Symmetrical Components

David Castor, P.E.

EasyPower®
Power made easy.

SYMMETRICAL COMPONENTS AND EASYPOWER - AN INTRODUCTION

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Why We Use them?

- Using standard single-line diagrams, complex impedances, and phasors, we can analyze steady-state conditions for all sorts of ac systems and configurations – **as long as the three phase voltages and currents are equal in magnitude.**
- For *imbalanced* conditions (ground faults) things get extremely complicated to analyze due to the coupling between the three phases.

Symmetrical Components

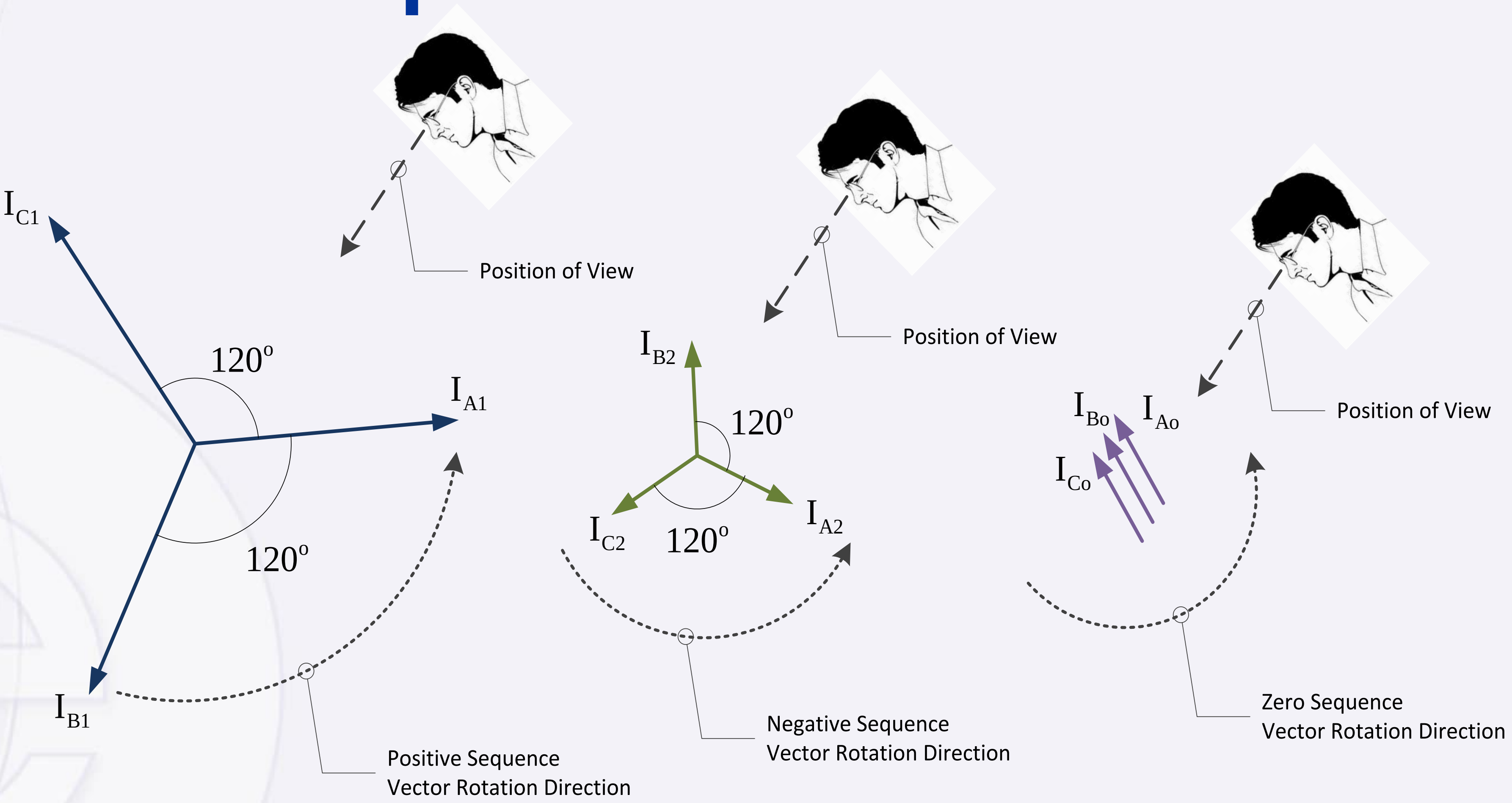
- C. L. (Charles Legeyt) Fortescue (1918): Any set of N unbalanced phasors can be represented by N sets of balanced phasors.
  - Balanced system can be simulated with single phase. Easier to analyze and compute.
  - Three phase unbalanced vectors → three balanced “sequence vectors.”

We still use this mathematical technique to this day!

Three Sets of "Sequence" Vectors (Phasors)

- Each set of sequence vectors is balanced – that is what makes this approach easier to solve
- Positive Sequence (e.g. V_{A1}) – this is the normal power system phase sequence quantities
- Negative Sequence (e.g. V_{A2}) – Balanced phasors with negative phase sequence
- Zero Sequence (e.g. V_{A0}) – Three identical phasors – same phase angle.

Sequence Vectors



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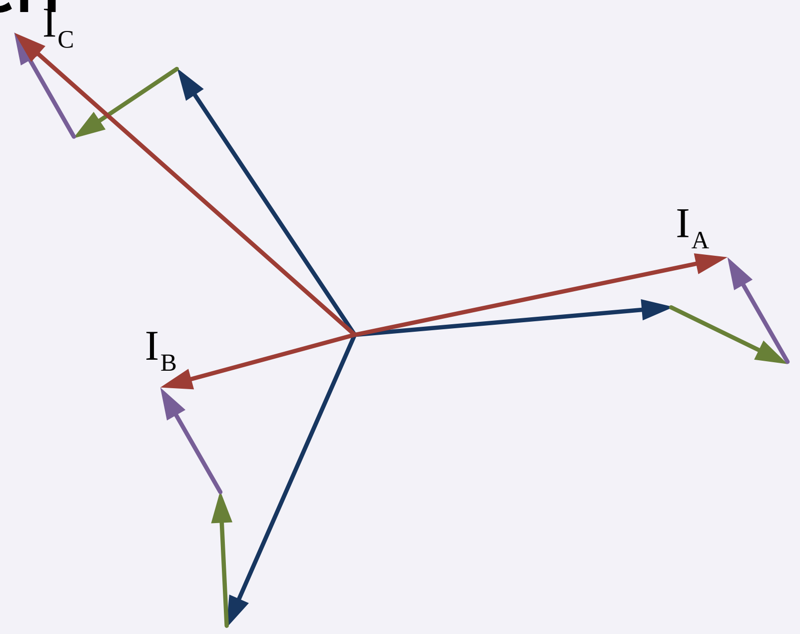
Symmetrical Components

Written in terms of sequence vectors (which are all symmetrical):

$$I_A = I_{A0} + I_{A1} + I_{A2}$$

$$I_B = I_{B0} + I_{B1} + I_{B2}$$

$$I_C = I_{C0} + I_{C1} + I_{C2}$$



Symmetrical Components Math

Since sequence vectors are symmetrical and balanced, they have clearly defined relationships:

$$I_{B1} = a^2 \cdot I_{A1}, I_{C1} = a \cdot I_{A1}$$

$$I_{B2} = a^2 \cdot I_{A2}, I_{C2} = a \cdot I_{A2}$$

$$I_{A0} = I_{B0} = I_{C0}$$

Where:

$$\boldsymbol{a = 1\angle 120°}$$

Symmetrical Components Math

$$I_A = I_{A0} + I_{A1} + I_{A2}$$

$$I_B = I_{A0} + a^2 \cdot I_{A1} + a \cdot I_{A2}$$

$$I_C = I_{A0} + a \cdot I_{A1} + a^2 \cdot I_{A2}$$

Sequence Impedances

Transmission lines:

- Pos. & Neg. sequence impedances are equal.
- Zero sequence impedance includes ground wires, shield wires, earth.

Cables, Busway, etc:

- Pos. & Neg. sequence impedances are equal.
- Zero sequence similar to transmission line, but can be higher.

Sequence Impedances

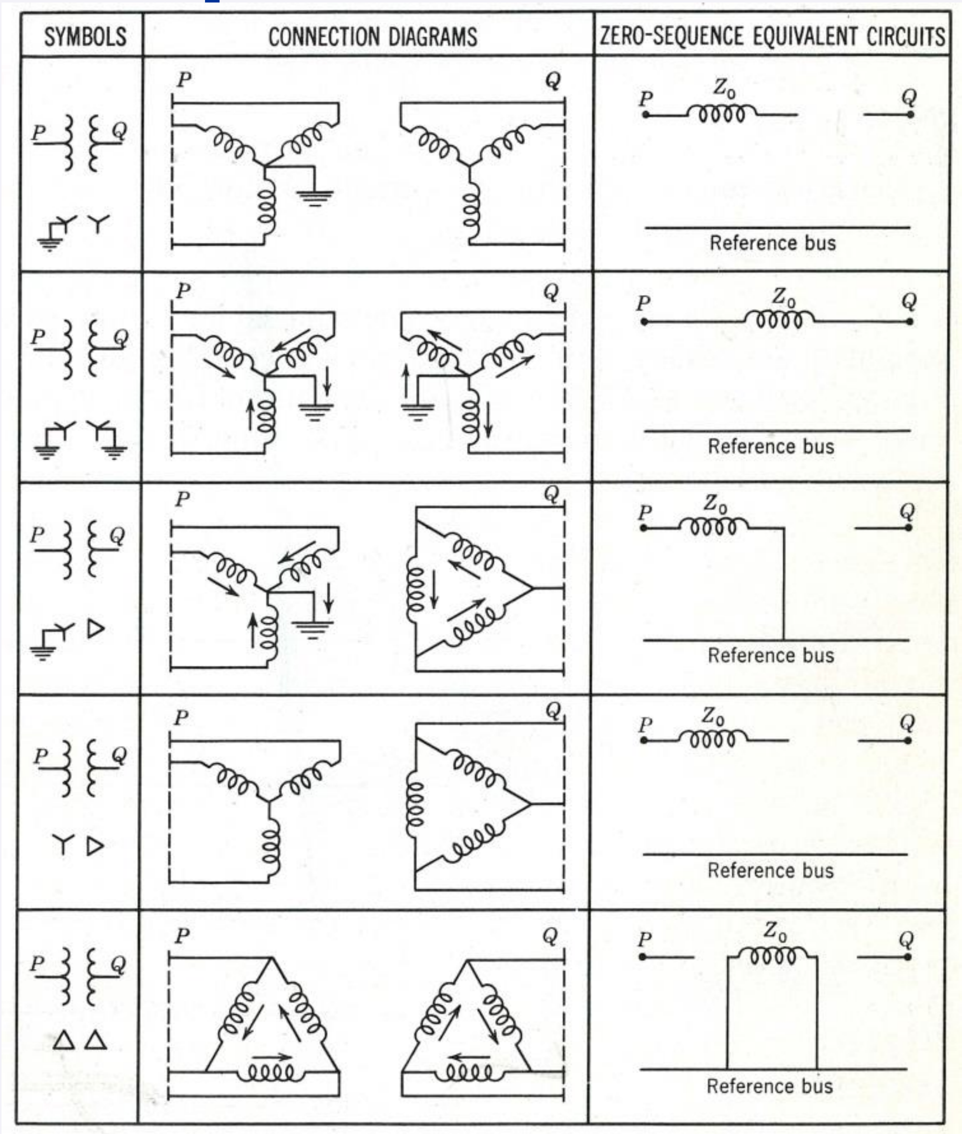
Generators:

- Pos. & Neg. similar except for impedances and voltage induced by rotating machinery.
- Zero sequence varies, but generally smaller than positive and negative sequence impedances.
  - MV generators normally impedance grounded.

Sequence Impedances

Transformers:

- Pos. & neg. sequence impedances are equal.
- Zero sequence depends on transformer connections



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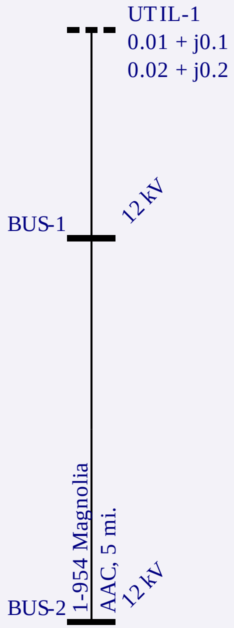
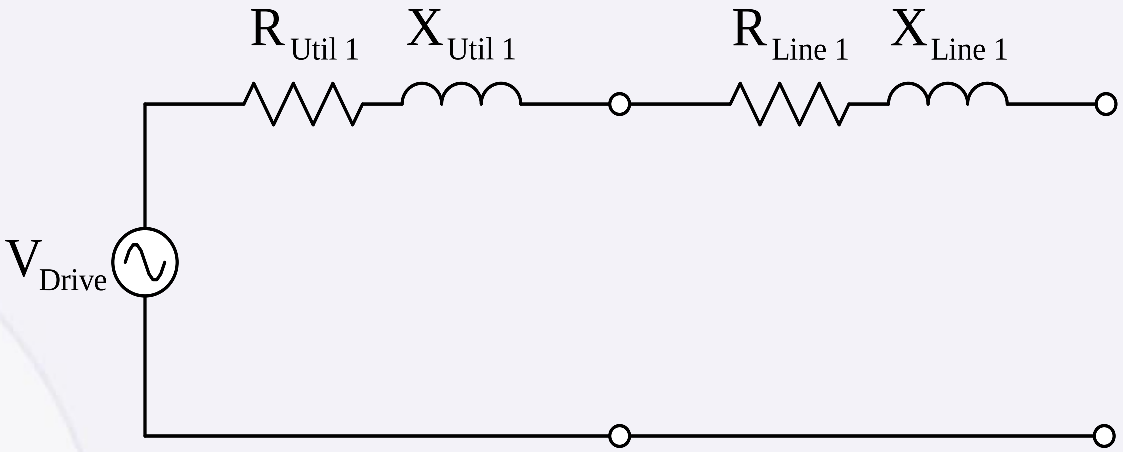
Fault Calculation Example

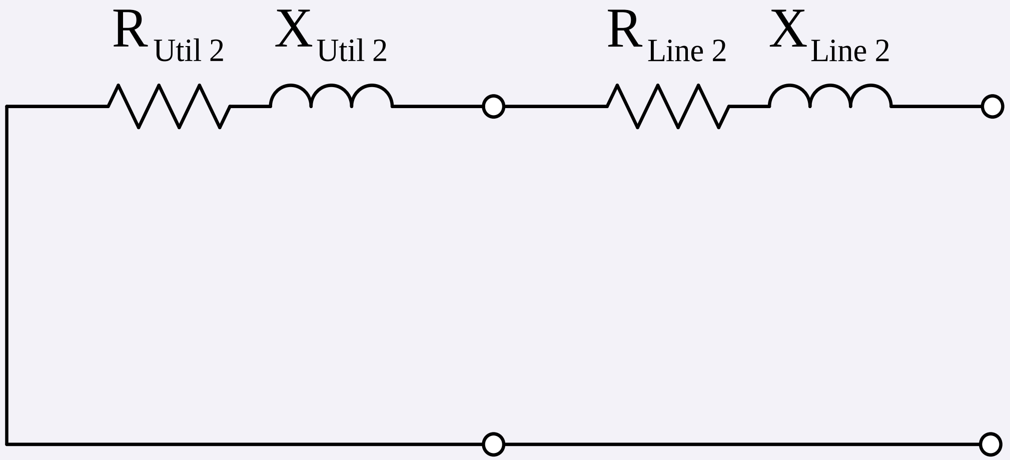


Look at **Line-to-Ground** Fault for this simple system

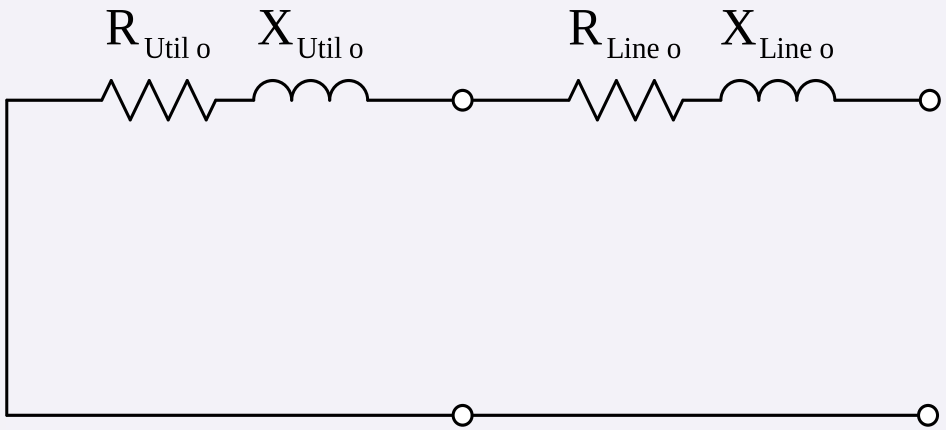
Positive Sequence Network



Negative Sequence Network



Zero Sequence Network



Combine Networks

- Once the sequence networks are defined, we need to determine how they are interconnected at the fault – this depends on the type of fault
- For a single line-to-ground fault on Phase A, I_B and I_C equal zero. It can be shown that to satisfy the fault conditions, the three sequence current for Phase A must be equal
- The only way this can happen is for the three sequence networks to be in <u>series</u>.

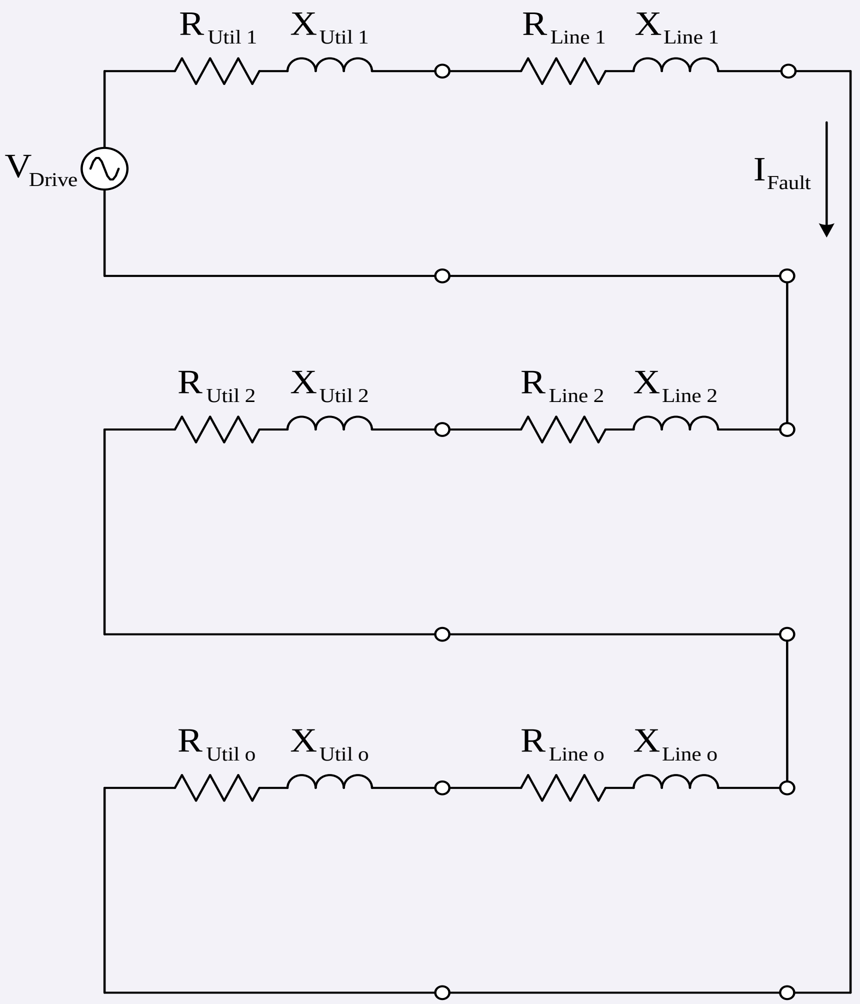
Resulting Sequence Diagram

- Since the positive and negative sequence impedances are equal, this simplifies to :

$$I_{\text{Fault pu}} = \frac{V_{\text{Drive}}}{2Z_{1\text{ pu}} + Z_{o\text{ pu}}}$$

Any fault impedance would show up as 3Zf in the sequence diagram since it will be each sequence

ONLY VALID FOR SLG FAULTS!

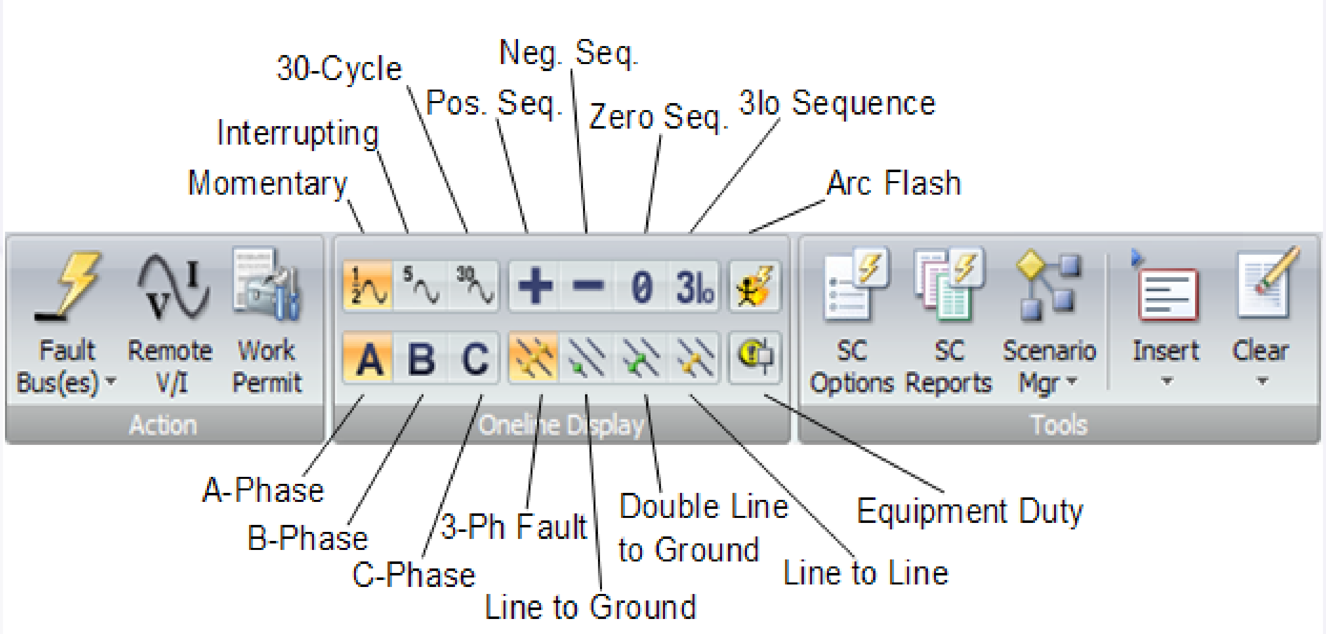


Other Fault Types

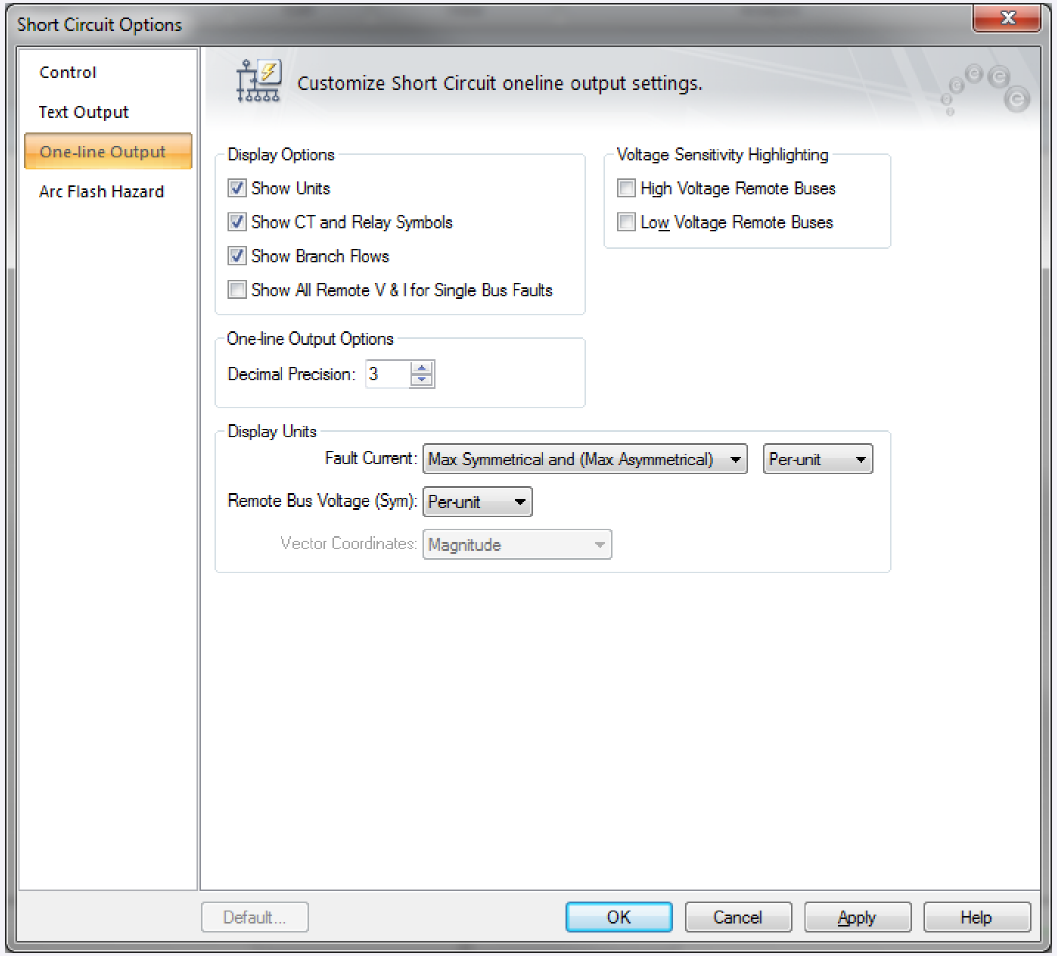
- Process is similar for other types of unbalanced faults
- Sequence networks are the same.
- The difference is in how the sequence networks are interconnected based on the fault conditions.
- Standard references have tables of interconnection of networks for various faults types.
- This is all handled automatically in EasyPower

Short Circuit in EasyPower

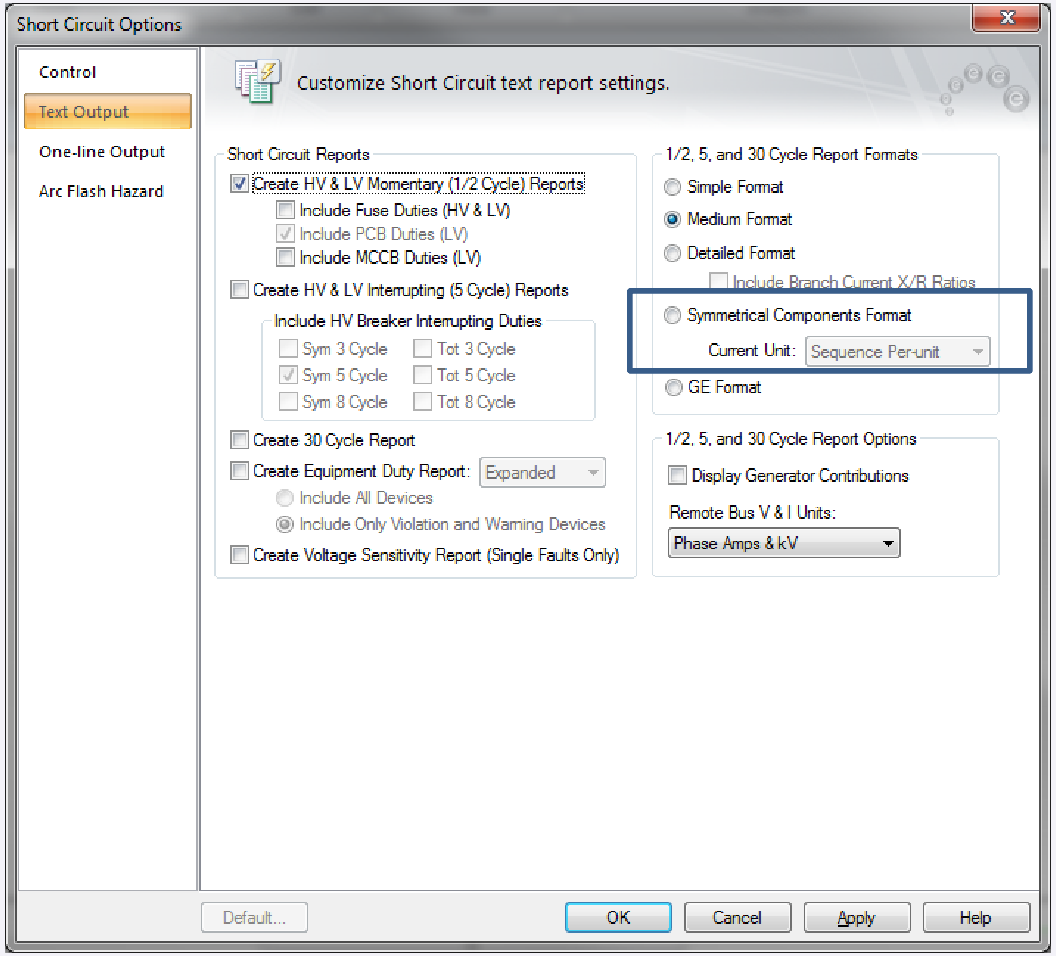
- One-line display options



Short Circuit in EasyPower



Short Circuit in EasyPower



EasyPower Example

- We'll look at doing unbalanced fault calculations in EasyPower
- Look at symmetrical component results