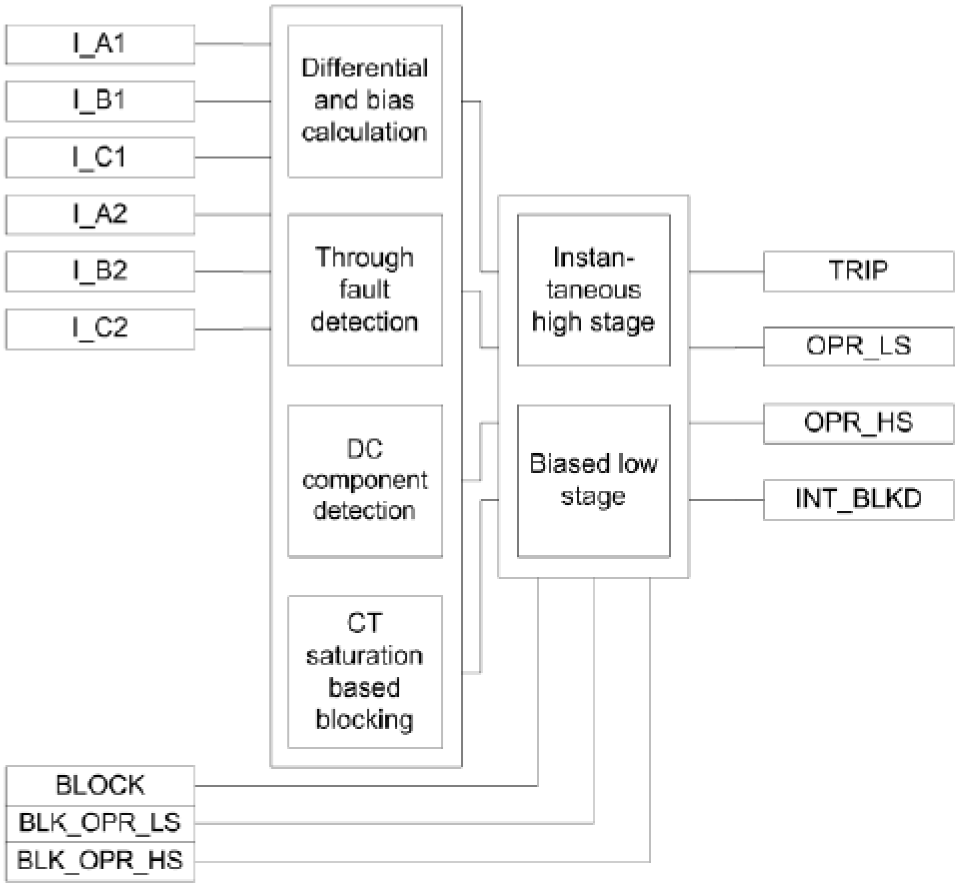
- The through-fault (TF) detection.
  - In a through-fault situation, CTs can saturate because of a high fault current magnitude. Such AC saturation does not happen immediately when the fault begins. The TF module sees the fault as external because the bias current is high, but the differential current remains low. However, if the AC saturation then occurs, a CT saturation-based blocking prevents the tripping of the element.

ADAPTIVE TECHNIQUES TO ENHANCE STABILITY & SECURITY OF 87G OPERATION



- DC component detection and DC restrain.
  - On detection of a DC component, the function temporarily desensitizes the differential protection as a function of this highest DC offset. The calculated DC restraint current is not allowed to decay (from its highest ever measured value) faster than with a time constant of one second.

ADAPTIVE TECHNIQUES TO ENHANCE STABILITY & SECURITY OF 87G OPERATION

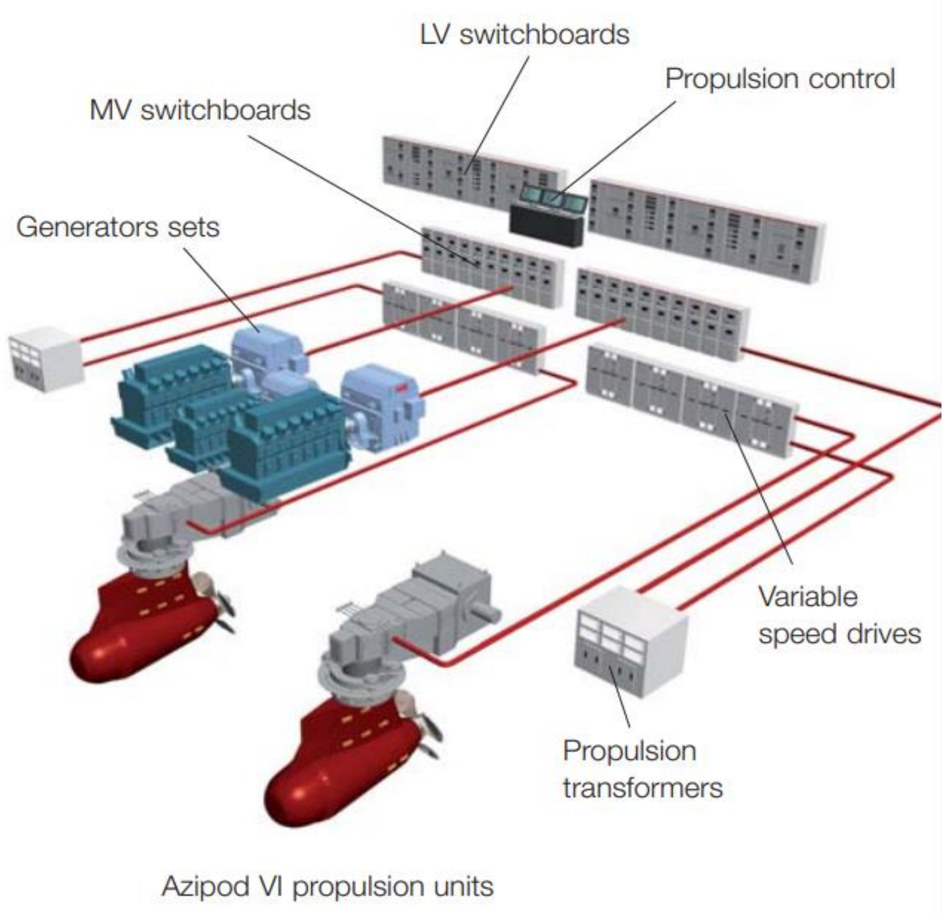


- CT saturation-based blocking.
  - The uneven saturation of the neutral and line side CTs (for example, due to burden differences) may lead to a differential current which can cause a differential protection to trip. This module blocks the operation of 87G biased low stage internally in case of the CT saturation.

ADAPTIVE TECHNIQUES TO ENHANCE STABILITY & SECURITY OF 87G OPERATION

- Based on the conditions checked from the through-fault module, the DC (component) detection module and the CT saturation-based blocking modules, the biased low-stage module decides whether the differential current is due to the internal faults or some false reason.

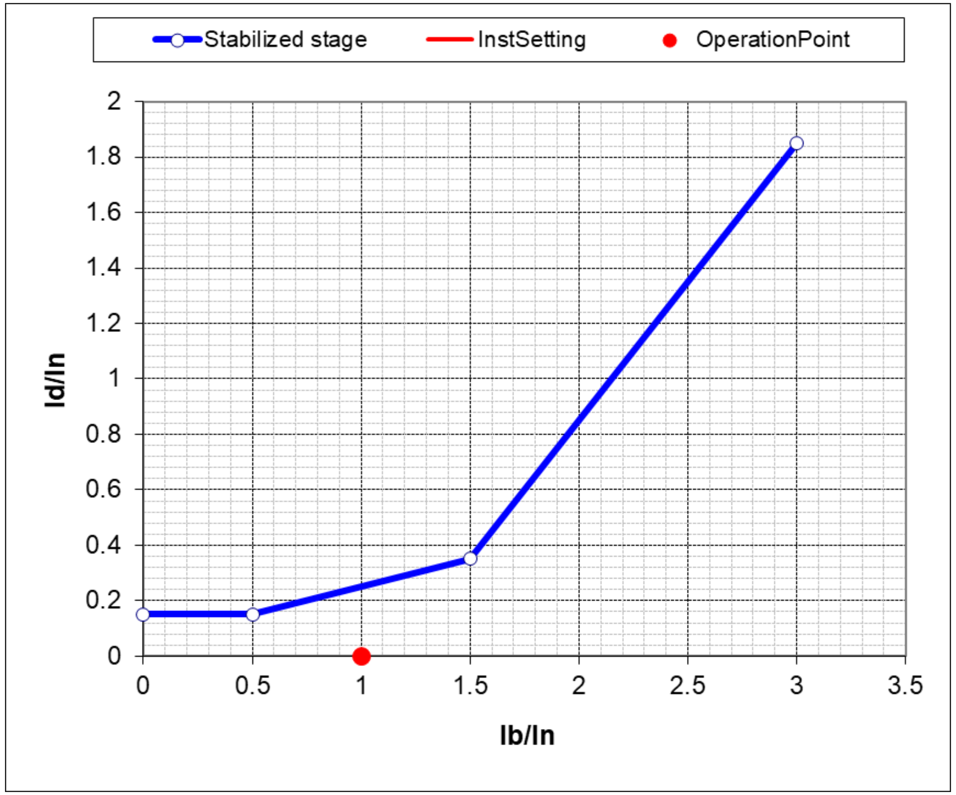
ANALYSIS OF A REAL FAULT INCIDENT



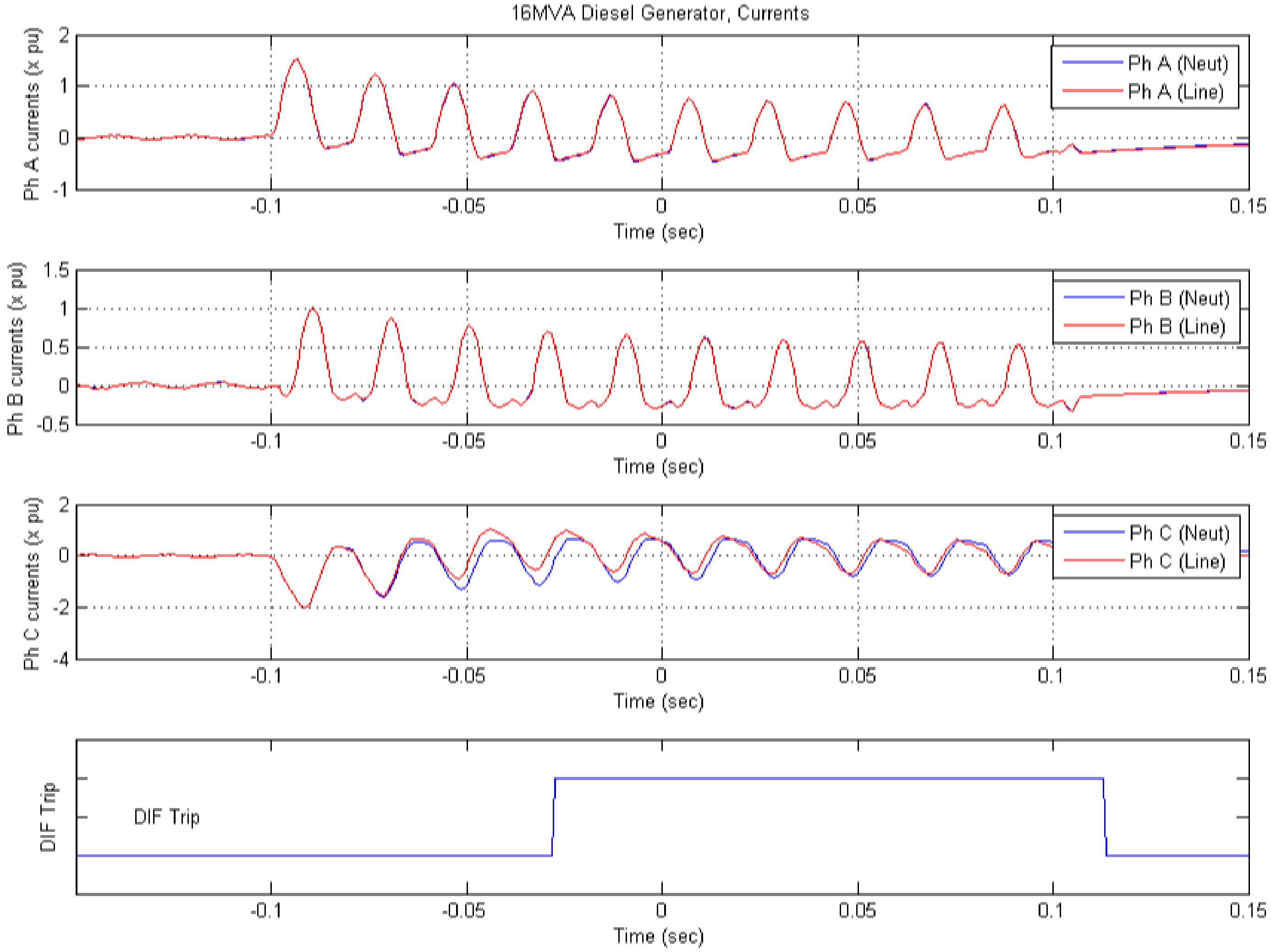
- Many modern ships are equipped with electrical propulsion systems.
- The electrical system of such ships is powered by several small diesel generators rather than for example two large machines.
- The event of false trip was energizing of one of these propulsion transformers.

ANALYSIS OF A REAL FAULT INCIDENT

- The example case shows a false trip of generator differential protection in case of an external event, which is inrush current of a large transformer's energization.
- Rating of protected machine
- Sn =16 MVA
- Un =11 kV
- Differential protection settings
  - Rated current (pu) = 840A
  - Low operate value = 15%
  - Slope section 2 = 20%
  - End section 1 = 50%
  - End section 2 = 150%

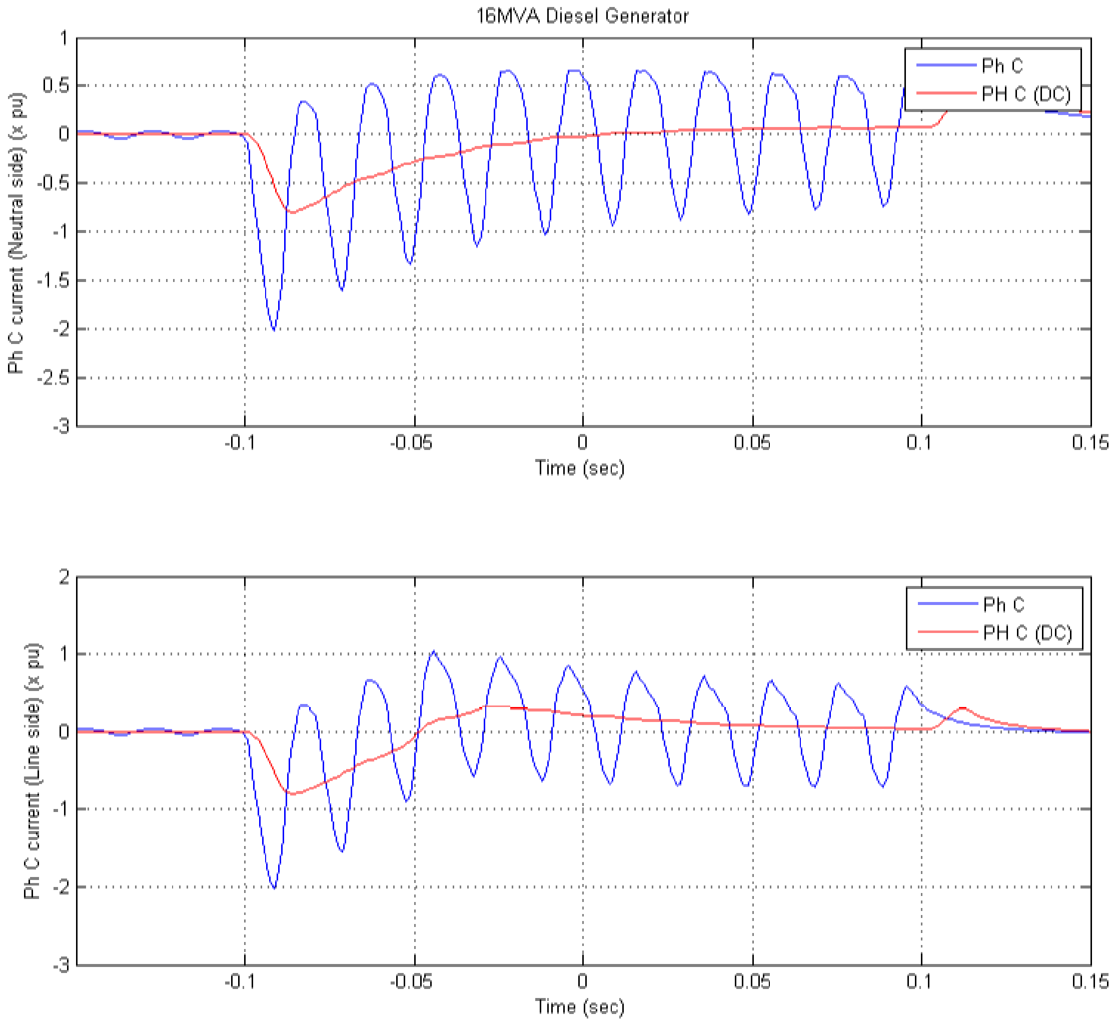


ANALYSIS OF A REAL FAULT INCIDENT



The currents match very well for phases A and B, but For Phase C there is a notable difference

ANALYSIS OF A REAL FAULT INCIDENT

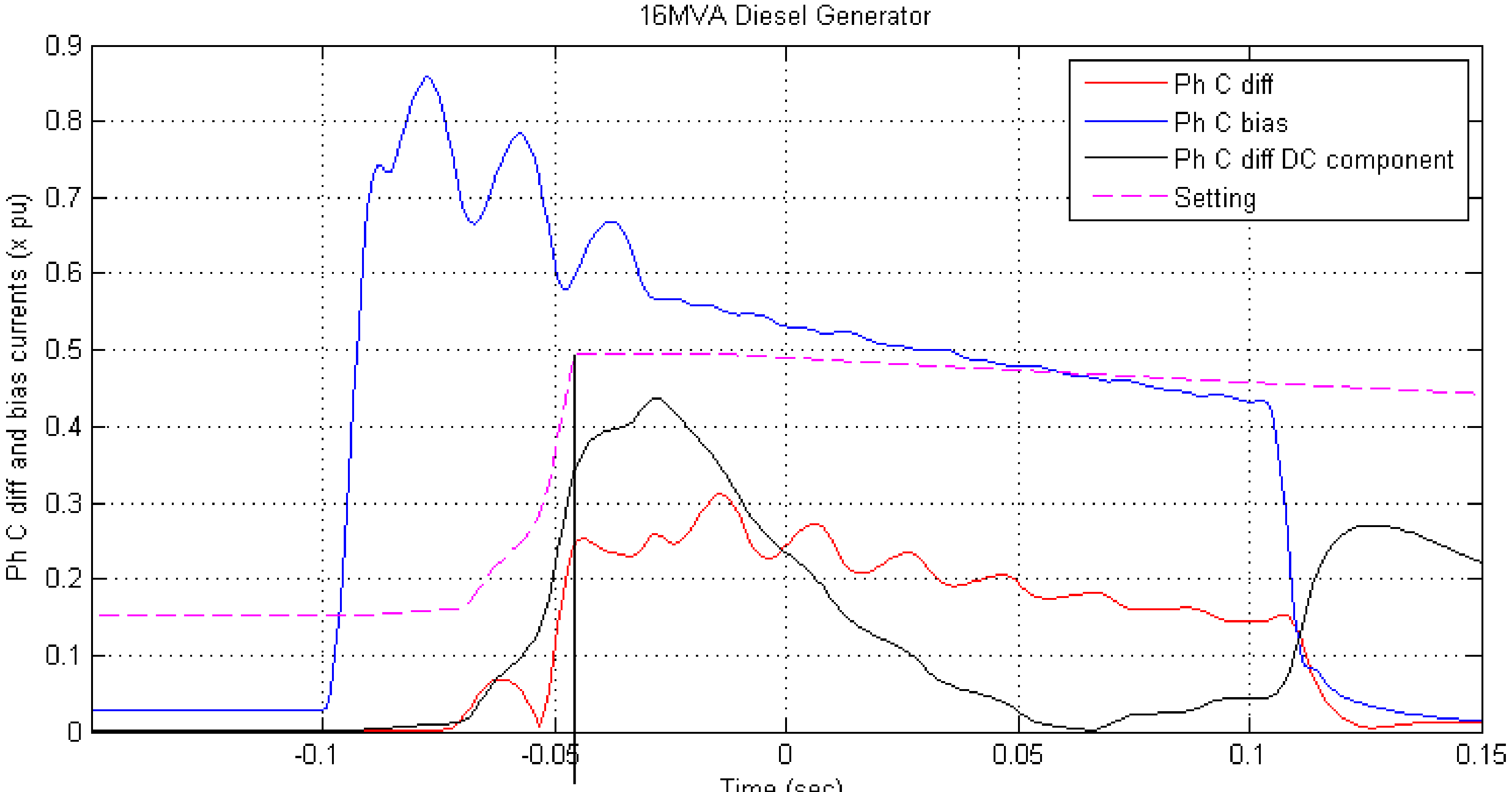


The DC component changes its sign from minus to plus at t= 50 ms from the start of the event. This is not possible in real primary currents, neither in short circuits nor inrush currents.

When this false trip occurred, the DC restrain feature was not enabled in the settings

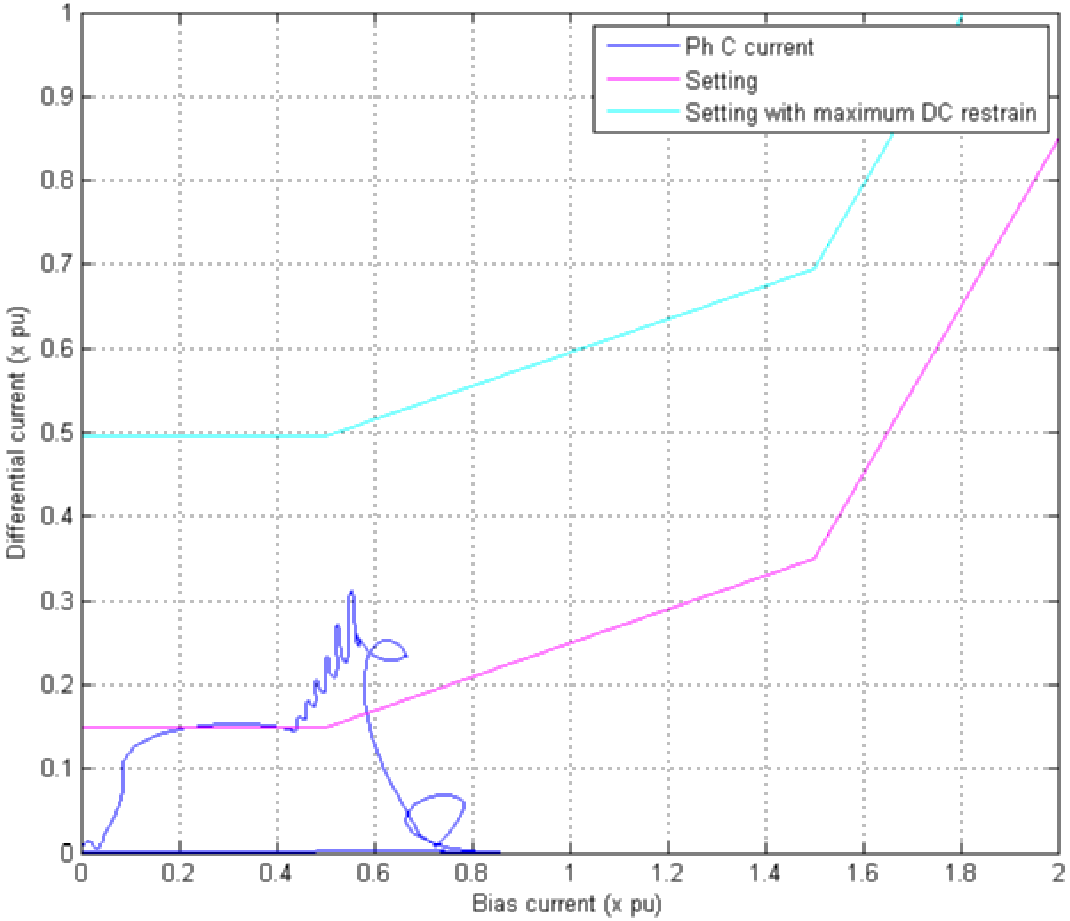
ANALYSIS OF A REAL FAULT INCIDENT

Effect of the DC-restrain feature



ANALYSIS OF A REAL FAULT INCIDENT

Effect of the DC-restrain feature



Tools for Testing

- Modern relay testing devices offer ready-made test modules and templates for almost all protection functions.
- Adaptive features have no pre-made testing possibilities. They are considered as part of the function design and are not included in scope of commissioning testing.
- The adaptive techniques discussed here have no setting parameters, apart from the enable/disable setting of the DC-restraint feature.

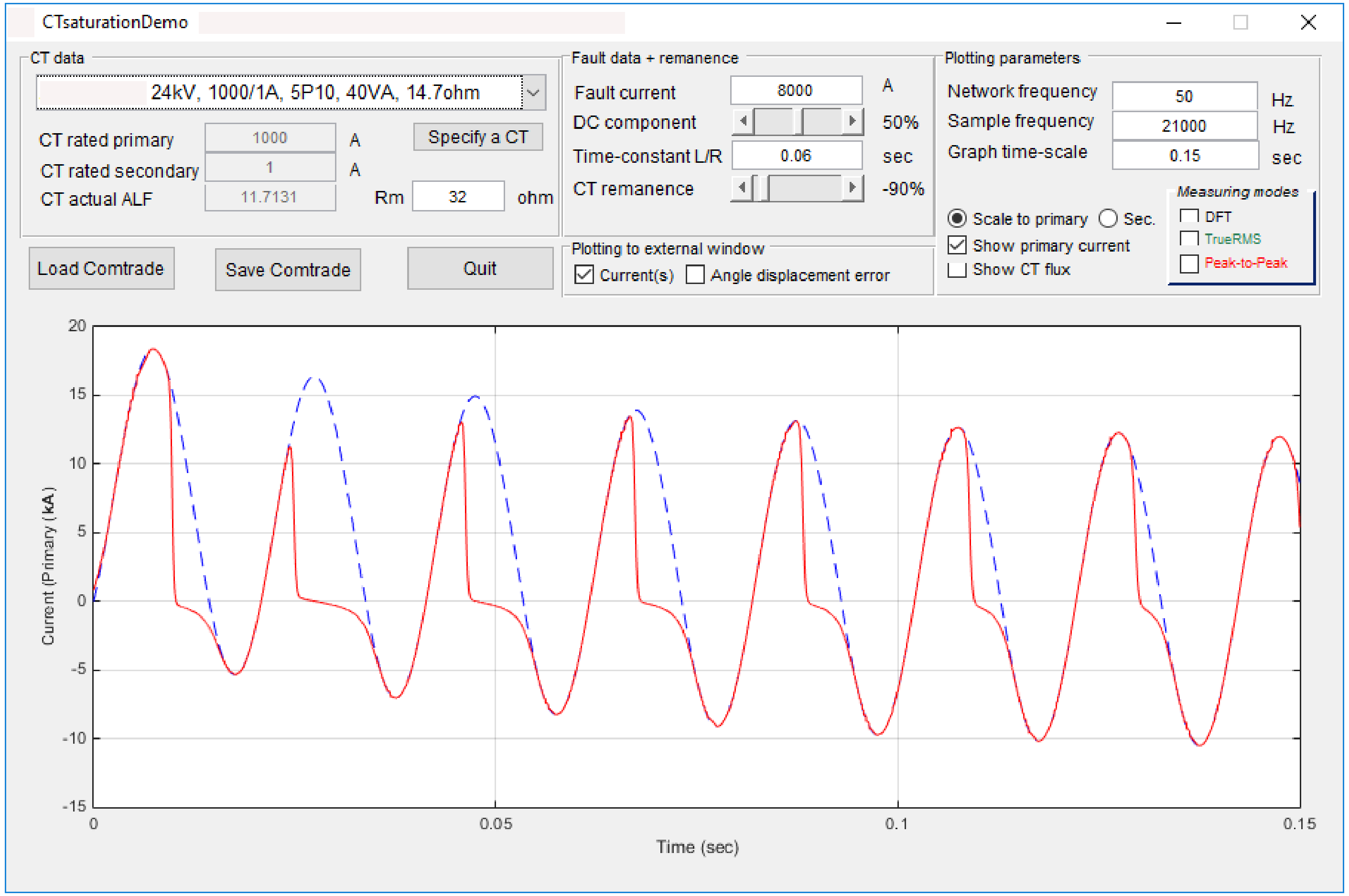
Methods for Testing Adaptive Features

Creating test files for CT saturation detection

- Blocking or de-sensitizing of 87G function can occur only when differential current is present. Therefore, CT-saturation detection cannot be demonstrated by injecting the same saturated current on both sides of the generator, as then the differential current will be zero.

Methods for Testing Adaptive Features

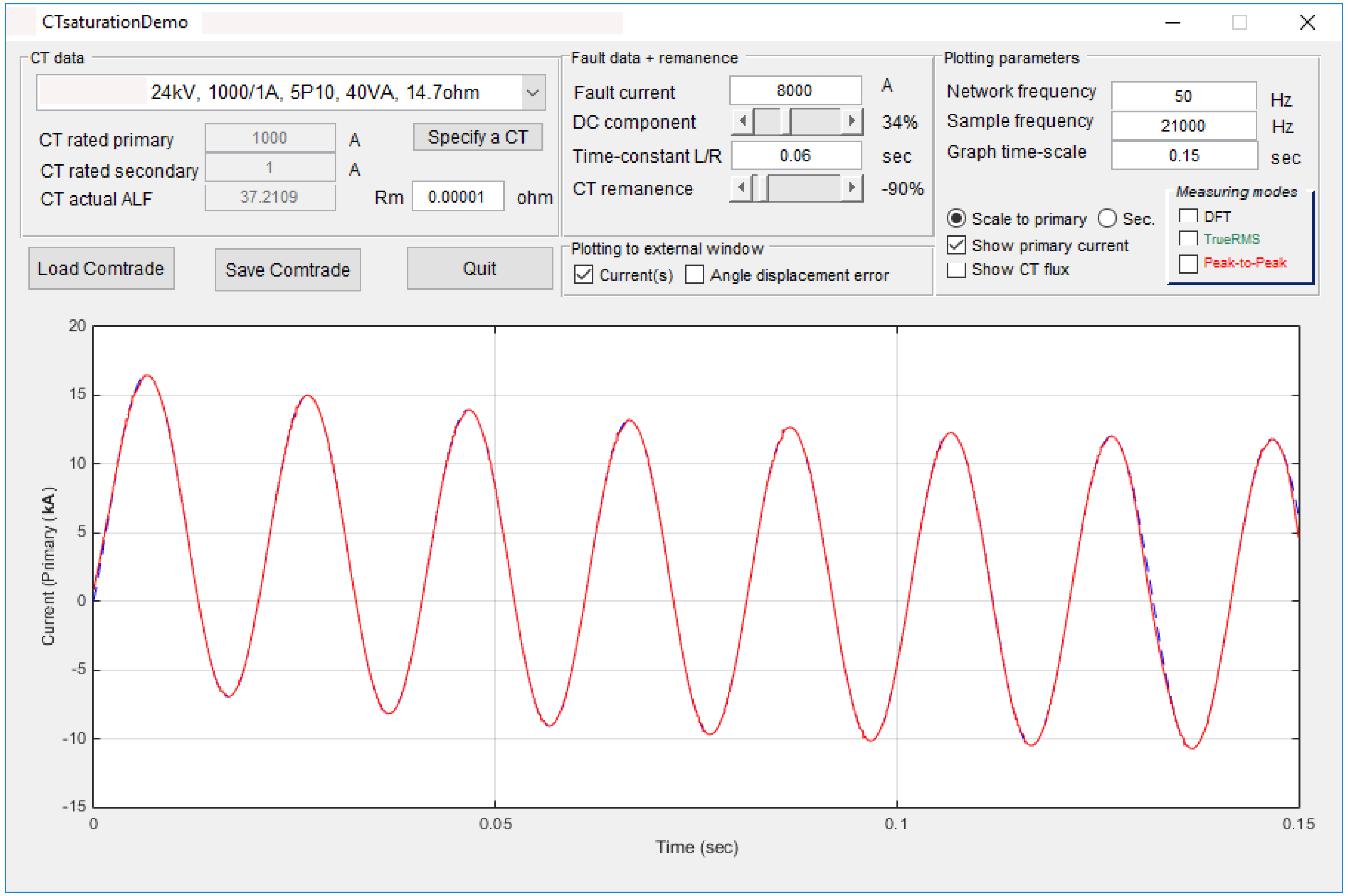
Creating test files for CT saturation detection



- 1A secondary current is chosen, so that the test currents don't get too big.
- Fault current should be below the high-set stage operate value
- CT ratio 1000/1 is chosen .
- The Accuracy Limit Factor can be adjusted by the value of the measurement circuit resistance.
- The DC component and the remanence are adjusted so, that the CT saturates after about 10 ms (8.3 ms for 60 Hz) after the start of the fault.
- Then the waveform is saved as a COMTRADE file

Methods for Testing Adaptive Features

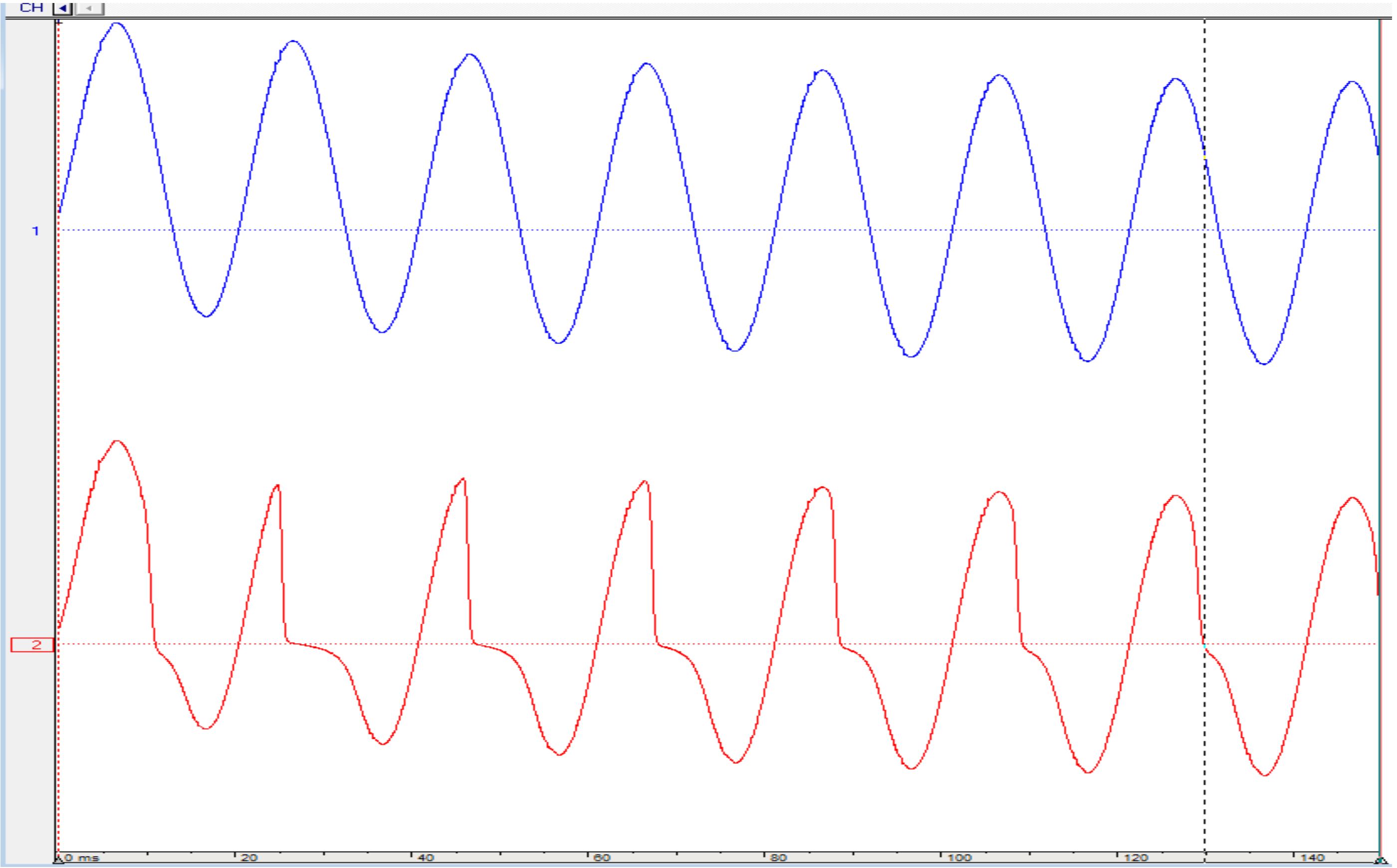
Creating test files for CT saturation detection



- Next step is to make the current record for the other (neutral) side of the generator. The fault current is kept the same, but the CT saturation is removed completely by reducing the external burden.

Methods for Testing Adaptive Features

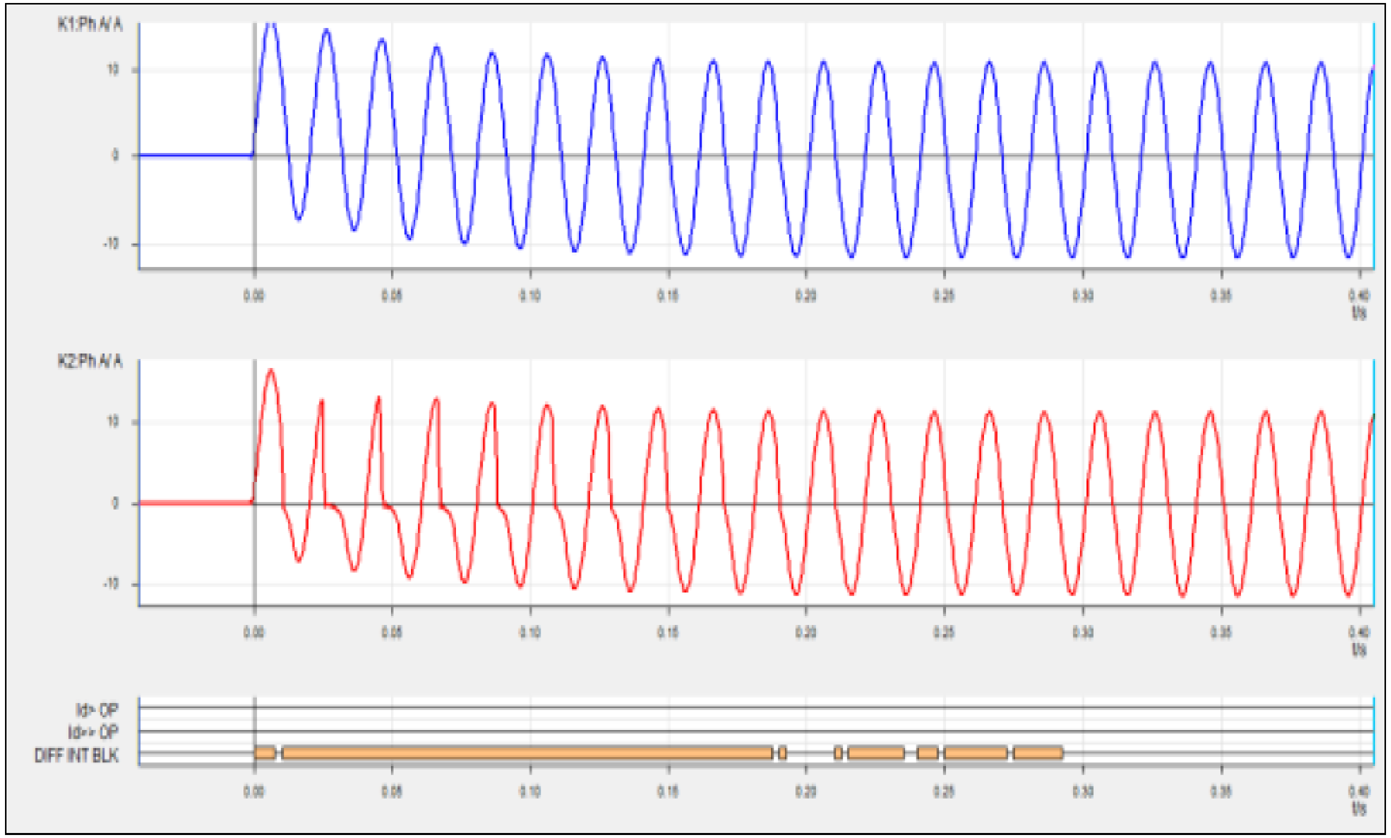
Creating test files for CT saturation detection



- Merge the two COMTRADE files using a COMTRADE viewer software.
- The file is now ready for playback testing

Methods for Testing Adaptive Features

Creating test files for CT saturation detection



- Result of playback testing with created test files for CT saturation detection.
- The “DIFF INT BLK” signal shows when the differential protection was blocked. Protection did not operate

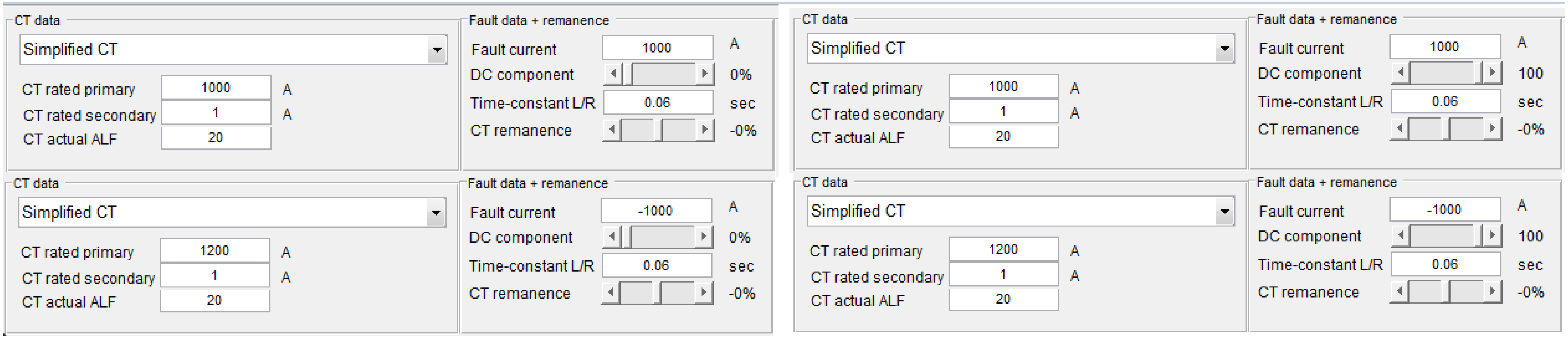
Methods for Testing Adaptive Features

Creating test files for Testing of DC Restraint Feature

- Test files can be created using similar steps as for the CT saturation detection.
- As DC restraint feature will only activates in the presence of a differential current, One way to create one is to use two different CT ratios, for example 1000/1A and 1200/1A. Then in the relay the ratio of 1000/1 A is used for both sides. This will make an apparent 17% differential current, when the load current is nominal 1000A.
- Then two sets of files are created, one with full 100% DC component and another without any.

Methods for Testing Adaptive Features

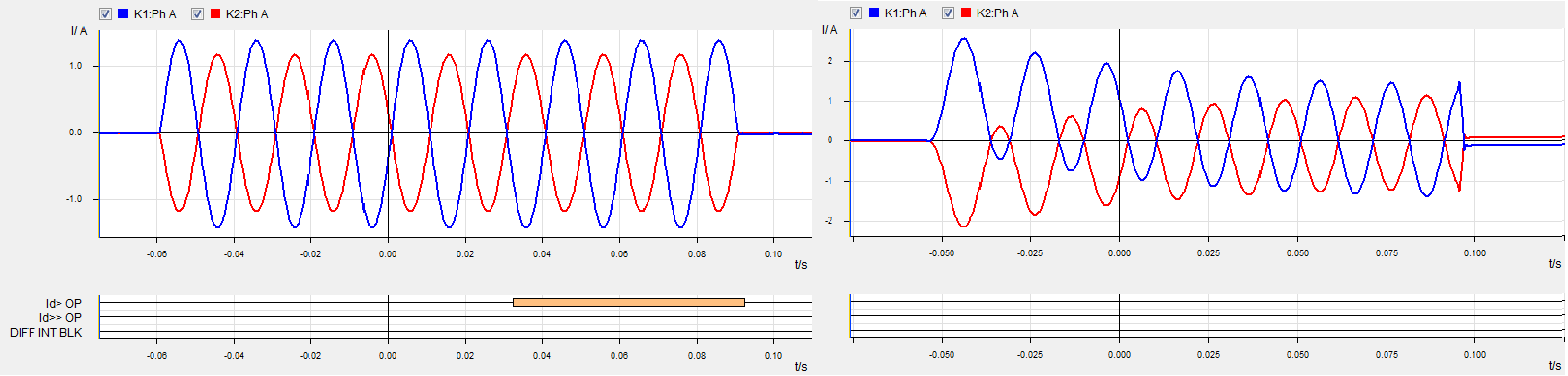
Creating test files for Testing of DC Restraint Feature



- The differential current will exceed the operate value this way. But in case when DC component is present, the operate value will rise to maximum 3.3 x 10% = 30 % and no trip should occur with 17 % differential current.

Methods for Testing Adaptive Features

Creating test files for Testing of DC Restraint Feature



- Test results with 17% differential current. On left, without DC component, and on right, with 100% DC component. As excepted, the protection operates on test without DC component, and does not operate, when DC component is included.

CONCLUSIONS

- Modern microprocessor relays with advanced 87G algorithm provide adaptive capabilities to automatically adjust the operation based on the power system condition.
- By enabling CT saturation-based blocking and DC saturation restraint features, undesired operation of 87G element can be avoided, thus getting an uninterrupted service from the generator in the event of external faults.
- At the same time, these modern adaptive algorithms detect and operate for faults within the protected zone, without compromising the sensitivity of the protection.
- The testing methods of adaptive techniques discussed in the paper will be a valuable tool for the design and the testing engineers and technicians involved with synchronous machine protection

Questions