



3V0 – Zero Sequence Protection

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Utilities are seeing an increase in distribution connected generation.

- The loss of traditional spinning generation, and expected increase in electric vehicle charging, are contributors.
- Most of this generation uses inverters (solar, wind, etc.)
- Inverters are fault current limited, typically about 1.1 per unit of maximum generation output.
- Thus, inverters are not a reliable source of fault current.

Two types of inverter operation; Grid following mode vs grid forming mode

- In grid following mode, inverters shut down upon loss of incoming frequency signal from the utility.
- In grid forming mode the inverter can operate without a connection to the utility.

Most inverters to date in First Energy are operating in grid following mode.

Pressure from outside groups to allow grid forming mode, to ride through interruptions, we are seeing more and more of this.

Most step-down transformers from higher voltages are delta-wye.

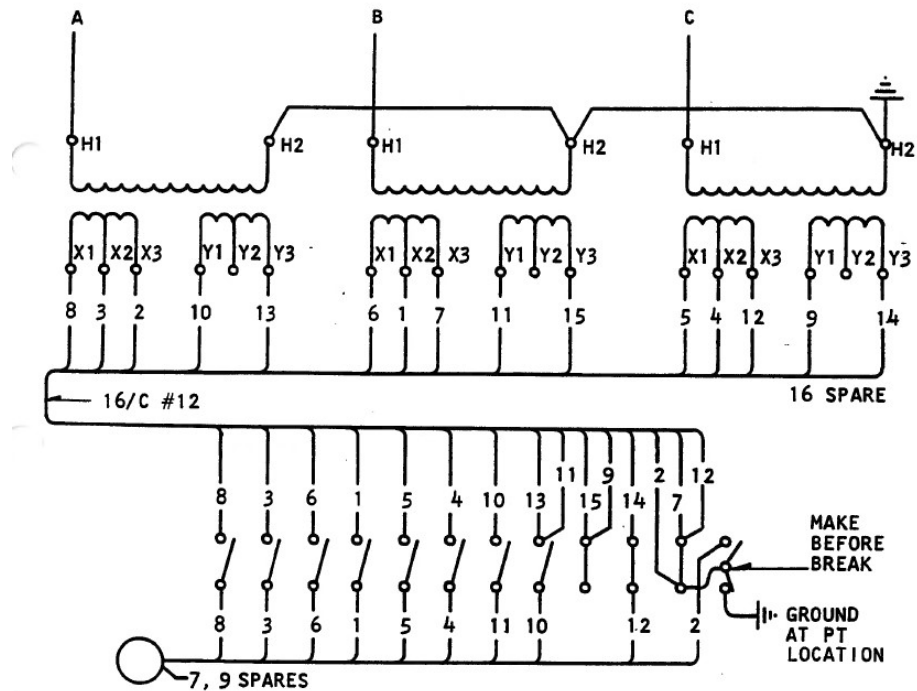
Challenges for Protection:

- Protecting the distribution line
- Detecting and clearing the low (wye) side of such transformers for a ground fault on the high (delta) side. Delta winding is not a ground source.

Zero sequence voltage ($3V_0$) to the rescue!

But what is zero sequence voltage?

- Traditionally derived from a broken delta secondary of three phase wye-ground connected potential devices. Below is an example of an old Allegheny Power standard PT connection. The 11 and 12 wires connected to the bottom of the switch are connected across a broken delta connected winding. 10-12 provides a test voltage.



When a three-phase primary voltage to which the PTs are connected becomes imbalanced, as is the case for a phase – ground fault, the result is a voltage across the terminals of a broken delta secondary.

This voltage can be monitored and used by a relay to trip a breaker.

Modern microprocessor relays derive $3V_0$ internally, mathematically.

Below are standard settings for an SEL-321 that are used in several regions of First Energy:

- EVOLT = Yes
- 59N = 120V
- LOGIC X = 59N
- TXPU = 30 cycles (pickup timer)
- TXDO = 9 cycles (trip duration timer)
- OUT(x) = XT (OUT(x) trips breaker to isolate ground fault).

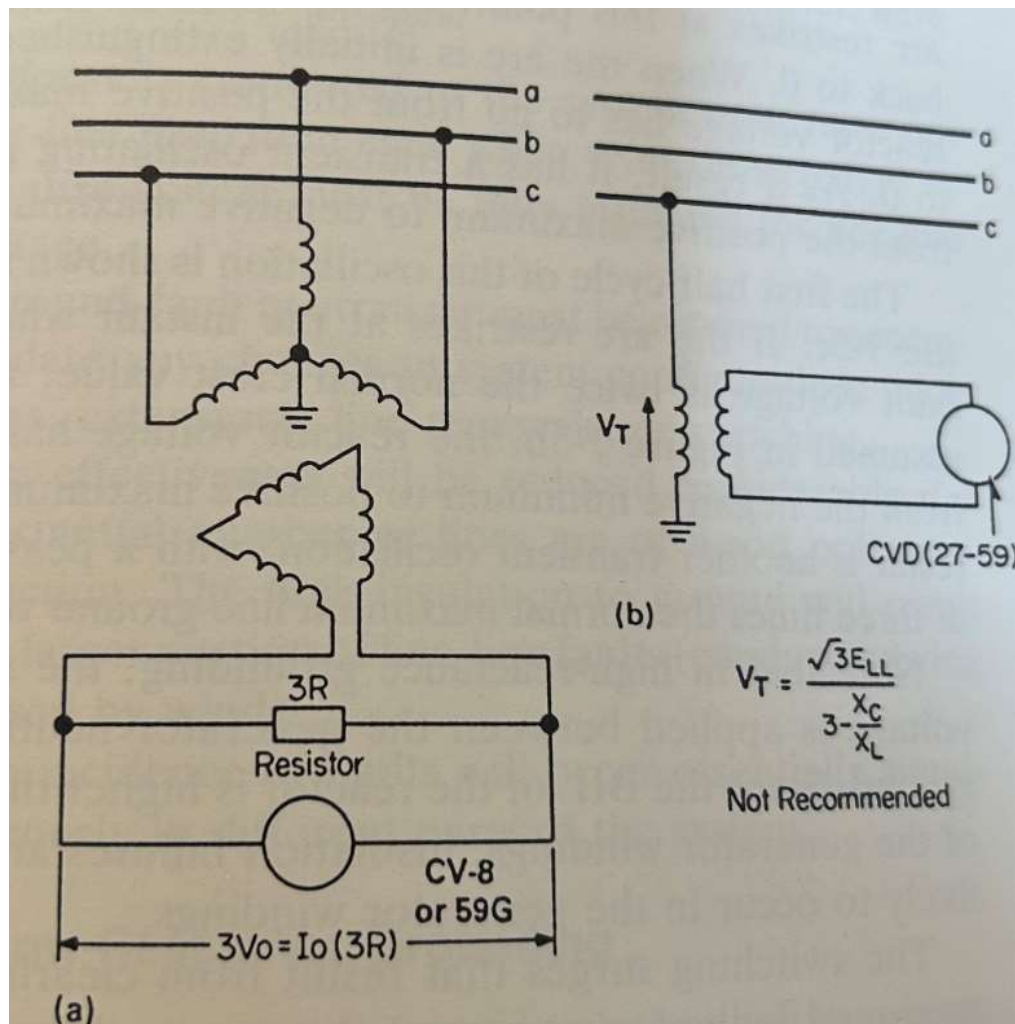
These settings can be applied to other relays which use the same elements.

A common application on a delta - wye transformer is to connect the relay to a three-phase high side PT and trip the low side breaker. This clears the transformer if it is back feeding the fault from distribution connected generation.

A “poor man’s” method to mimic 3V0 protection is to use a single-phase PT with overvoltage and undervoltage relays/elements connected to the secondary. A phase – ground fault on the phase to which the PT is connected will result in an undervoltage, a phase – ground fault on either of the other phases will result in an overvoltage. This method is rather crude and not recommended.

(Picture source: ABB Protective Relaying and Applications)

Voltage transformer ratio	Resistor (Ω)
2400–120	250
4200–120	125
7200–120	90
14,400–120	60



Other uses for 3V0 include:

- PT (and more aptly, CVT) health monitoring. If the capacitor stack of a CVT is deteriorating, 3V0 can detect this.
- Directional polarization for ground protection electromechanical relays.

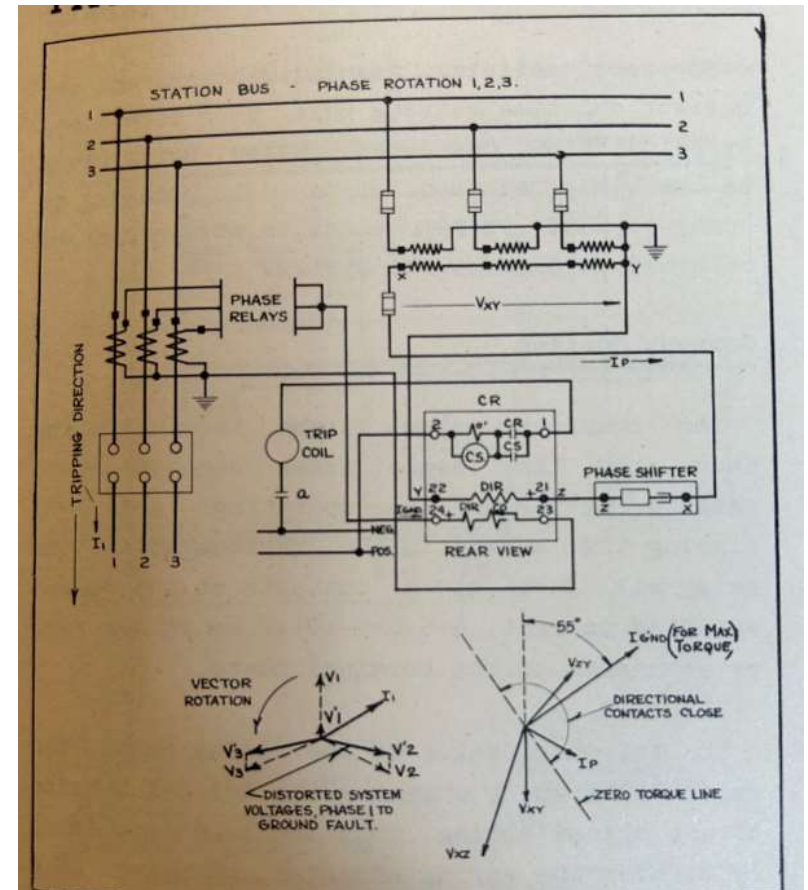


Fig. 18—External Connections Of The Type CR Ground Relay In The Standard Case For Ground Fault Protection Using An External Phase Shifter.

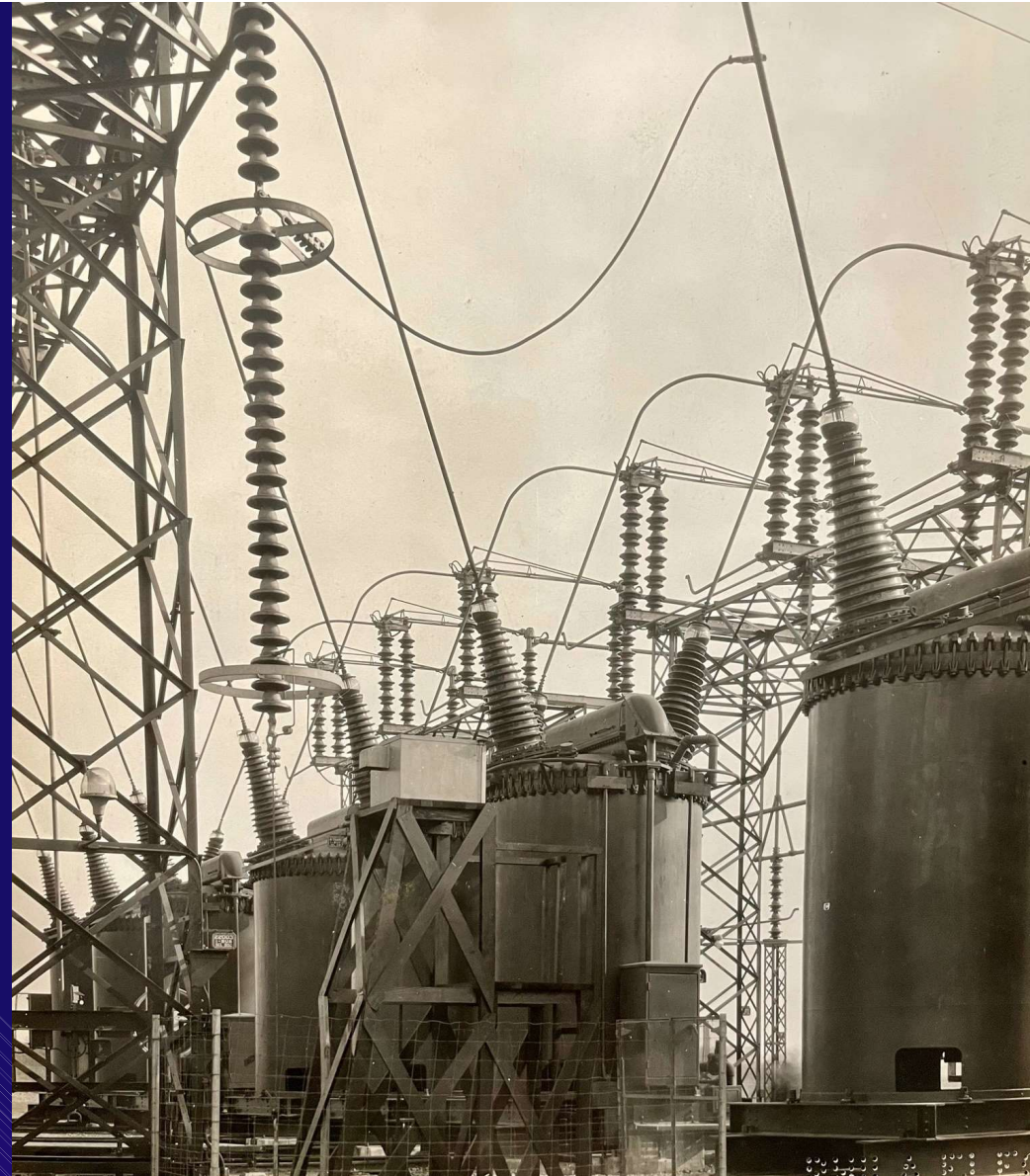
(Picture source: WHSE IL 41-285K dated January 1950)

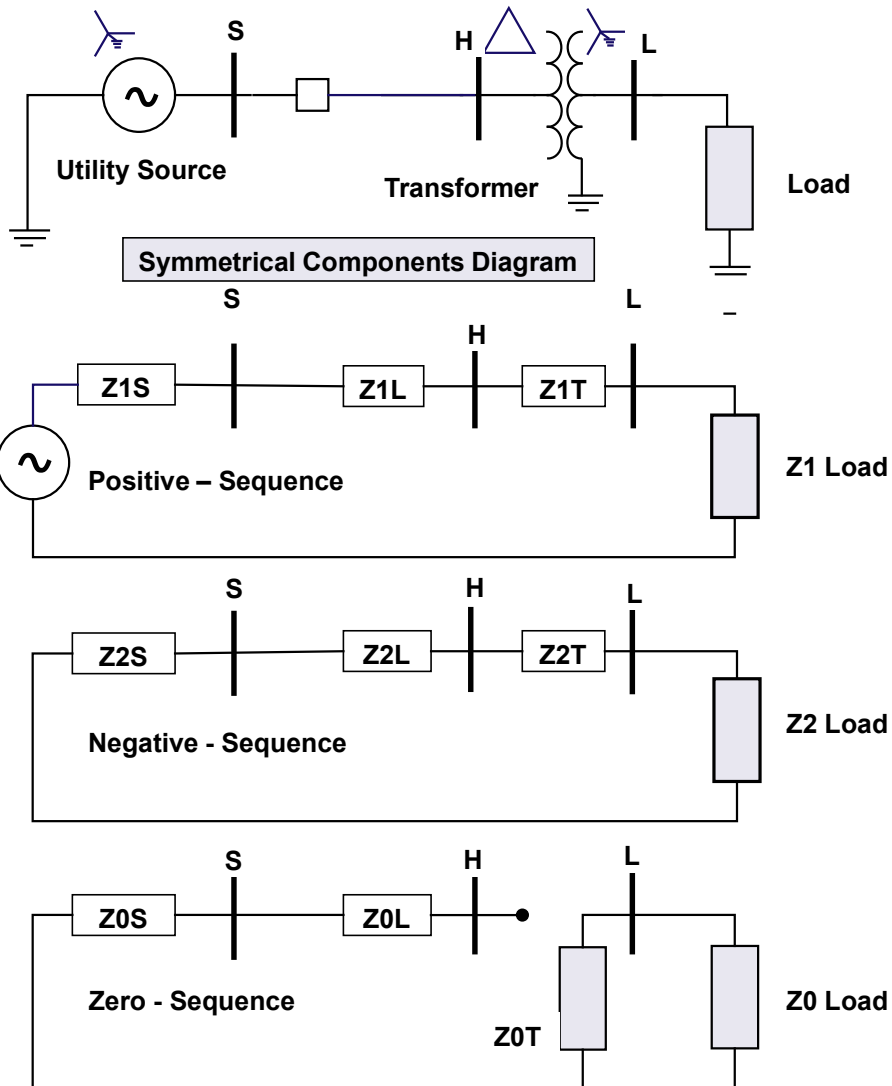


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Symmetrical Components:

$$I_A = I_1 + I_2 + I_0$$

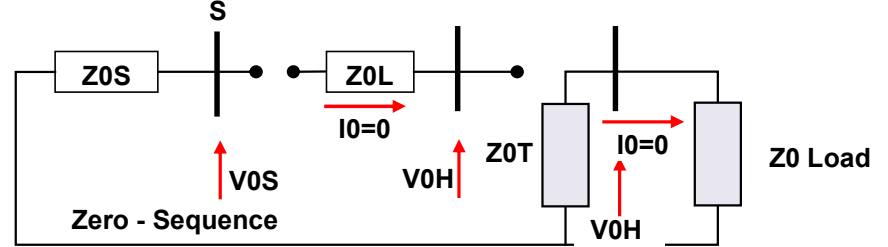
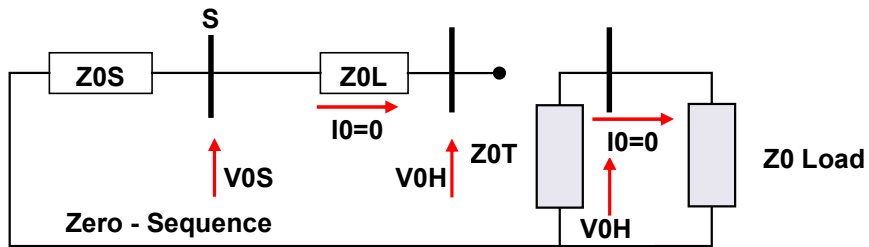
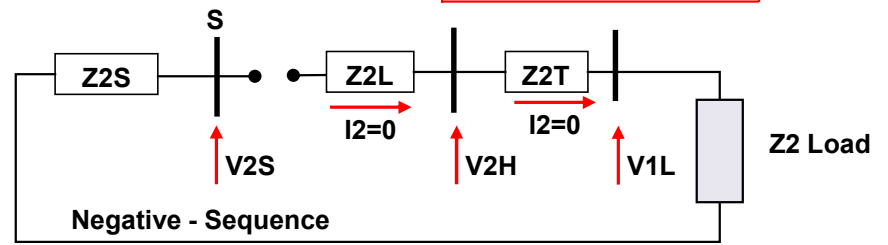
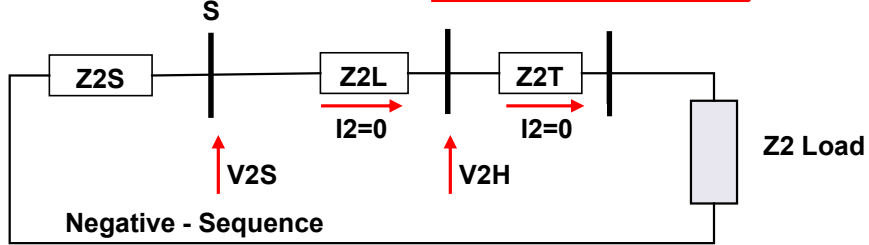
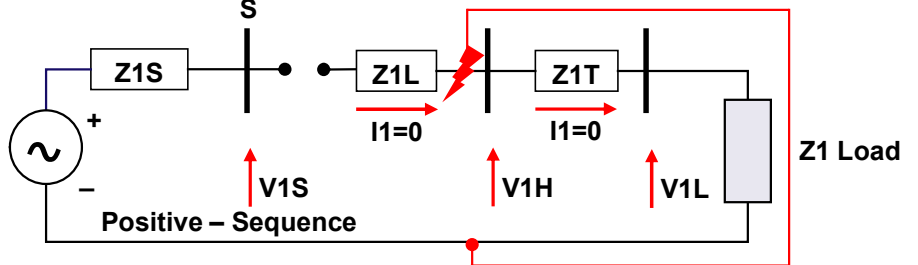
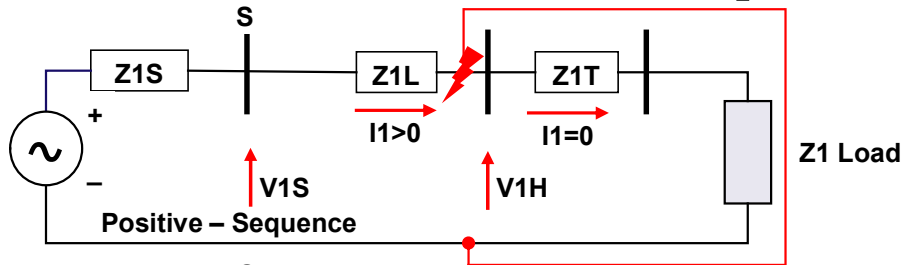
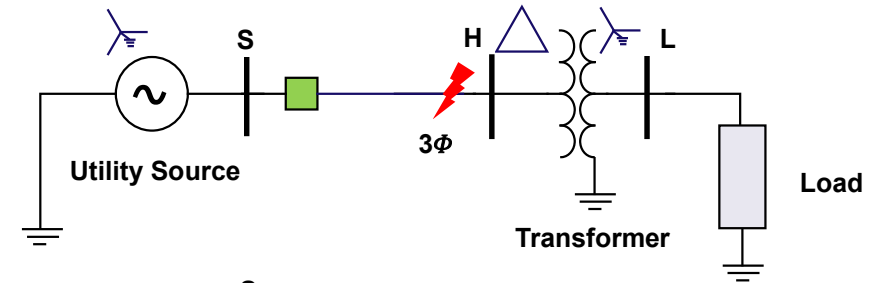
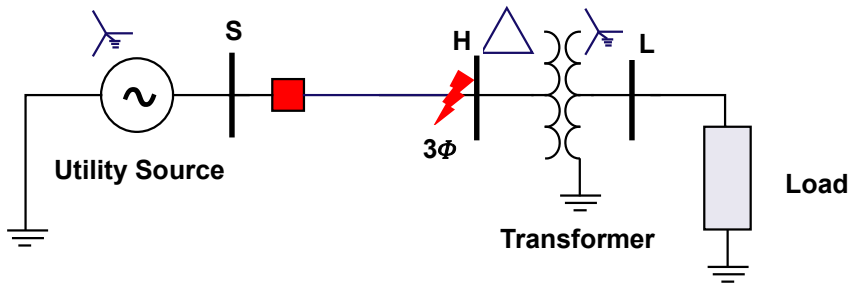
$$I_B = a^2 I_1 + a I_2 + I_0$$

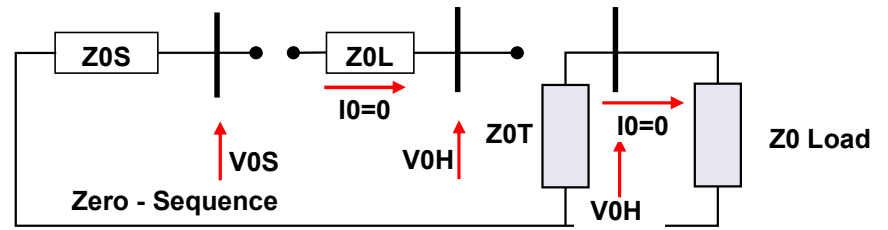
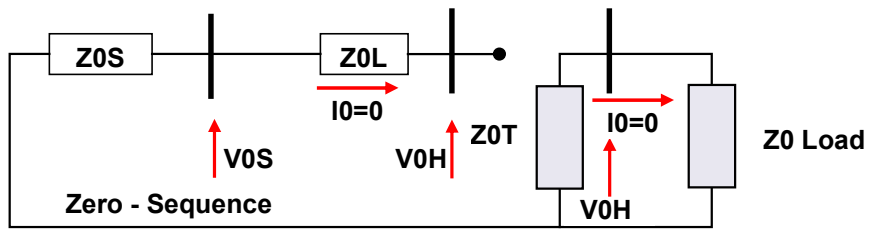
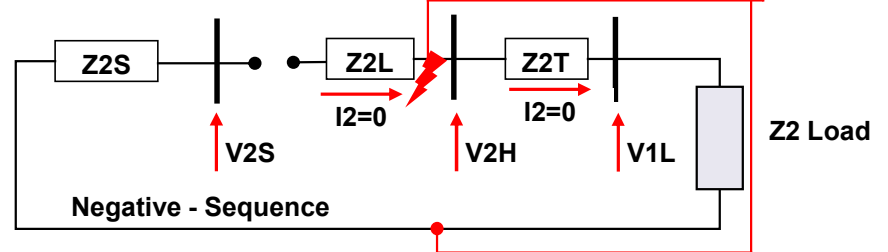
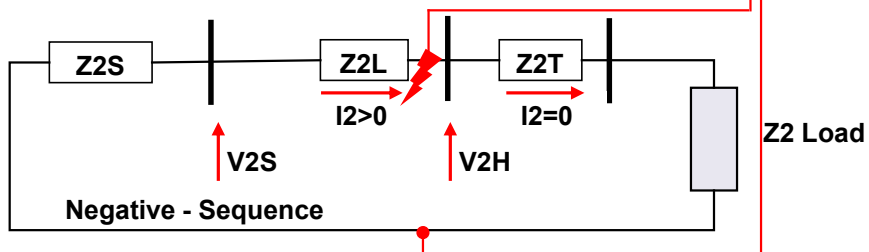
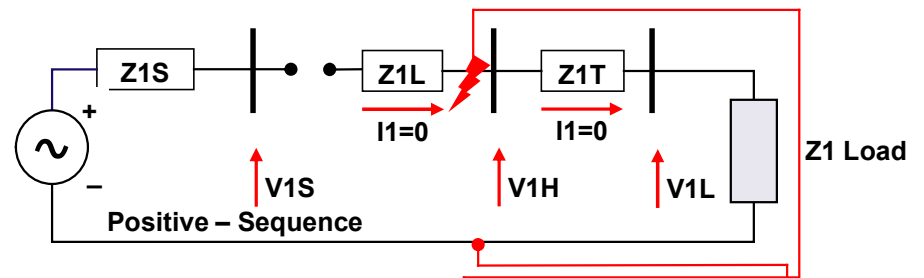
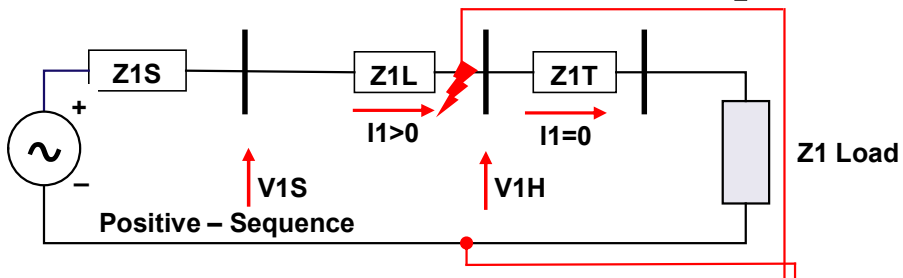
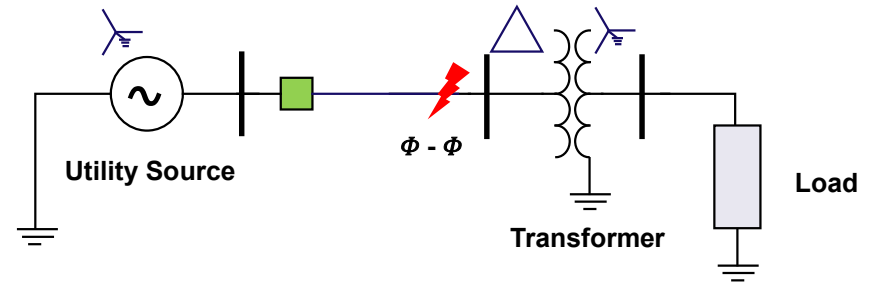
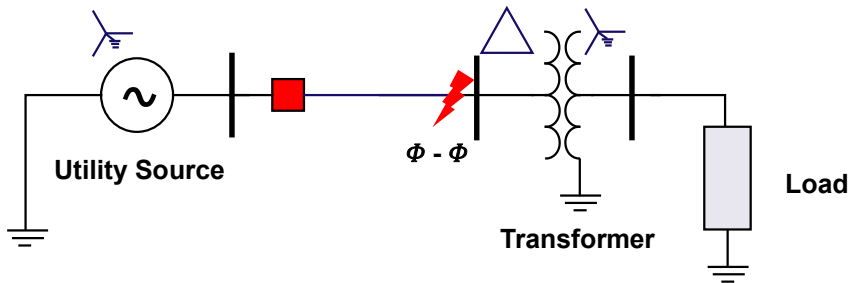
$$I_C = a I_1 + a^2 I_2 + I_0$$

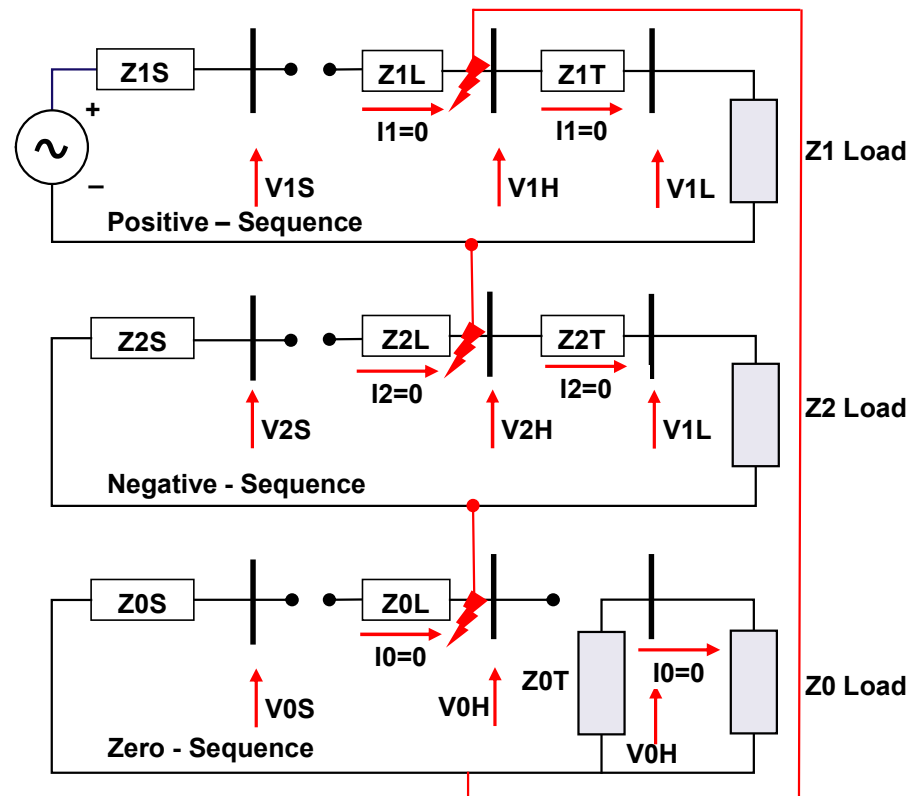
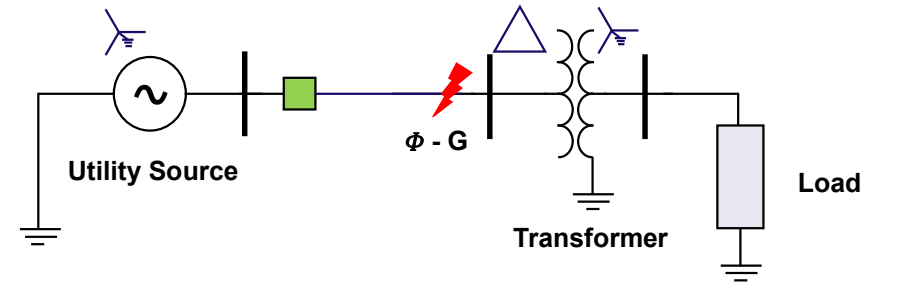
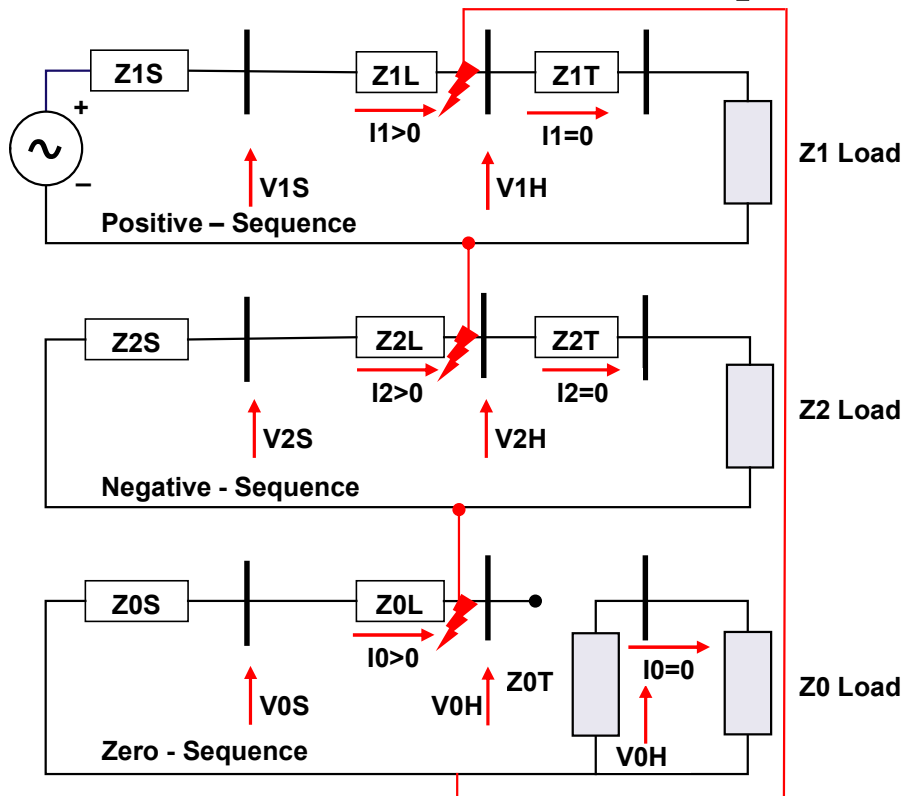
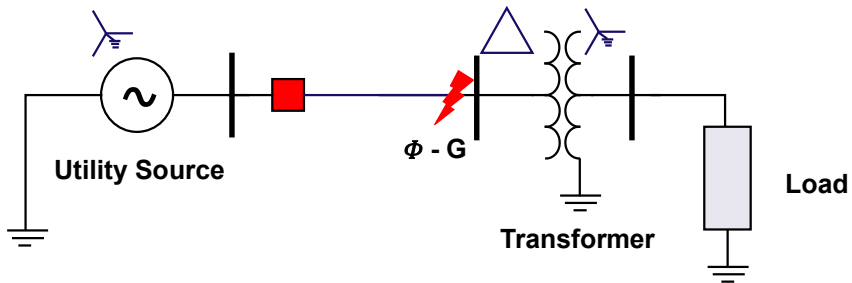
$$V_A = V_1 + V_2 + V_0$$

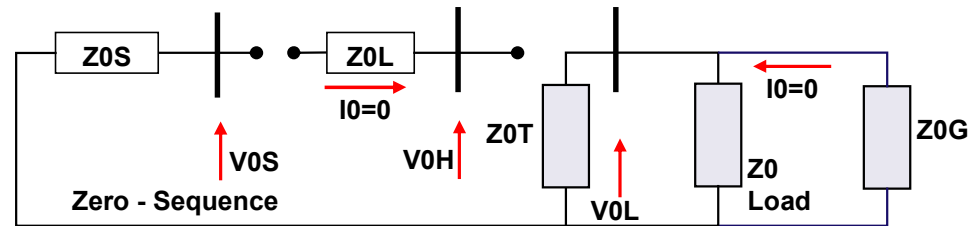
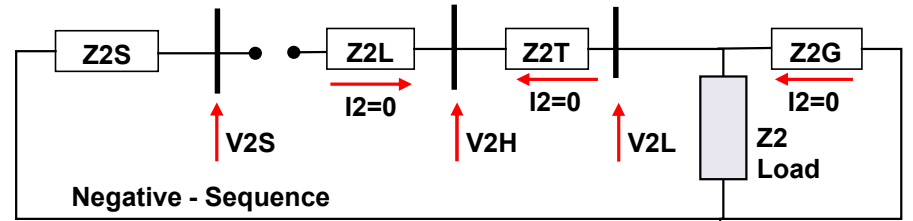
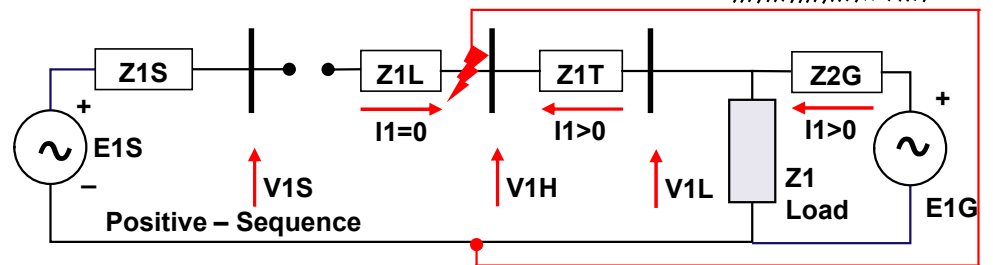
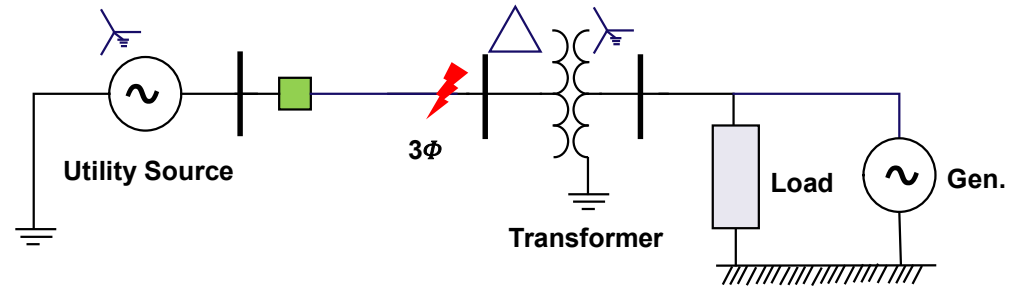
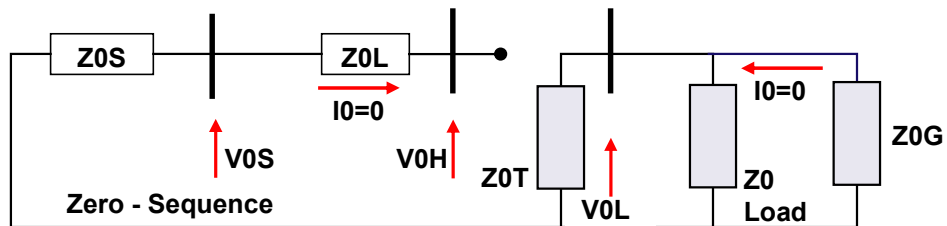
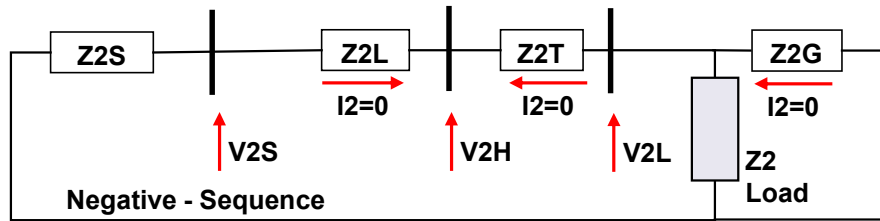
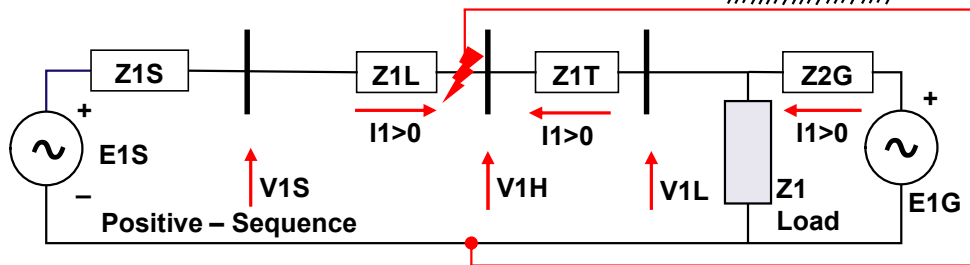
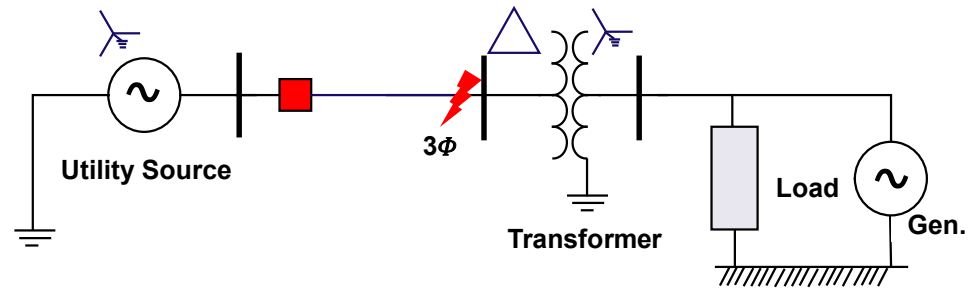
$$V_B = a^2 V_1 + a V_2 + V_0$$

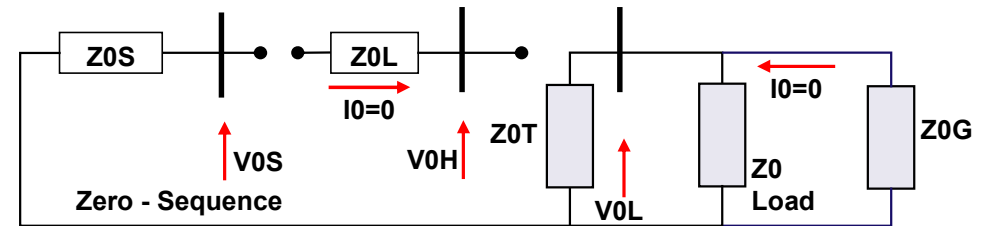
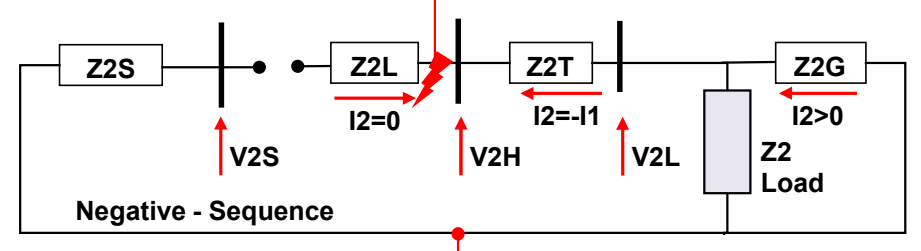
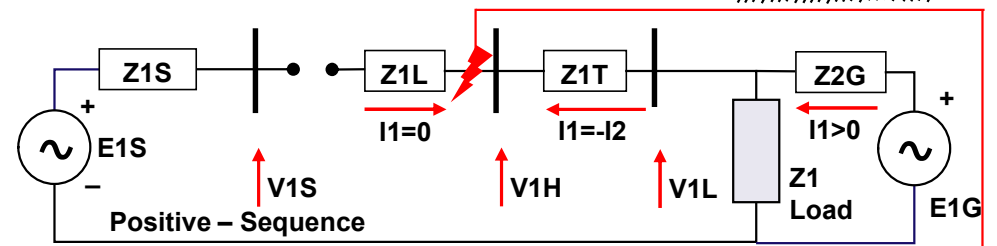
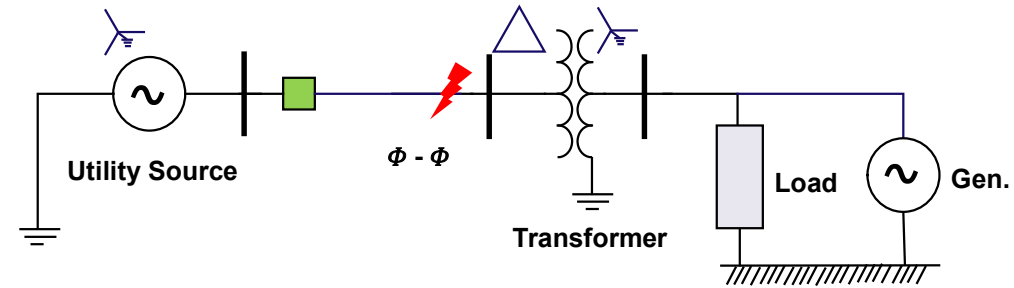
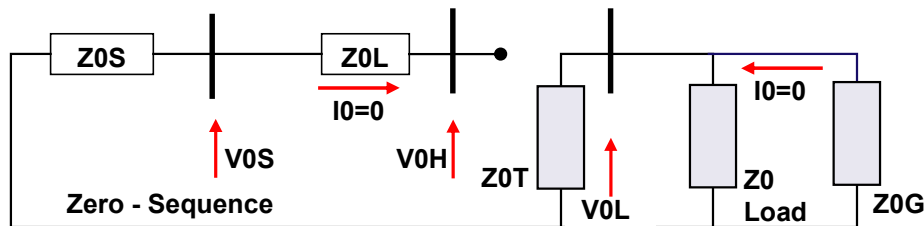
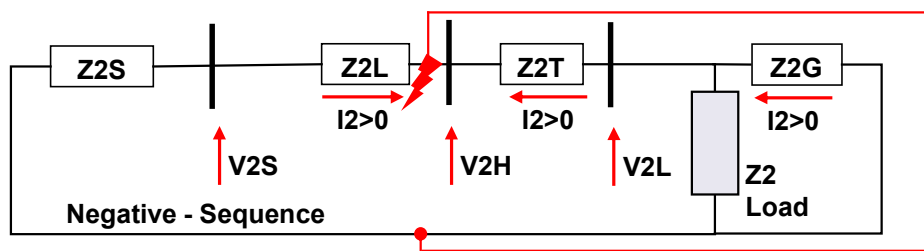
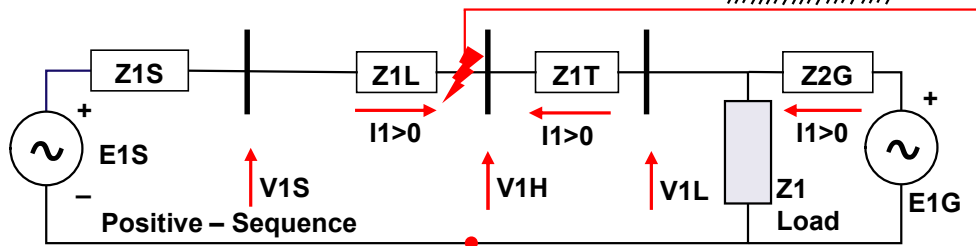
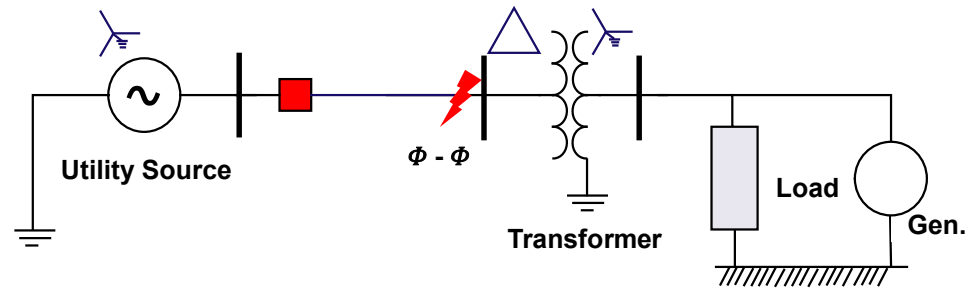
$$V_C = a V_1 + a^2 V_2 + V_0$$

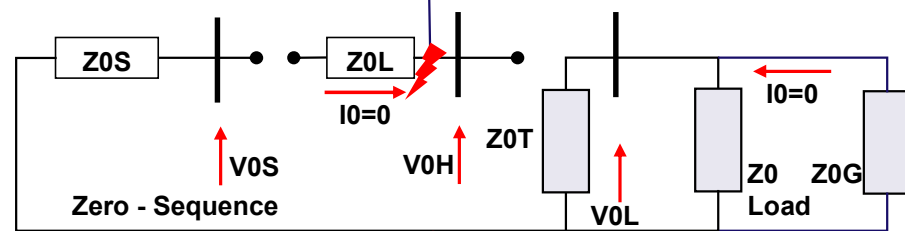
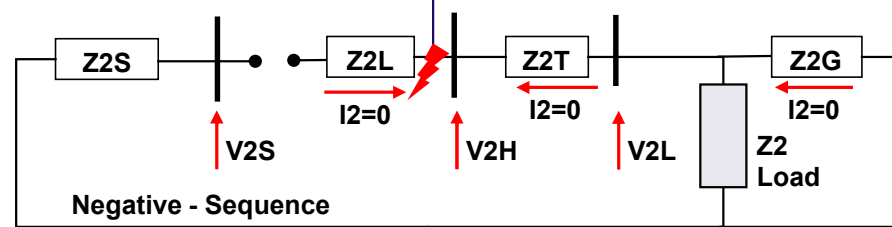
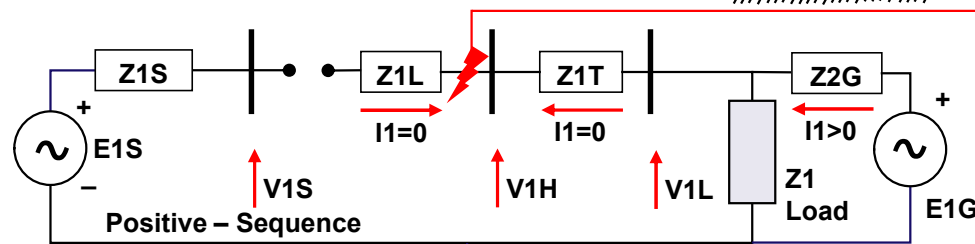
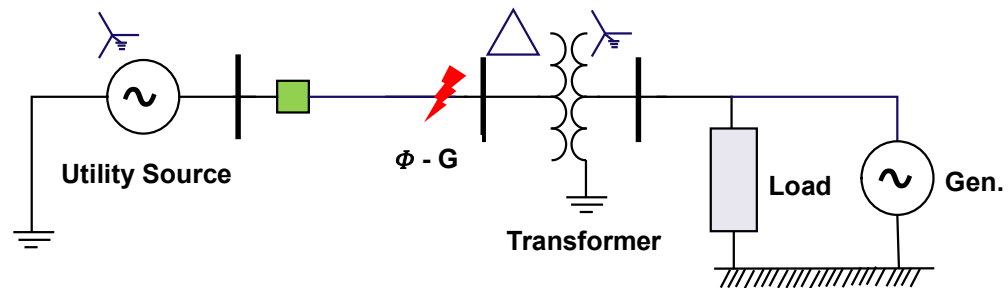
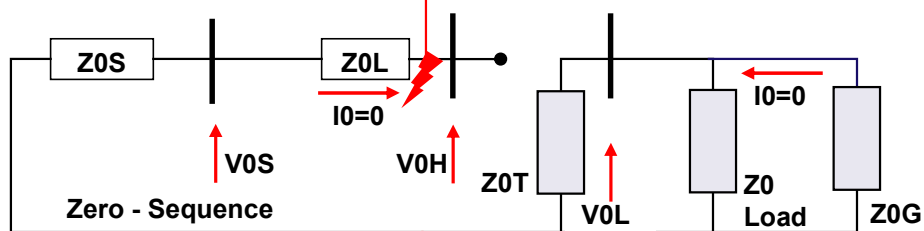
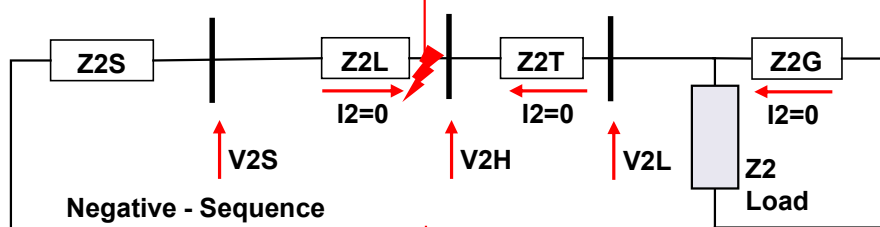
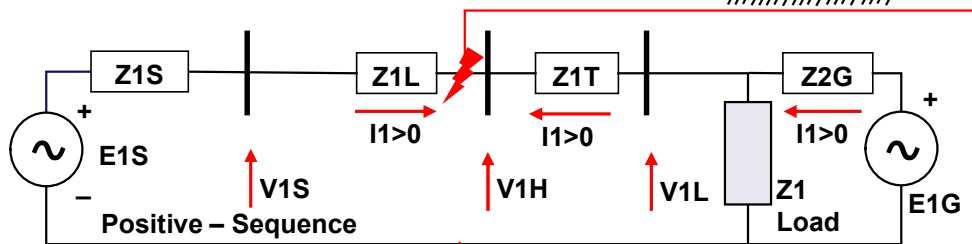
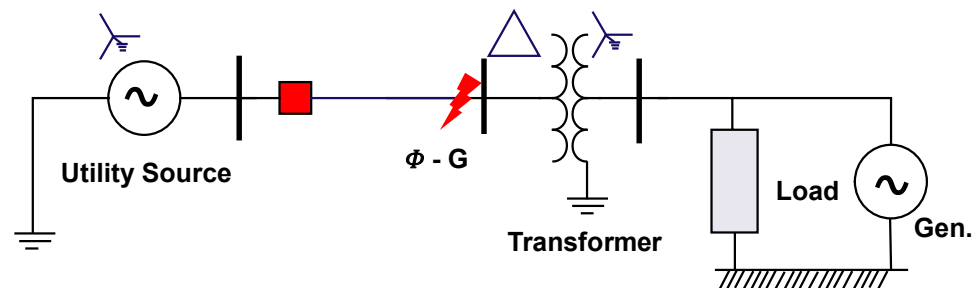






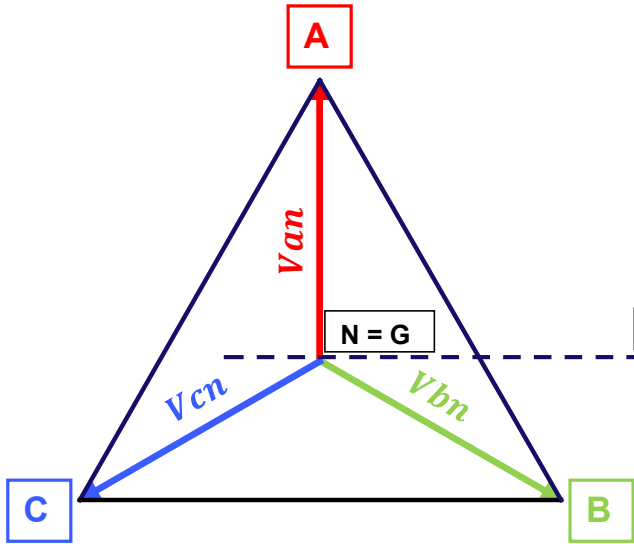




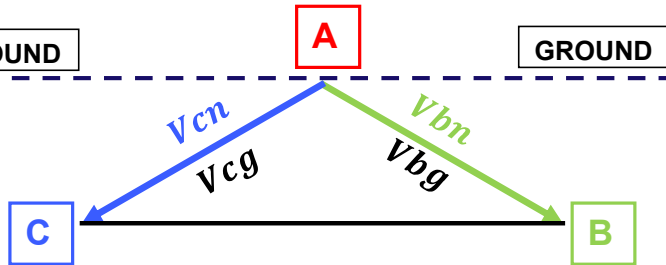


Voltage Shifts – A-Phase Fault on Ungrounded System

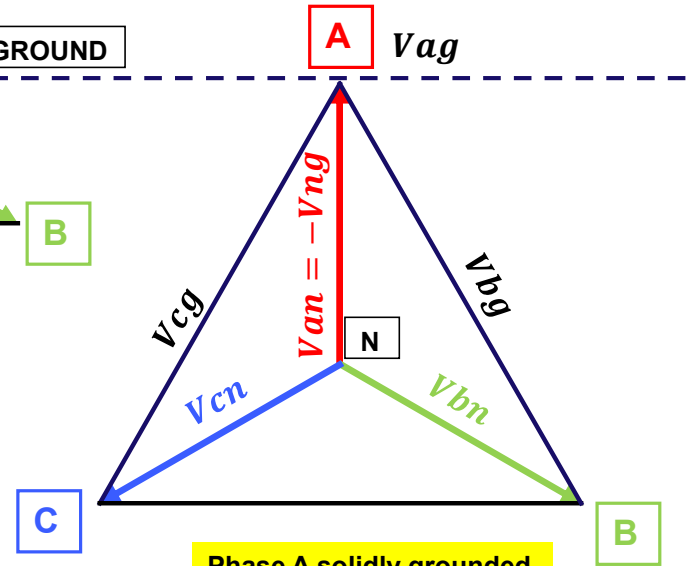
$$\begin{aligned}
 V_{bg} - V_{bn} - V_{ng} &= 0 \\
 V_{cg} - V_{cn} - V_{ng} &= 0 \\
 V_{ng} + V_{an} &= 0 \\
 V_{ag} + V_{bg} + V_{cg} &= 3V_o \\
 V_{an} + V_{bn} + V_{cn} &= 0 \\
 V_{ag} - V_{an} + V_{bg} - V_{bn} + V_{cg} - V_{cn} &= 3V_o \\
 V_{ng} + V_{ng} + V_{ng} &= 3V_o \\
 V_{ng} &= V_o
 \end{aligned}$$



Normal Balanced System

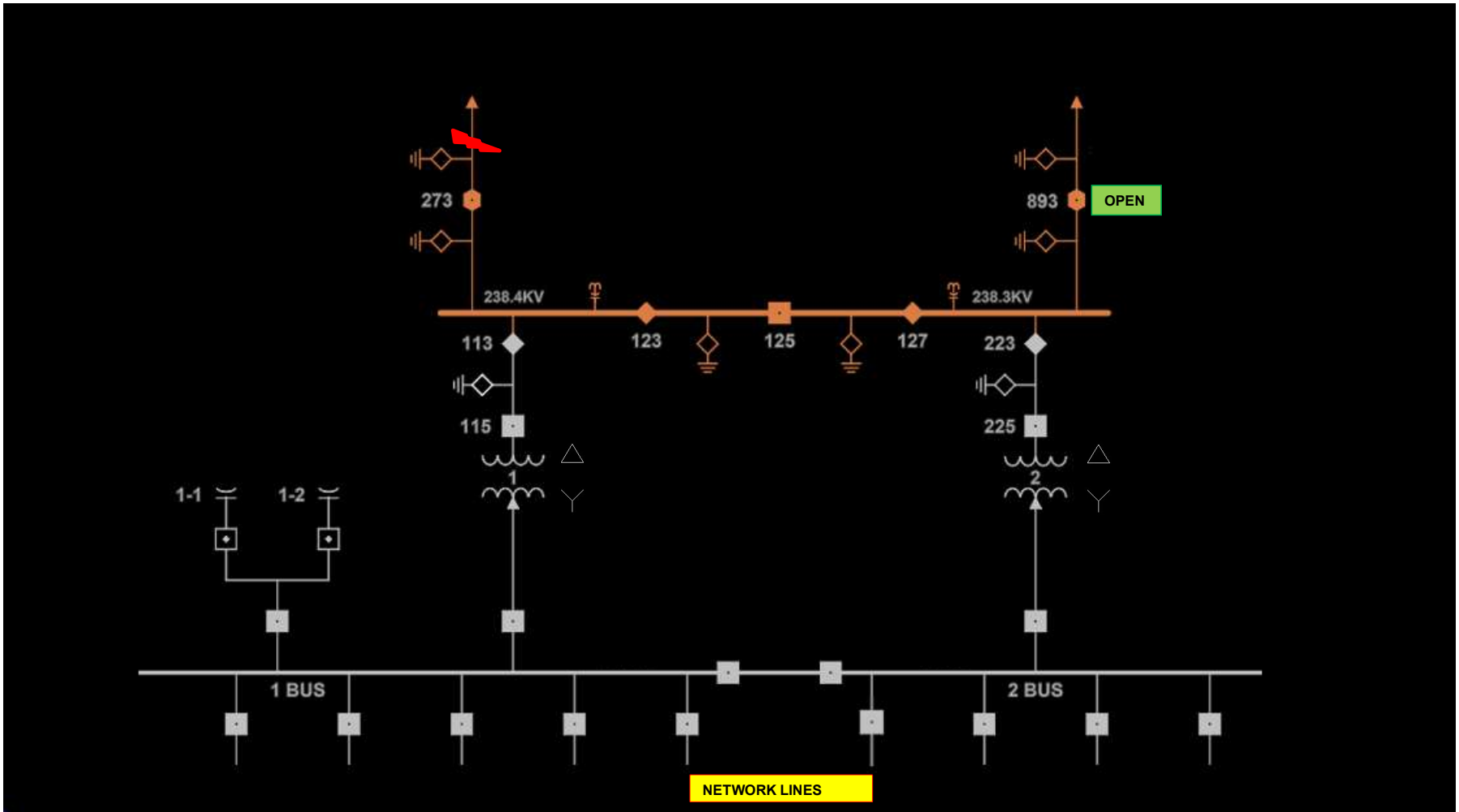


Phase A solidly grounded Paralleled Operation

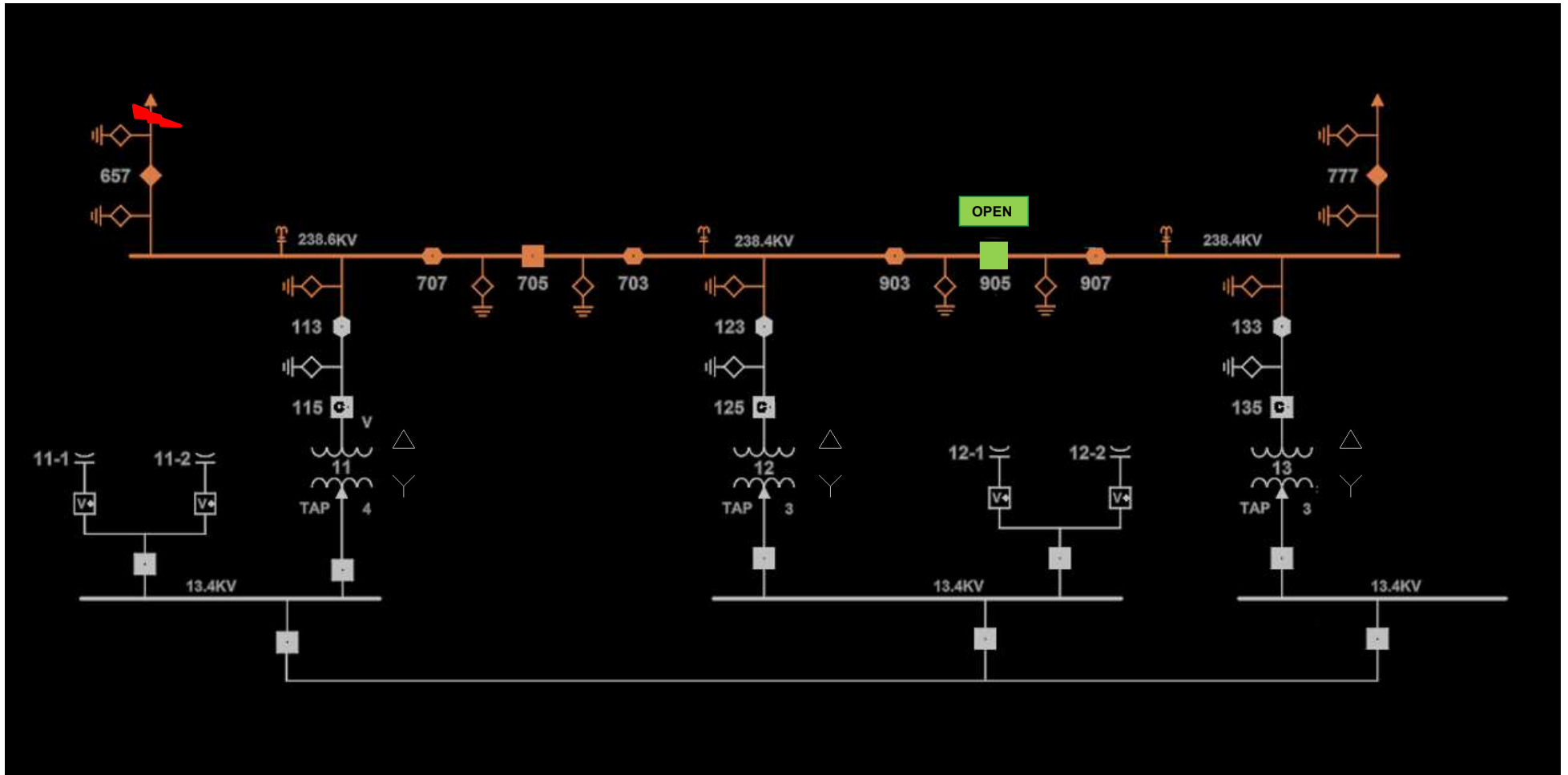


Phase A solidly grounded Islanded Operation

Two Transformers – Case 1



Three Transformers – Case 2



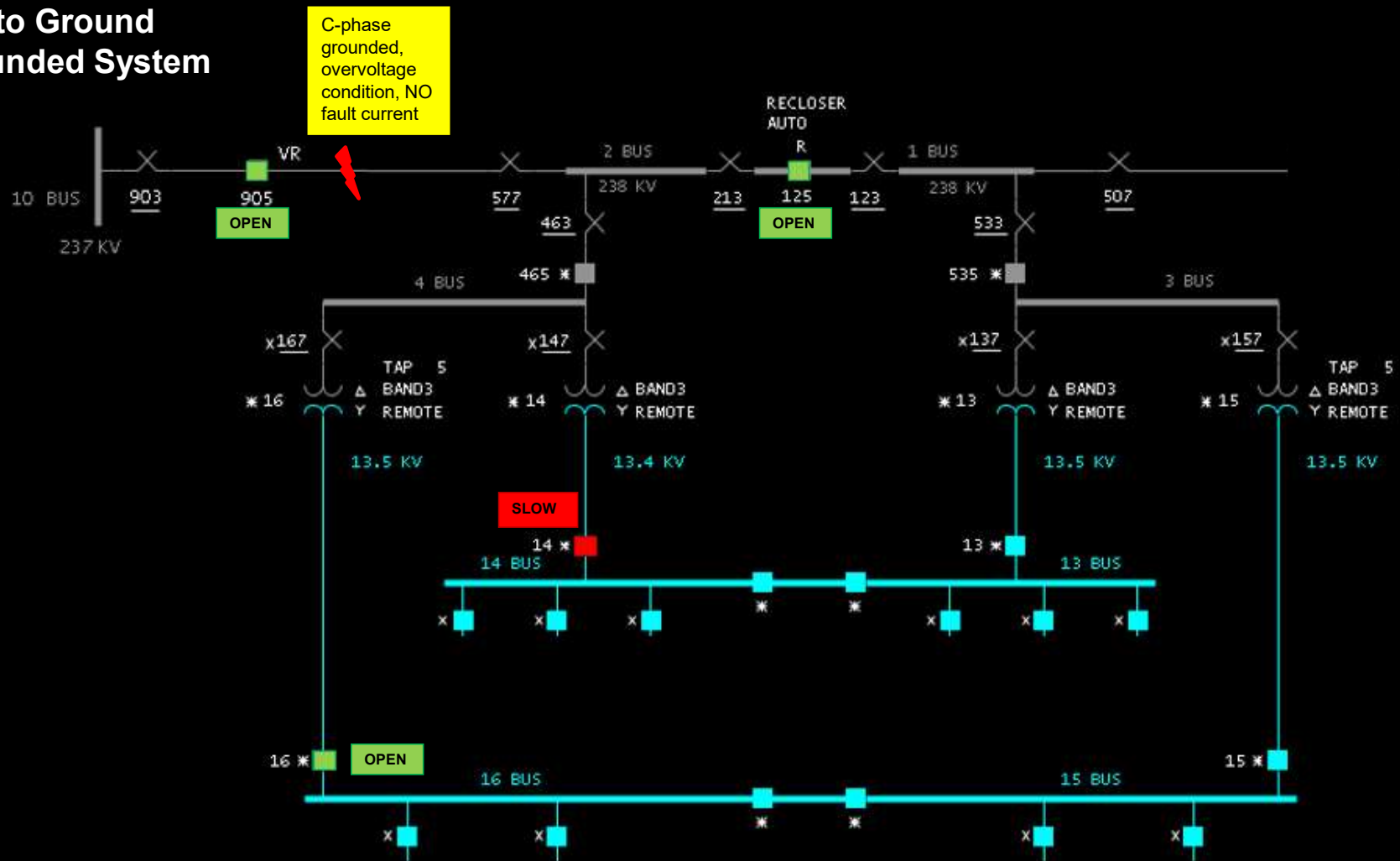
CCVT – Monitoring



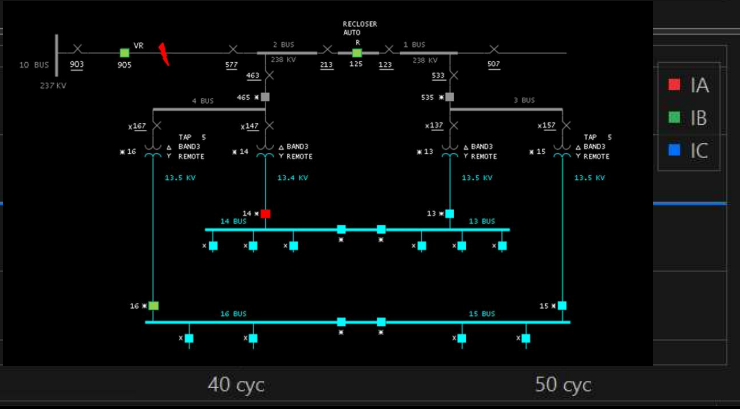
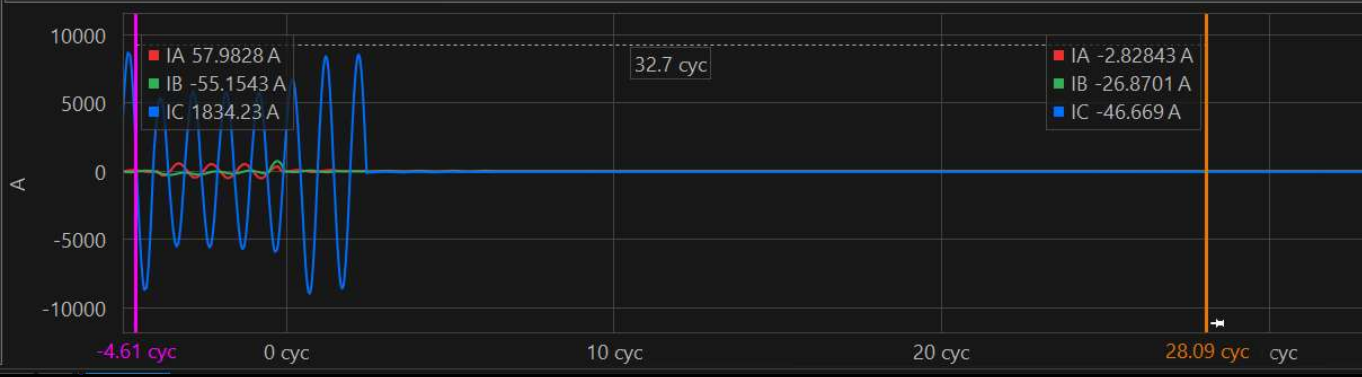
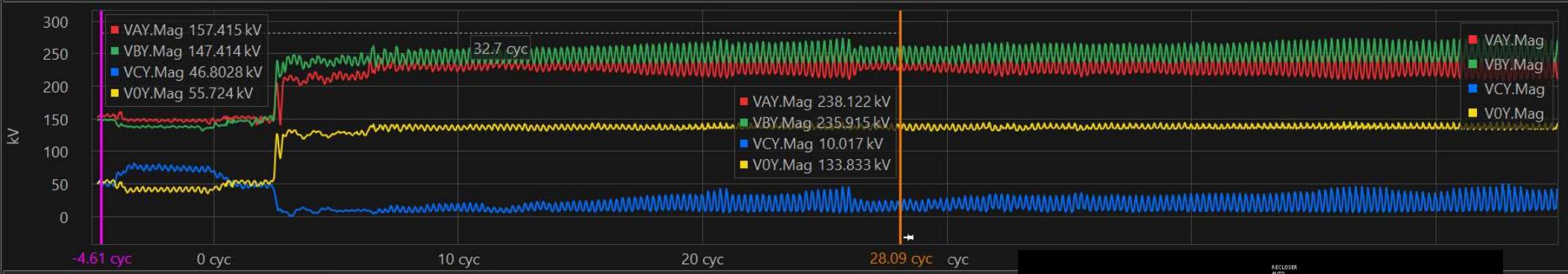
CCVT – Monitoring



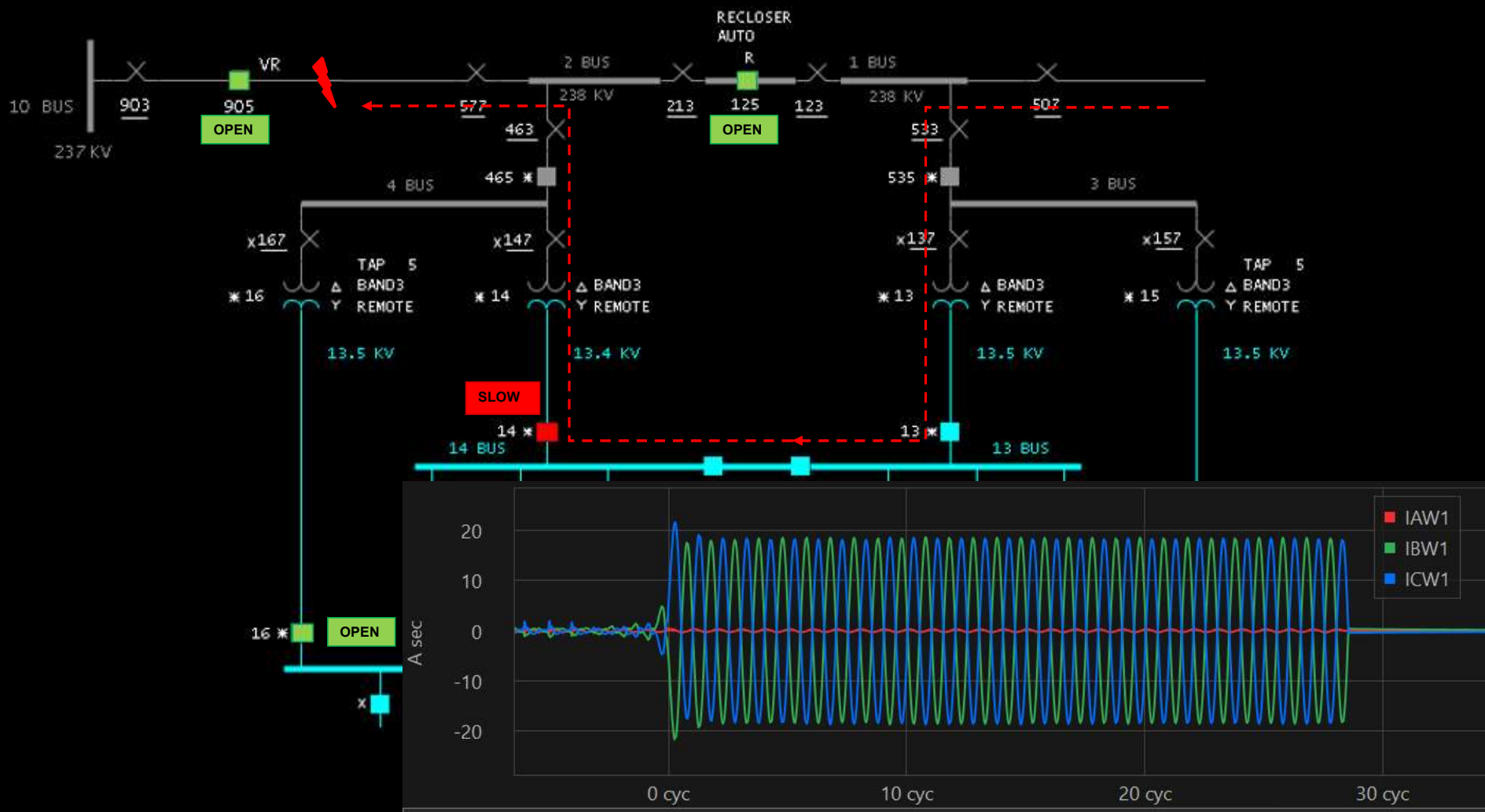
Phase to Ground Ungrounded System



Phase to Ground Ungrounded System



Phase to Ground Ungrounded System



Phase to Ground Ungrounded System



References:

1. *“Protection for Unexpected Delta Sources”*, Ken Behrendt – SEL, Protective Conference, Atlanta Georgia, 2003
2. *“Protective Relaying Principles and Applications” Third Edition*, J. Lewis Blackburn, Thomas J Domin