A fault is an undesired current flow (short circuit) or interruption of flow (open). These faults may also occur in substations or distribution systems, not just transmission lines.

Transient or Permanent Faults and Reclosures

Transient Faults

Most faults are short-duration short circuits cause by tree branches, birds or mylar balloons. All of these would be blown to smithereens by the large short-circuit current and not cause permanent damage, at least to the power system.

Sometimes a short-duration short circuit or a lightning strike can establish an arc from line to line or from a line to the tower (flashover). An arc through the air ionizes the air and makes it a conductor. Once the air is ionized, the arc typically continues until the power is shut off for a short time. Relays at both ends of a transmission lines should detect this short and cut the power using large circuit breakers. It is common for these relays to automatically reclose the breakers after a short time (1/3 second or so) to see if the problem has cleared. You have almost certainly experienced these very short power outages that make the lights flicker and alarms and microwaves go "beep".

Permanent Faults

If a reclosure relay makes one or more attempts to re-energize the line and the fault persists, then it opens the circuit breakers "permanently", or rather, until the fault has been found and repaired by a repair crew. Then, after safety protocols have been met, an operator will reclose the circuit breaker(s).

Local distribution lines are usually protected by fuses rather than expensive reclosure devices, so even transient faults in local systems can result in longer-term outages.

Types of Transient or Permanent Faults

Short circuits (Listed from most common to least common)

1. Single line to ground (80% or more of all faults) SLG
2. Line to line (ground not involved) LL
3. Double line to ground DLG
4. Balanced three lines to ground (Symmetric 3-line fault) 3P

Shorts may have zero impedance (called "bolted" or "solid") or non-zero fault impedance, $\mathbf{Z_f}$

Open circuits

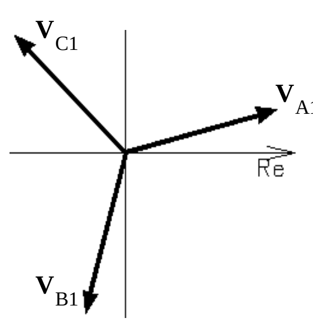
Open circuits can involve 1, 2, or all 3 lines

Any fault except the balance 3-phase short or 3 open lines is called "unsymmetrical" and will result in unbalanced currents and voltages. Therefore we need a way to deal with unbalanced systems. Symmetrical faults can be analyzed in the same way as unsymmetrical faults, they're just simpler. So we'll jump straight to unbalanced systems.

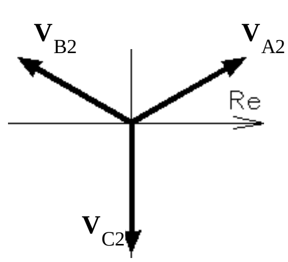
Unbalanced Systems

Unbalanced systems can be analyzed by an odd form of superposition of three balanced systems. Any unsymmetrical or unbalanced set of three-phase of voltages or currents can be broken down into three symmetrical sets of balance three-phase components. The voltages or currents of those three balanced components are:

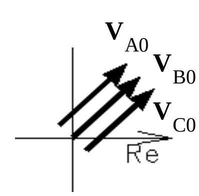
For voltages:



Positive sequence
(normal sequence)
(a-b-c)



Negative sequence
(reverse sequence)
(a-c-b)

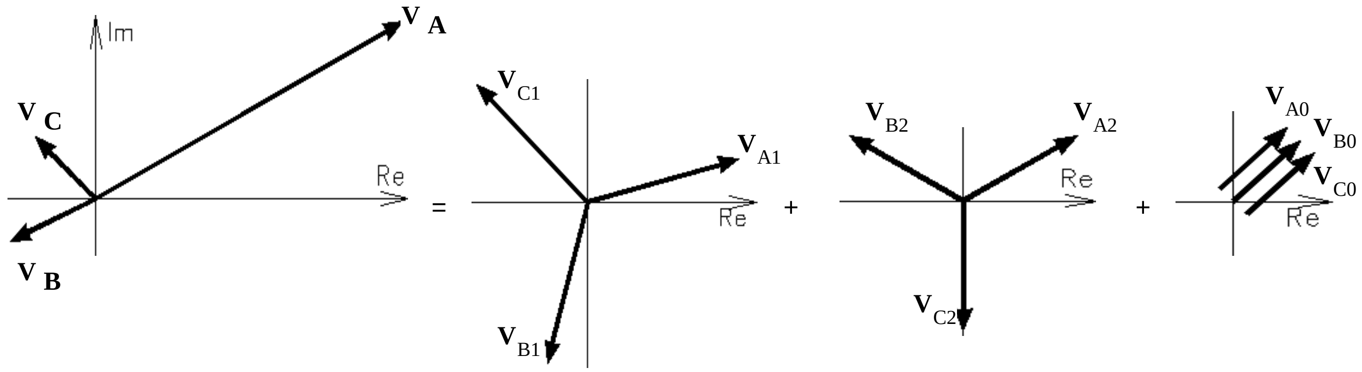


Zero sequence

Same sequences for currents

Expression of Unbalanced 3-phase voltages and currents

Any three voltages can be expressed as a sum of a positive sequence, a negative sequence, a zero sequence.



Any three voltages	Positive sequence (normal sequence) (a-b-c)	Negative sequence (reverse sequence) (a-c-b)	Zero sequence
	$\mathbf{V_{B1}} = \mathbf{V_{A1}} 1\angle{-120^o} = \mathbf{V_{A1}} 1\angle{240^o}$	$\mathbf{V_{B2}} = \mathbf{V_{A2}} 1\angle{120^o}$	$\mathbf{V_{B0}} = \mathbf{V_{A0}}$
	$\mathbf{V_{C1}} = \mathbf{V_{A1}} 1\angle{120^o}$	$\mathbf{V_{C2}} = \mathbf{V_{A2}} 1\angle{-120^o} = \mathbf{V_{A2}} 1\angle{240^o}$	$\mathbf{V_{C0}} = \mathbf{V_{C0}}$

Define: $a = 1\angle{120^o}$ so $a^2 = 1\angle{240^o}$ and $a^3 = 1$

Which means that: $\mathbf{V}_{\mathbf{B1}} = a^2 \cdot \mathbf{V}_{\mathbf{A1}}$ and $\mathbf{V}_{\mathbf{B2}} = a \cdot \mathbf{V}_{\mathbf{A2}}$

$\mathbf{V}_{\mathbf{C1}} = a \cdot \mathbf{V}_{\mathbf{A1}}$ $\mathbf{V}_{\mathbf{C2}} = a^2 \cdot \mathbf{V}_{\mathbf{A2}}$

We want to find the magnitudes (& angles) of our three sequences such that:

$$\mathbf{V}_{\mathbf{A}} = \mathbf{V}_{A1} + \mathbf{V}_{A2} + \mathbf{V}_{A0} = \mathbf{V}_{A1} + \mathbf{V}_{A2} + \mathbf{V}_{A0}$$

$$\mathbf{V}_{\mathbf{B}} = \mathbf{V}_{B1} + \mathbf{V}_{B2} + \mathbf{V}_{B0} = a^2 \cdot \mathbf{V}_{A1} + a \cdot \mathbf{V}_{A2} + \mathbf{V}_{A0}$$

$$\mathbf{V}_{\mathbf{C}} = \mathbf{V}_{C1} + \mathbf{V}_{C2} + \mathbf{V}_{C0} = a \cdot \mathbf{V}_{A1} + a^2 \cdot \mathbf{V}_{A2} + \mathbf{V}_{A0}$$

all referred to $\mathbf{V_{Ax}}$

$$\begin{bmatrix} \mathbf{V}_{\mathbf{A}} \\ \mathbf{V}_{\mathbf{B}} \\ \mathbf{V}_{\mathbf{C}} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \cdot \begin{bmatrix} \mathbf{V}_{A0} \\ \mathbf{V}_{A1} \\ \mathbf{V}_{A2} \end{bmatrix}$$

Please note a source of confusion The order of the sequences is 0,1,2 in the matrices, but 1,2,0 in most other sets of equations and in the drawings.

Invert matrix to find components:

$$\begin{bmatrix} \mathbf{V}_{A0} \\ \mathbf{V}_{A1} \\ \mathbf{V}_{A2} \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \mathbf{V}_{\mathbf{A}} \\ \mathbf{V}_{\mathbf{B}} \\ \mathbf{V}_{\mathbf{C}} \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & 120^o & 240^o \\ 1 & 240^o & 120^o \end{bmatrix} \cdot \begin{bmatrix} \mathbf{V}_{\mathbf{A}} \\ \mathbf{V}_{\mathbf{B}} \\ \mathbf{V}_{\mathbf{C}} \end{bmatrix}$$

\ Input any three complex voltages

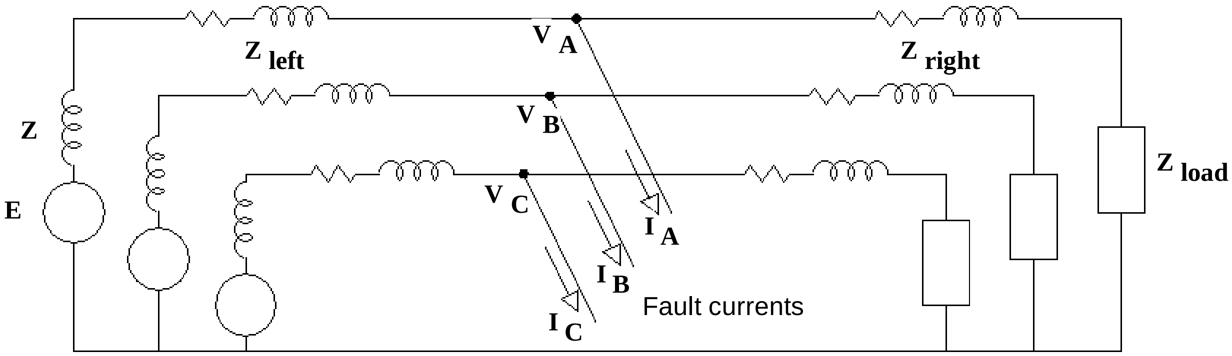
\ To get the magnitudes and angles of the three sequences which will add up to get those three voltages.

Same goes for currents. Now we can use these to analyze faults

Some Assumptions about Faults

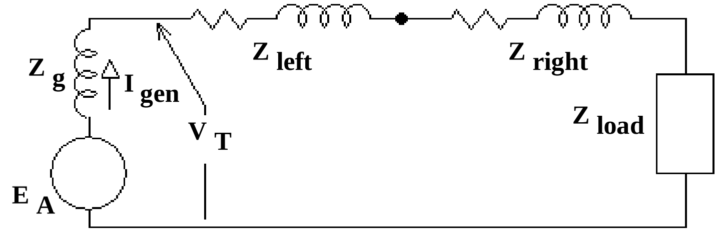
1. The system was balanced before the fault, so negative- and zero-sequence voltages and currents were all zero.
2. There is only one fault location at a time. This is the location where the negative- and zero-sequence voltages and currents interact.
3. Generators (and other large 50+ hp rotating machines) should be represented by their subtransient synchronous reactances ($\mathbf{Z''_g}$ or $\mathbf{X''_g}$) and a generated emf that would have resulted in the pre-fault voltages and currents with that special reactance. It's actually even more complicated than that. There's even a DC current component. Refer you to chapter 12 of the Chapman text if you want to know more.
   The additional compllexities are beyond the scope of this class.

Pre-Fault Setup



Draw the per-phase drawing of phase A, pre-fault.

Find the terminal voltage of the generator (V_T) and the generator current (I_{gen}).

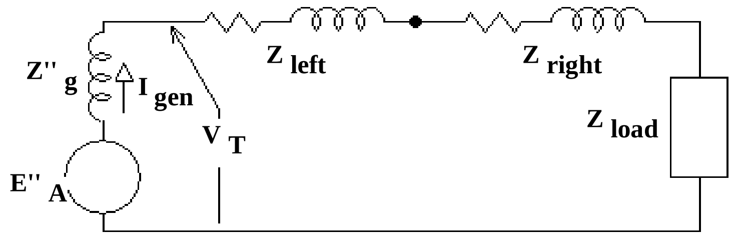


Now replace Z_g (or X_g) with the sub-transient impedance of the generator (Z''_g or X''_g)

Find the value of E''_A that will result in the same V_T and I_{gen}, usually like this:

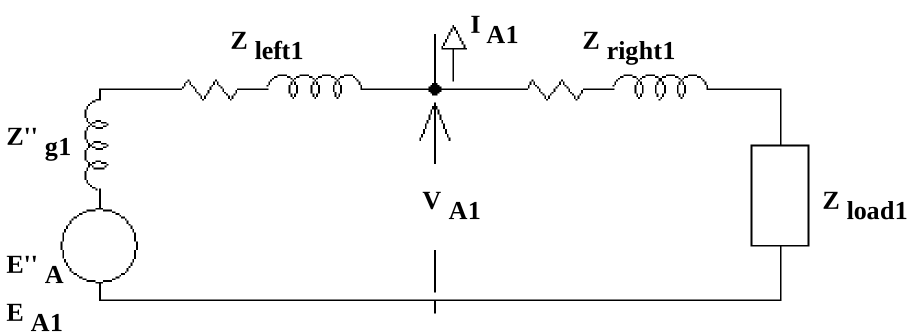
$$E''_A = V_T - I_{gen} \cdot j \cdot X''_g$$

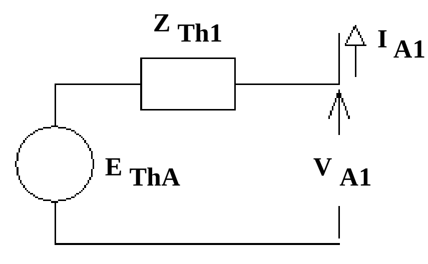
OR $$E''_A = V_T - I_{gen} \cdot Z''_g$$

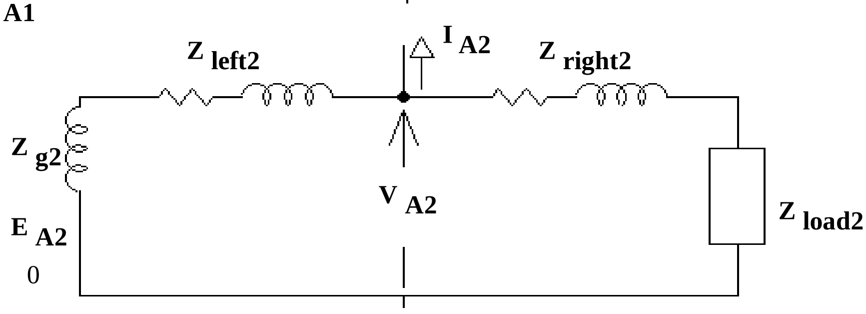


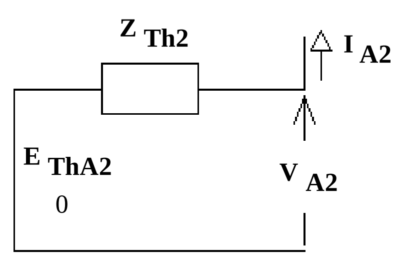
Sequence-components per-phase drawings of phase A

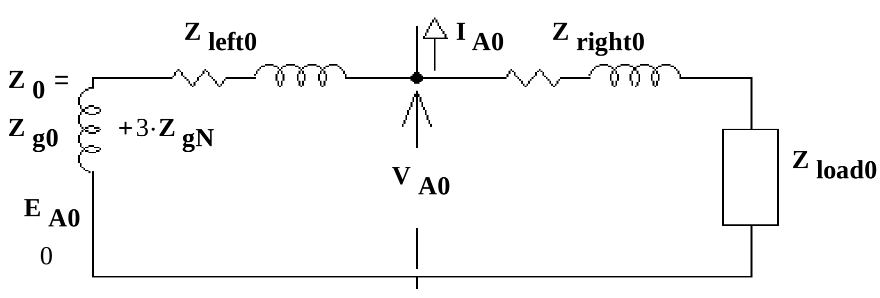
<u>Thévenin equivalents:</u>
helpful for the short-circuit faults

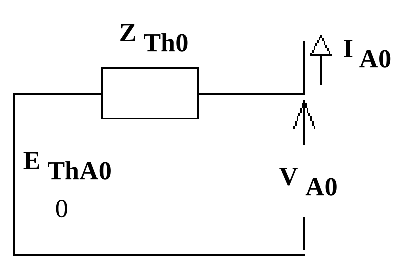




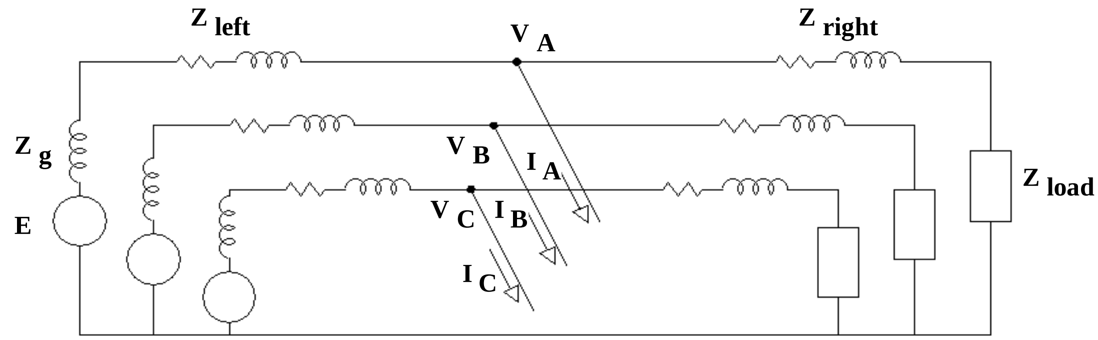








Symmetrical 3-phase to ground fault

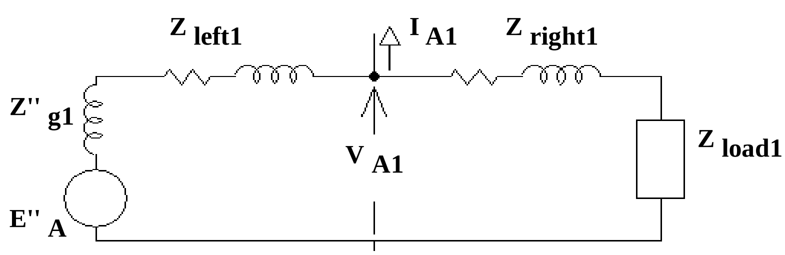


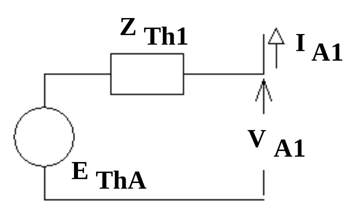
$$\begin{bmatrix} I_{A0}\\ I_{A1}\\ I_{A2}\end{bmatrix} = \begin{bmatrix} \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&a&a^2\\1&a^2&a\end{bmatrix}\cdot\begin{bmatrix}I_A\\ I_B\\ I_C\end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&120^o&240^o\\1&240^o&120^o\end{bmatrix}\cdot\begin{bmatrix} \\ \\ \end{bmatrix}$$

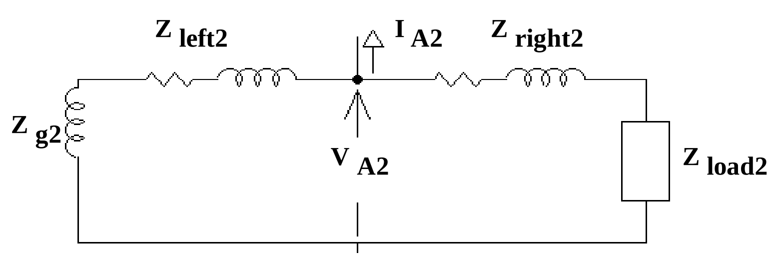
$$\begin{bmatrix} V_{A0}\\ V_{A1}\\ V_{A2}\end{bmatrix} = \begin{bmatrix} \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&a&a^2\\1&a^2&a\end{bmatrix}\cdot\begin{bmatrix} \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&120^o&240^o\\1&240^o&120^o\end{bmatrix}\cdot\begin{bmatrix} \\ \\ \end{bmatrix}$$

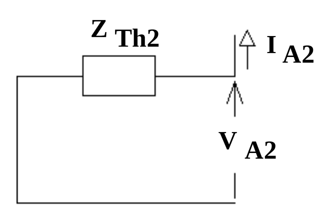
Sequence-components per-phase drawings of phase A

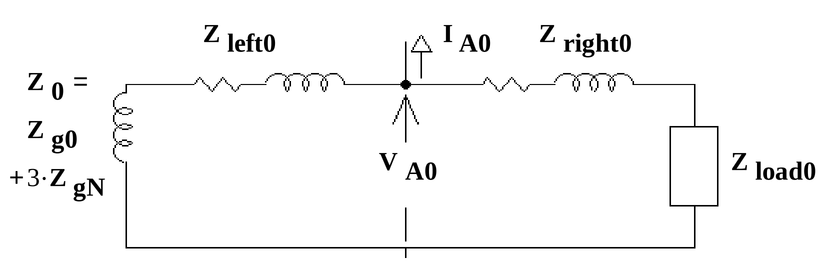
Thévenin equivalents:

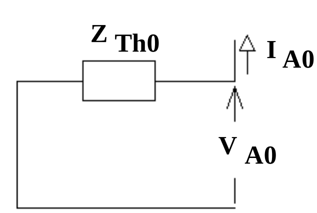




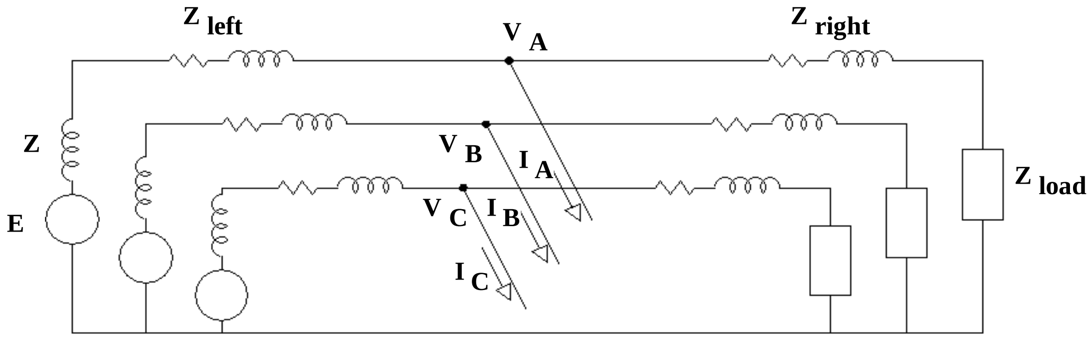








Single line to ground fault

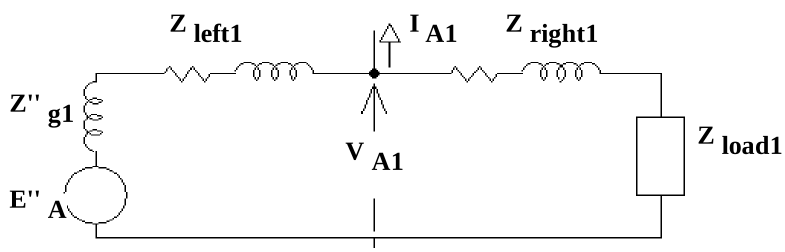


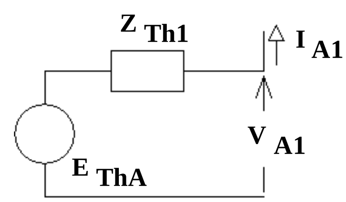
$$\begin{bmatrix} I_{A0}\\ I_{A1}\\ I_{A2}\end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&a&a^2\\1&a^2&a\end{bmatrix}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&120^o&240^o\\1&240^o&120^o\end{bmatrix}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

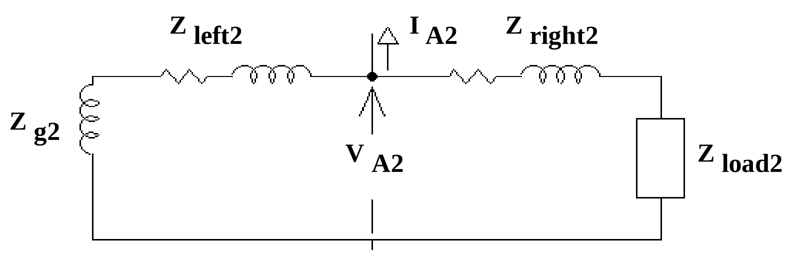
$$\begin{bmatrix} V_{A0}\\ V_{A1}\\ V_{A2}\end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&a&a^2\\1&a^2&a\end{bmatrix}\cdot\begin{bmatrix} 0 \\ V_B \\ V_C \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix}1&1&1\\1&120^o&240^o\\1&240^o&120^o\end{bmatrix}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

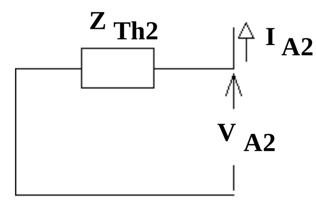
Sequence-components per-phase drawings of phase A

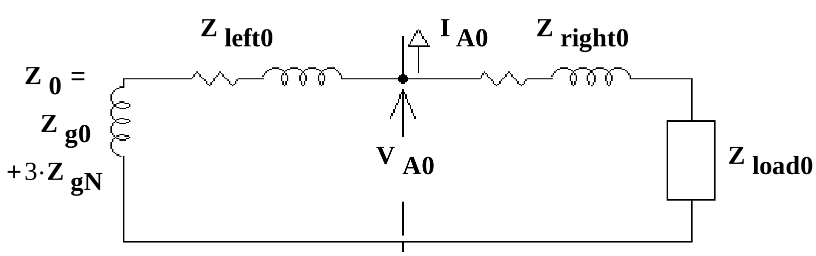
Thévenin equivalents:

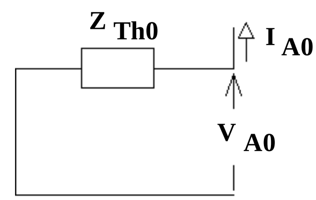




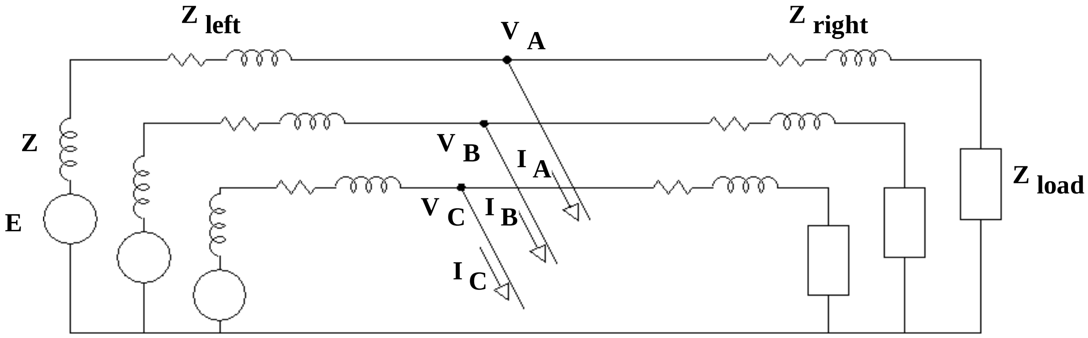








Double line to ground fault

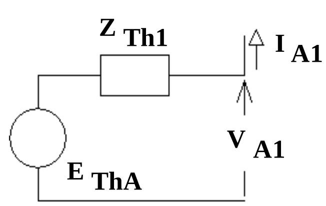


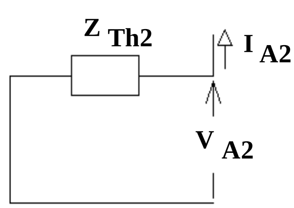
$$\begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \begin{bmatrix} \\ \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} \\ \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\cdot\begin{bmatrix} \\ \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & 120^o & 240^o \\ 1 & 240^o & 120^o \end{bmatrix}\cdot\begin{bmatrix} \\ \\ \\ \end{bmatrix}$$

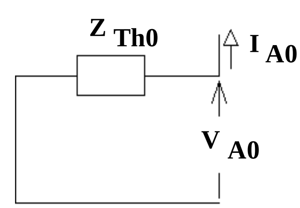
$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \begin{bmatrix} \\ \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\cdot\begin{bmatrix} V_A \\ \\ \\ \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & 120^o & 240^o \\ 1 & 240^o & 120^o \end{bmatrix}\cdot\begin{bmatrix} \\ \\ \\ \end{bmatrix}$$

Sequence-components per-phase drawings of phase A

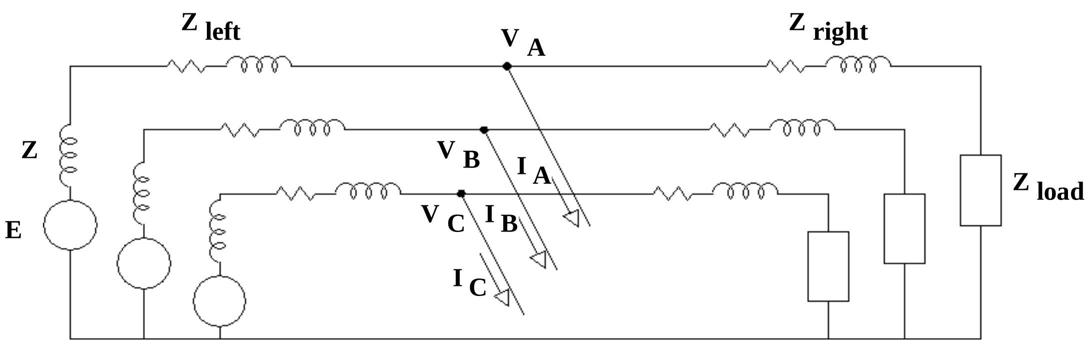
Thévenin equivalents:







Double line fault (ground not involved)

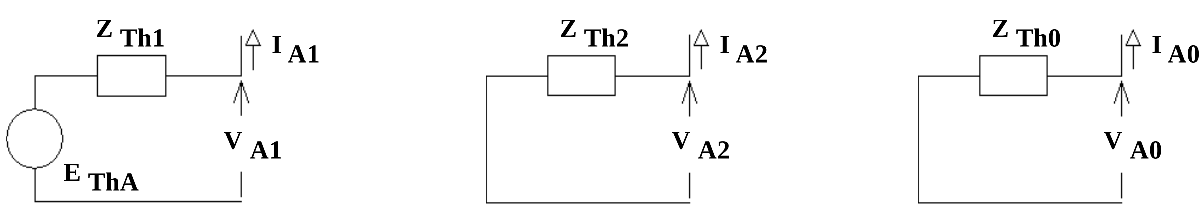


$$\begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\cdot\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & 120^o & 240^o \\ 1 & 240^o & 120^o \end{bmatrix}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

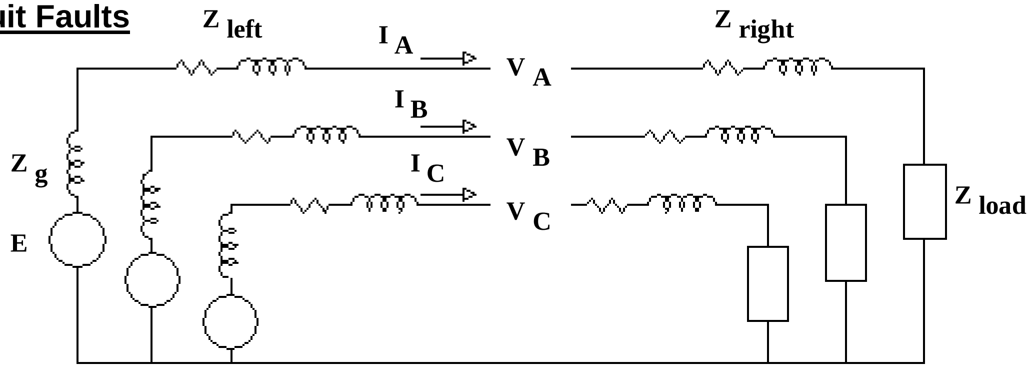
$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix}\cdot\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \frac{1}{3}\cdot\begin{bmatrix} 1 & 1 & 1 \\ 1 & 120^o & 240^o \\ 1 & 240^o & 120^o \end{bmatrix}\cdot\begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

Sequence-components per-phase drawings of phase A

Thévenin equivalents:



Open-Circuit Faults

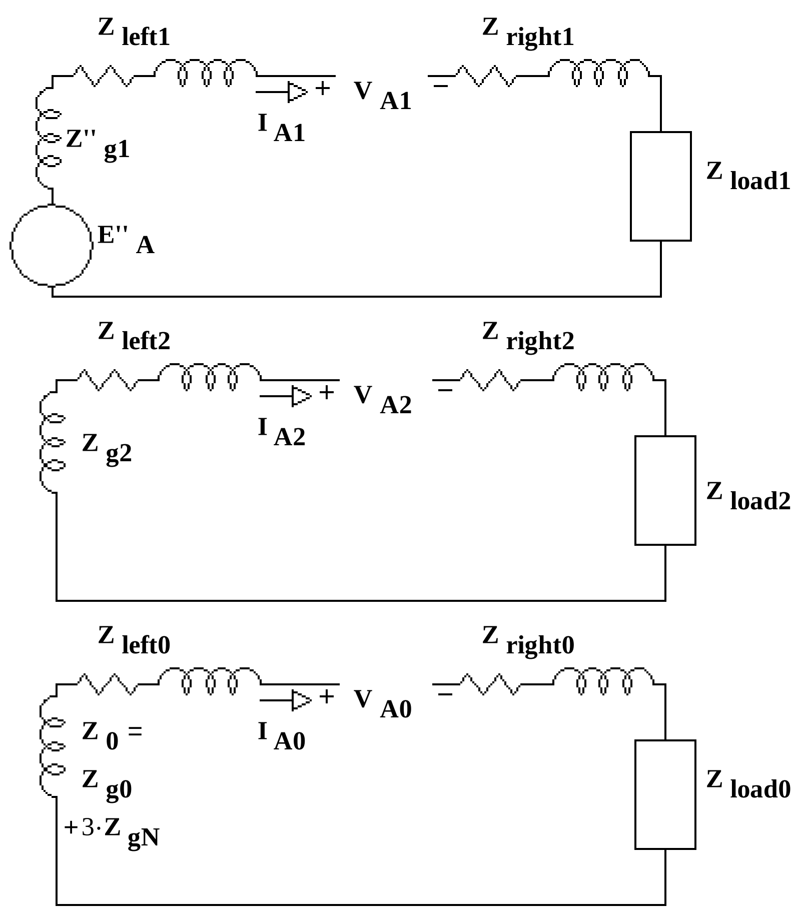


Now the voltages are measured across the fault point and the "fault" currents are the line currents.

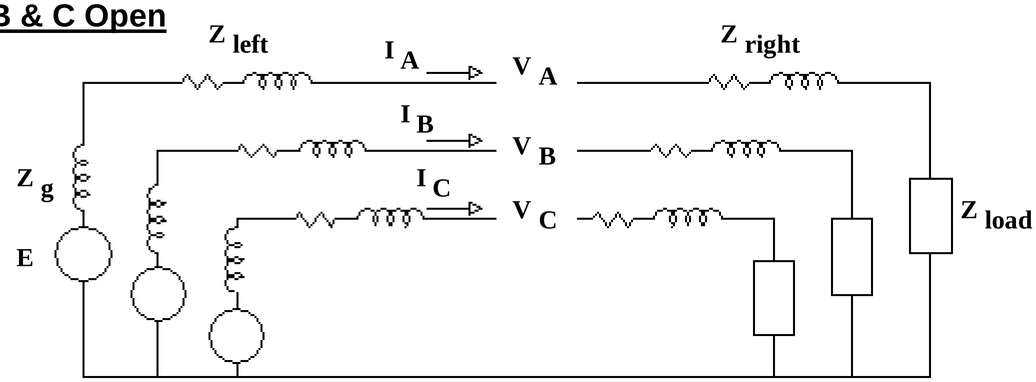
Single line A Open

$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} \qquad \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

Sequence-components per-phase drawings of phase A

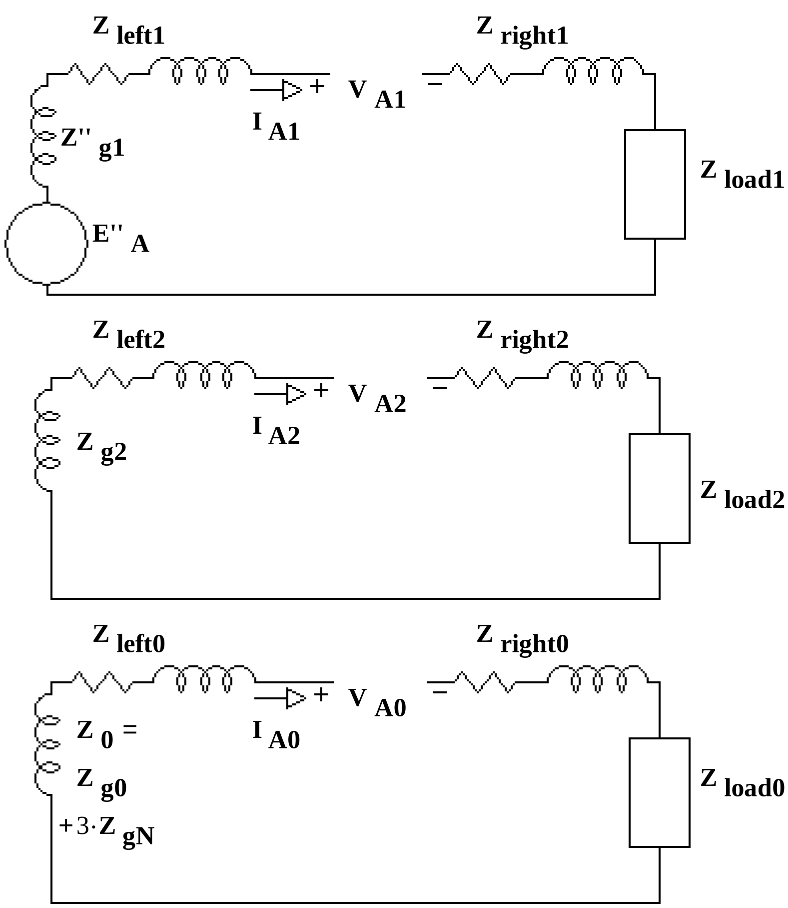


Double line B & C Open



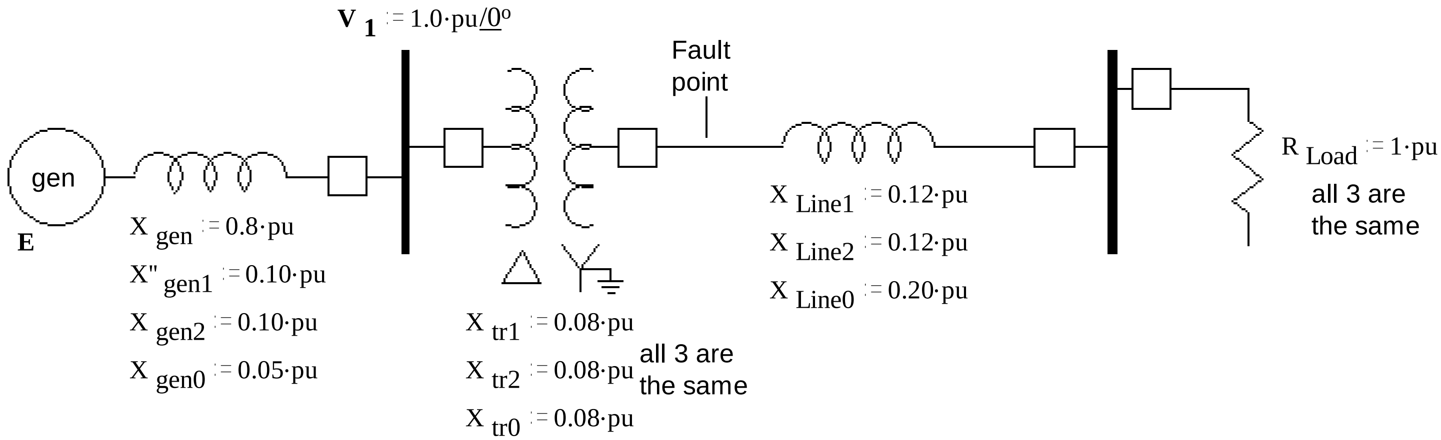
$$\begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} \qquad \begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \quad \\ \quad \\ \quad \end{bmatrix}$$

Sequence-components per-phase drawings of phase A

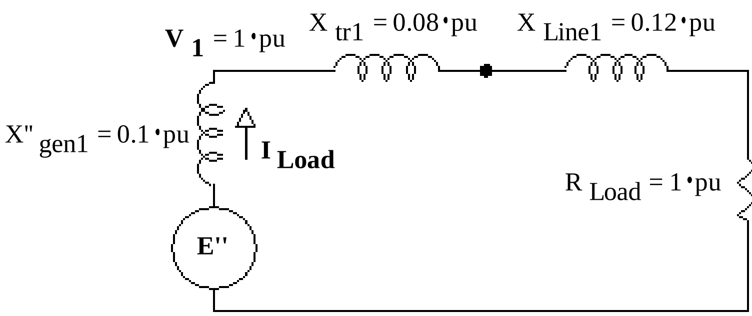


$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \cdot \begin{bmatrix} V_{A0} \\ V_{A1} \\ V_{A2} \end{bmatrix}$$

Example Consider this power system



Create a per-phase diagram of the pre-fault system, using all the positive sequence impedances. Only one weirdity, instead of using $\mathbf{X_{gen}}$ and $\mathbf{E_A}$ for the generator, use **X''** to find **E''**. That's because we need to find **E''**. **E''** is found such that **E''** in series with **X''** would produce the same current and terminal voltage at the generator as the original $\mathbf{E_A}$ and $\mathbf{X_{gen}}$ in pre-fault conditions.



$$\mathbf{I_{Load}} := \frac{\mathbf{V_1}}{R_{Load} + j \cdot (X_{tr1} + X_{Line1})}$$

$$|\mathbf{I_{Load}}| = 0.9806 \cdot pu$$

$$\arg(\mathbf{I_{Load}}) = -11.31 \cdot deg$$

Pre-fault, back-calculate **E''** as though **X''** were valid at that time:

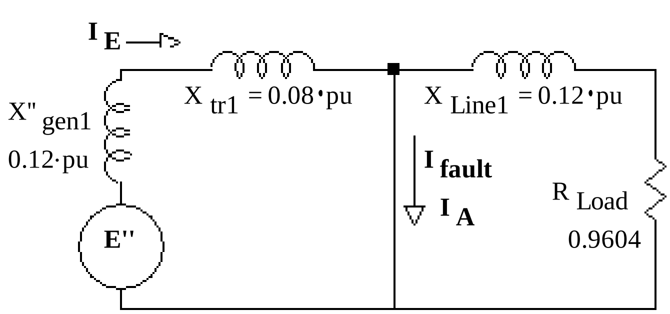
$$\mathbf{E''} := \mathbf{V_1} + \mathbf{I_{Load}} \cdot X''_{gen1} \cdot j$$

$$|\mathbf{E''}| = 1.024 \qquad \arg(\mathbf{E''}) = 5.389 \cdot deg$$

See item 3, under "Some Assumptions about Faults", way back on page 2 of the notes.

Note: in this case we had the pre-fault generator terminal voltage ($\mathbf{V_1}$) and could find the pre-fault current ($\mathbf{I_{Load}}$).
If we didn't have those numbers, we might need to find them using a pre-fault diagram with the original $\mathbf{E_A}$ and $\mathbf{X_{gen}}$.

a) A three-phase fault (all three lines grounded) occurs at the fault point. Find the fault current.
Since it's a symmetrical fault, we only need the positive sequence drawing.



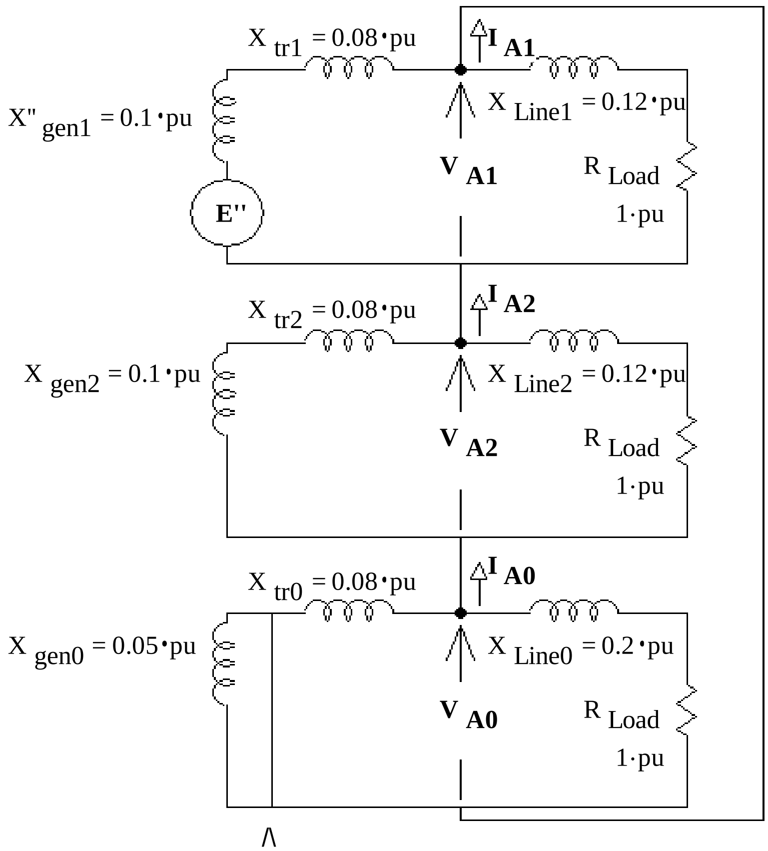
$$\mathbf{I_{fault}} := \frac{\mathbf{E''}}{(X''_{gen1} + X_{tr1}) \cdot j}$$

$$|\mathbf{I_{fault}}| = 5.6875 \qquad \arg(\mathbf{I_{fault}}) = -84.611 \cdot deg$$

$$\mathbf{I_{fault}} = 5.69\ A\ \underline{/-88.6^o}$$

Example Continued

b) Instead of a three-phase fault, a single-line to ground (SLG) fault occurs at the fault point. Find the fault current.
We don't have to do anything with the matrices, since that's already been figured out for the SLG fault.



Note the short here.
Caused by the Δ winding
of the transformer

define: $\mathbf{Z}_{A1} := X_{Line1} \cdot j + R_{Load}$

$\mathbf{Z}_{A1} = 1 + 0.12j \cdot pu$

$|\mathbf{Z}_{A1}| = 1.0072 \cdot pu \quad \arg(\mathbf{Z}_{A1}) = 6.843 \cdot deg$

define:

$$\mathbf{Z}_{A2} := \frac{1}{\dfrac{1}{(X_{gen2} + X_{tr2}) \cdot j} + \dfrac{1}{X_{Line2} \cdot j + R_{Load}}}$$

$\mathbf{Z}_{A2} = 29.725 + 171.083j \cdot 10^{-3} \cdot pu$

$|\mathbf{Z}_{A2}| = 0.1736 \cdot pu \quad \arg(\mathbf{Z}_{A2}) = 80.144 \cdot deg$

define:

$$\mathbf{Z}_{A0} := \frac{1}{\dfrac{1}{(X_{tr0}) \cdot j} + \dfrac{1}{X_{Line0} \cdot j + R_{Load}}}$$

$\mathbf{Z}_{A0} = 5.935 + 78.338j \cdot 10^{-3} \cdot pu$

$|\mathbf{Z}_{A0}| = 0.0786 \cdot pu \quad \arg(\mathbf{Z}_{A0}) = 85.668 \cdot deg$

$$\mathbf{Z}_{tot} := (X''_{gen1} + X_{tr1}) \cdot j + \frac{1}{\left(\dfrac{1}{\mathbf{Z}_{A1}} + \dfrac{1}{\mathbf{Z}_{A2} + \mathbf{Z}_{A0}}\right)}$$

$\mathbf{Z}_{tot} = 82.424 + 395.564j \cdot 10^{-3} \cdot pu$

$|\mathbf{Z}_{tot}| = 0.4041 \cdot pu \quad \arg(\mathbf{Z}_{tot}) = 78.23 \cdot deg$

$$\mathbf{I}_E := \frac{\mathbf{E''}}{\mathbf{Z}_{tot}}$$

$|\mathbf{I}_E| = 2.5337 \cdot pu \quad \arg(\mathbf{I}_E) = -72.84 \cdot deg$

$\mathbf{V}_{A1} := \mathbf{E''} - \mathbf{I}_E \cdot (X''_{gen1} + X_{tr1}) \cdot j \qquad \mathbf{V}_{A1} = 583.47 - 38.4j \cdot 10^{-3} \cdot pu$

$|\mathbf{V}_{A1}| = 0.5847 \cdot pu \quad \arg(\mathbf{V}_{A1}) = -3.765 \cdot deg$

$$\mathbf{I}_{A1} := \frac{\mathbf{V}_{A1}}{\mathbf{Z}_{A2} + \mathbf{Z}_{A0}}$$

$|\mathbf{I}_{A1}| = 2.3208 \cdot pu \quad \arg(\mathbf{I}_{A1}) = -85.629 \cdot deg$

$\mathbf{I}_{A2} = \mathbf{I}_{A0} = \mathbf{I}_{A1} \qquad \mathbf{I}_A := 3 \cdot \mathbf{I}_{A1} \qquad |\mathbf{I}_A| = 6.9623 \cdot pu \quad \arg(\mathbf{I}_A) = -85.629 \cdot deg$

= The fault current

ECE 3600 homework LF1 Due: Tue, 12/8/22

1. A transmission line suffers a single-line to ground fault on phase-A.

   The fault currents are: $I_A := 6 \cdot pu \;\; \underline{/0^o}$ $\quad I_B := 0$ $\quad I_C := 0$

   Calculate the symmetrical components of the fault current, I_{A1}, I_{A2} and I_{A0} .

2. A transmission line suffers a line-line fault between phase-A and phase-B.

   The fault currents are: $I_A = 0$ and $I_B = -I_C = 4 \underline{/0^o}$ pu .

   Calculate the symmetrical components, I_{A1}, I_{A2} and I_{A0} .

3. A transmission line suffers an unknown fault.

   The symmetrical components of I_A are: $I_{A1} := -2 + 3 \cdot j \;\; pu$ $\quad I_{A2} := 2 - 3 \cdot j \;\; pu$ $\quad I_{A0} := 0$

   a) Find the fault currents, I_A, I_B and I_C .

   b) What kind of fault is it?

4. If a short occurs between lines b and c of a 3-phase transmission line, the zero-sequence circuit can be ignored in the analysis, why?

5. A transmission line suffers an unknown fault.

   The symmetrical components of I_A are: $I_{A1} := 1 + \sqrt{3} \cdot j \;pu$ $\quad I_{A2} := 1 - \sqrt{3} \cdot j \;pu$ $\quad I_{A0} := 4$

   a) Find the fault currents, I_A, I_B and I_C .

   b) What kind of fault is it?

6. At point X in the power system, there is an open-circuit fault. Phase-A is open. The voltage across the open-circuit is: $V_A = 0.9 \underline{/0^o}$ pu. Since the other two lines are intact, the other two voltages across point X are $V_B = V_C = 0$.

   a) Calculate the sequence components V_{A1}, V_{A2} and V_{A0} at the fault point.

      Note: this is the same as the calculations of the short-circuit sequence currents, only now the voltages are measured across the fault point and the "fault" currents are the line currents.

   b) Is there anything you can say about the symmetrical line current components, I_{A1}, I_{A2} and I_{A0} ?

Answers

1. all $2 \cdot pu$

2. $2.309 \cdot j \cdot pu \quad -2.309 \cdot j \cdot pu \quad 0$ OR $\begin{bmatrix} I_{A0} \\ I_{A1} \\ I_{A2} \end{bmatrix} = \begin{pmatrix} 0 \\ 2.309 \cdot j \\ -2.309 \cdot j \end{pmatrix} \cdot pu$

3. a) $0 \quad 5.196 + 3.464 \cdot j \quad -5.196 - 3.464 \cdot j$ b) Since $I_B = -I_C$, must be a line-to-line fault between phase-A and phase-B

4. No connection to ground means no zero-sequence current can flow.
   Since there is no zero-sequence voltage source ($E_{A0} = 0$), no current means no voltage as well.

5. a) $6 \quad 6 \quad 0$ b) Since $I_A = I_B$, and $I_A = 0$, must be a double line-to-ground fault with phase-A and phase-B grounded

6. a) all $0.3 \cdot pu$ b) $I_A = I_{A1} + I_{A2} + I_{A2} = 0$

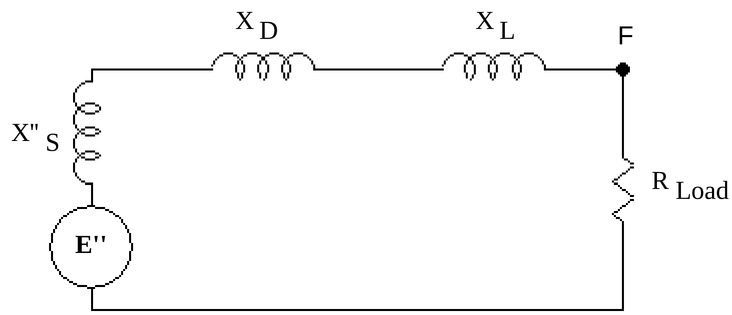
ECE 3600 homework LF2 Due: Tue, 12/8/22

May be handed in on day of final for full credit a

1. One phase of a balanced 3-phase system is shown here.

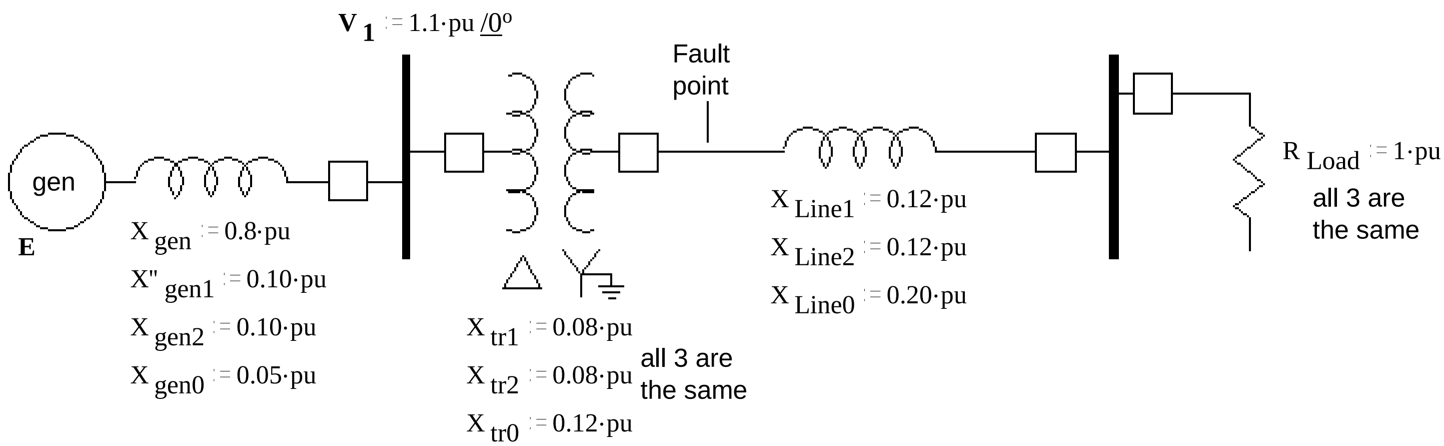
   A fault occurs point F. It is a short between lines b and c with an impedance of $\mathbf{Z_f}$.

   a) Draw the circuit you would have to analyze to find the fault current. Identify the parts and Include the component voltages and currents at the fault.



   b) Set up a mathematical expression (or expressions) to find the fault current. (don't forget j & that the fault current is NOT $\mathbf{I_{A1}}$)

2. Consider this power system. Same as the example in the notes, except for $\mathbf{V_1}$ and X_{tr0} .



   There is a phase-A single-line to ground (SLG) fault with a fault impedance of $\mathbf{Z_f} := 0.15\cdot\text{pu}\ \underline{/0^o}$

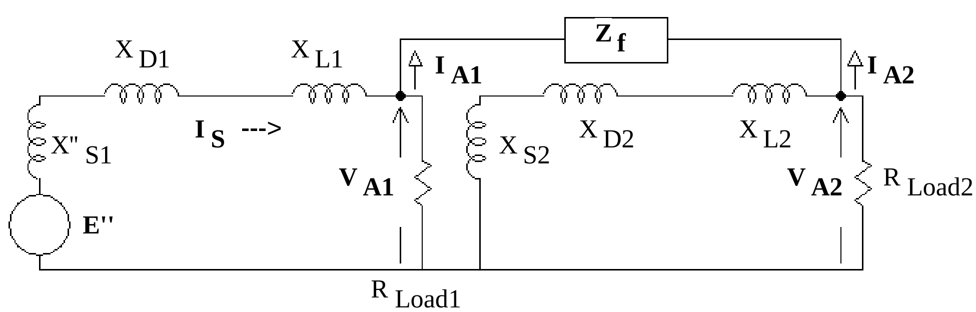
   Find the fault current. You may be able to use some numbers already calculated in the example

3. Repeat problem 2 if before the fault, the load was zero, that is, $\mathbf{P_{Load}} = 0$ and $R_{Load} := \infty$

   hint: this problem is considerably easier now

Answers

1. a)



   b) define $\mathbf{Z_X} = \mathbf{Z_f} + \dfrac{1}{\dfrac{1}{(X_{S2}+X_{D2}+X_{L2})\cdot j} + \dfrac{1}{R_{Load2}}}$ $\quad \mathbf{I_S} = \dfrac{\mathbf{E''}}{(X''_{S1}+X_{D1}+X_{L1})\cdot j + \left(\dfrac{1}{R_{Load1}} + \dfrac{1}{\mathbf{Z_X}}\right)}$

$$\mathbf{V_{A1}} = \mathbf{I_S}\cdot\frac{1}{\left(\dfrac{1}{R_{Load1}} + \dfrac{1}{\mathbf{Z_X}}\right)} \qquad \mathbf{I_{A1}} = \frac{\mathbf{V_{A1}}}{\mathbf{Z_X}} \qquad \mathbf{I_{fault}} = \mathbf{I_B} = a^2\cdot\mathbf{I_{A1}} + a\cdot\mathbf{I_{A2}} = \left(a^2 - a\right)\cdot\mathbf{I_{A1}}$$

2. $4.69\cdot\text{pu}\ \underline{/-45.7^o}$ 3. $5.016\cdot\text{pu}\ \underline{/-46.85^o}$