Severe Overvoltage During Single-Phase Open Period

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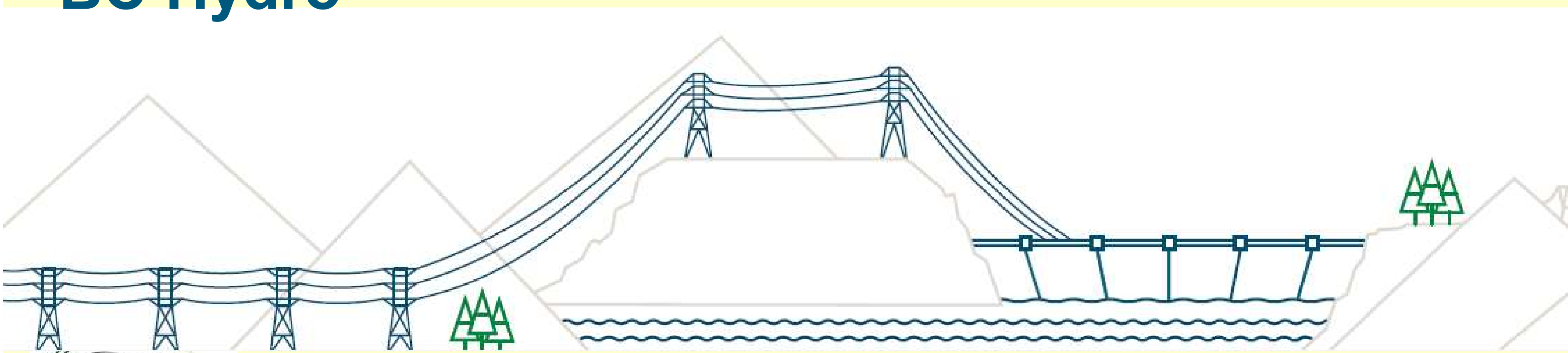
BC Hydro



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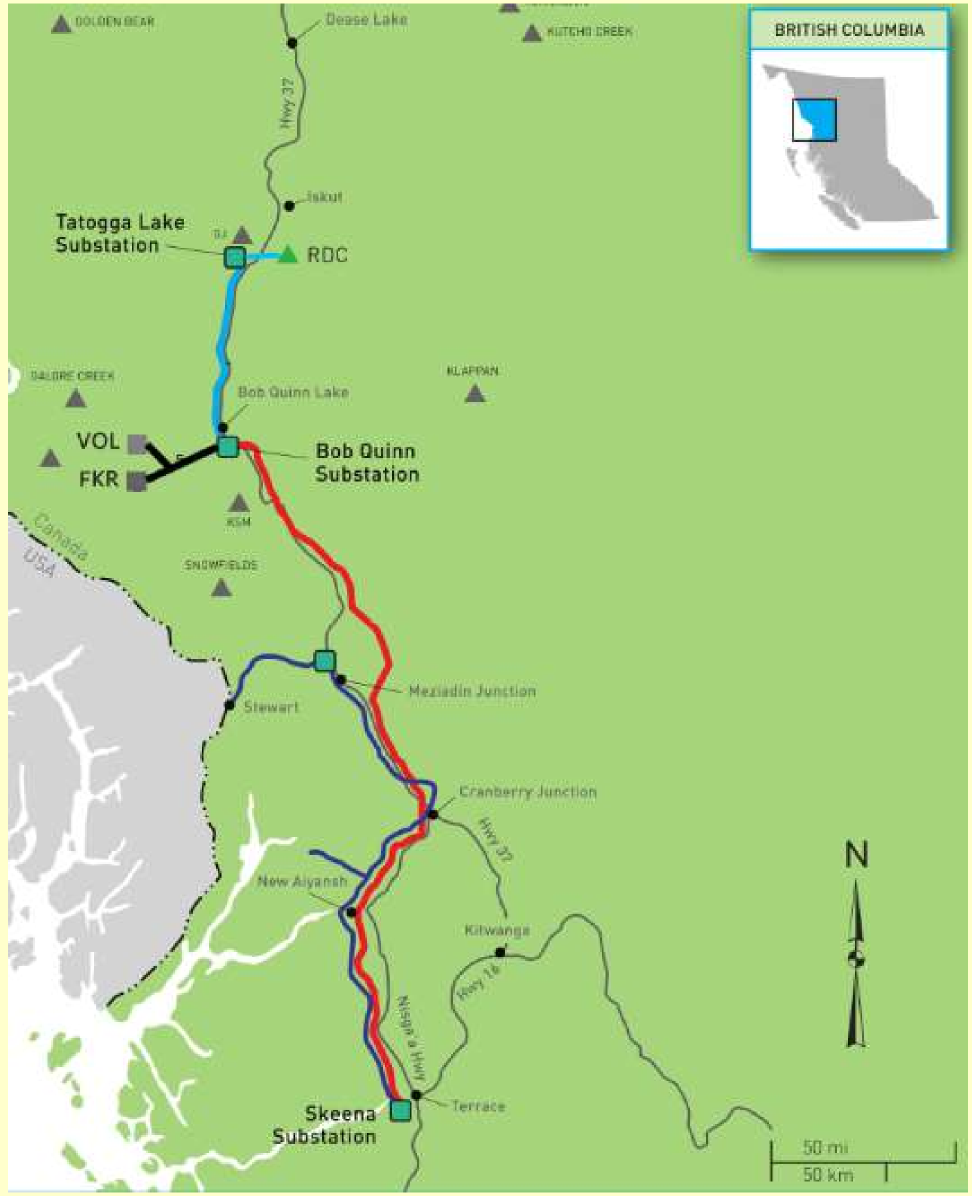
Outline

- The Northwest Transmission System (NTL)
- What system events happened on January 7th?
  - Single-Phase Auto-reclose - Background
- What did protection do during those events?
  - Overexcited Transformer - Background
- System analysis
- Solutions

NTL

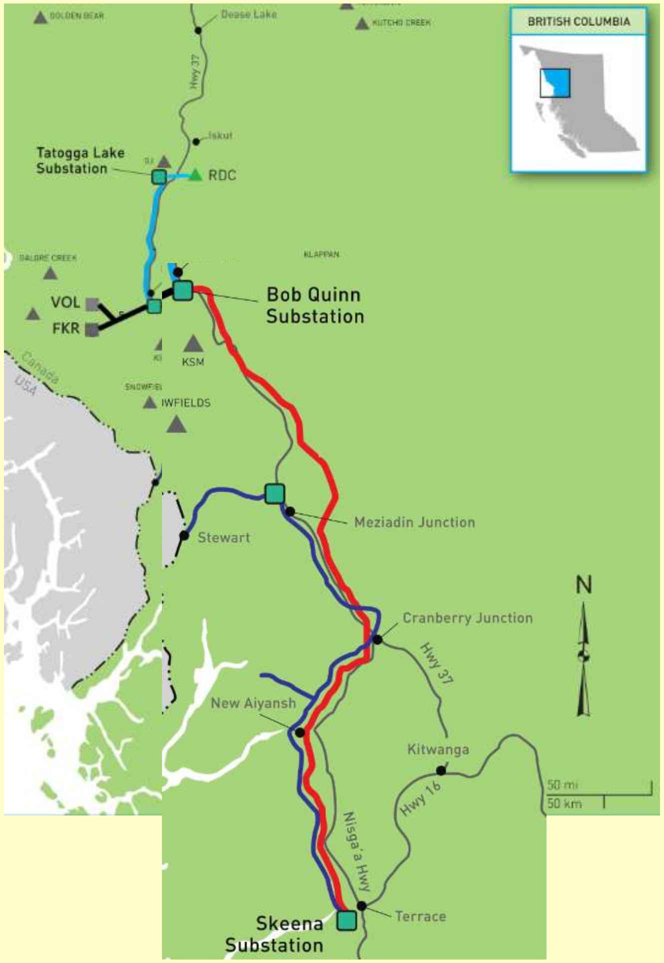
Three 287 kV lines



BC Hydro System

2L102

287 kV – 340 km



BC Hydro System

Connects Skeena (SKA) to Bob Quinn (BQN)

- Line current differential protection
- Single-pole tripping
- Optical ground wire
- 2nd longest line in BC Hydro
- 35% series capacitor compensation at BQN end
- 84% shunt compensated

Three-phase

versus

Single-phase
Trip and Reclose

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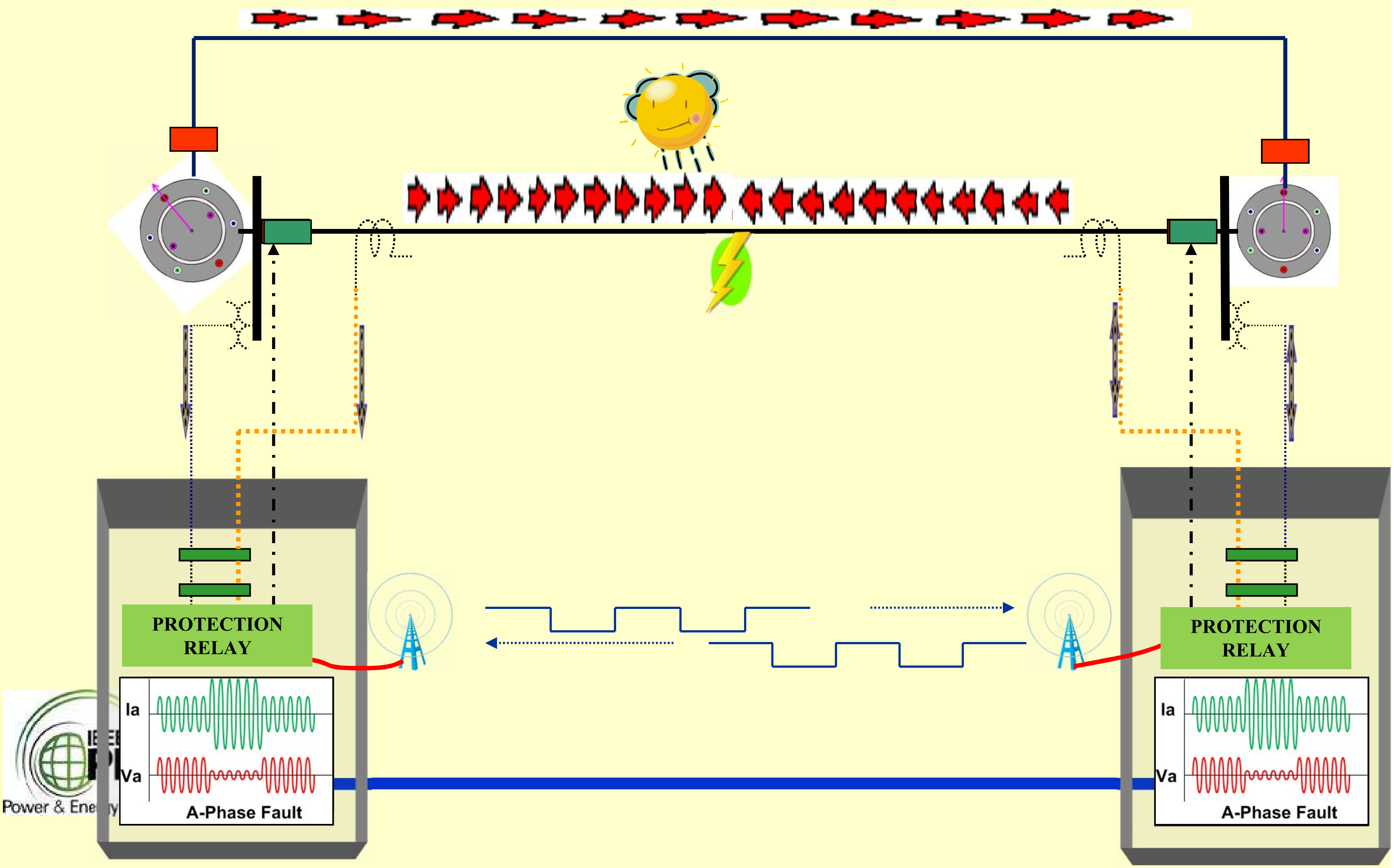
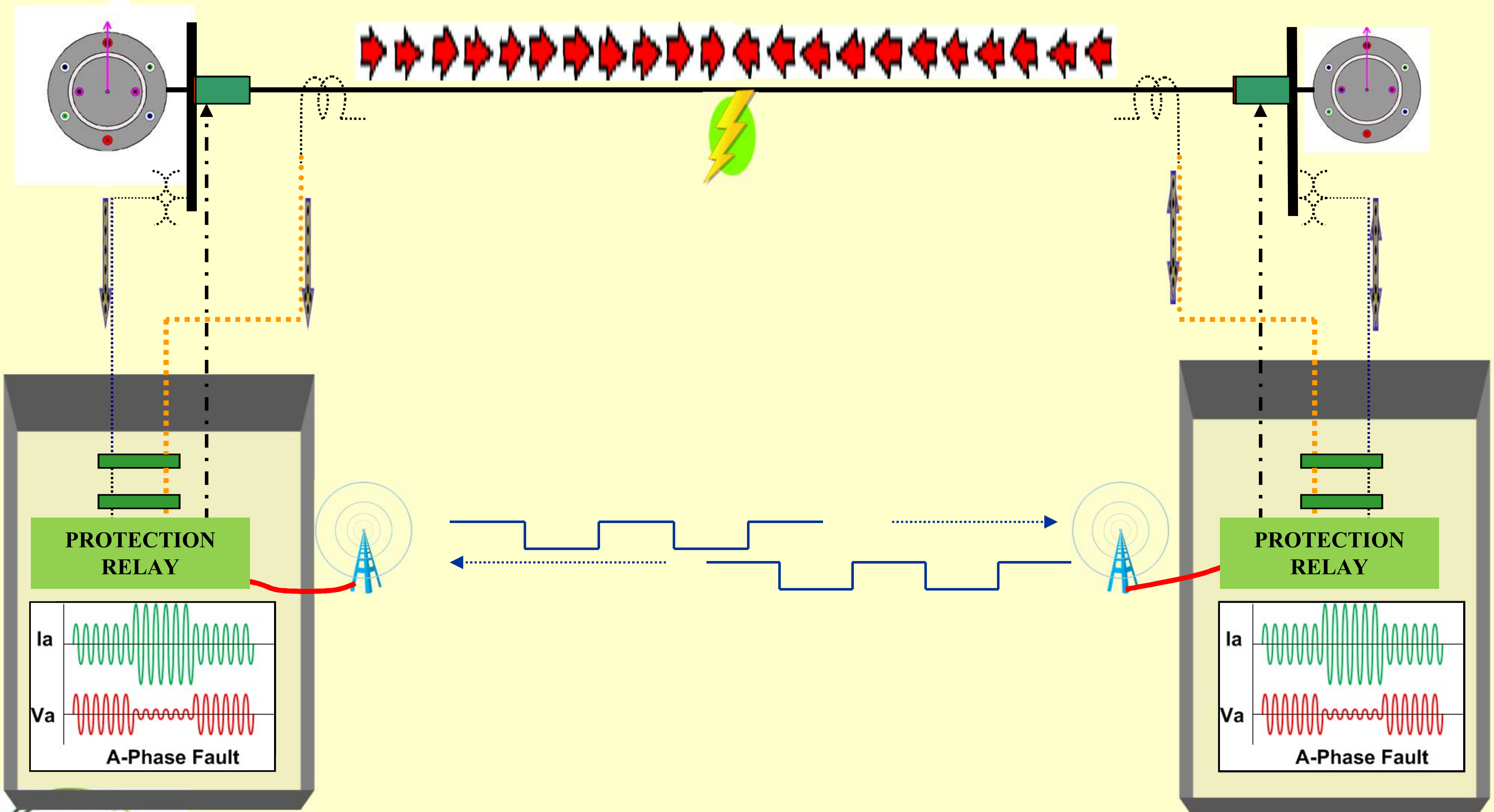
Three-Phase Auto-Reclosing



Three-Phase Auto-Reclosing



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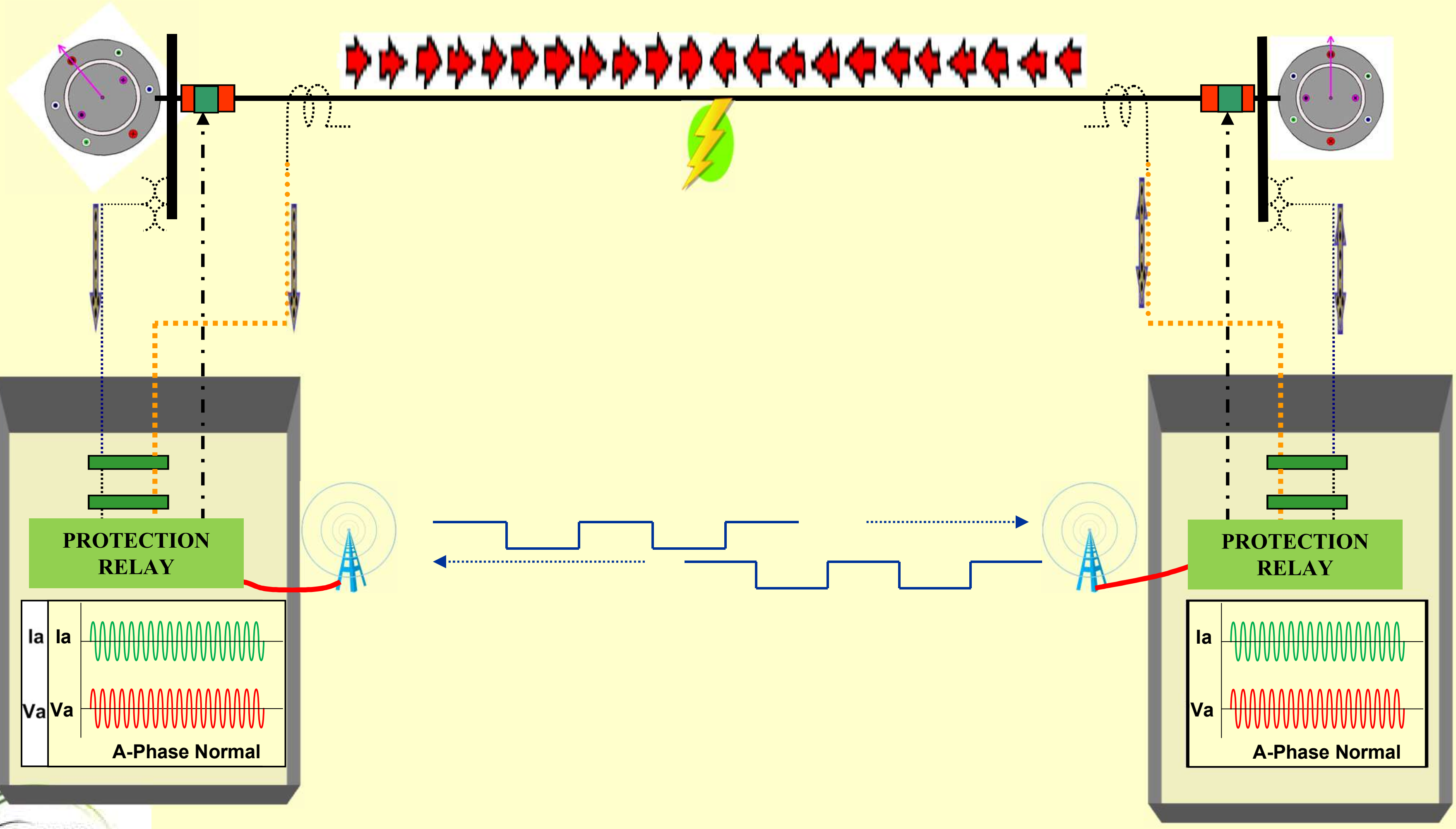
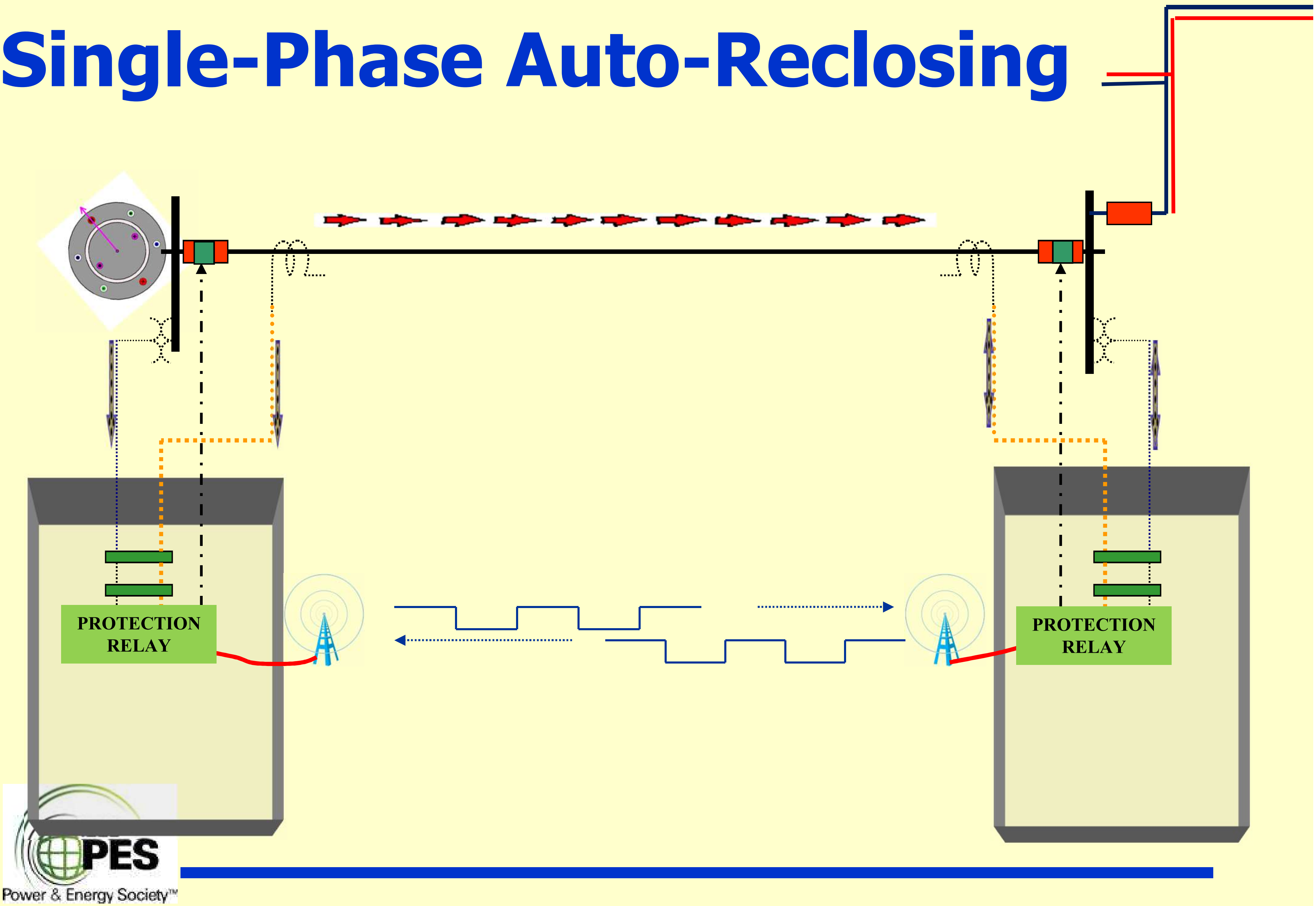
Single-Phase Auto-Reclosing



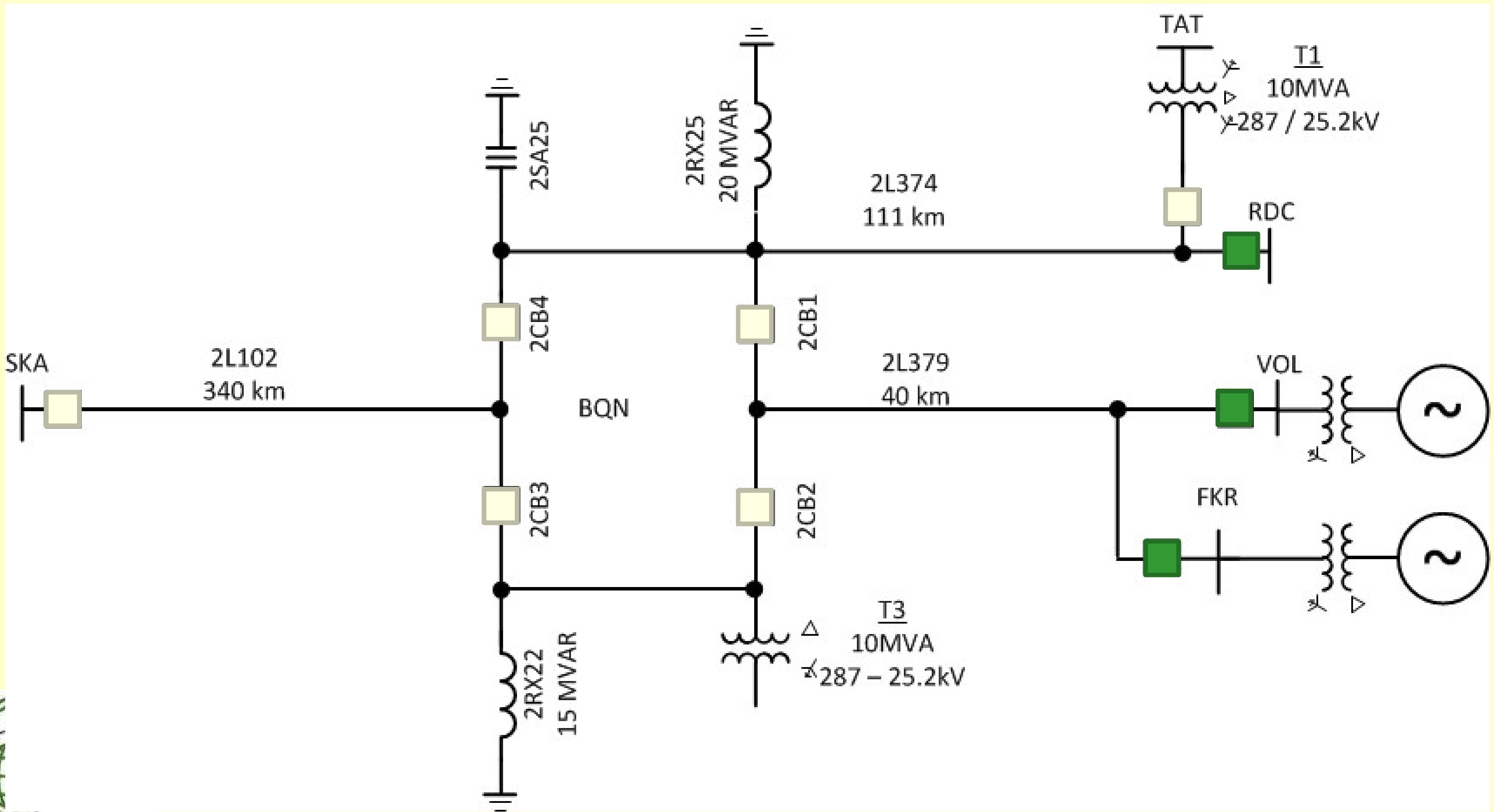
Single-Phase Auto-Reclosing



Events of January 7th

Morning of Faults

Event 5 6:21 AM



Morning of Faults

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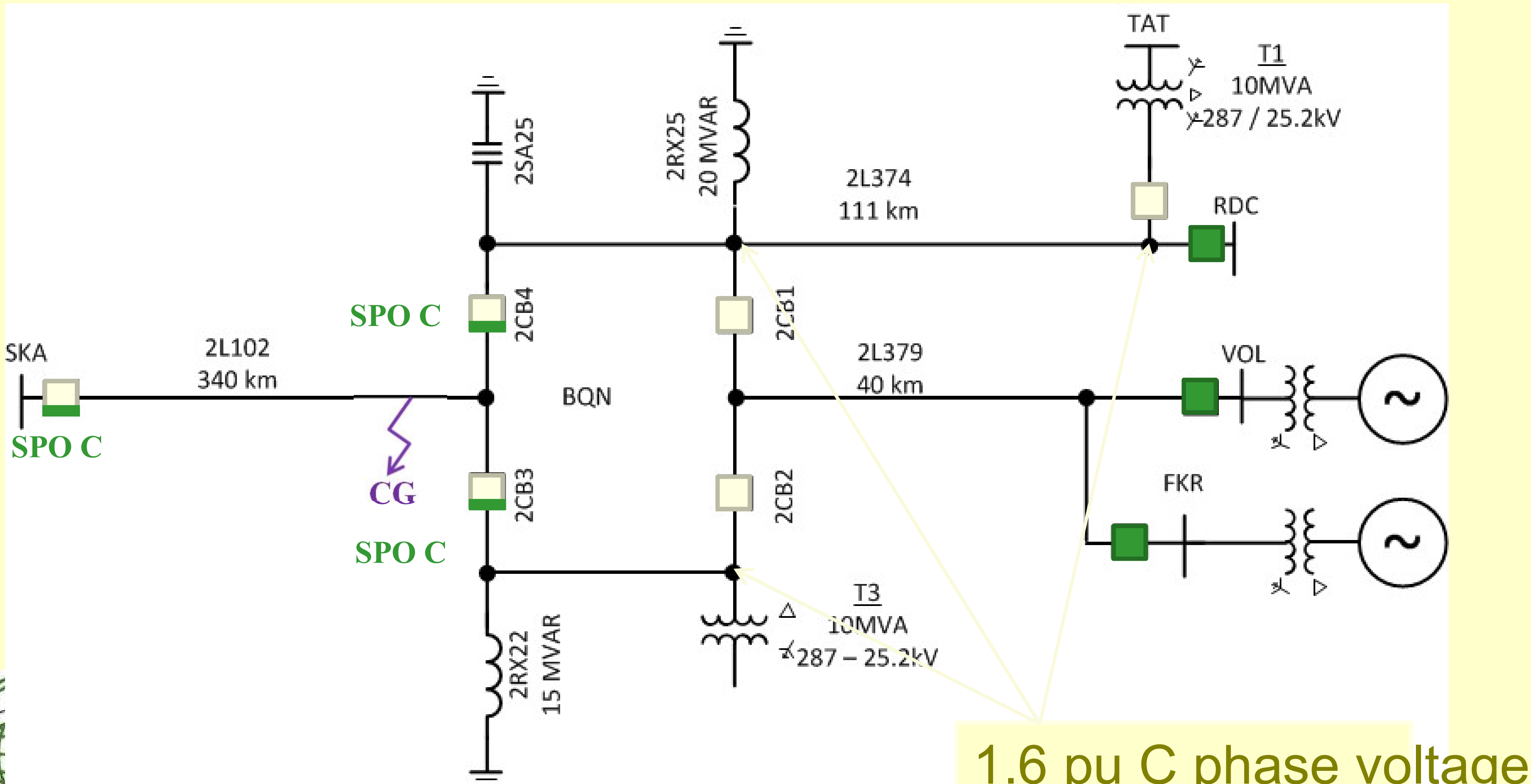

Morning of Faults

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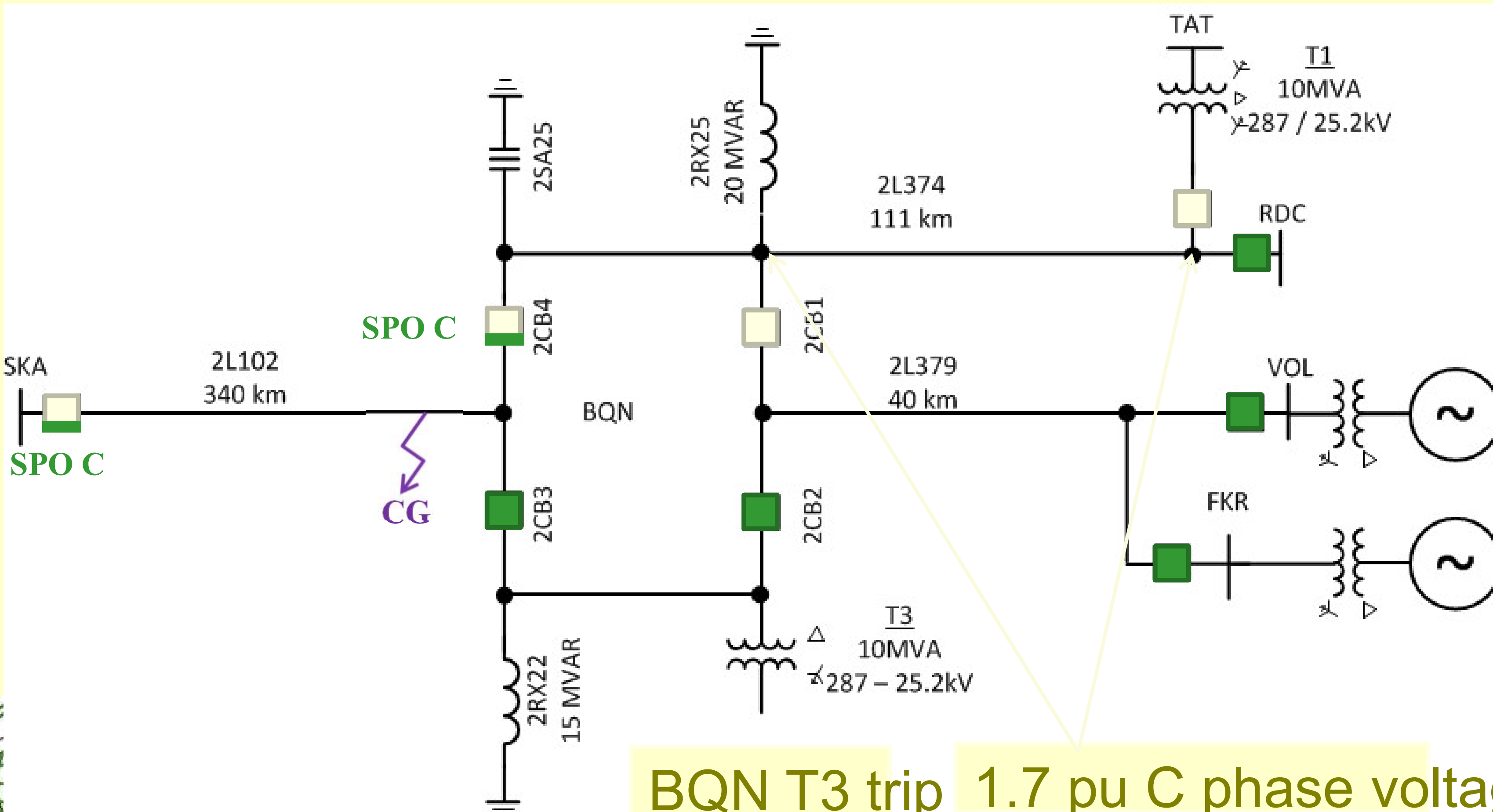
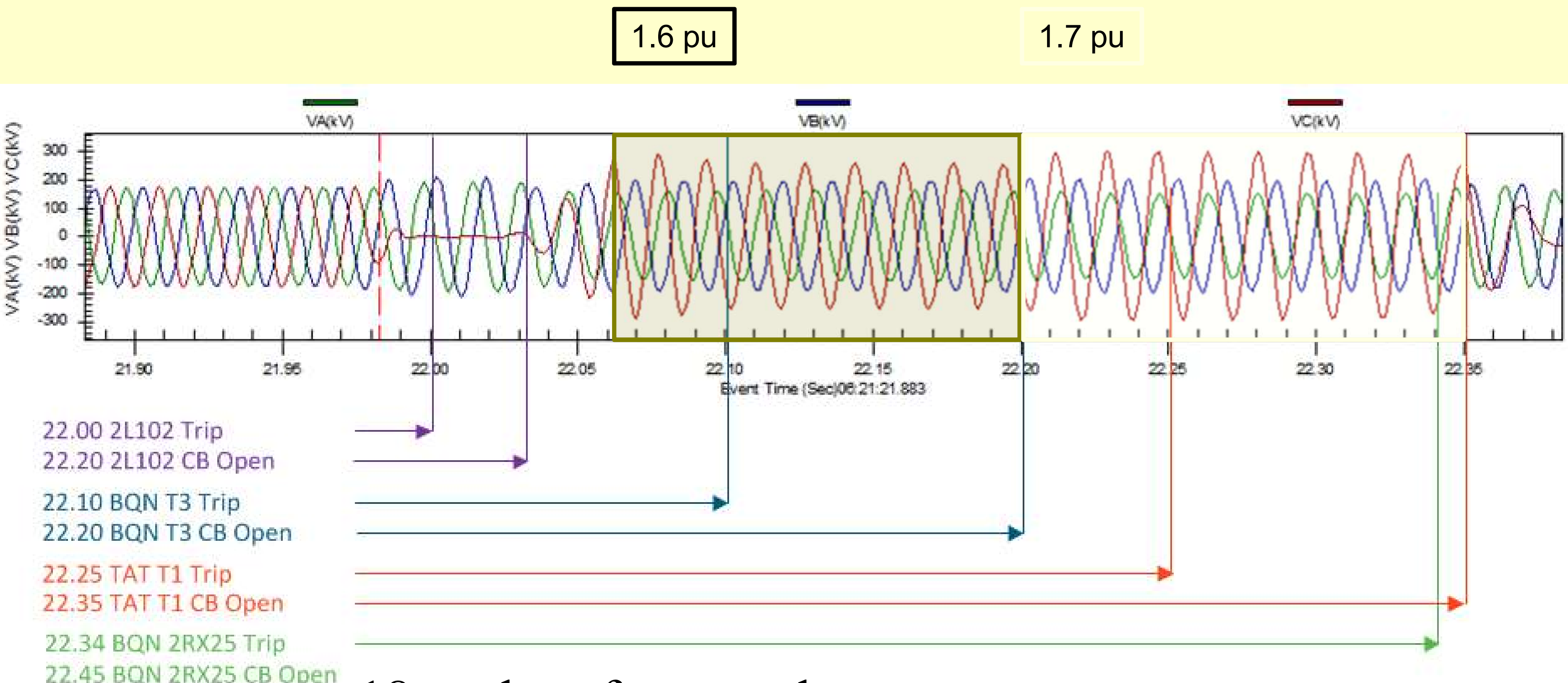


BQN T3 trip

1.7 pu C phase voltage

Composite Protection Operations



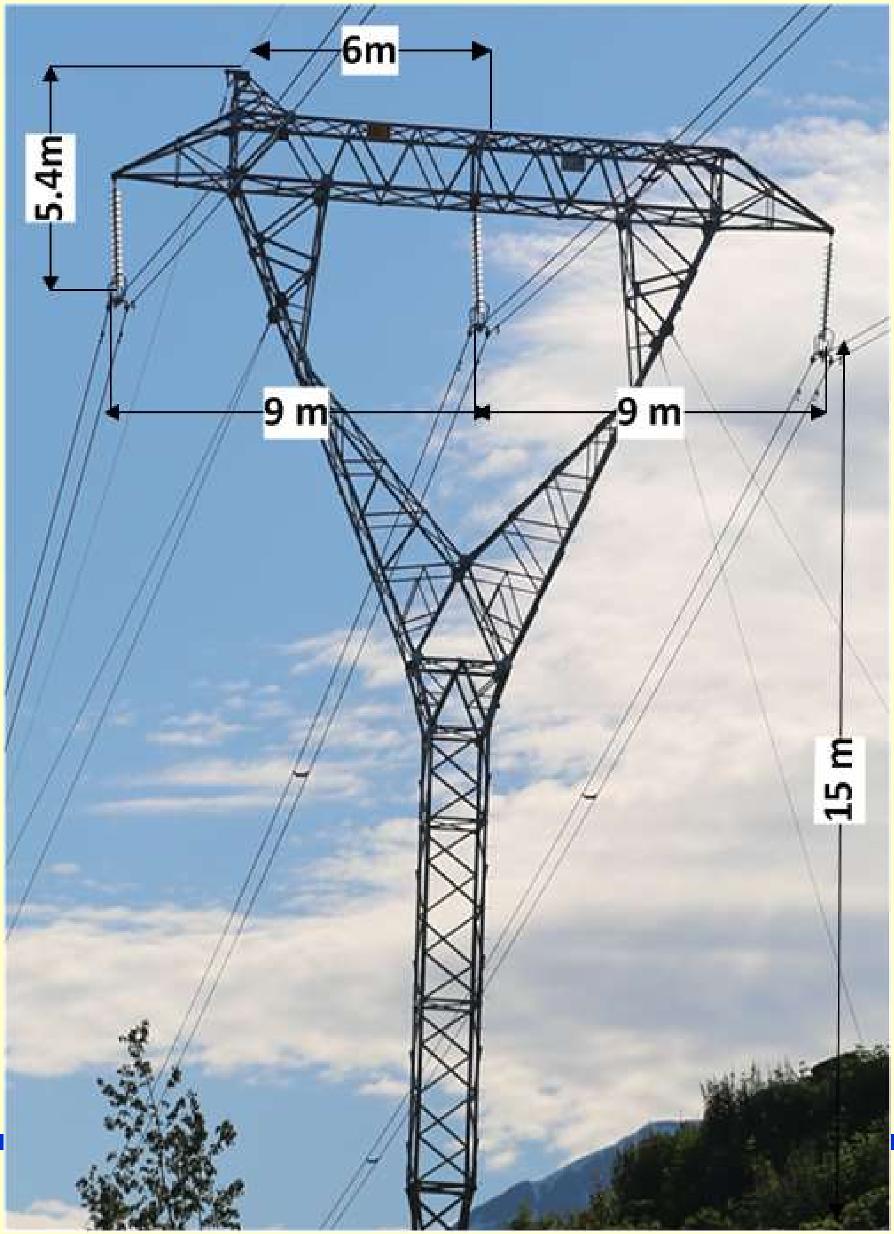
18 cycles of over-voltage

Voltage increased from 1.6 to 1.7 pu when BQN T3 and 2RX 22 tripped off

Tower Configuration

5.4 m vertical separation between conductor and

3.0 m horizontal separation between conductor and OPGW



OPGW at point of fault

Tramsformer Protection Operations

There were two transformer protection operations for no internal faults. While one of them was fortuitous, yet they were baffling because they were designed not to operate on overvoltage as per our standard practice. So they were thoroughly investigated to assess if there was any reliability risk to BC Hydro.

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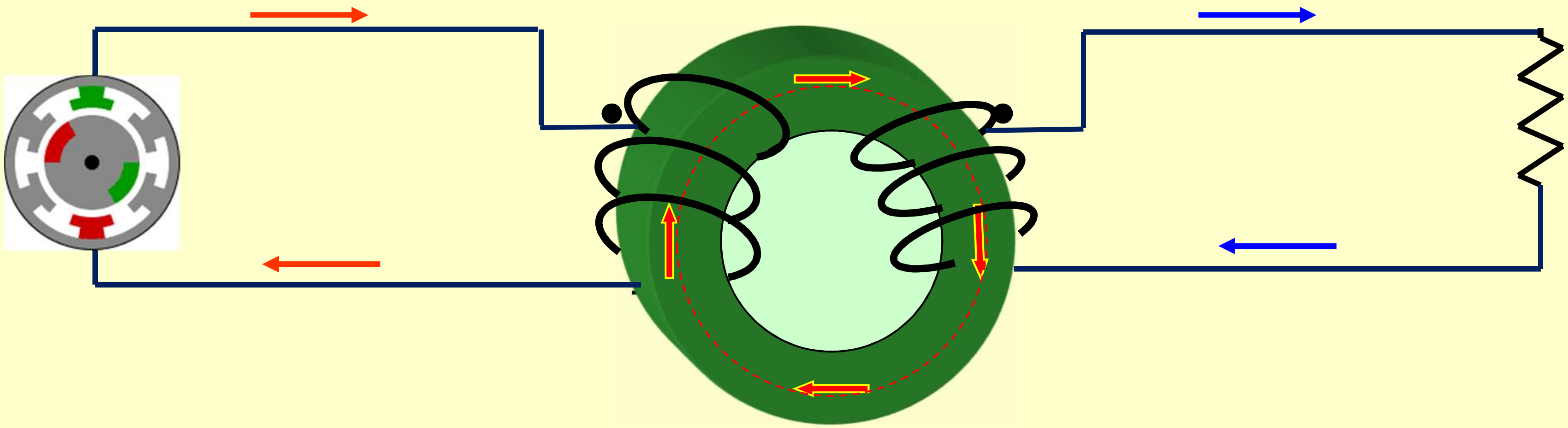
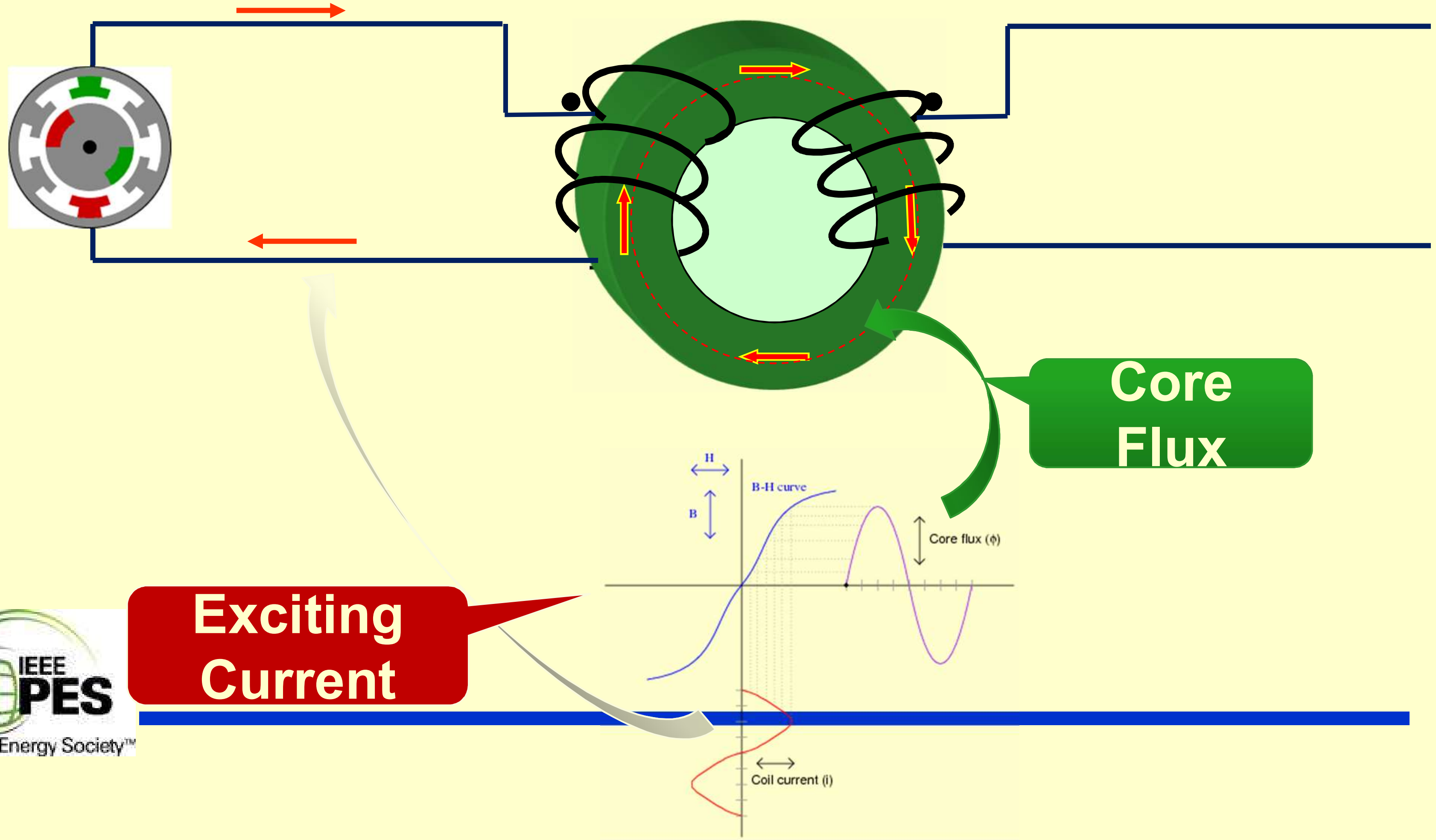
Transformer Differential Protection



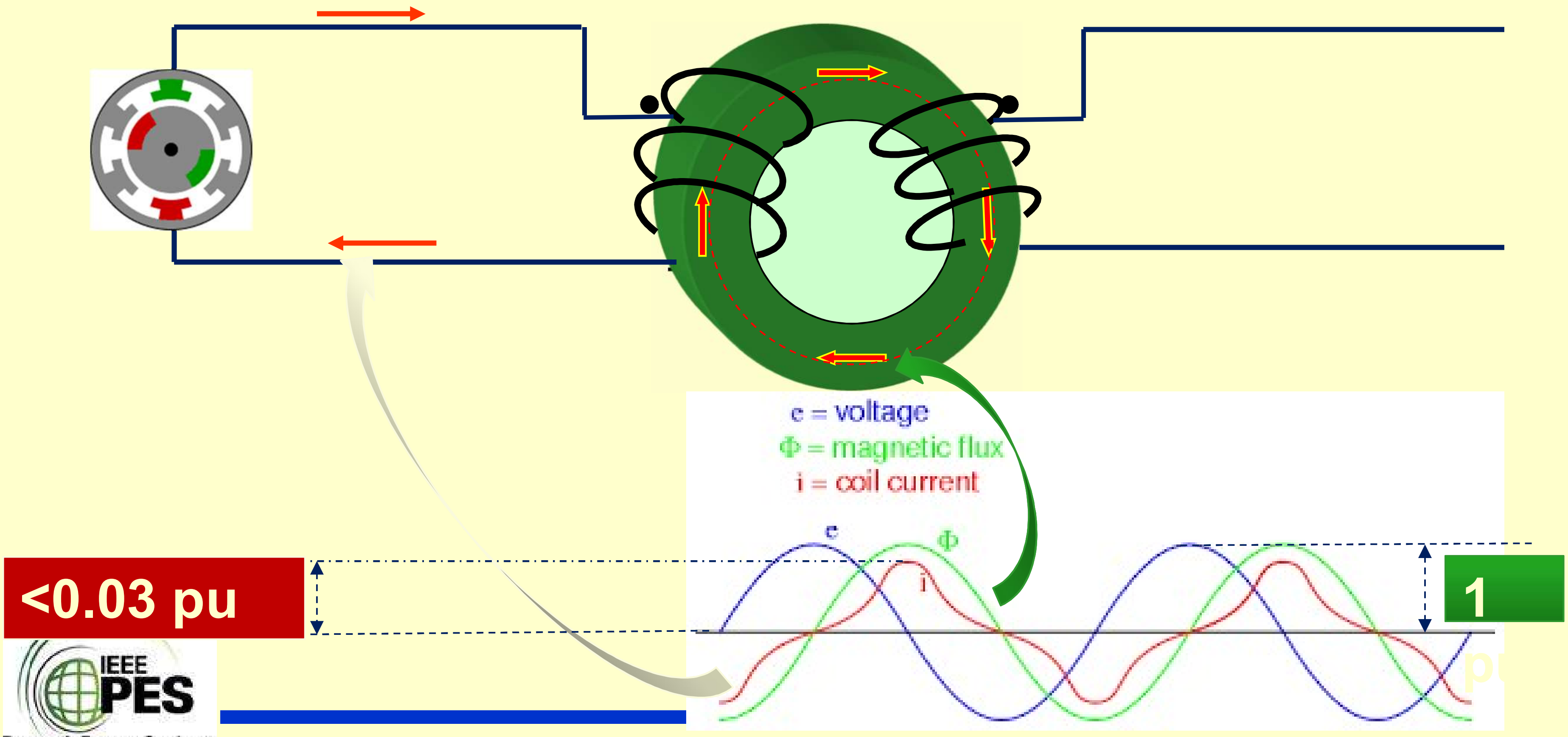
Healthy Transformer:

Primary ampere turns (1-3% of rating) are slightly higher to establish the magnetizing flux.

Transformer at No Load



Transformer at No Load



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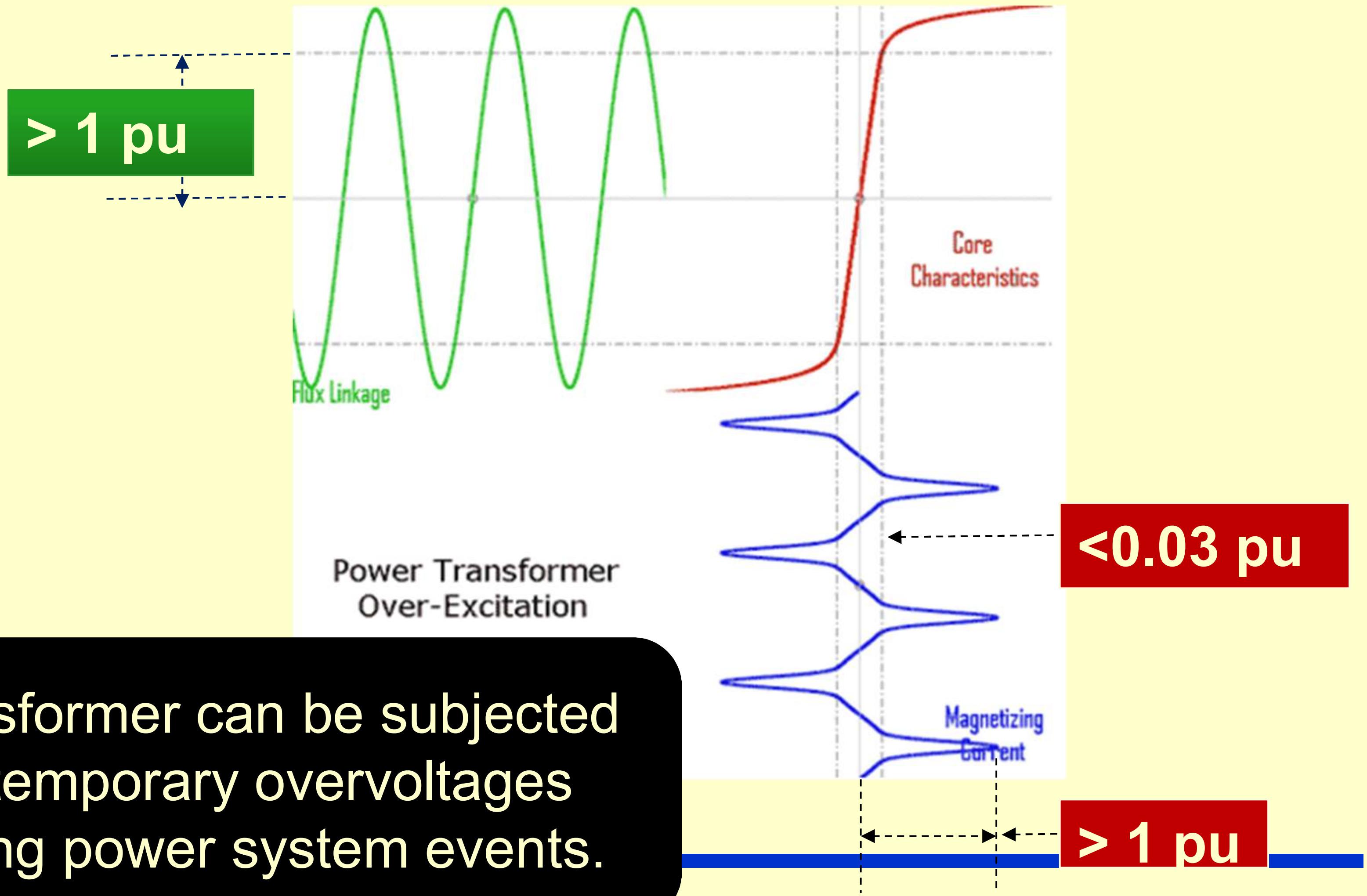
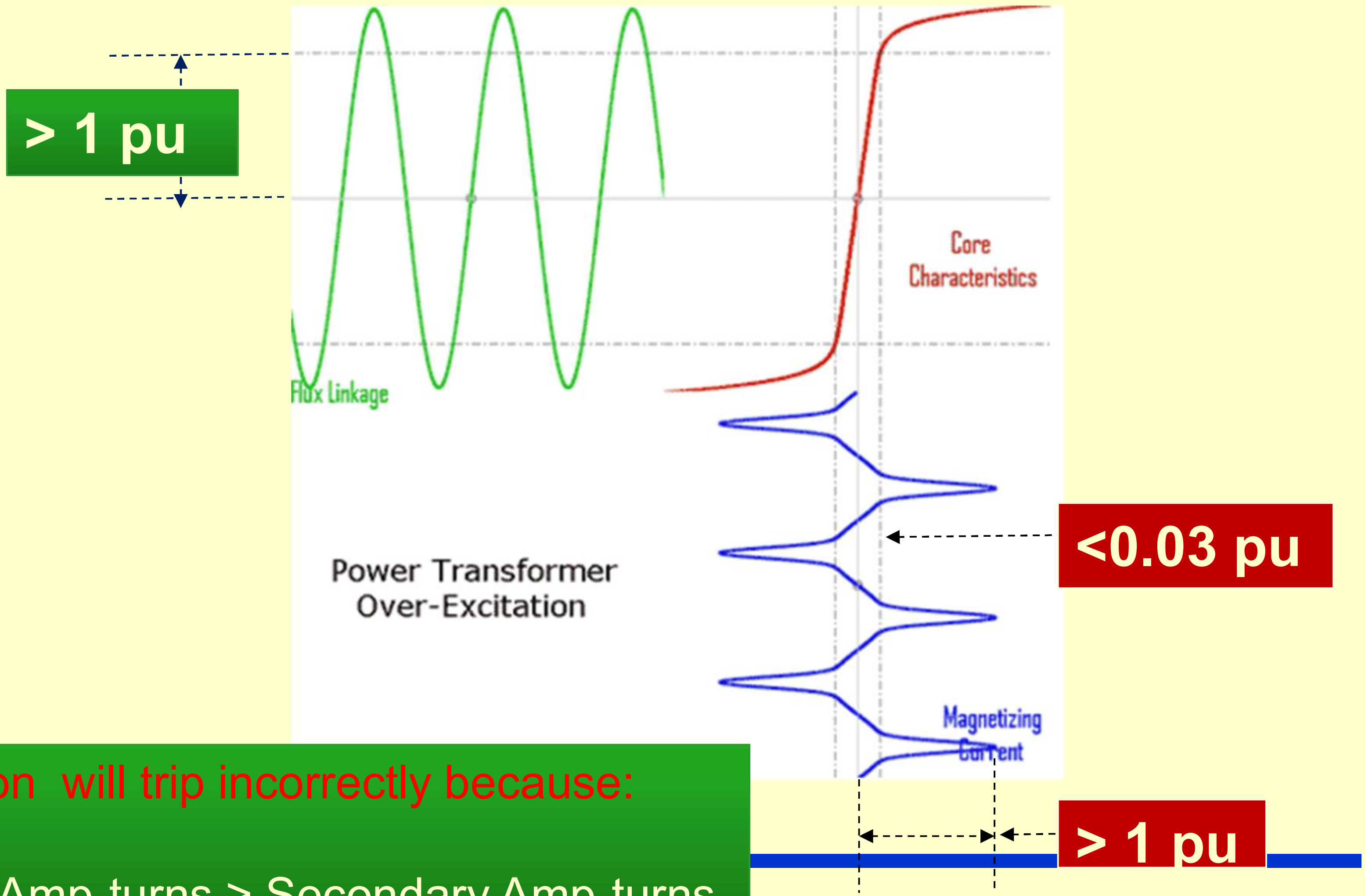
Transformer Overexcitation Current



Transformer can be subjected to temporary overvoltages during power system events.

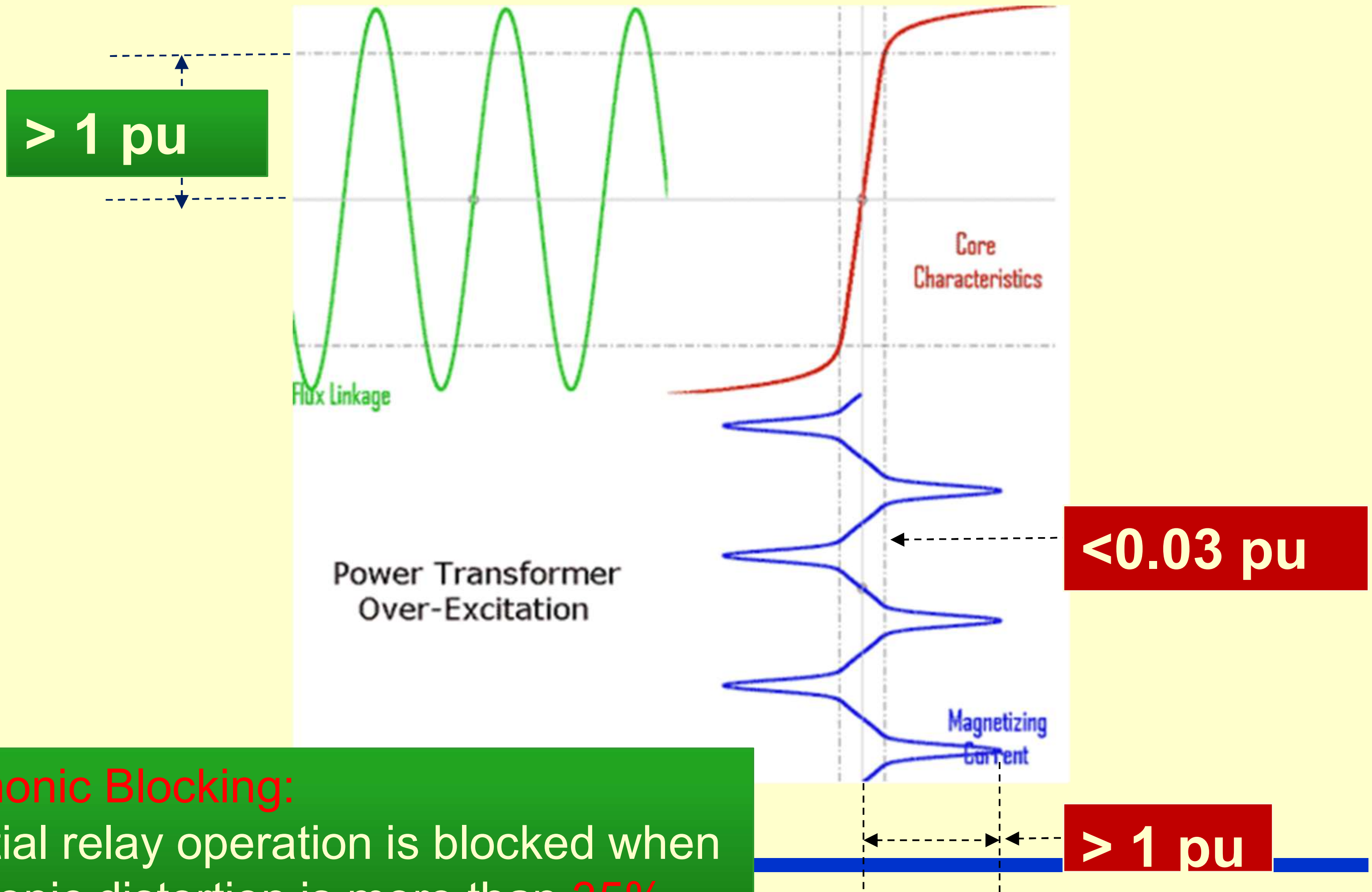
Transformer Differential Protection



Protection will trip incorrectly because:

Primary Amp-turns > Secondary Amp-turns

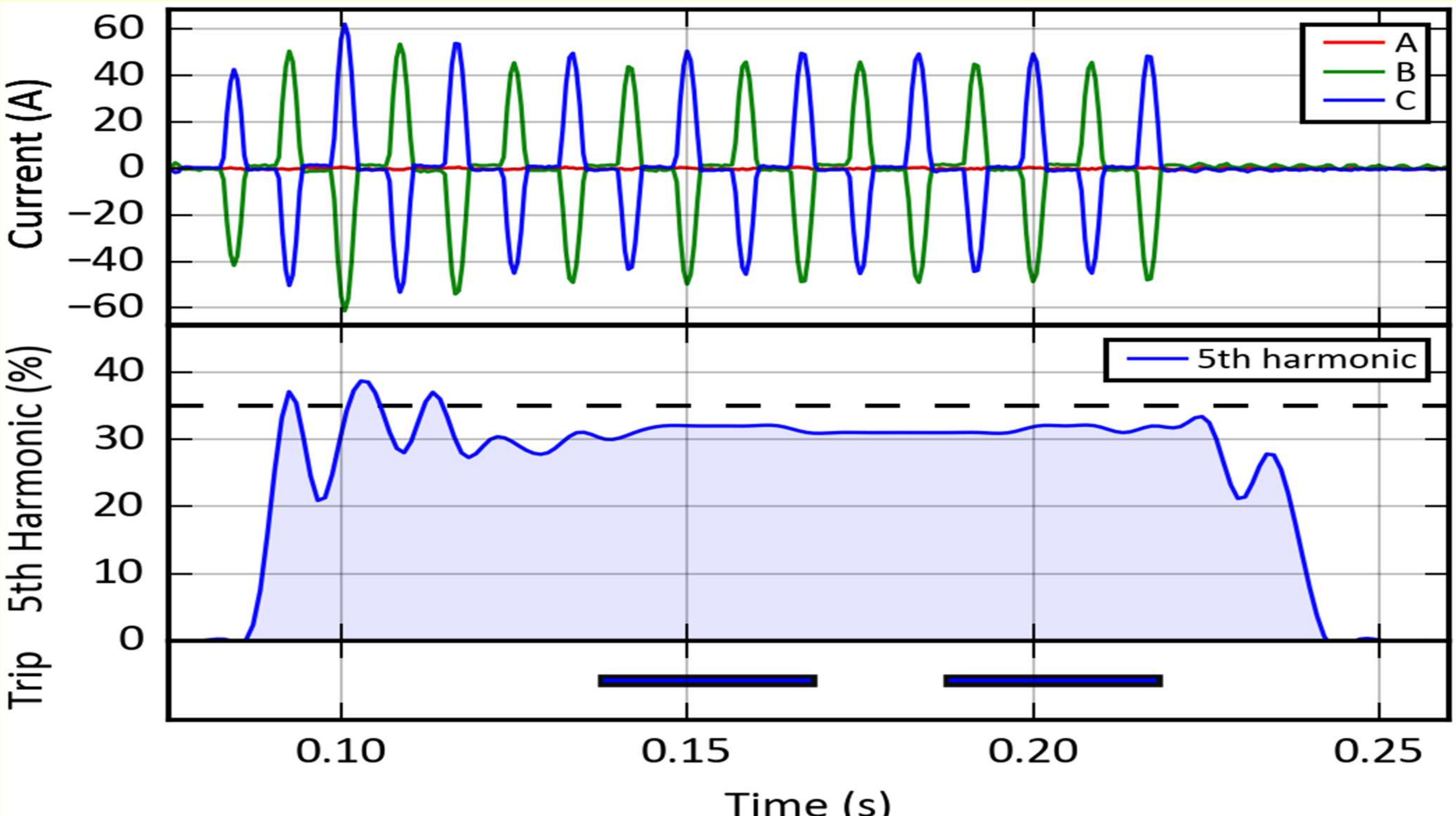
5^{th} Harmonic Blocking in Differential Protection



5^{th} Harmonic Blocking:

Differential relay operation is blocked when 5^{th} harmonic distortion is more than 35%.

BQN T3 – unfiltered event record



10 MVA – HV delta, LV wye

BQN T3

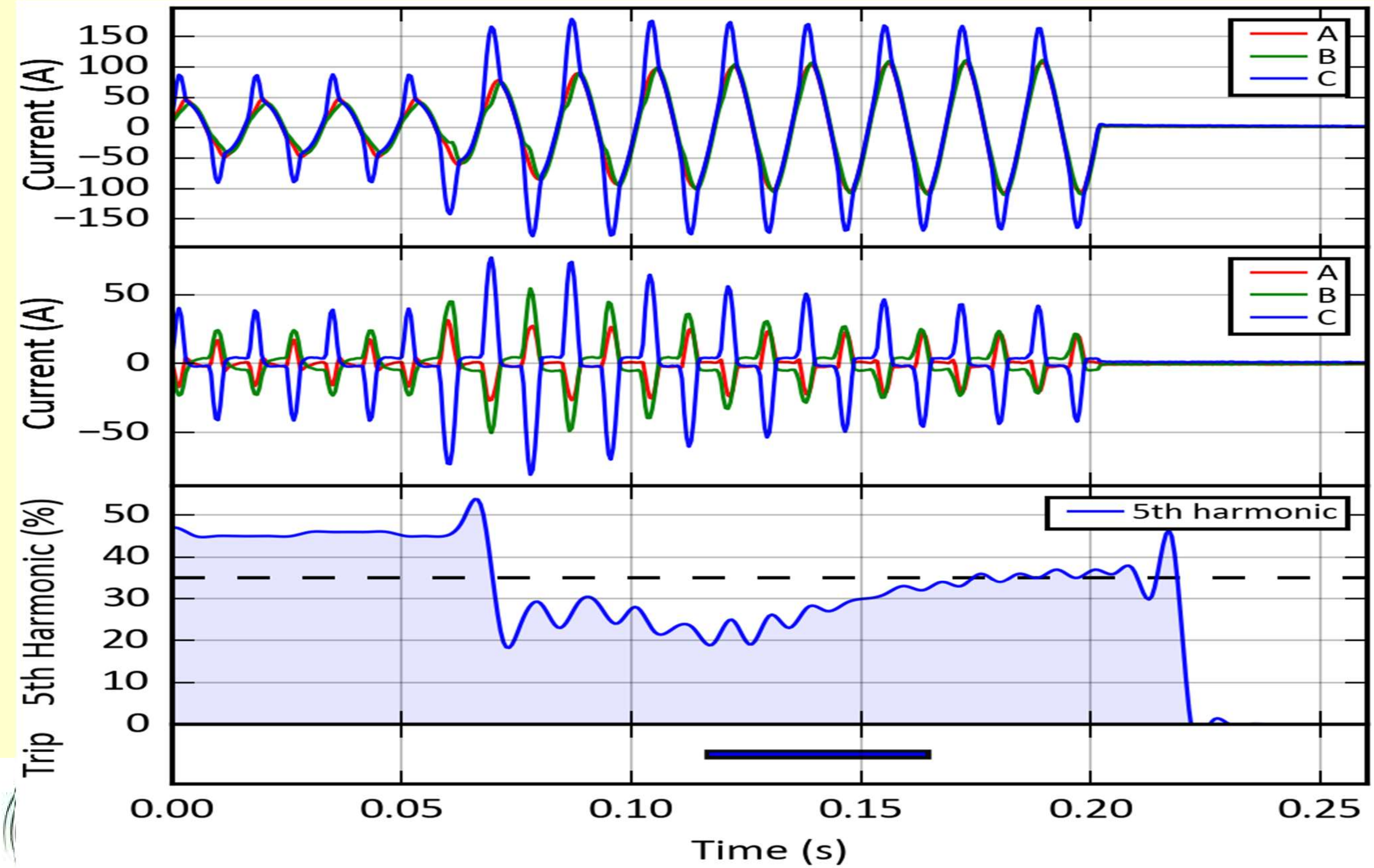
What happened?

Over-voltage led to core saturation

- High 5th harmonic current
- Relay blocked by > 35% 5th harmonic current at onset
- Relay tripped in 3.5 cycles

Cleared BQN 2RX22 in same tripping zone

TAT T1 – unfiltered event record



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10 MVA – HV wye, LV wye, delta tertiary

TAT T1

What happened?

Over-voltage led to core saturation

- High 5th harmonic current
- Relay blocked by > 35% 5th harmonic current at onset
- Relay tripped in 12.5 cycles

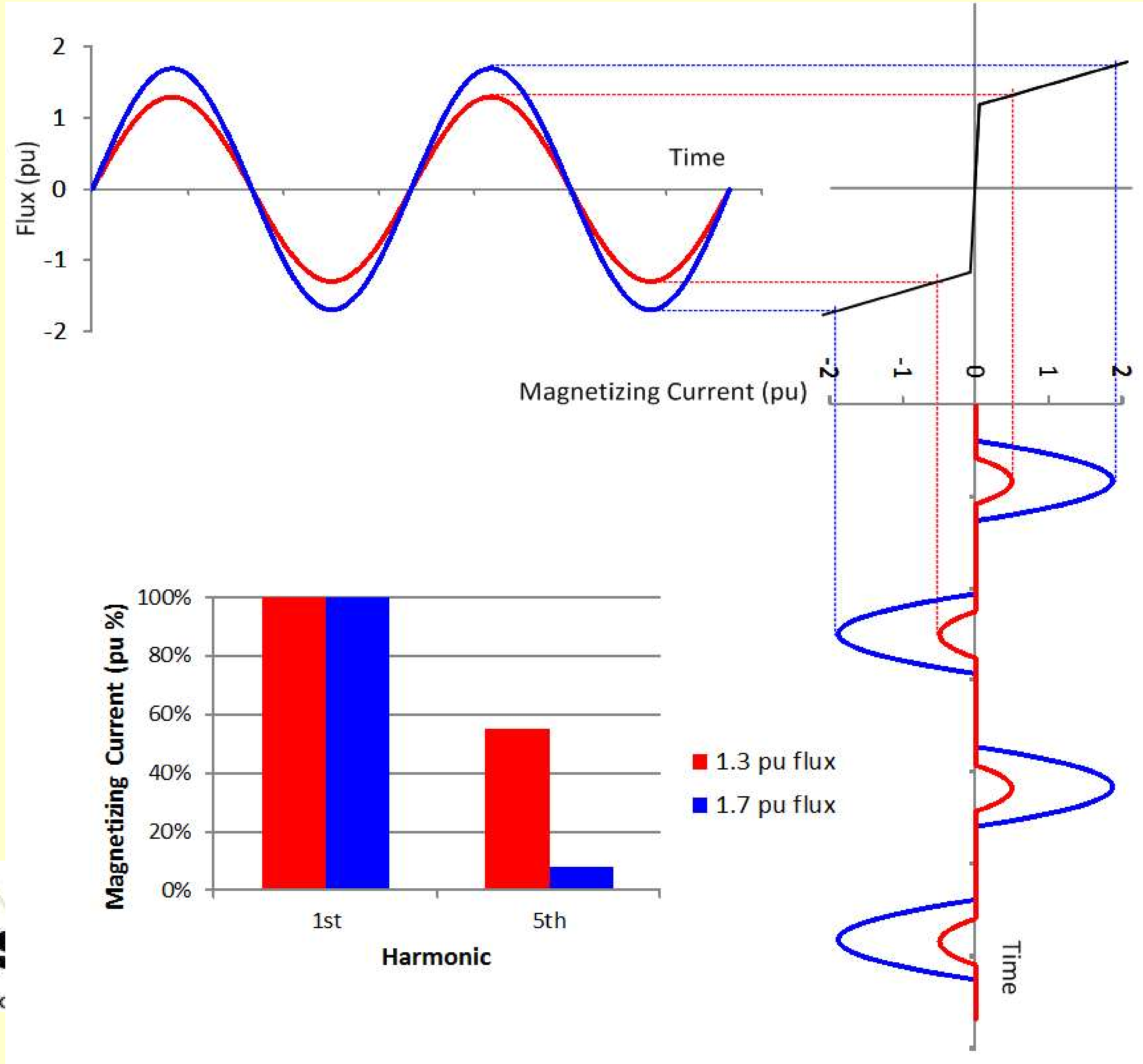
TAT T1

What happened?

Delta tertiary winding allowed for zero sequence current flow

System voltage began to drop as soon as TAT T1 breaker opened

Saturation Versus Harmonic Distortion



Tramsformer Protection Operations

Simple graphical analysis demonstrates that the transformer differential relay with 5th harmonic blocking poses no reliability risk. With 35% blocking threshold, it can be relied on to prevent tripping for temporary overvoltages (such as 1.3 pu) yet allow tripping to “help” protect the transformer from extreme overvoltages (such as 1.7 pu) causing overexcitation.

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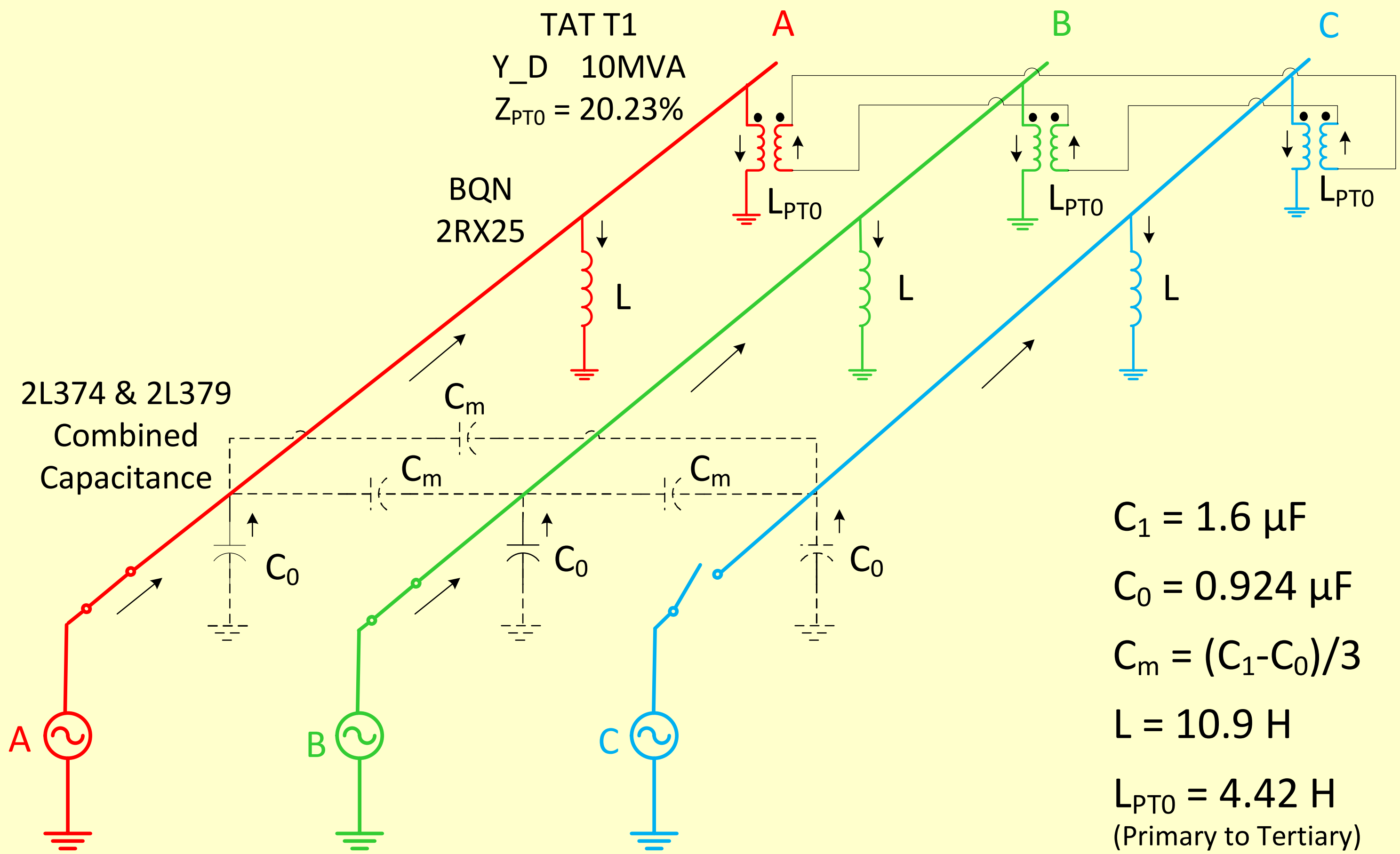
Analysis

Steady state, linear, and non-linear analysis

Steady state analysis



C_1 = 1.6 μF

C_0 = 0.924 μF

$C_m = (C_1 - C_0)/3$

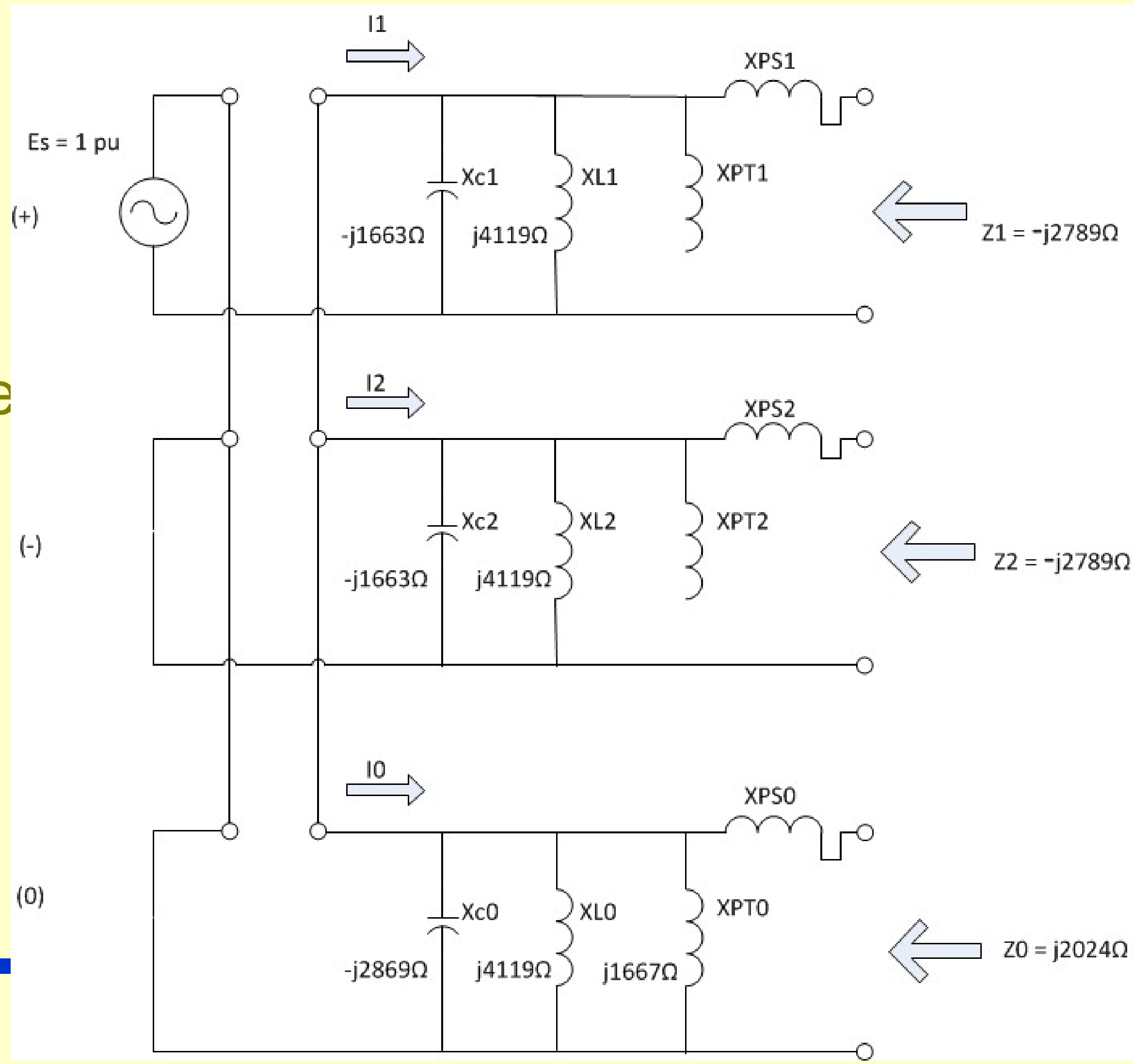
L = 10.9 H

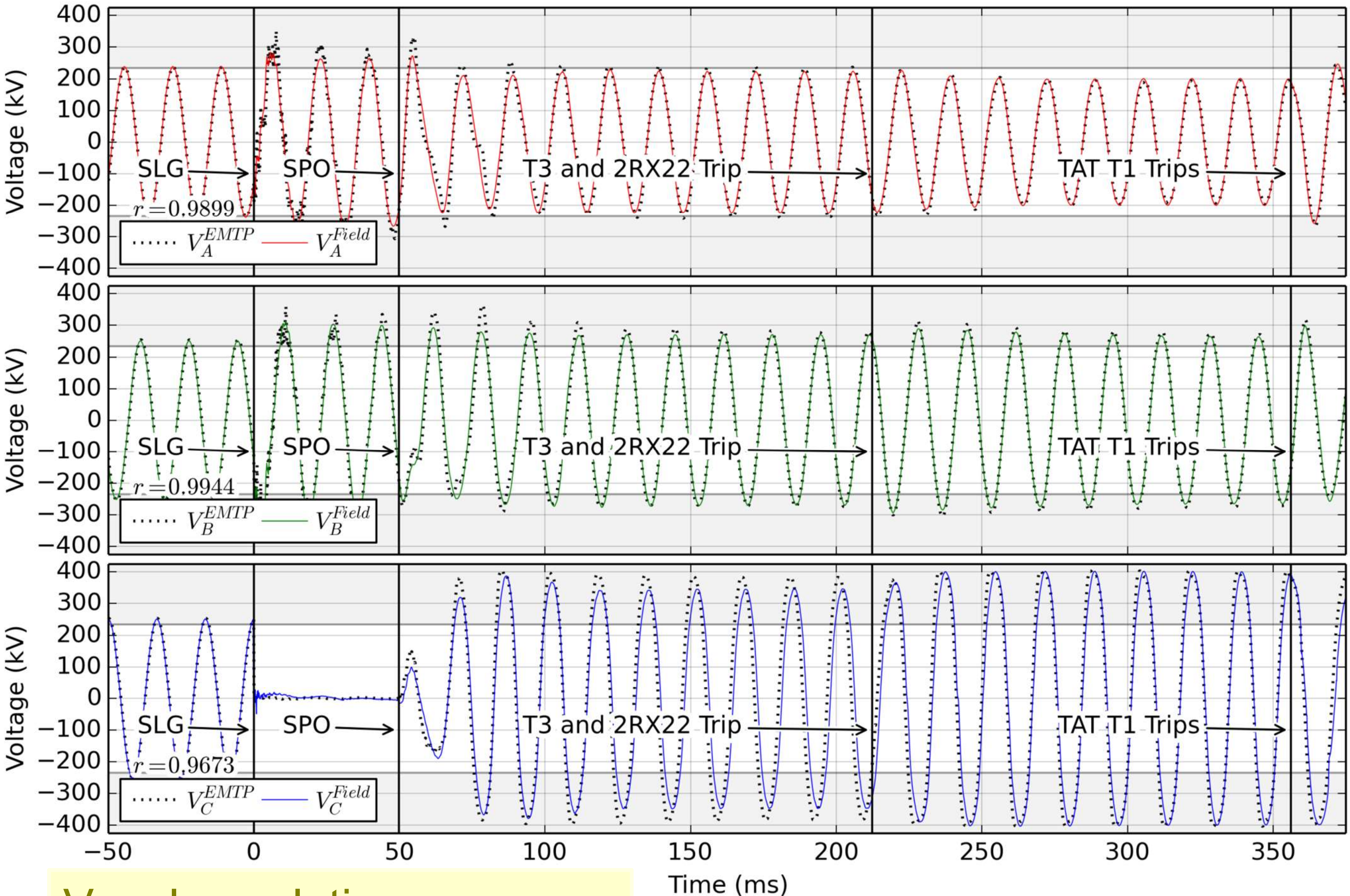
L_{PT0} = 4.42 H
(Primary to Tertiary)

Steady state analysis

55 Hz resonant freque

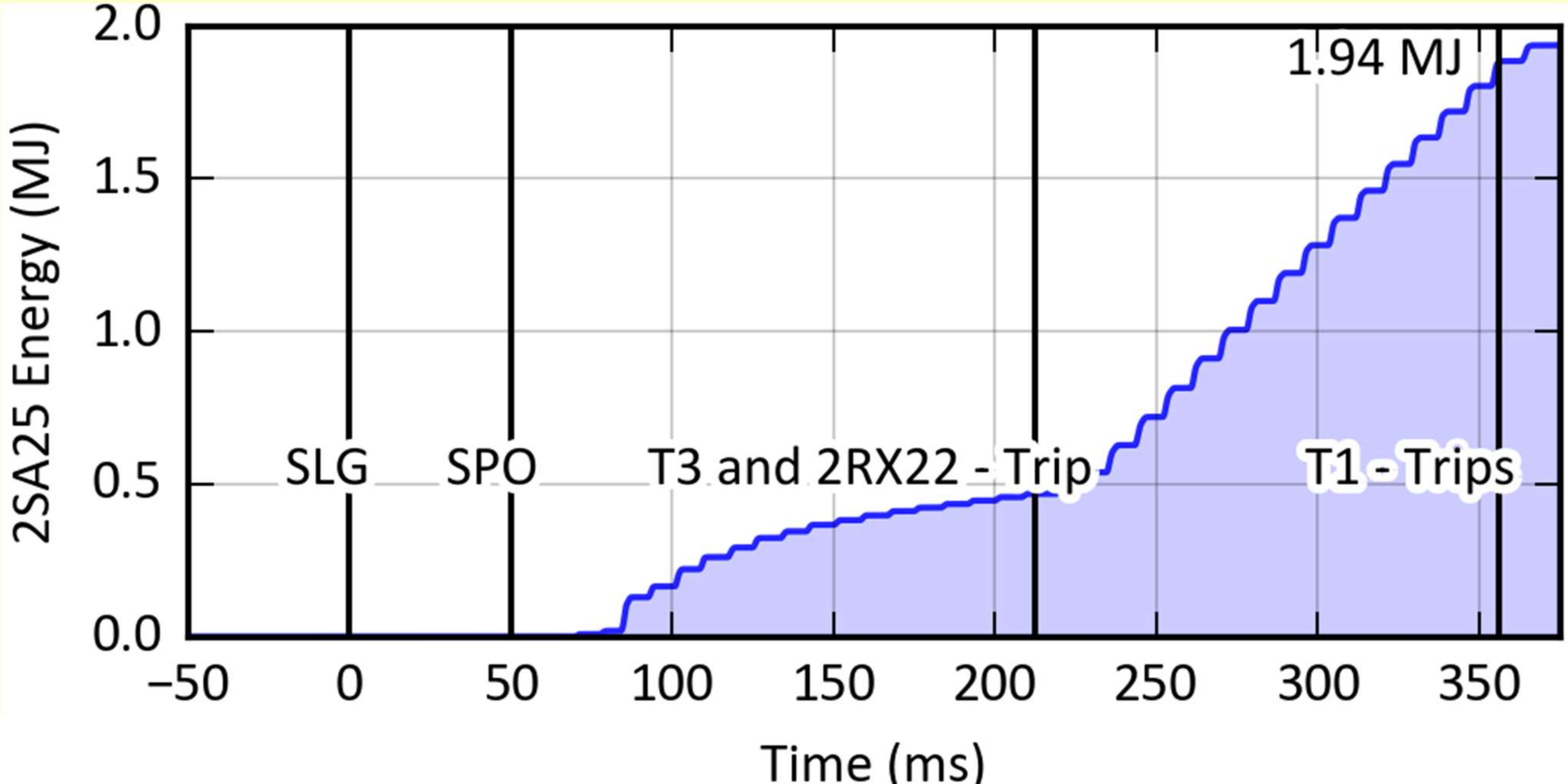
$$Eopen = \frac{Z1 -}{Z1 +}$$





Very low relative mean square error

Surge Energy Absoption

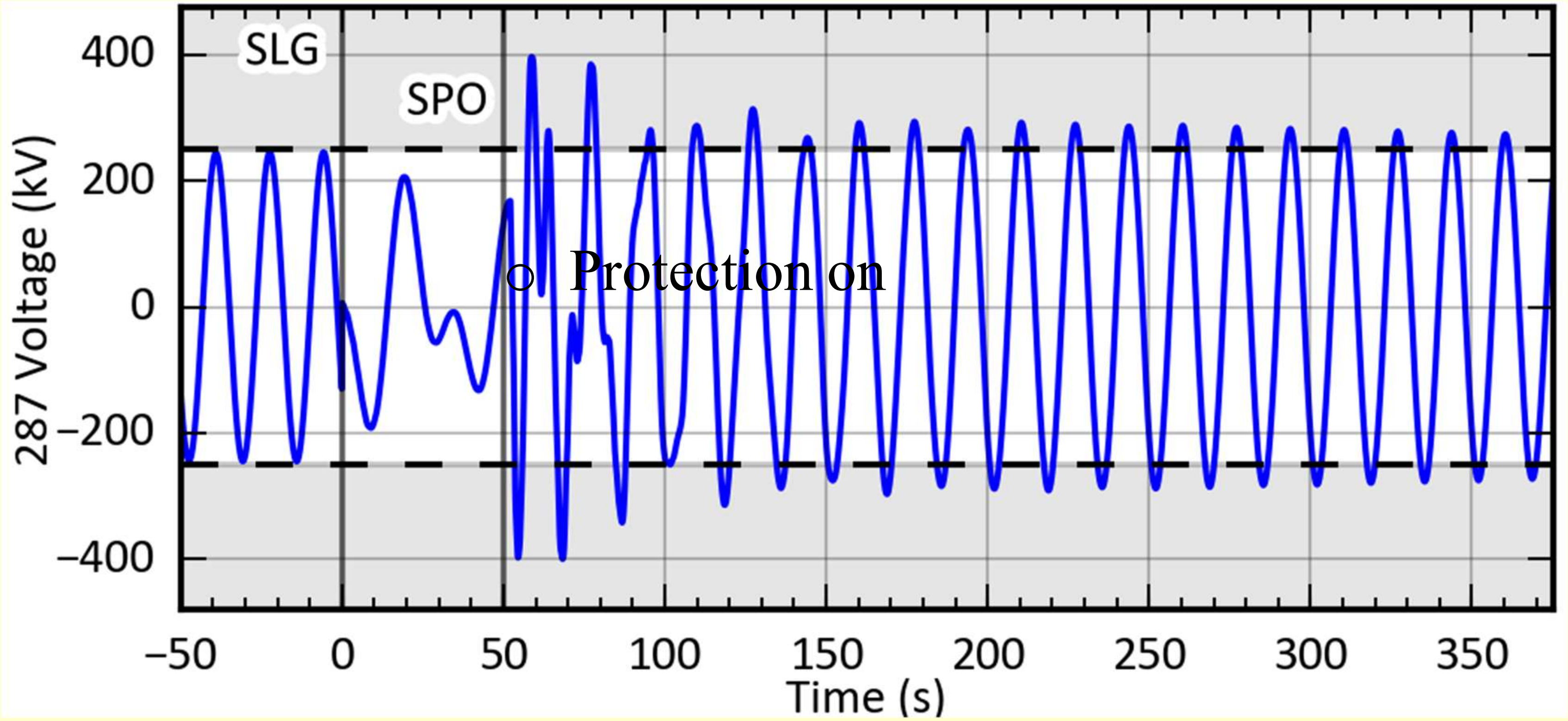


Mitigation

Let's not do this again

Long term solution

EMTP simulation of single-phase open voltage with 45 MW Generation



○ Protection on

Single-phase trip on 2L102 is automatically disabled during periods of low generation.

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Conclusions

Be careful applying radial single-pole tripping lines – back-energization of floating phase

The 5th harmonic blocking functions performs better than anticipated i.e. blocking is released during extreme (unsafe) overvoltages

Reinforces the benefits of performing disturbance analysis – uncover the unexpected