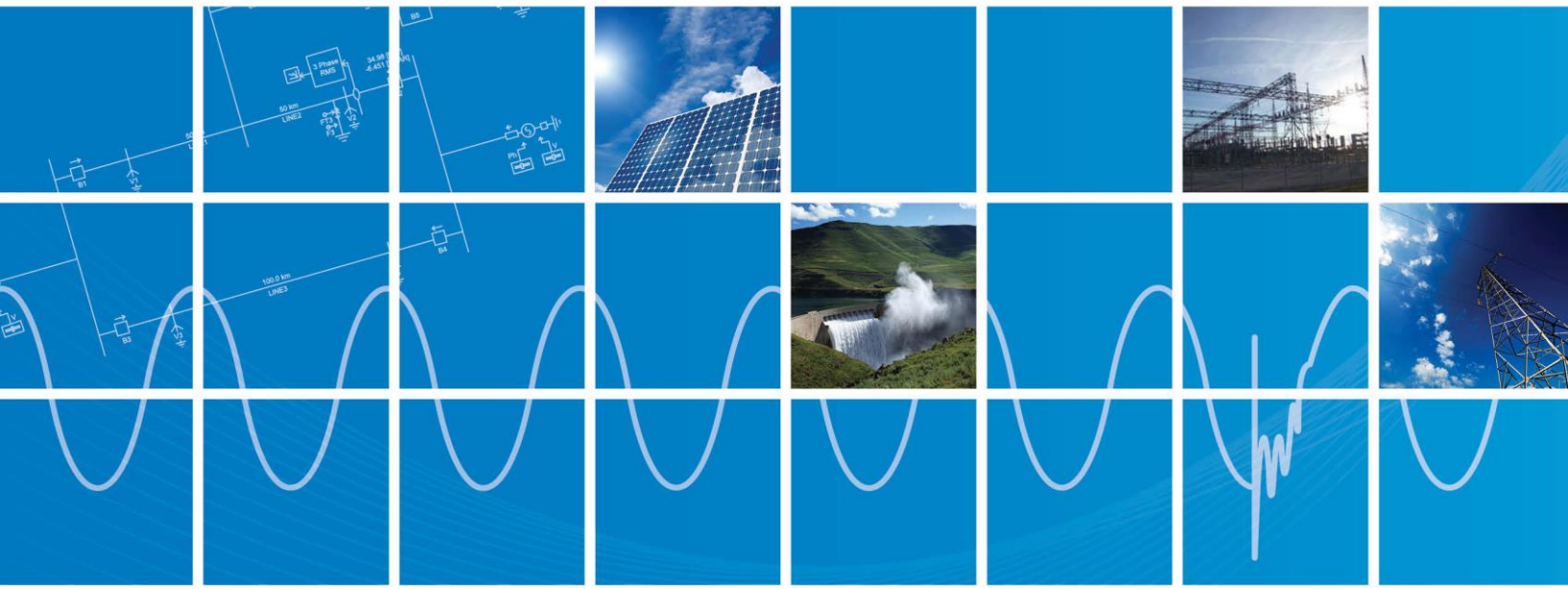
PSCAD Cookbook

Protection Studies

Written for PSCAD v4.5

Revision 1, November 22, 2018



Powered by Manitoba Hydro International Ltd.
211 Commerce Drive
Winnipeg, Manitoba
R3P 1A3 Canada
mhi.ca

Contents

7. PROTECTION STUDIES 1

7.1 CURRENT TRANSFORMER SATURATION STUDY 1
7.2 DISTANCE RELAYS STUDY 13

7. Protection Studies

7.1 Current Transformer Saturation Study

Motivation

This study is used to illustrate the effects of current transformer (CT) saturation. The key parameters that impact CT saturation are discussed. The magnetic characteristic of the CT is shown in Figure 3. In the linear region, the CT will behave almost like an ideal ratio changer. That is, the CT secondary current is an identical but scaled down replica of the primary current. CTs exhibit magnetization characteristics which can make their behaviour non-linear. If the CT saturates, more current is required to magnetize the core, and as a result the secondary current (I_S) available as inputs to the relay may not be an identical scaled down replica of the actual primary current (I_P). This can lead to protection issues and should be given due consideration.

System Overview

The ac system shown in Figure 1 consists of two 230 kV, 60 Hz Thevanin's voltage sources, a 75 MVA load and three 230 kV transmission lines (125 km, 75 km and 200 km). A single phase (Phase A) to ground fault is applied between the first two transmission lines.

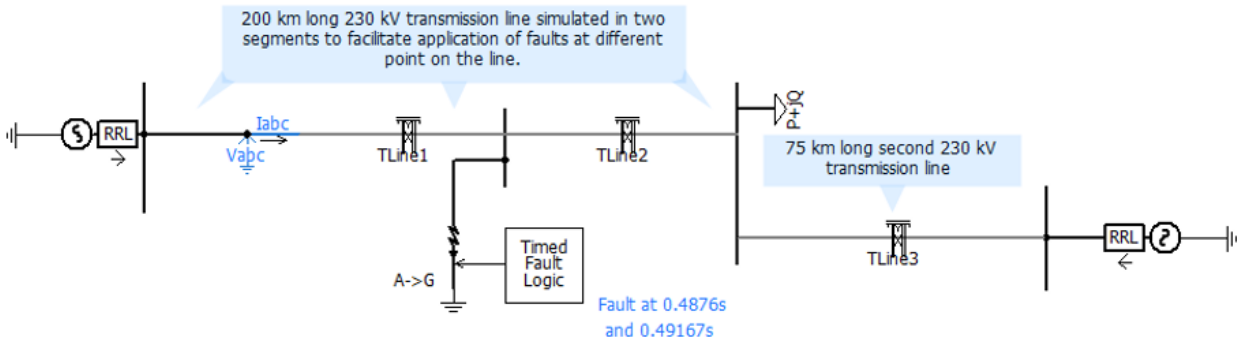


Figure 1: AC System

Current Transformer Saturation

CT saturation can be explained using the simplified equivalent circuit shown in Figure 2.

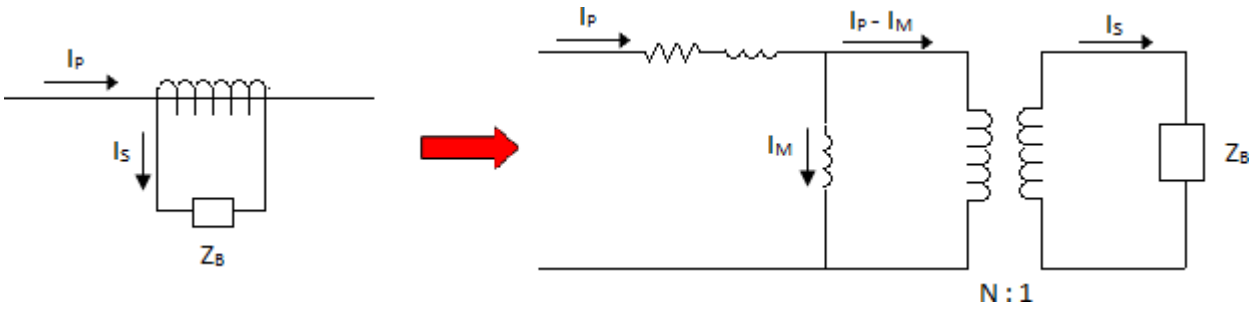


Figure 2: Schematic Representation of CT (left) and the Simplified Equivalent Circuit (right)

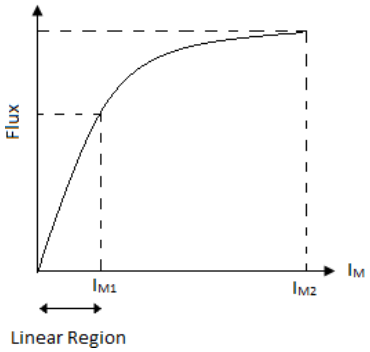


Figure 3: I_M-Flux Curve

In the linear region of operation, magnetizing current (I_{M1}) is very small, and hence I_P–I_M is approximately equal to I_P. Thus I_S would be a scaled-down version (by a factor of N). If the CT saturates, the magnetizing current increases (I_{M2}). As a result, only a part of I_P is available for transformation to the secondary.

In this simulation study, a fault is simulated on the transmission line, and the CT is at the end of the line (i.e. where Iabc is measured).

Notes

1. Figure 4 shows how the CT model is used in PSCAD.
2. The input primary current (Iabc) is in kilo-amps and the secondary current (Isabc) is in amps.

The CTs are modeled as independent blocks and do not have to be connected to the electric circuit. This representation is valid since the CT is essentially a short circuit (in series) from the primary power system network perspective.

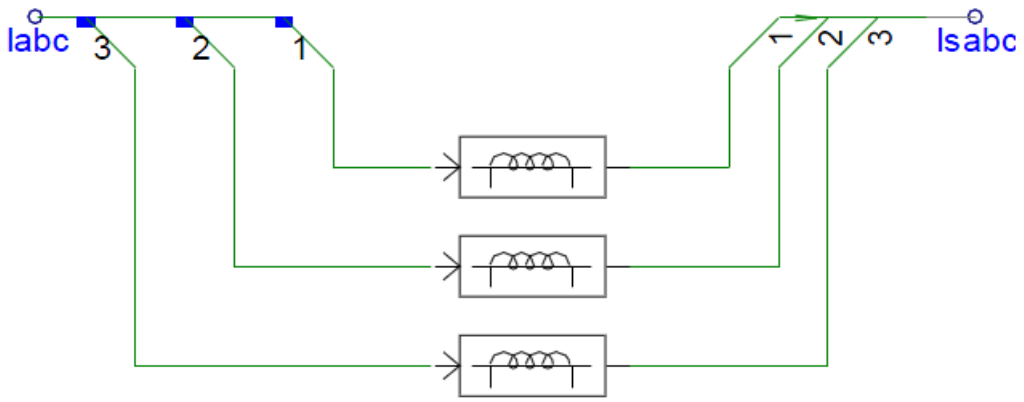


Figure 4: CT PSCAD Implementation

Simulation Results

The following key parameters can have a significant impact on CT saturation:

- DC offset in the primary side fault current
- Remnant flux on the CT prior to the fault (if any)
- Secondary side impedance including those of the relay, connecting wires and CT secondary impedance

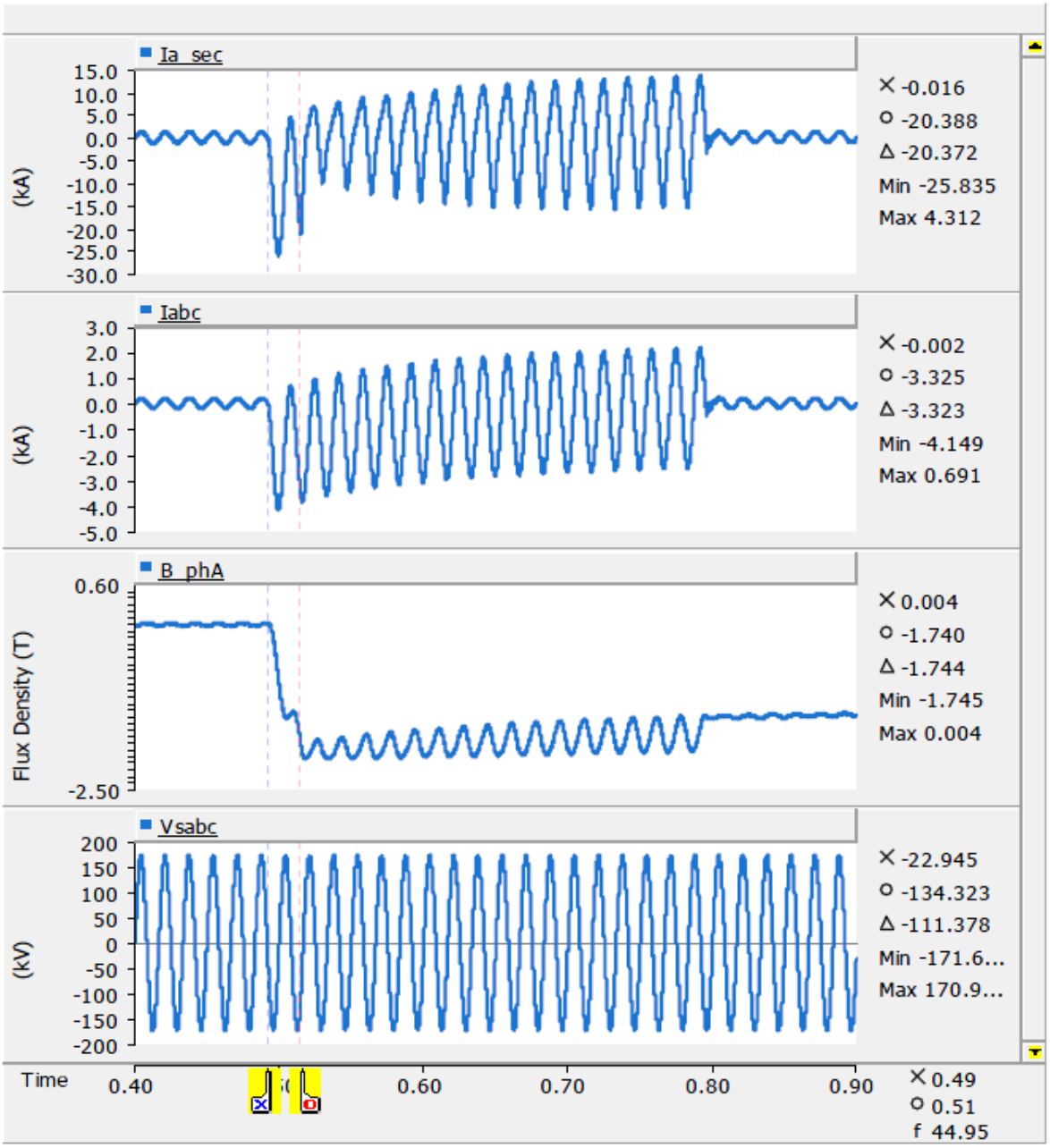
Simulation results for three cases are discussed below.

Case 1 – Impact of dc Offset in the Primary Fault Current

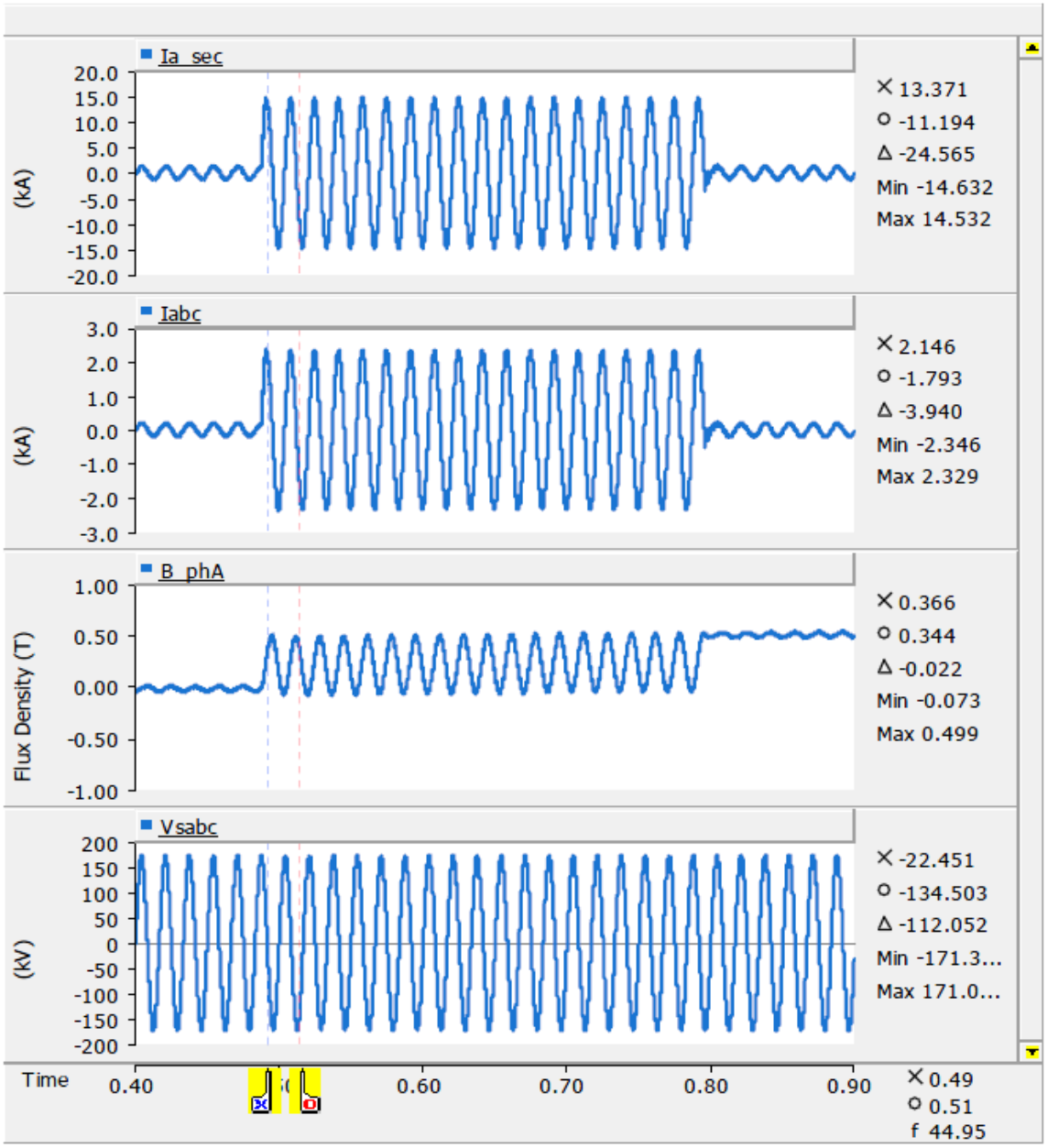
The point on the voltage waveform at the instant of the fault determines the level of the dc offset. The maximum dc offset will occur when the fault is applied at a voltage minimum (t=0.49167 s). The results in Figure 5(a) occur when the dc offset is significant.

As can be seen, the dc offset causes the flux (B) to be driven down and into saturation. The CT has saturated after about two cycles. The reduction of the secondary current is evident in Figure 5(a).

The simulation results in Figure 5(b) demonstrate a situation in which there is no dc offset (fault is applied at t=0.4876 s, voltage maximum). As can be seen, the CT does not go into saturation and only a small amount of magnetizing current is required to magnetize the core. Therefore, the secondary current is an exact but scaled down replica of the primary current.


Ia_sec
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
(kA)
-0.016
-20.388
-20.372
Min -25.835
Max 4.312
Iabc
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-4.0
-5.0
(kA)
-0.002
-3.325
-3.323
Min -4.149
Max 0.691
B_phA
0.60
-2.50
Flux Density (T)
0.004
-1.740
-1.744
Min -1.745
Max 0.004
Vsabc
200
150
100
50
0
-50
-100
-150
-200
(kV)
-22.945
-134.323
-111.378
Min -171.6...
Max 170.9...
Time
0.40
0.60
0.70
0.80
0.90
0.49
0.51
f 44.95

(a)



(b)

Figure 5: a) saturated (b) non-saturated waveform of CT

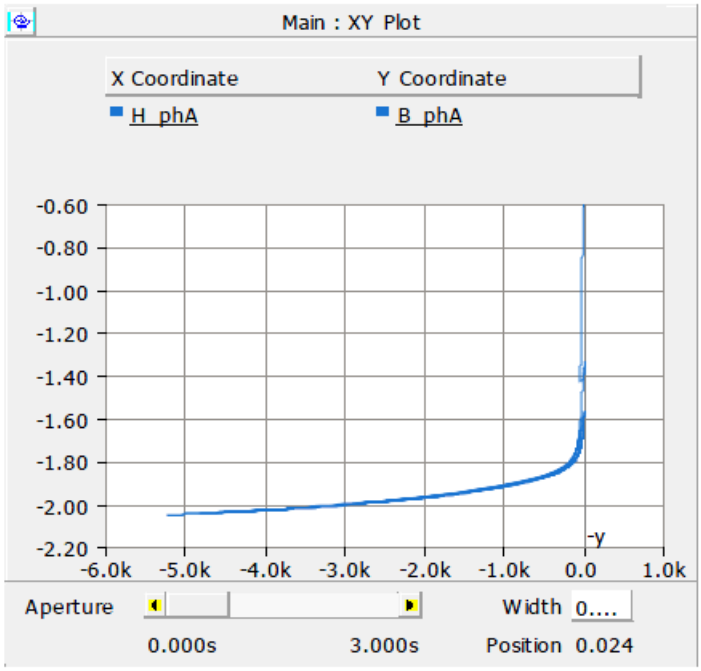
In Figure 5(a), also note the remnant flux in the CT core once the fault is cleared. Effects of remnant flux will be discussed in Case 2.

The B-H loop trajectory of the CT during the fault is illustrated in Figure 6. Figure 6 (a) shows the B-H loop when the fault occurs at the minimum voltage and the CT saturated. Figure 6 (b) shows the B-H loop when the fault occurs at the maximum voltage and the CT is not saturated. The formation of the minor B-H loops and hysteresis are accurately modeled based on Jiles-Atherton theory of ferromagnetic hysteresis. Such detailed representations of the CT behavior are necessary for

detailed protection system analysis, such as:

- CT response during auto reclose
- Protection schemes with CTs operating in parallel
  - Six CTs in parallel in a three-phase transformer differential scheme
  - Three CTs in parallel in an earth fault relay scheme
  - CT connections in generator protections

(a)



(b)

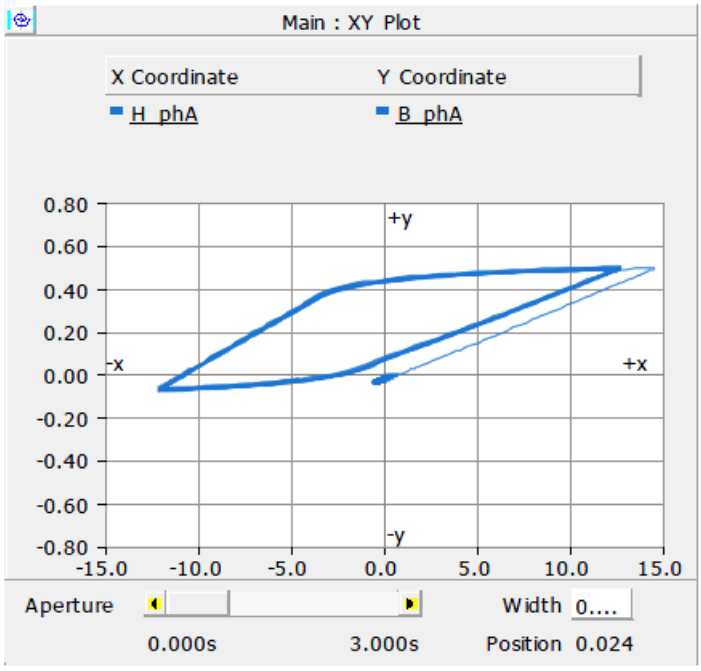


Figure 6: a) saturated (b) non-saturated B-H Loop Trajectory

Case 2 – Reclosing the Line while the Fault is still Present (Auto Reclose)

In the first fault event, saturation had taken approximately two cycles. If the line is reclosed while the fault is present, now the CT may saturate much faster due to the presence of the remnant flux. This is demonstrated in Figure 7. As can be seen, the saturation occurs in approximately half a cycle, possibly before the relay had time to respond.

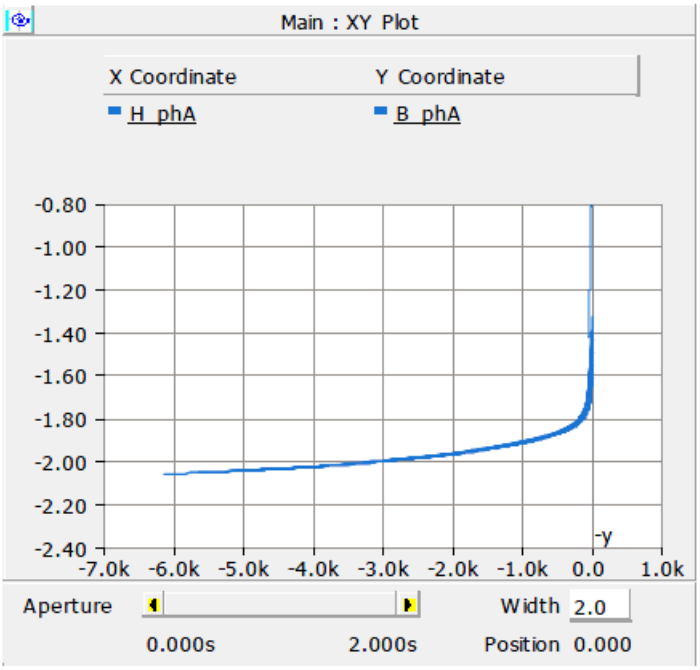


Figure 7: Highly saturated B-H Loop Trajectory

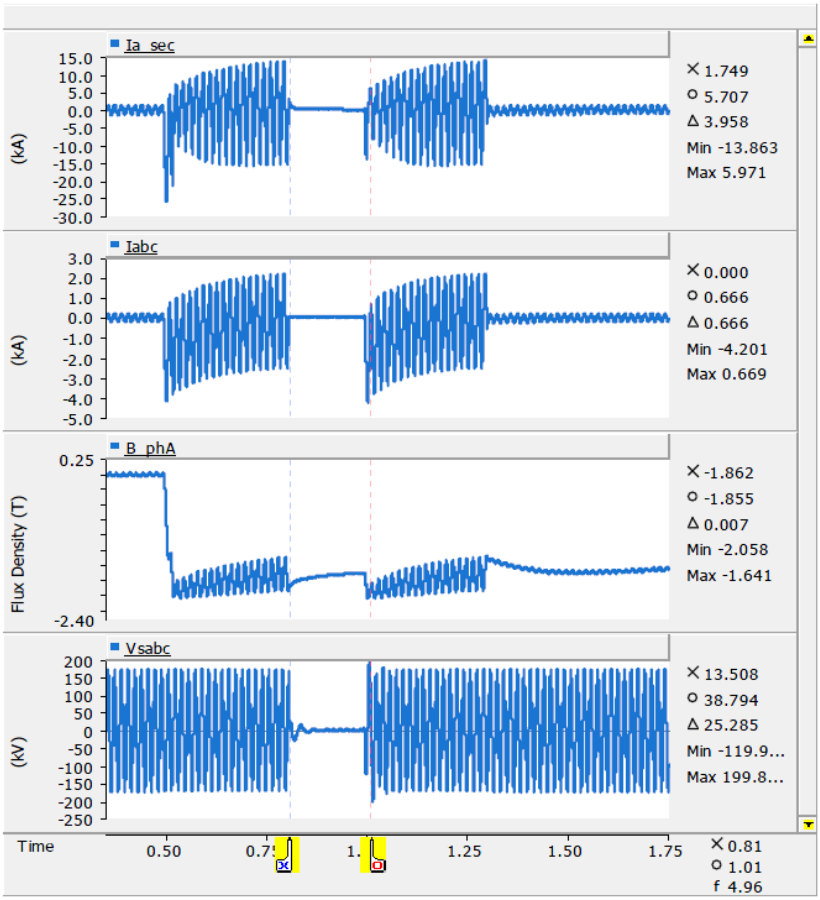


Figure 8: simulation results showing the reclosing action of breaker

Case 3 – Effect of the Secondary Impedance

The CT secondary side burden impedance has a significant impact on CT saturation. In Case 1, the burden was set to 2.5 Ω. The results displayed in Figure 10 were obtained by reducing the burden to 0.5 Ω in the simulation. As can be seen from the results, the flux is not driven down as far. It also takes a longer time for the CT to become saturated (approximately six cycles).

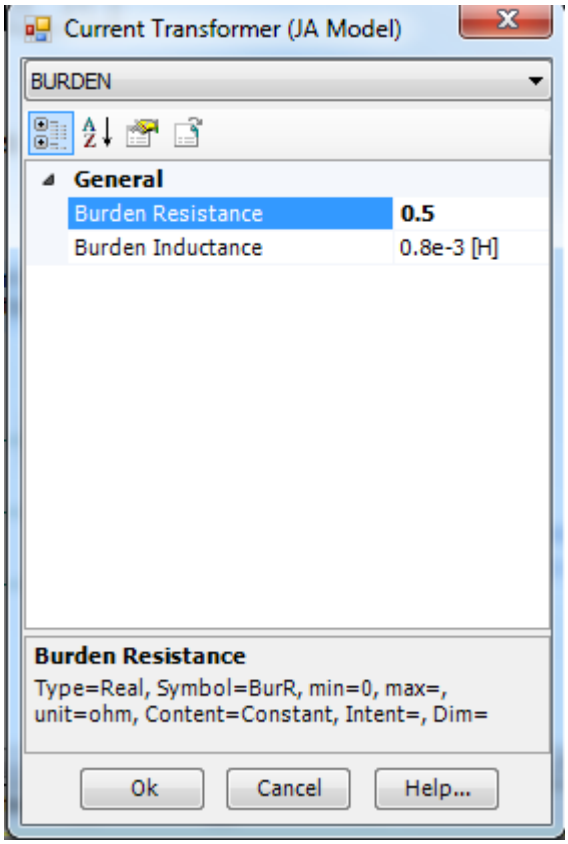


Figure 9: the burden resistance reduced from 2.5 ohm to 0.5 ohm

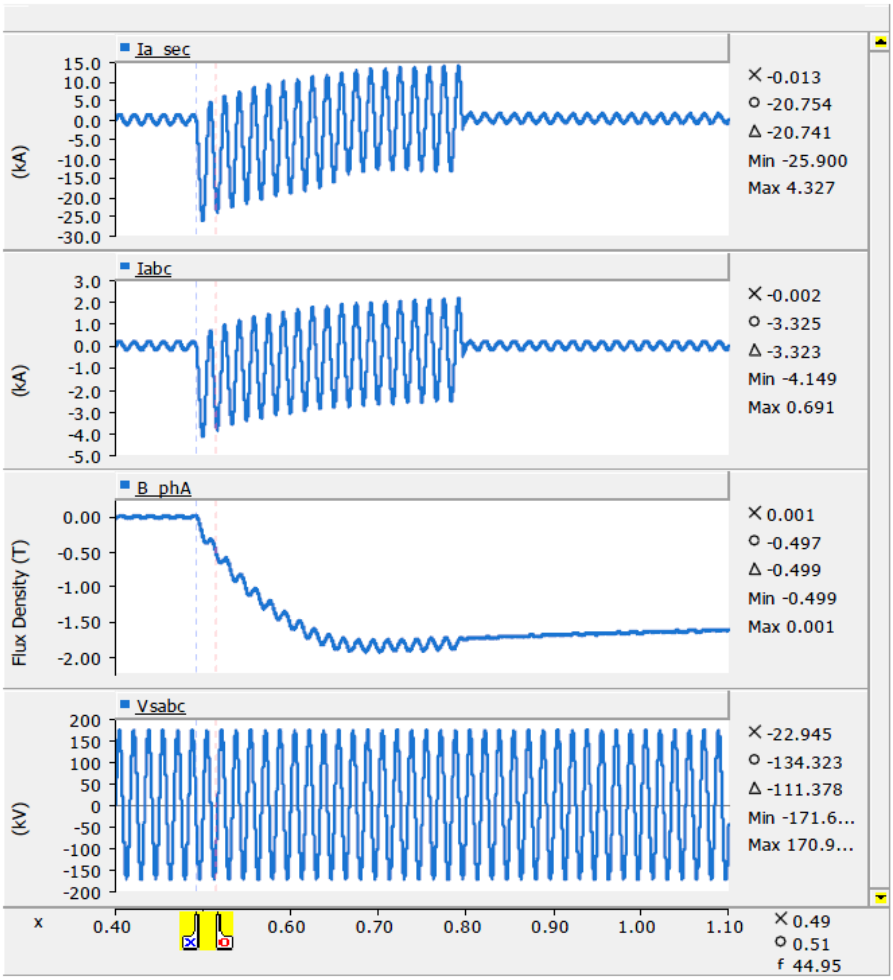


Figure 10: the flux is less negative magnitude compared to Case 1

Discussion

The "time to saturate" the CT core is an important design consideration when selecting the CT specifications for a specific application.

PSCAD

Refer to PSCAD case: Protection_study_01Case1.pscx, Protection_study_01Case2.pscx, and Protection _study_01Case3.pscx

7.2 Distance Relays Study

Motivation

This study demonstrates how the basic functions of a distance relay may be implemented in PSCAD. A distance relay estimates the distance to a fault by calculating the voltage to current ratio. Both the voltage and the current are the secondary quantities sampled from the voltage transformer (VT) and current transformer (CT). If the CT is pushed into saturation (referto Section 7.1), the distance estimated by the relay may be affected, which leads to protection issues. One problem could be the "relay under-reach" problem.

System Overview

The 230 kV ac system shown in Figure 11 is similar to the system in Section 7.1. A distance relay is being used to control the opening of the breaker (BKR1) in the case of a fault. The current (Iabc) and voltage (Vabc) are being measured by CTs and VTs, respectively.

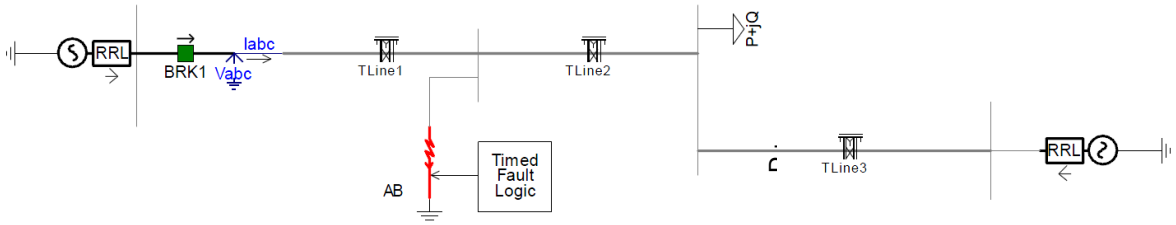


Figure 11: AC System

Distance Relay

The protected area of a distance relay spans from the location of the relay to its reach point (recall that the impedance of a transmission line is proportional to its length). Therefore, to determine if a fault has occurred in the protected area (i.e. zone), the measured impedance by the relay $\left(Z_M = \frac{V_s}{I_s}\right)$ is compared against the known impedance of the reach point (Z_{RP}). If Z_M is less than Z_{RP} then a fault will be detected and the breaker will open. If it is larger, no action will be taken.

One of the problems associated with distance relays is under-reach. This can occur when the CT is pushed into saturation, which reduces the secondary current and, hence, increases the impedance estimated by the relay. Therefore, for faults close to the reach point, Z_M may appear to be larger than Z_{RP} and the relay will incorrectly estimate that the fault is beyond the reach point (i.e. the breaker will not be opened).

The 'Distance Relay' component and its connection to the circuit are shown in Figure 12. The relay accepts the breaker status (Sabc), the secondary voltage of the VT (Vsabc) and the secondary current of the CT (Isabc) as inputs. The component will output a trip signal.

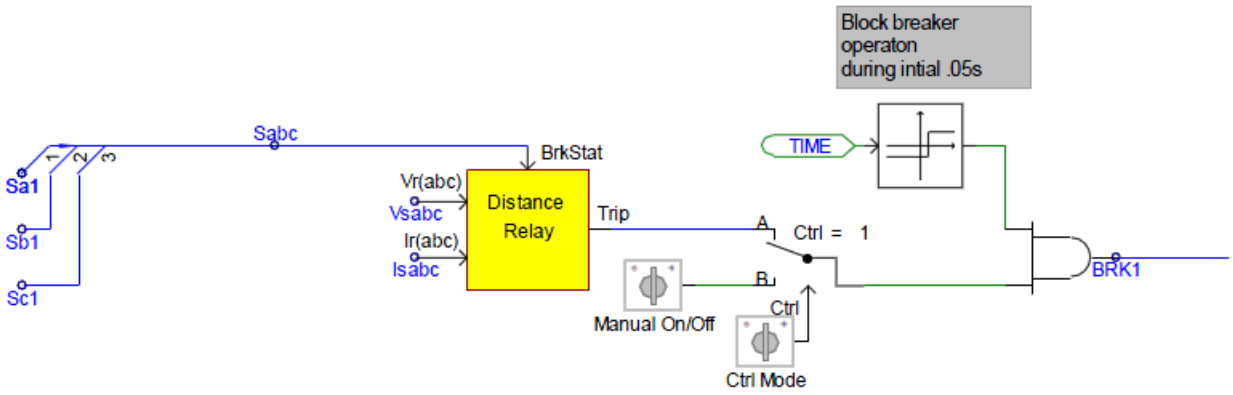


Figure 12: 'Distance Relay' Connection to Circuit

The PSCAD implementation of the distance relay component consists of a variety of parts:

- Fourier transform (FFT) is used to determine the fundamental harmonic (magnitude and phase) of the secondary voltage and current. Figure 13 shows the FFT of the secondary voltage (VRabc).

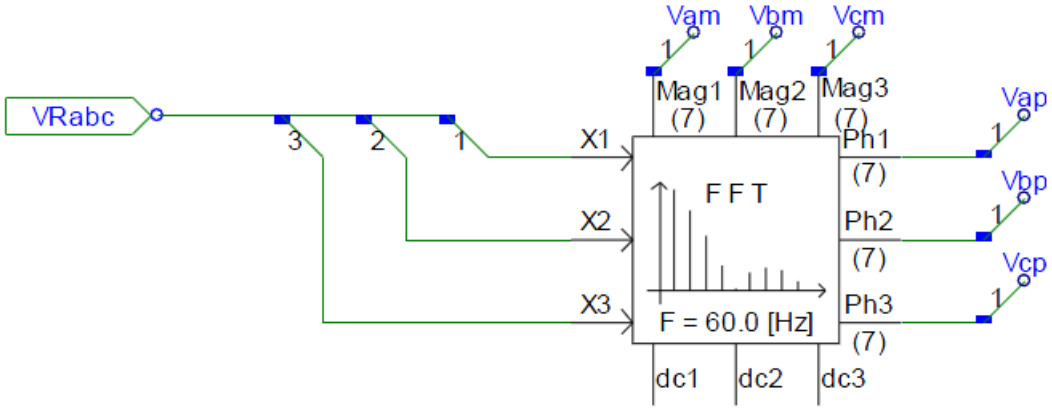


Figure 13: FFT of Vsabc

- The impedance by the relay (Z_M) is calculated using the impedance calculation units as shown in Figure 14.

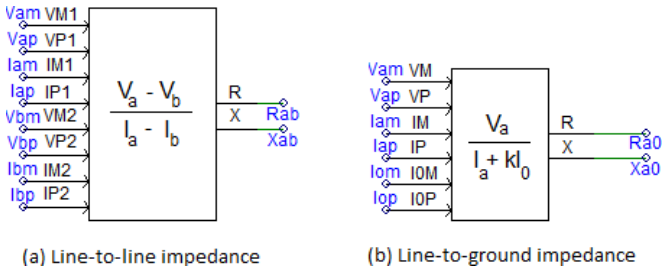


Figure 14: Impedance Calculation Units

- The 'Mho circle' component is used to determine if Z_M (found above) falls within the trip zone. If it does, the trip signal goes high ('1'). If it does not, the trip signal will go low ('0'). Figure 15 shows the Mho circle implementation in PSCAD.

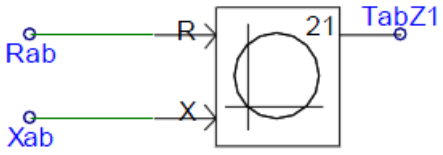


Figure 15: 'Mho Circle' Implementation in PSCAD

- A basic relay logic is shown in Figure 16. Once all the zone tripping signals have been determined, if they remain high after their respective delay times, TRIP (controlling the breaker) will go high and hence the corresponding breaker (BRK1) will open.

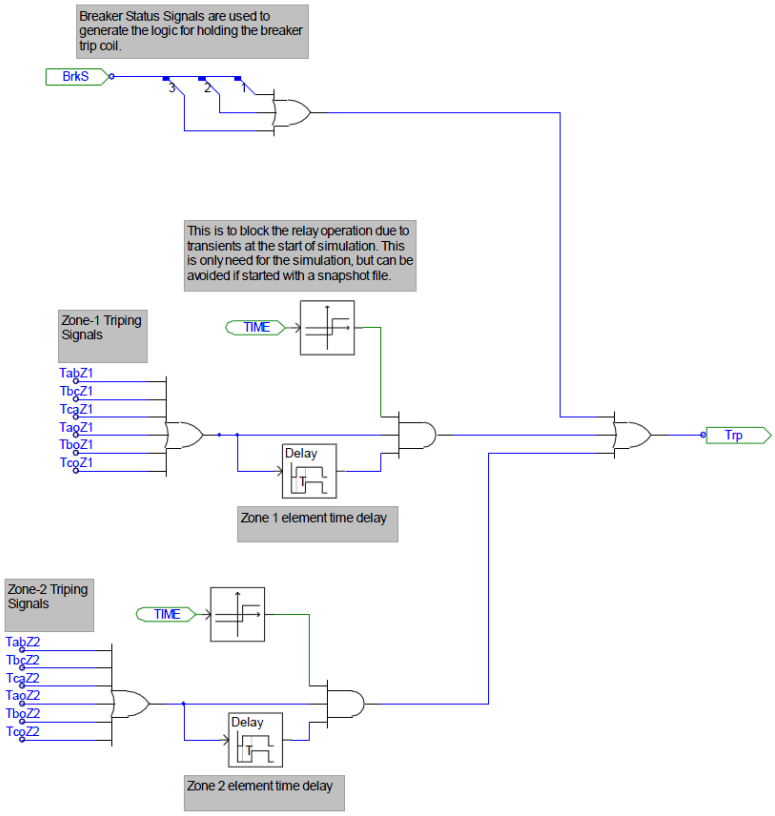


Figure 16: Basic Distance Relay Logic

Simulation Results

A phase-to-ground fault (A-G) is simulated for two different condition. First the fault occurs at maximum voltage (t=0.4876 sec) and the results are shown in Figure 17. As can be seen the CT is not saturated and it takes 2 cycles for the distance relay to detect the fault and trip the breaker (see Figure 18).

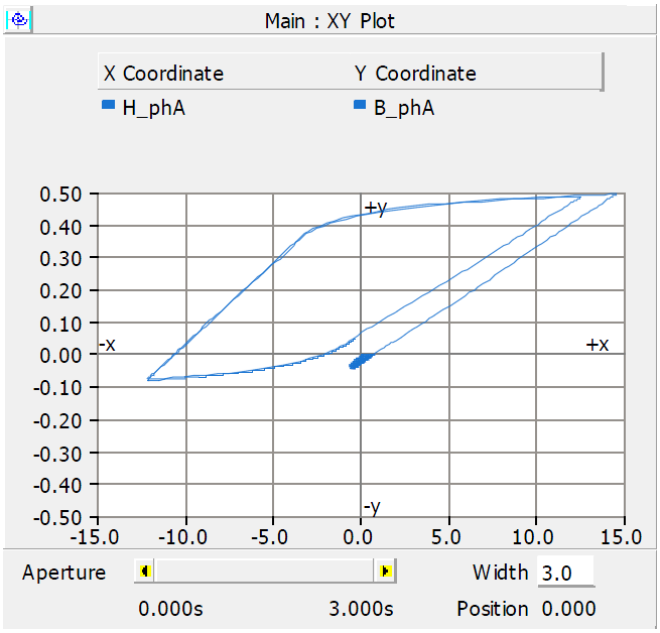


Figure 17: the fault occurs at maximum voltage and the CT is not saturated.

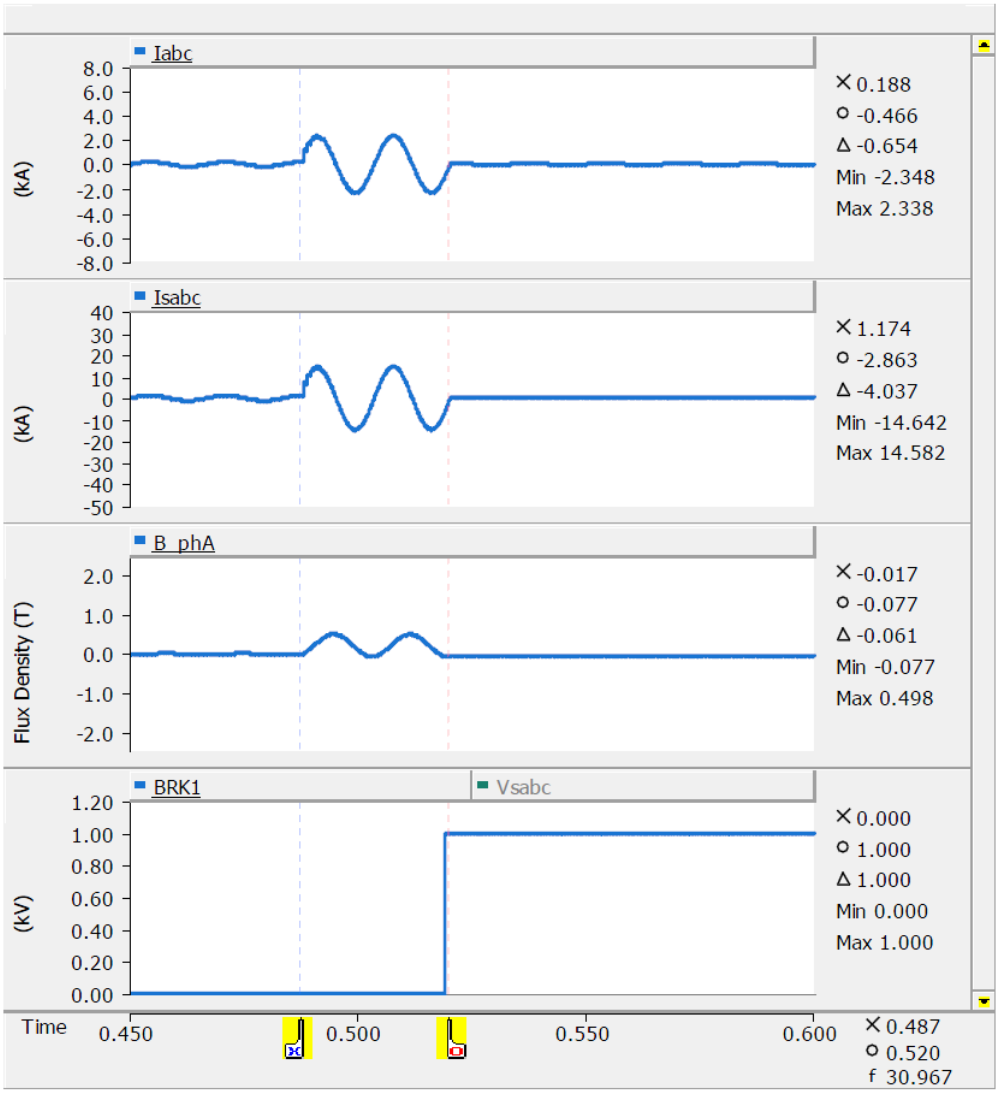


Figure 18: The breaker opens by the distance relay after almost 2 cycles

The system impedance during fault and the impedance of zone 1 and zone 2 are shown in Figure 19.

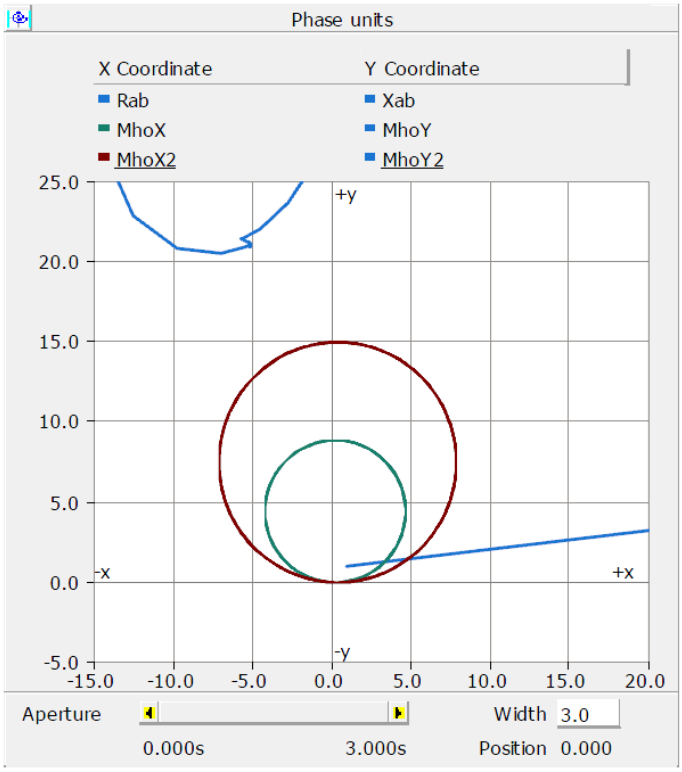


Figure 19: Impedance Comparison of zone 1 and 2 of the relay with the power system

Second, the fault occurs at minimum voltage (t=0.49167 sec) and the results in Figure 20 show that the CT is saturated. As can be seen in Figure 21 the fault is still detected, after almost 10 cycles.

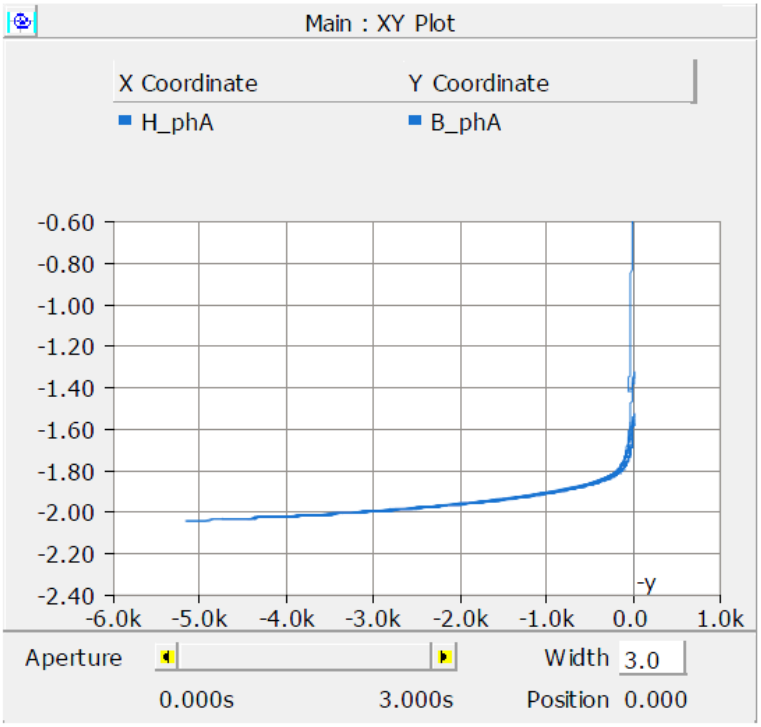


Figure 20: the fault occurs at minimum voltage and the CT is saturated.

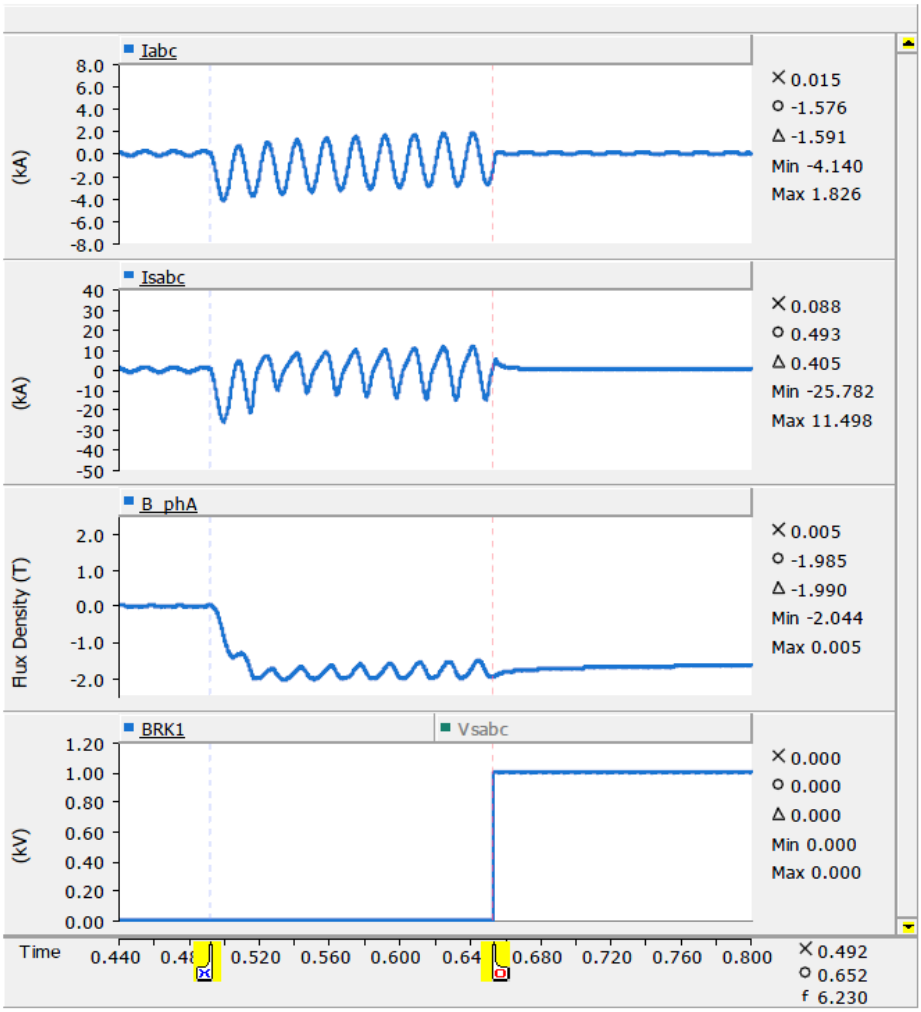


Figure 21: The breaker opens by the distance relay after almost 10 cycles

The system impedance during fault and the impedance of zone 1 and zone 2 are shown in Figure 22.

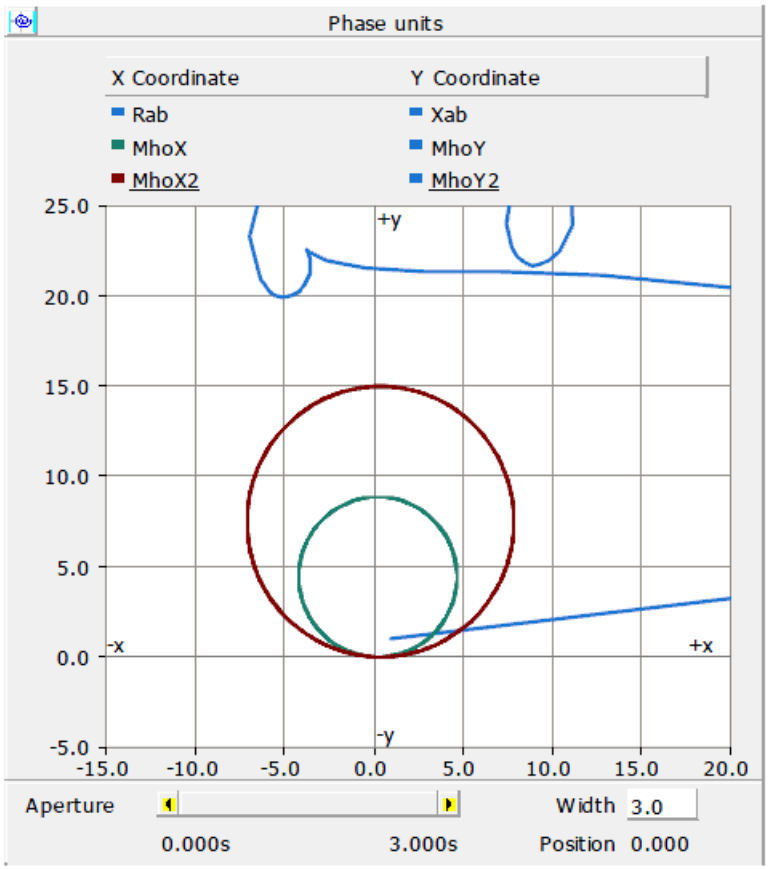


Figure 22: Impedance Comparison of zone 1 and 2 of the relay with the power system

Discussion

PSCAD implementation of a distance relay is illustrated in this study and shown that the protection relay performance can be degraded by saturation of CT.

PSCAD

Refer to PSCAD case: Protection_study_02.pscx

DOCUMENT TRACKING

Rev.	Description	Date
0	Initial	01/Jun/2013
1	Update to New Branding Guidelines	22/Nov/2018