Shunt Reactor Events and Failures

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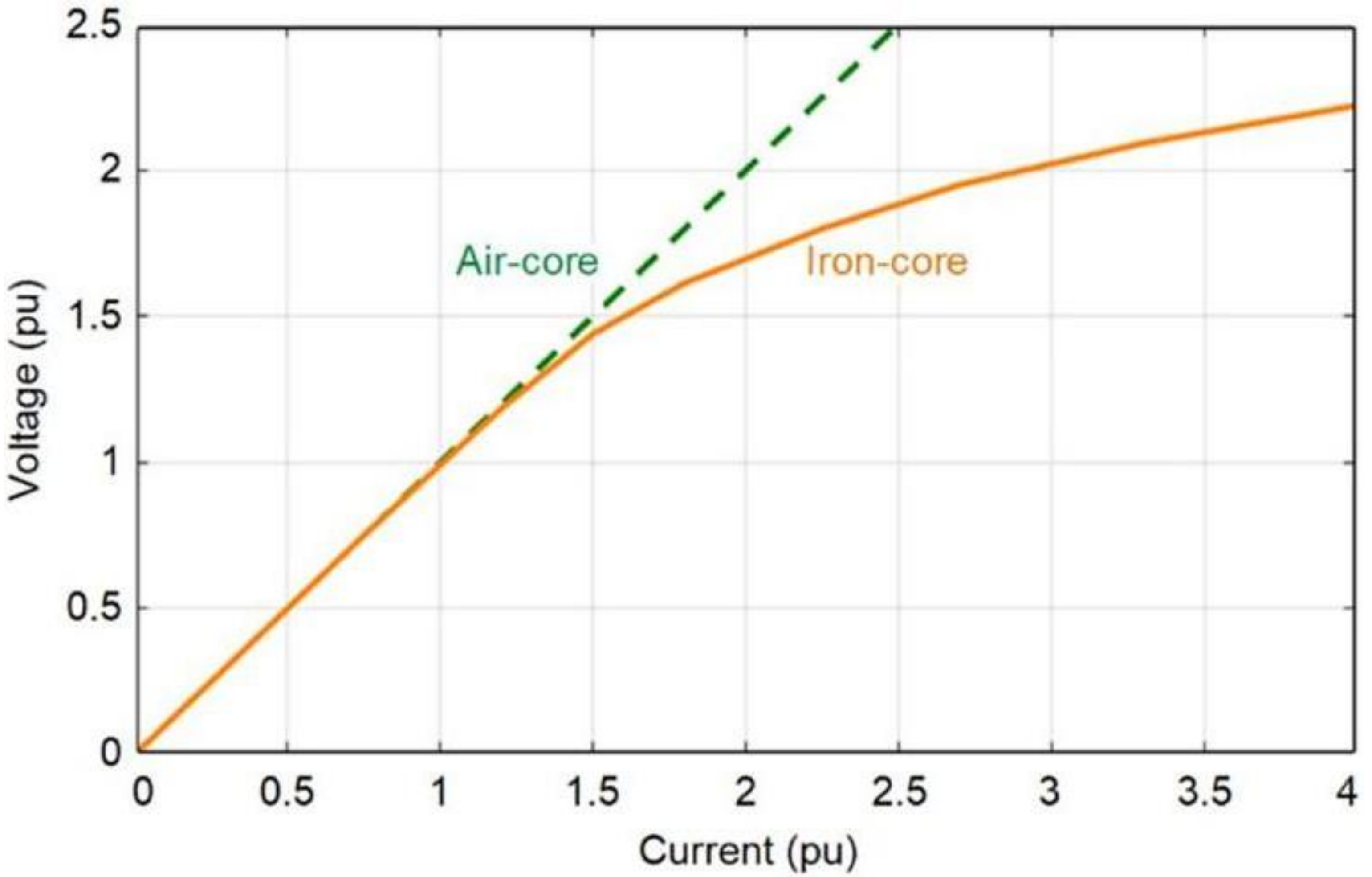
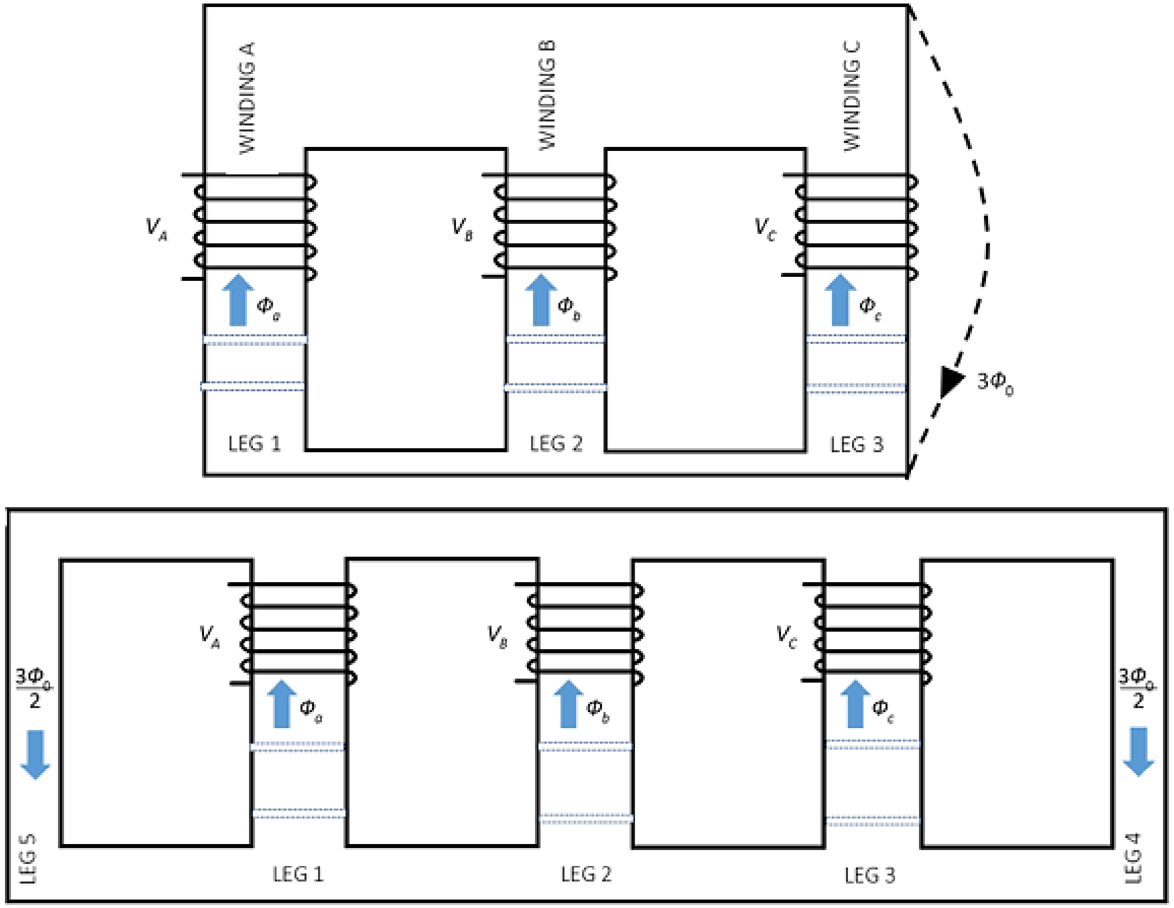
Shunt Reactor Types

- Dry-type or oil-immersed
- Air-core or gapped iron-core
- Fixed or variable



Magnetizing characteristic (air-core and gapped iron-core reactors)

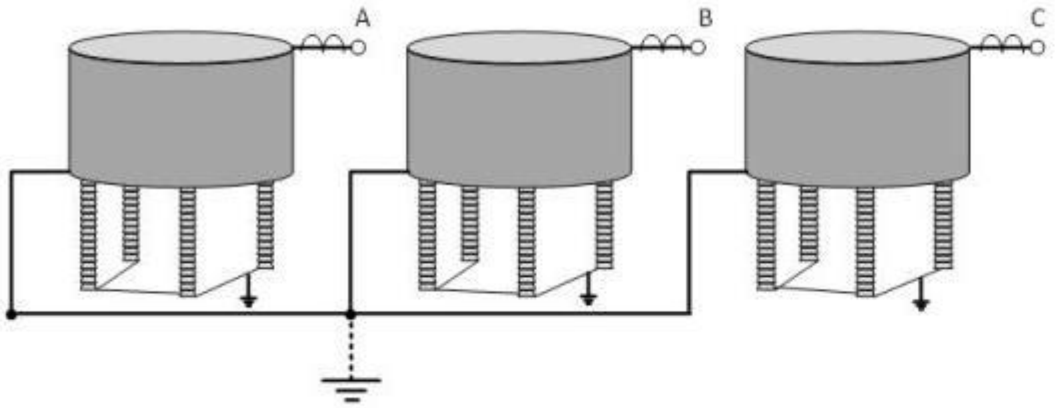
Shunt Reactor Design



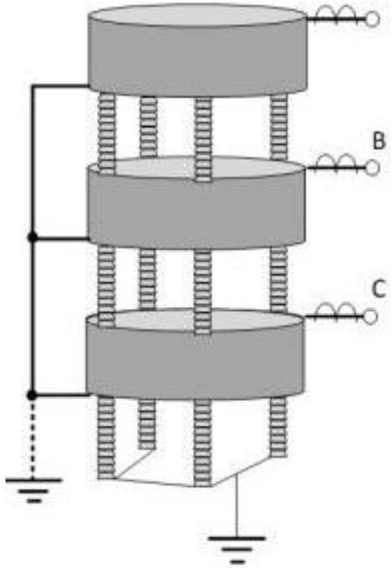
Three-leg and five-leg shunt reactor designs

- Three-leg design – zero-sequence is 80–90% of positive and negative sequence
- Five-leg design – zero sequence is equal to positive and negative
- Reactor X/R is high and dc component may last 1–10 seconds
- Air core and iron core have many differences – one air core has many more turns compared to iron core; hence, X/R is typically lower in air core

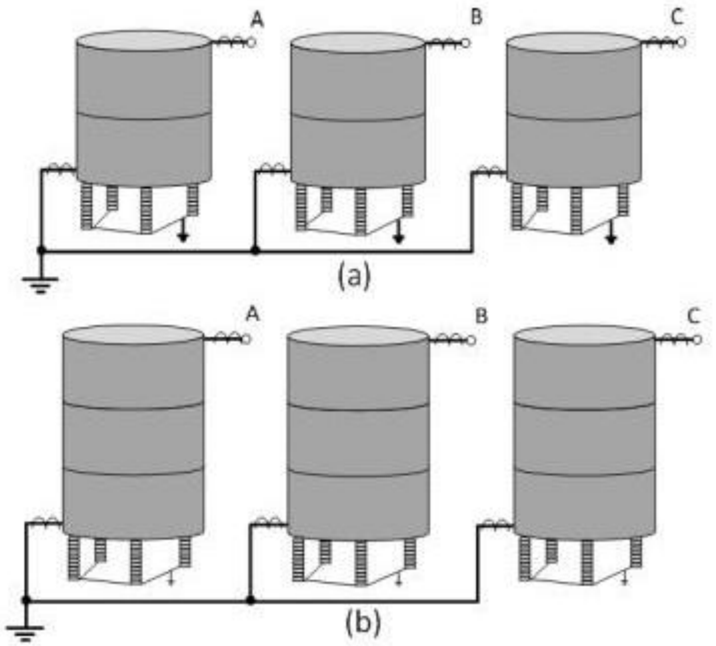
EHV Dry-Type Reactors: Air Core



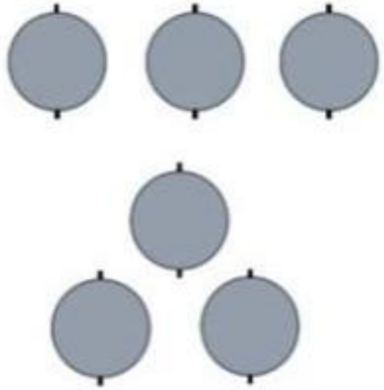
Various mounting arrangements



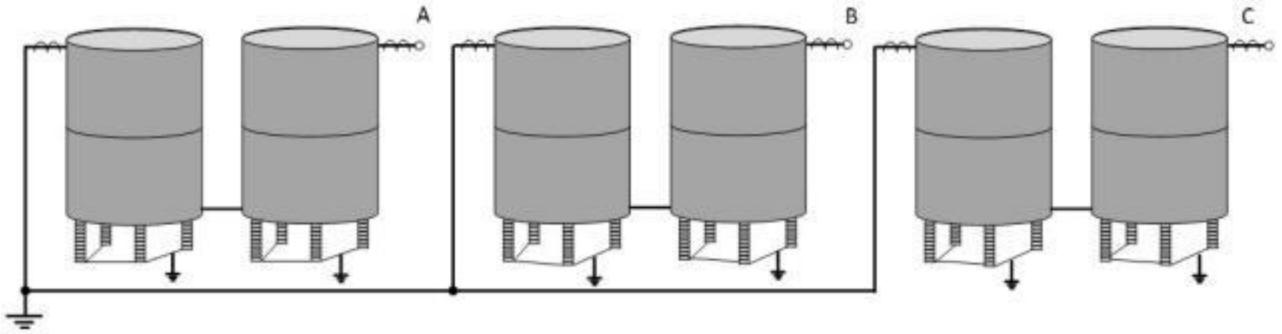
Three-phase stack mounting



Multiple coil mounting arrangements



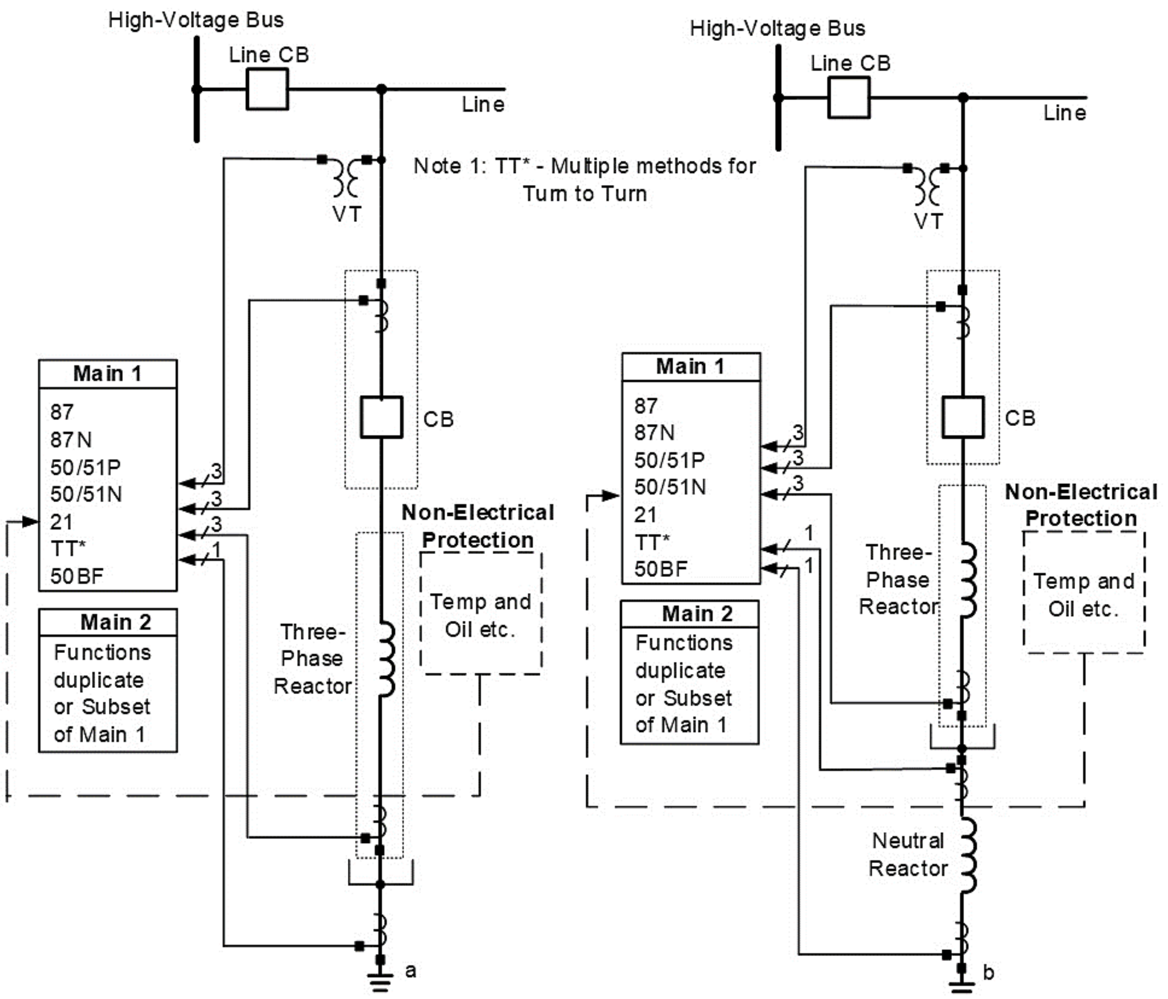
In-line and triangular mounting arrangements



Multiple series-connected columns

Shunt Reactor Failure Modes

- Turn-to-turn fault – oil and dry type
- Dry-type reactors – cabling and induced voltage
- CT saturation
- Overcompensation / undercompensation for line reactor – resonance and controlled closing
- Single-pole tripping and fourth-leg reactors
- Controlled closing and opening

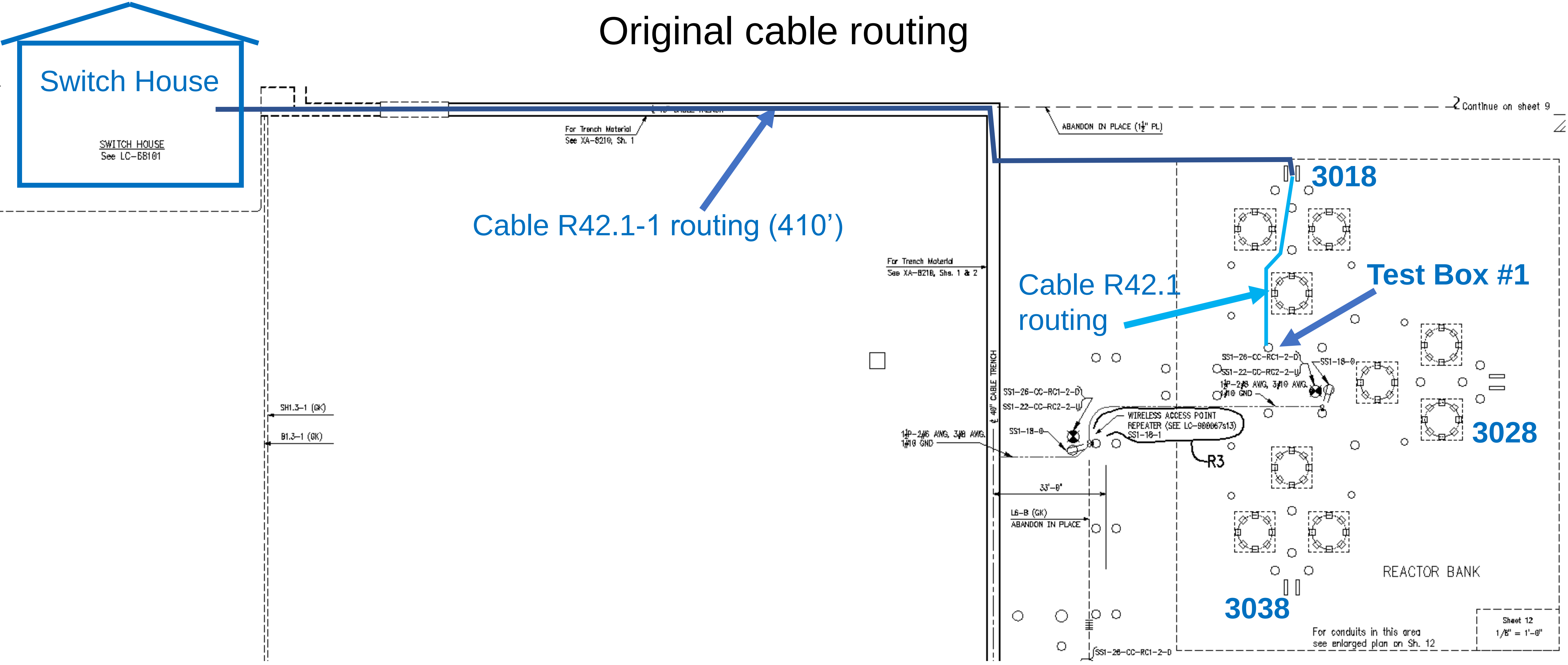


Typical reactor protection

Utility 1 Reactor Failures

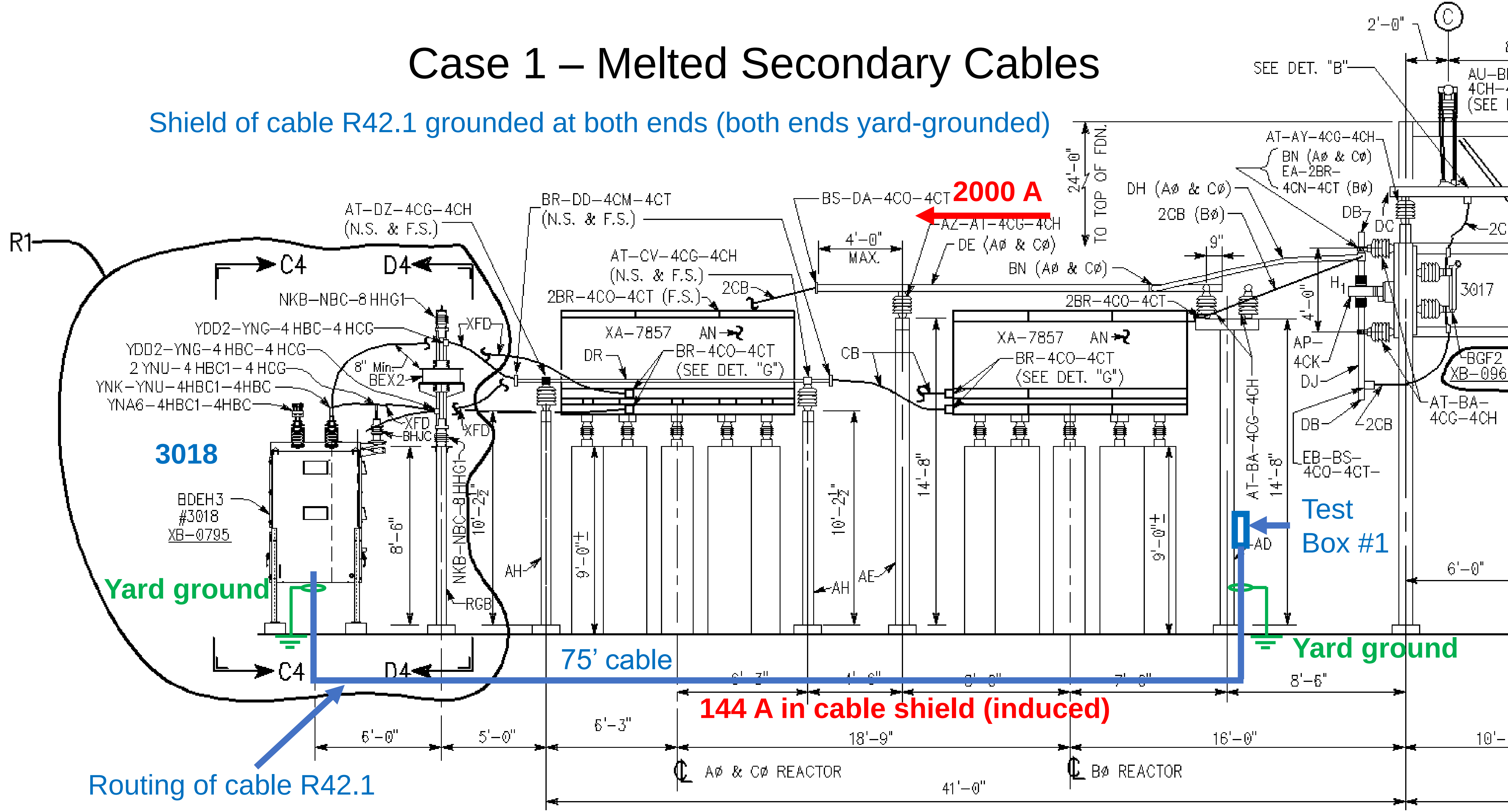
Case 1 – Melted Secondary Cables

Original cable routing

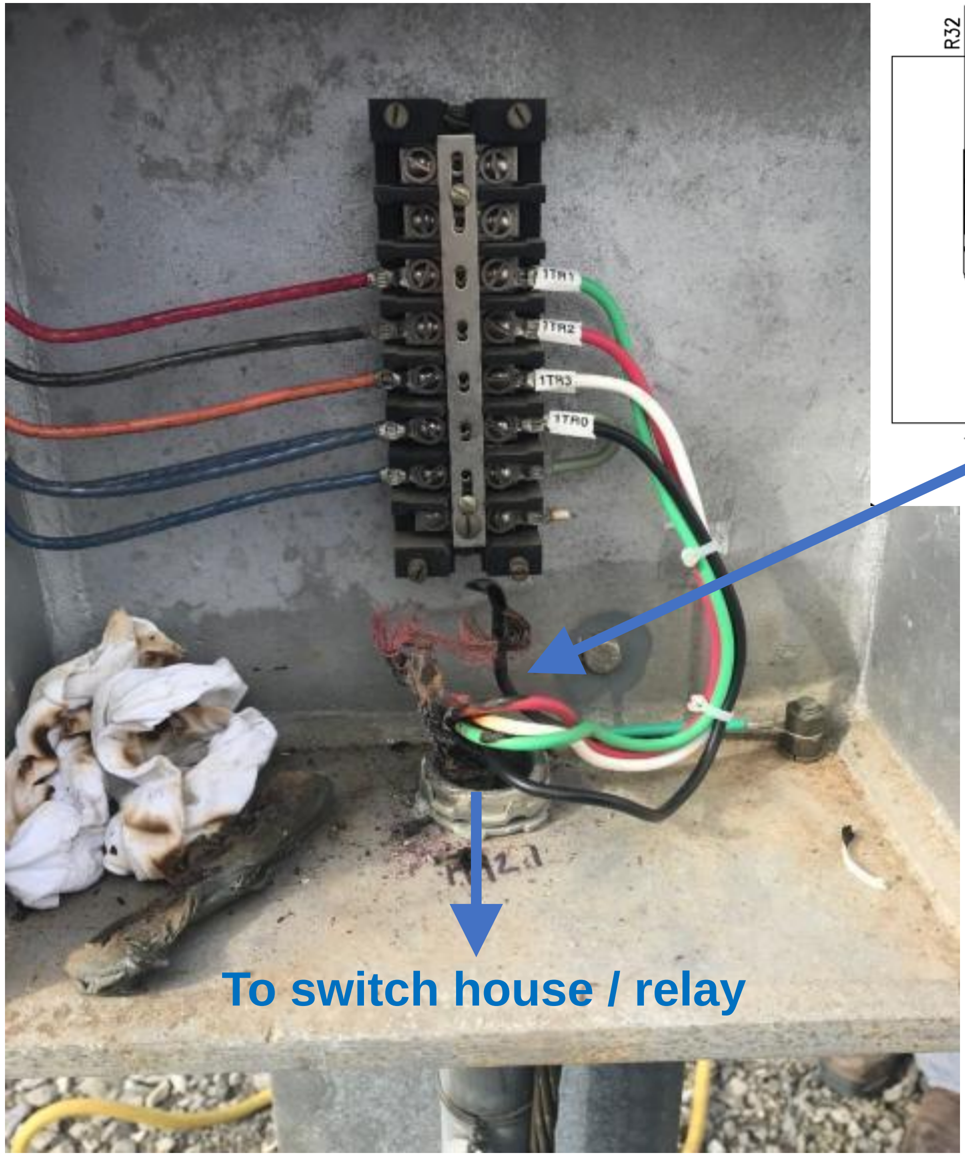


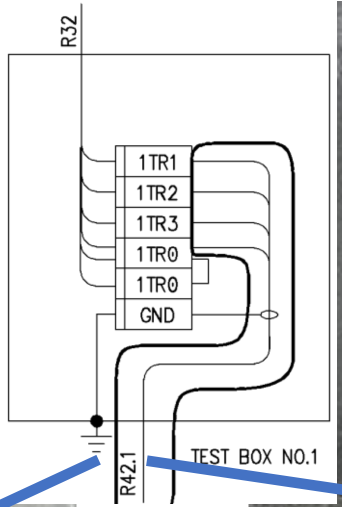
Case 1 – Melted Secondary Cables

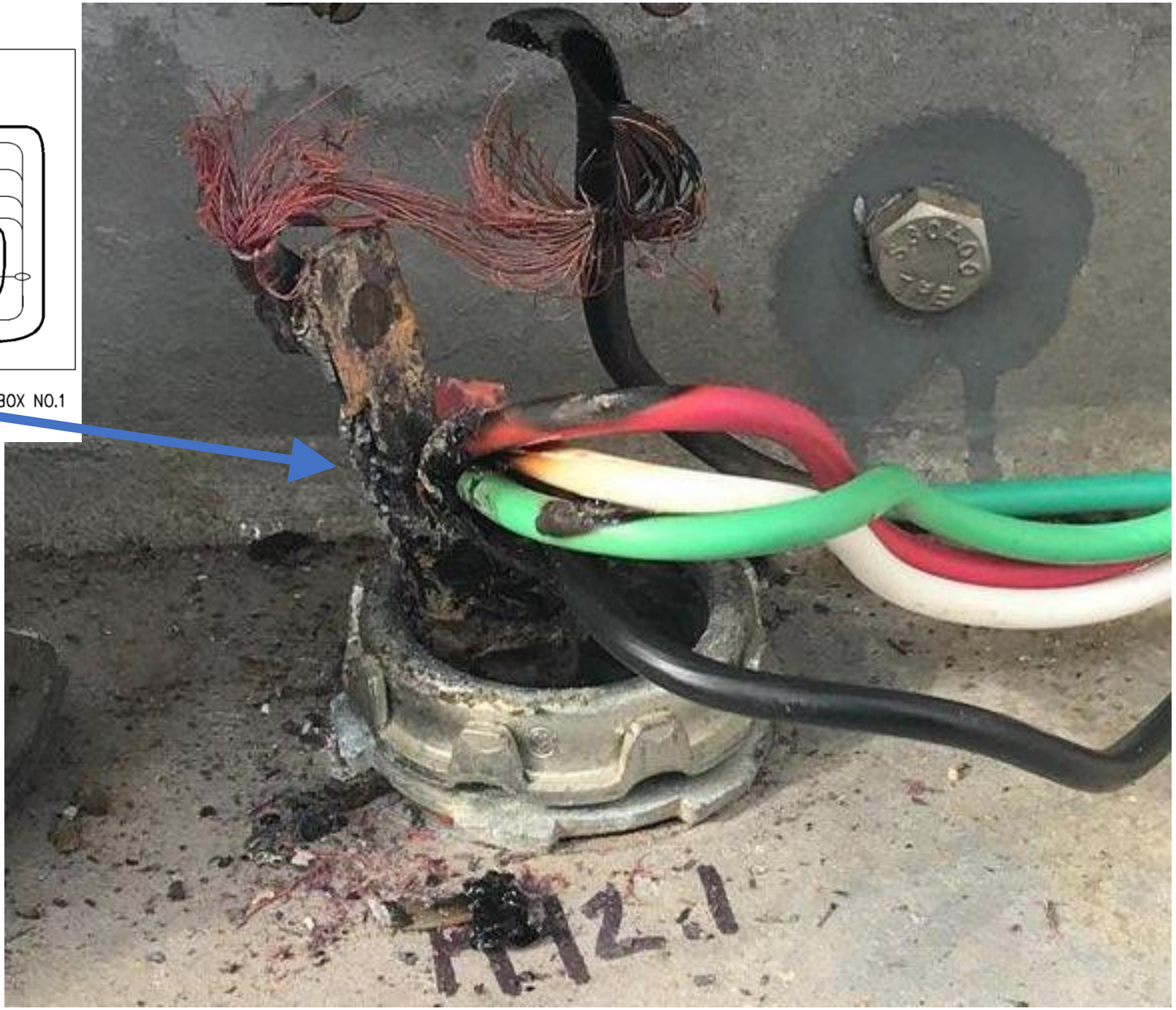
Shield of cable R42.1 grounded at both ends (both ends yard-grounded)



Case 1 – Melted Secondary Cables







Case 1 – Melted Secondary Cables

IEEE Std C57.21-2021
IEEE Standard Requirements, Terminology, and Test Code for Shunt Reactors Rated Over 500 kVA

12.3 Magnetic clearances

Since dry-type shunt reactors have no magnetic core, the magnetic field occupies a space around the reactor and, depending on the MVA of the unit, can be of a substantial strength even at some distance from the reactor. This alternating magnetic field can induce currents in nearby metallic geometries.

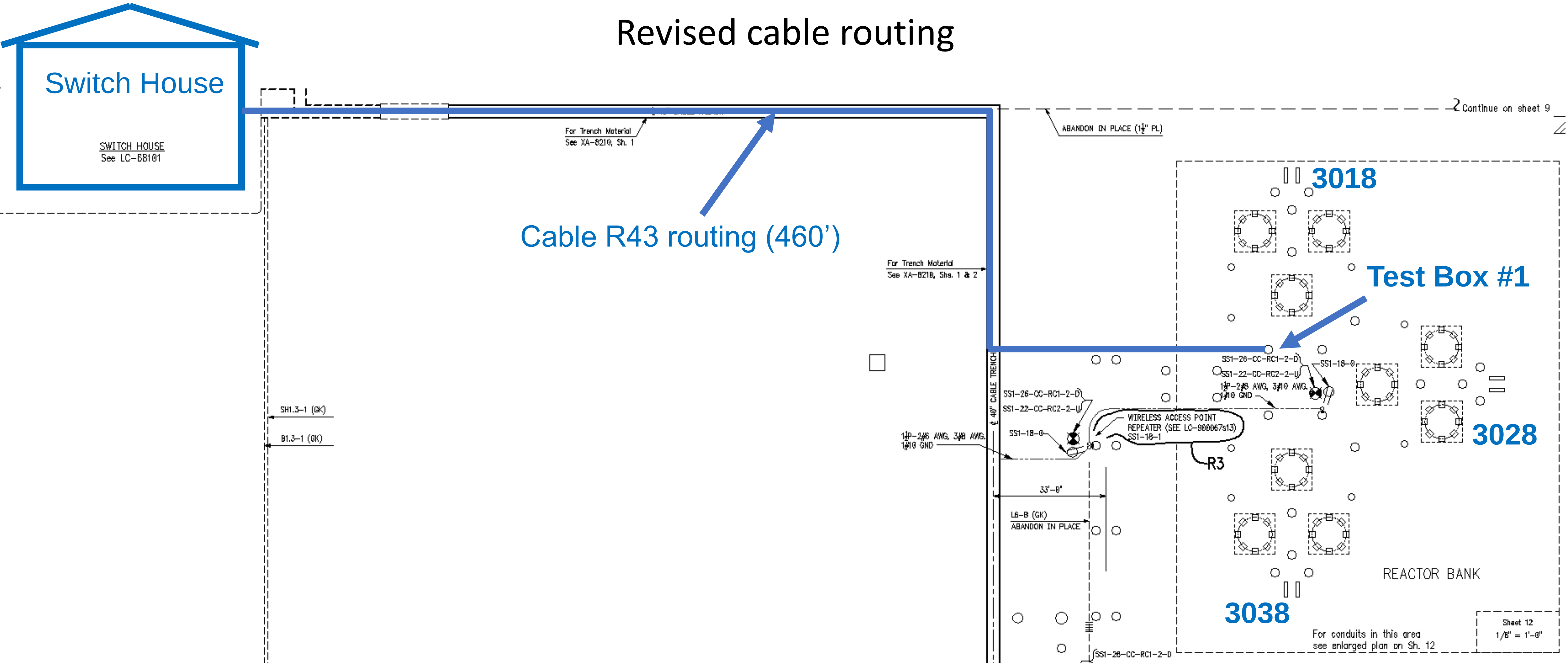
There are some simple rules of thumb that can be employed. Clearance to small metallic parts not forming closed loops should be at least one-half the coil diameter radially from the edges of the reactor. Larger geometries or closed loops should be located at least one coil diameter from all the surfaces of the reactor. These are rules of thumb that generally can keep the user out of trouble. However, it is advisable that the manufacturer be consulted. They should have at their disposal very accurate field-plot programs and sophisticated analysis tools to calculate losses and temperature rise in metallic geometries located in magnetic fields.

What this means is that circuit breakers, equipment housings, current transformers, surge arresters, and other equipment should be safely located to help ensure that the magnetic field of the reactor does not adversely affect equipment performance. In addition, any metallic support structures for bus bar, etc., should also be designed to avoid overheating due to induced eddy currents.

It should be emphasized that in cases where space is limited, the previously presented "rules of thumb" may be substantially reduced. With careful review by the manufacturer, the use of special materials, such as fiber-reinforced plastics, austenitic stainless steel, and nonmagnetic shielding, can allow the trouble-free installation of dry-type shunt reactors in limited space.

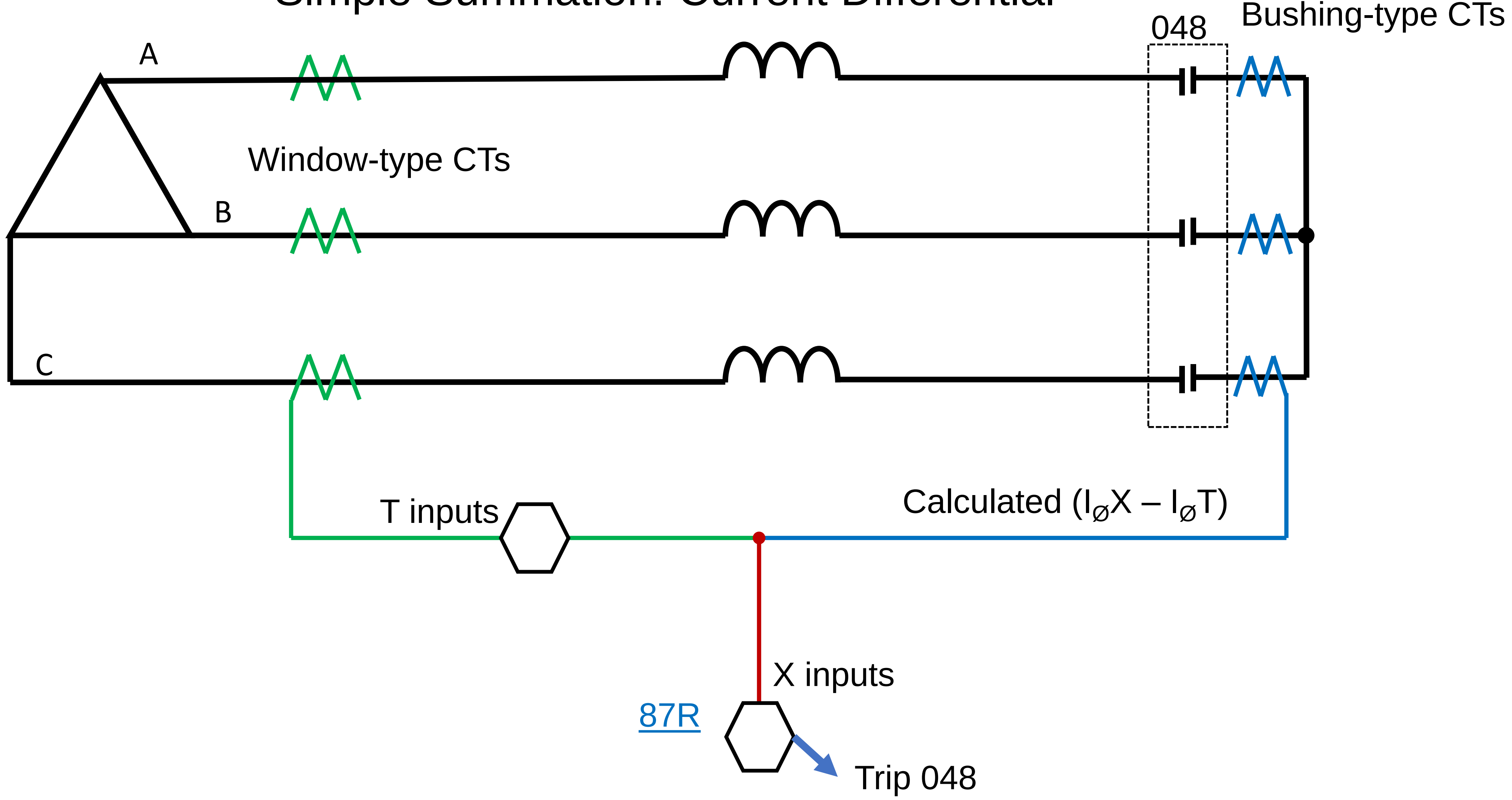
Case 1 – Melted Secondary Cables

Revised cable routing



Case 2A – Differential Misoperation on Energization

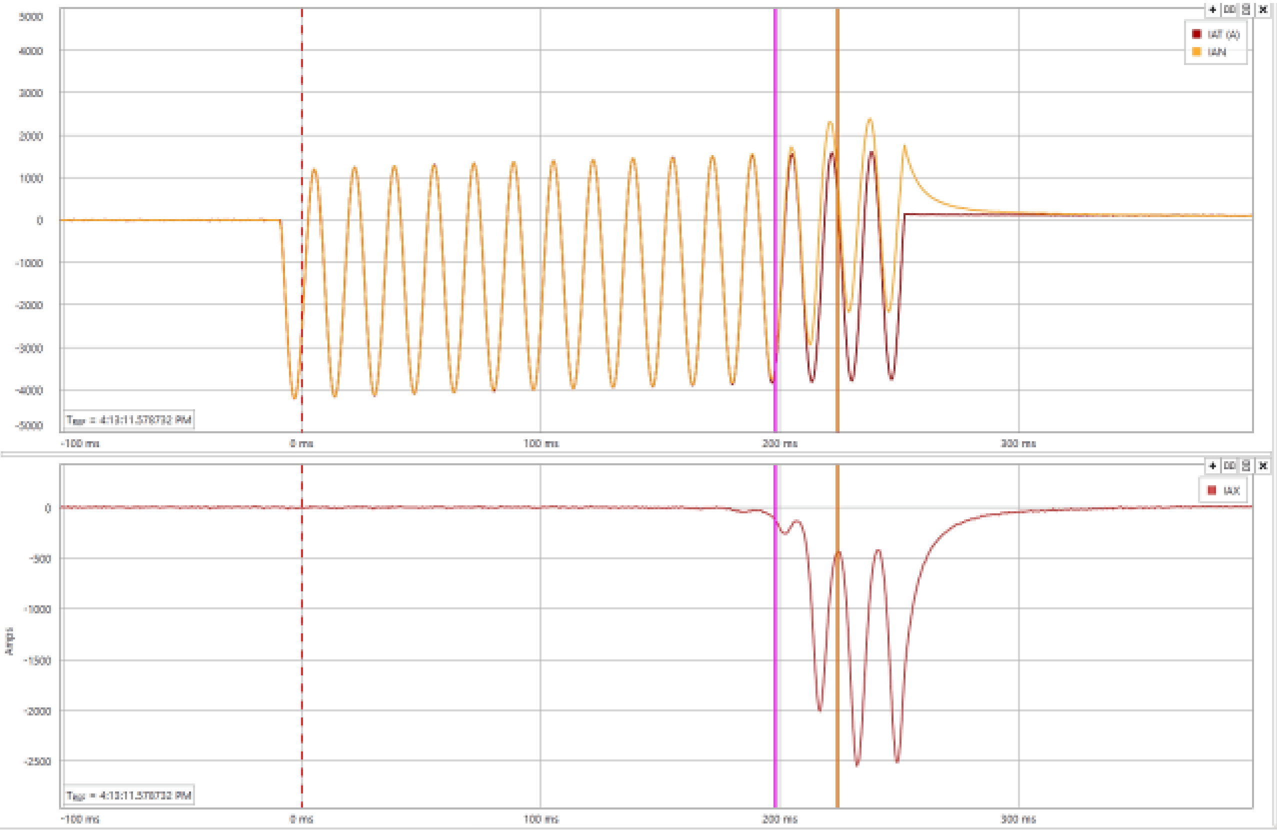
Simple Summation: Current Differential



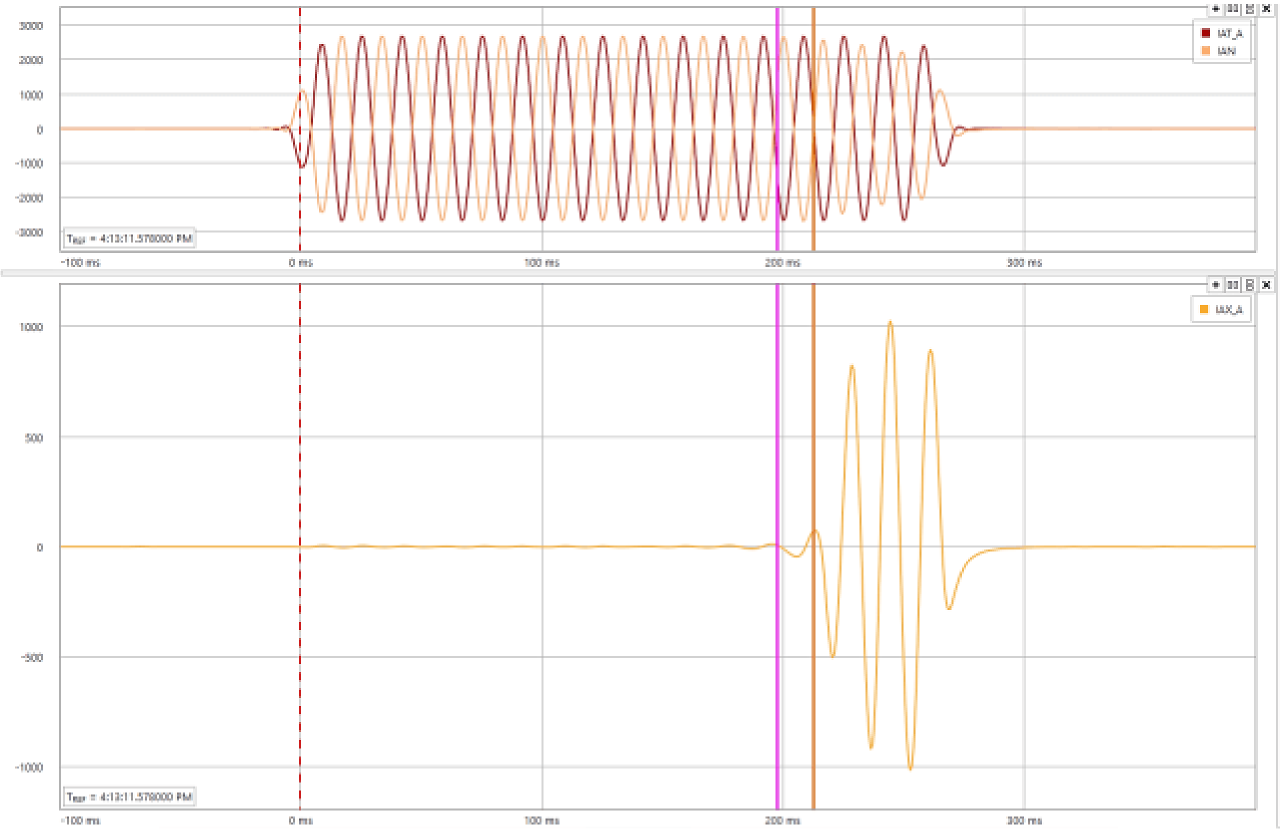
Case 2A – Differential Misoperation on Energization- Uneven DC CT Saturation

A-Phase

Raw currents



Fundamental currents



048 shunt reactor #2

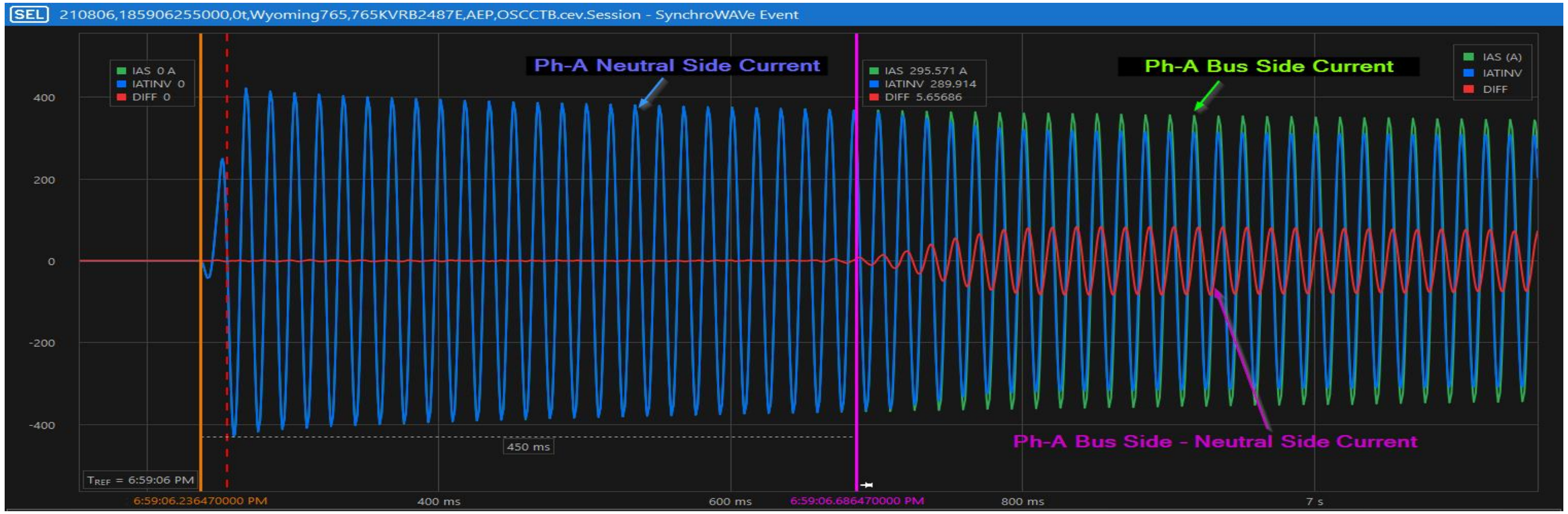
Reactor Bank No. 2:			
Diff. Current Imbal. (Ph. IOC), Term. X (50XP1)	0.5 A	200A	Pickup Delay = 5 ~
VCB 048 Phase TOC (51P02)	8.75A	3500A	TD (51TD01) = 0.4
			U5–Short-Time Inv.
Neutral Overvoltage (59P2P1)	2.16V	251V	Pickup Delay = 30 ~
Open Term. Negative Seq IOC (50TQ1P)	1.1A	440A	Pickup Delay = 45 ~

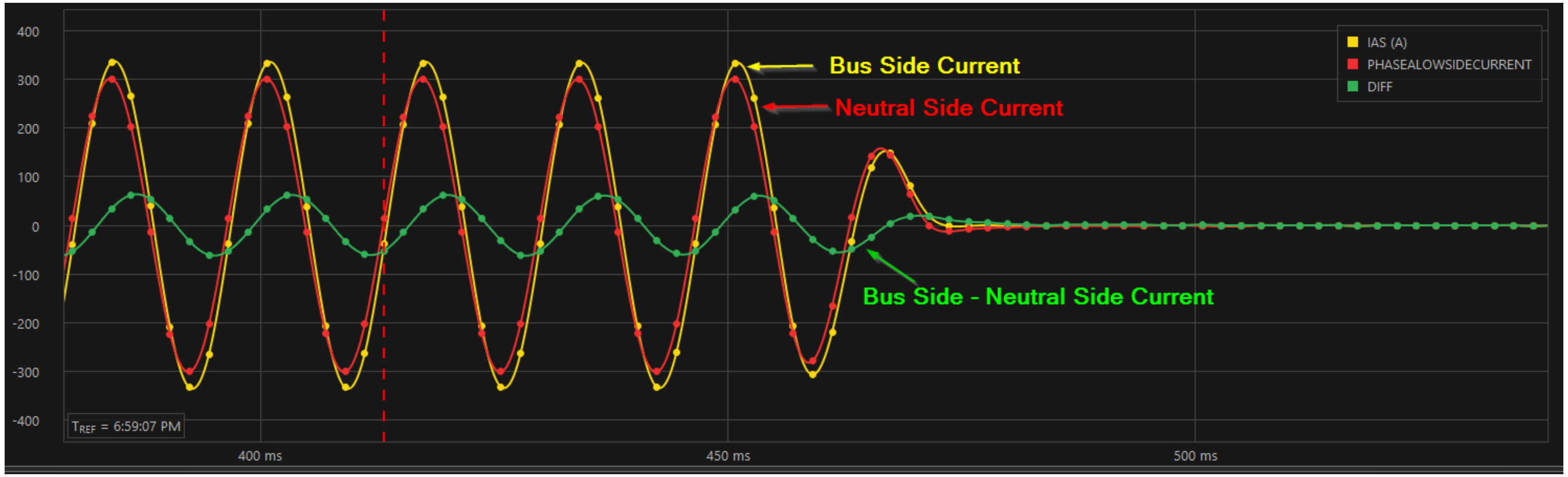
IAT / IBT / ICT = source-side CTs (window-type)

IAN / IBN / ICN = neutral-side CTs (bushing-type)

IAX / IBX / ICX = differential current

Case 2B – A Phase Uneven DC CT Saturation





- The neutral side Phase-A CT began to saturate at approximately 27 cycles after the reactor was energized. At that time, the bus side CT experienced less saturation, which resulted in the false current differences

Case 3 – Reactor Connection Orientation

Recommended Connection Arrangement for Air Core Reactors

Based on all of the foregoing, a connection arrangement as shown in Figure 12 and Figure 13 is recommended for sizeable Mvar ratings and/or reactors with significant short circuit current ratings. For small kvar ratings and low short circuit currents, the principles outlined here become less critical, but still represent good practice.

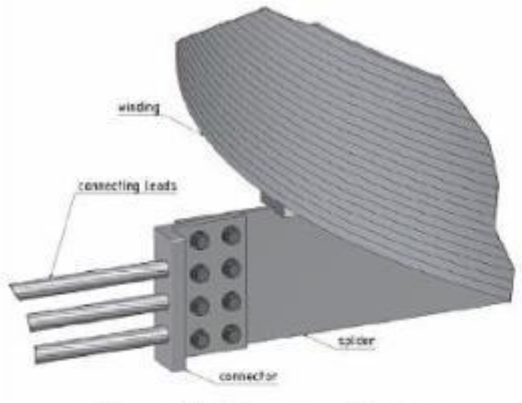


Figure 12 - Connector Design

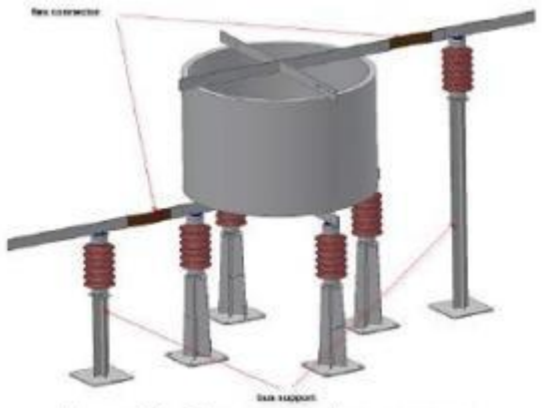


Figure 13 - Connection Arrangement

- The connector flag (as well as the terminal) should be arranged vertically.
- The height of the connector flag should preferably be the same as the height of the terminal and all holes of terminal should be used for bolting; use stainless steel bolts with Belleville spring washers on both sides.
- The thickness of the connector flag should not exceed approximately 1/2 inch or 12mm.
- The material of the connector may be either aluminum alloy or copper (in case of copper to aluminum, a bi-metal plate should be inserted). Nickel plating of the contact surface area may be considered, in order to allow higher terminal temperature (115°C instead of 90°C).
- The end of the customer connector flag may be configured as a crimped connection (Figure 14) or prepared for a welded connection as shown in Figure 15 or a clamped connector arrangement as shown in Figure 16. A minimum distance of this connection point of approximately 8 inches (or 200 mm) from the winding surface is recommended in order that it be located in a reduced field area.

Source: D. Caverly, et al, “Air Core Reactors: Magnetic Clearances, Electrical Connection, and Grounding of Their Supports”

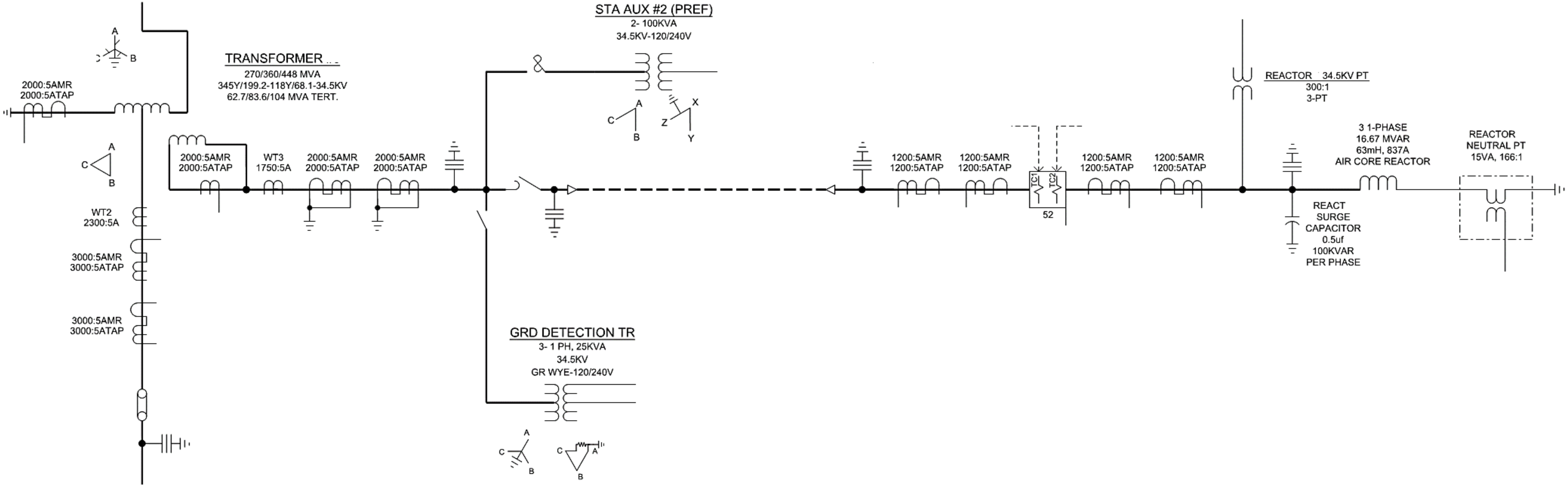
Case 3 – Reactor Connection Orientation

Utility 2 Reactor Failures

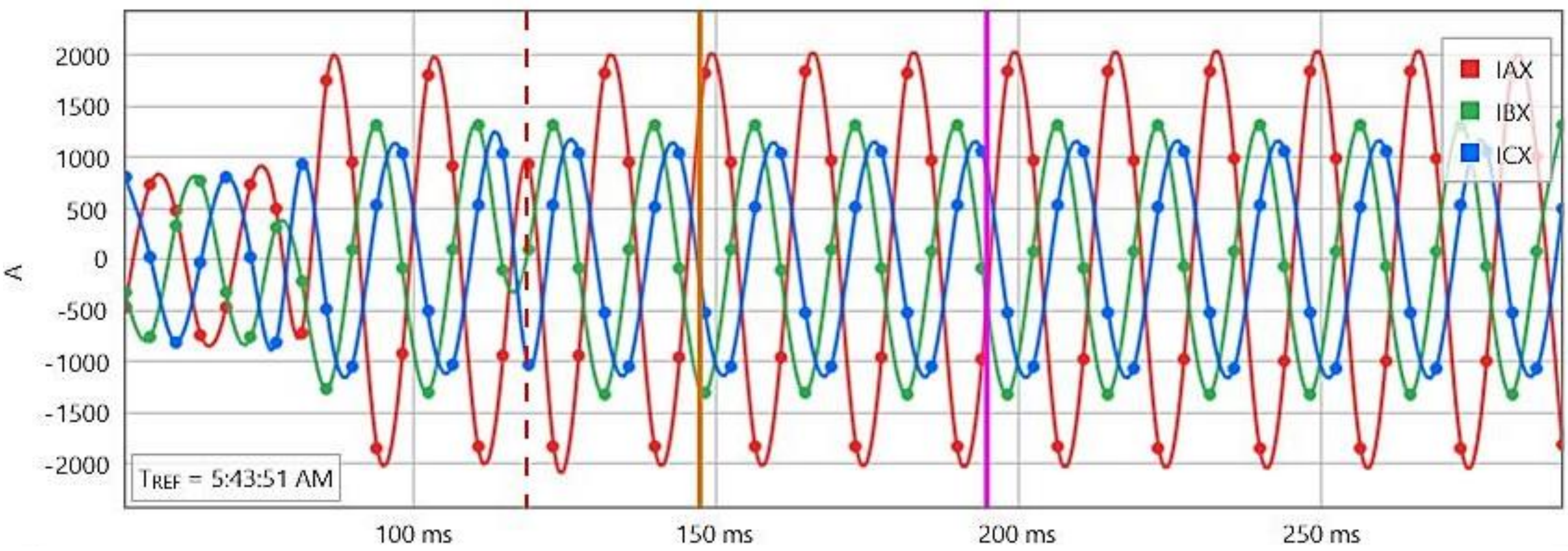

34.5 kV 50 MVAR
Reactor
Arrangement

Switching Arrangement

SF6 Circuit breaker is used on the phase side of the shunt reactor



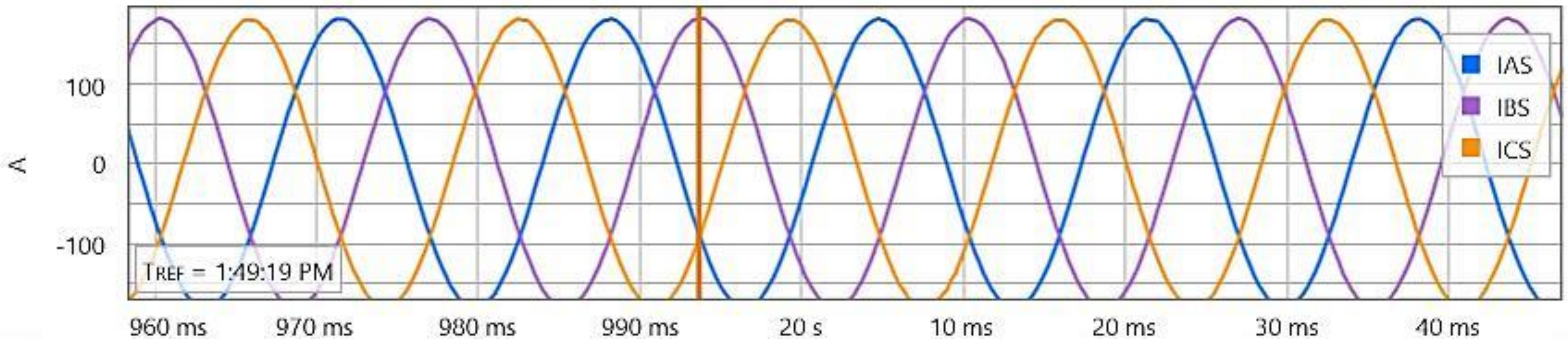
Case 1 – A-Phase reactor failure (while in service)



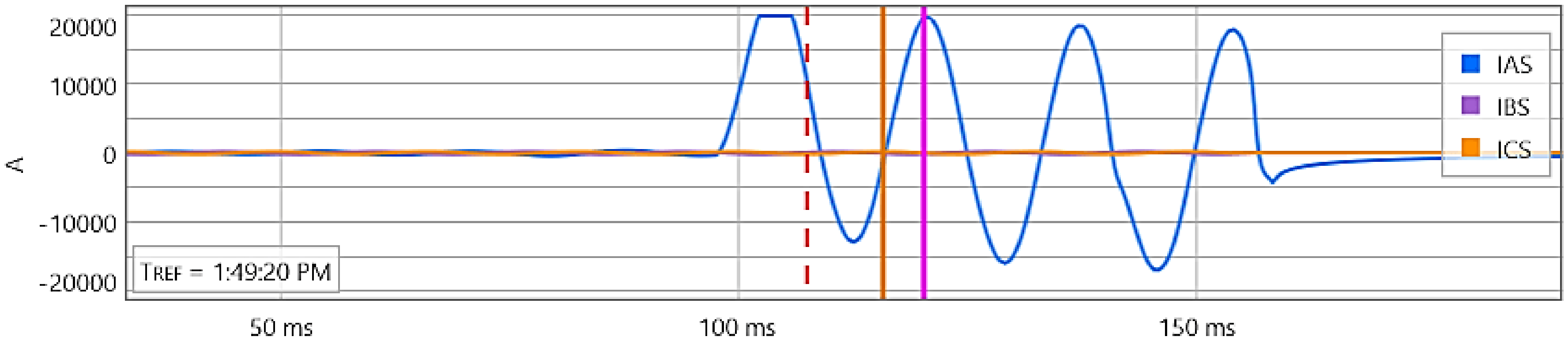
Case 2 – 115 kV Grounded-Y Shunt Reactor

- 115 kV, 25 MVAR grounded Y reactor A-Phase faulted because of surface contamination
- Flashover on the surface resulted in creating a turn-to-turn fault, resulting in 87N relay operation
- A-Phase of the reactor short resulted in a short-circuit current over 20 kA

Case 2 – A-Phase Reactor Failure (while in service)



Pre-fault current: 181 A peak



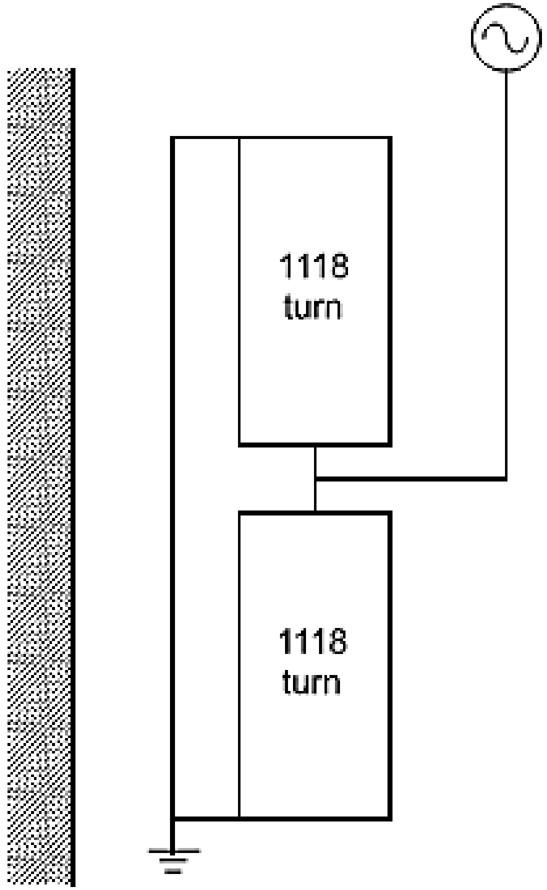
Fault current: >20,000 A; 400:5 CT saturated


Reactor on fire

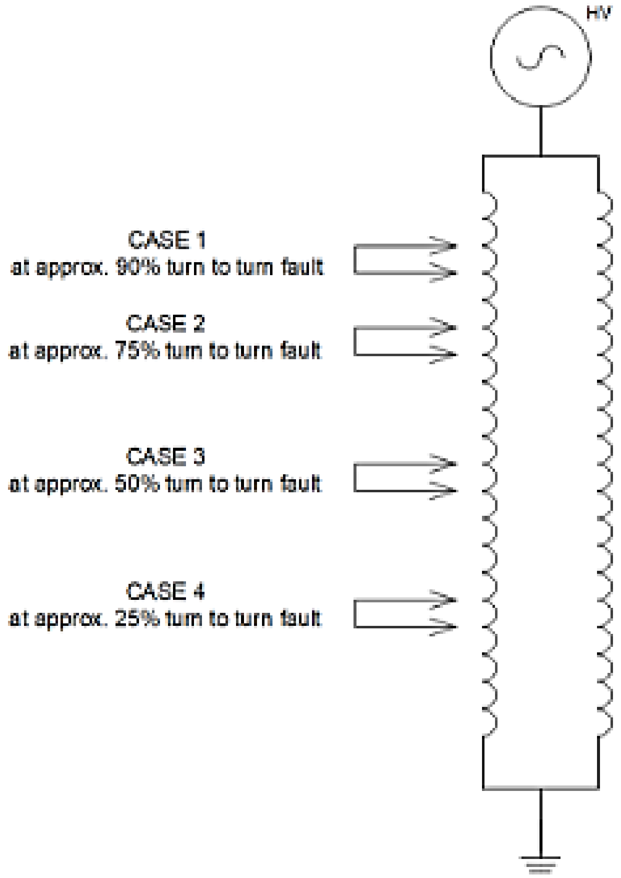
Protection ≠ Fault Prevention!

Turn-to-Turn Fault Case – One Turn Short

- **Winding diagram for turn to turn fault case**

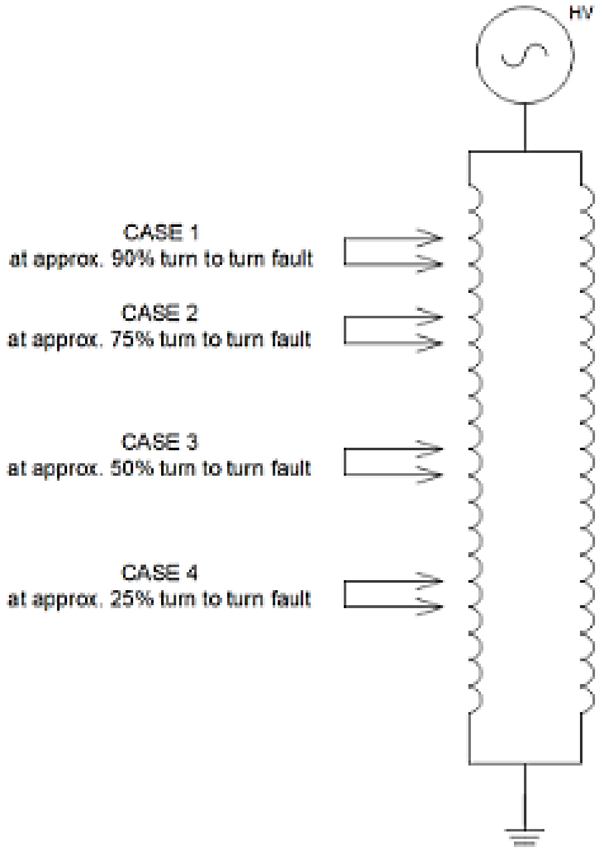


<Winding diagram>



<Fault case>

Shunt Reactor Impedance



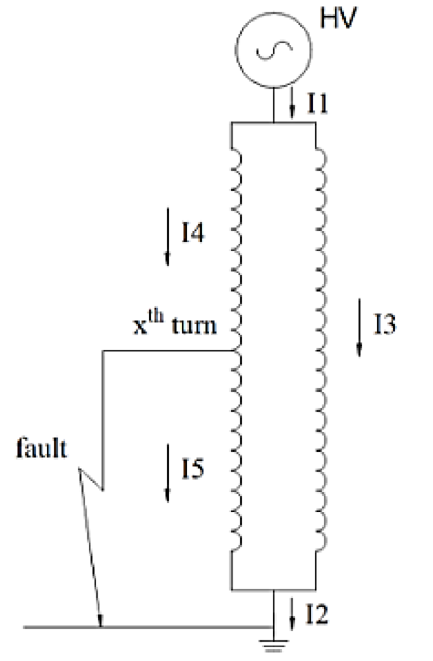
- Calculation result (reactance)

Case No.	Reactance (% of normal)
Normal	100%
Case1 – Fault between turn and next turn in 90% position	71.8%
Case2 - Fault between turn and next turn in 75% position	71.5%
Case3 - Fault between turn and next turn in 50% position	71.9%
Case3 - Fault between turn and next turn in 25% position	76.0%

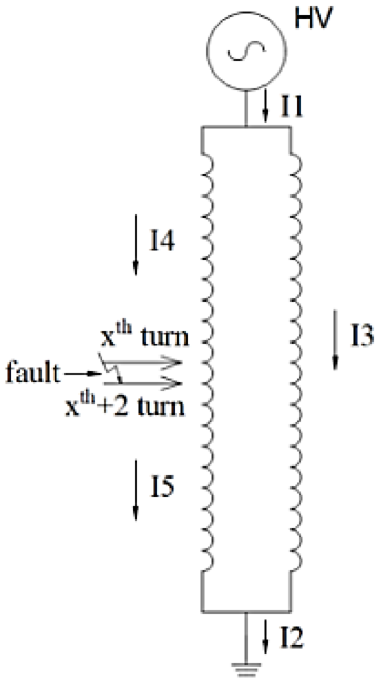
Calculations of Currents Through Windings During a Fault

- Results of fault current

Fault condition	Case No.	Xth turn	Xth + 2 turn	I1 (A)	I2 (A)	I3 (A)	I4 (A)	I5 (A)
	Normal	-	-	351	351	175	175	-
Turn to ground fault	Case 1	112	-	18214	1782	643	18857	1139
	Case 2	280	-	3164	673	94	3257	580
	Case 3	560	-	890	359	84	896	443
	Case 4	840	-	570	425	140	430	565
Turn to turn fault	Case 1	110	112	467	467	206	261	261
	Case 2	278	280	476	476	183	293	293
	Case 3	558	560	476	476	164	312	312
	Case 4	838	840	456	456	159	297	297



<Turn to ground fault diagram>



<Turn to turn fault diagram>

C37.109 Guide for Shunt Reactor Protection

New revision to be published in 2024