Power System Analysis
供電=用電

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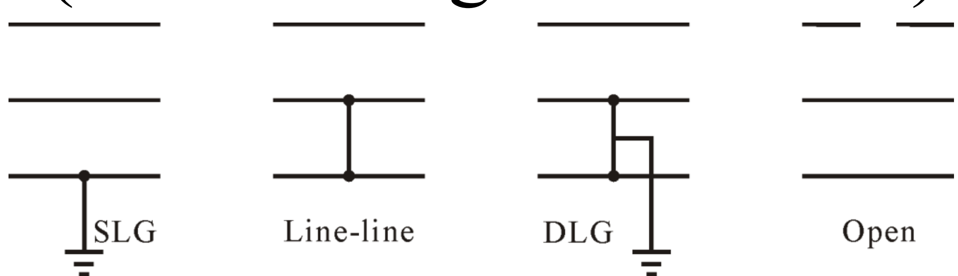


13.不均衡系統操作(Unbalanced System Operation)

$V_a = 180\cos(377t)$

$V_b = 180\cos(377t-120^\circ)$

$V_c = 180\cos(377t+120^\circ)$

正序 → ① 正序 ② 負序 ③ 零序

$V_a = 180\cos(377t)$

$V_b = 180\cos(377t+120^\circ)$

$V_c = 180\cos(377t-120^\circ)$

$V_0 = \frac{V_a+V_b+V_c}{3} \neq 0$

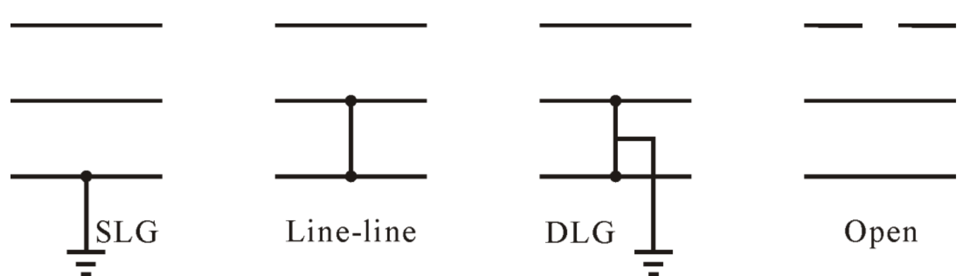
13.0簡介(Introduction)

Normally, a power system operates under balanced conditions. Effort are made to ensure this desirable state of affairs. Unfortunately, under abnormal (i.e., fault) conditions, the system may become unbalanced.

Some typical non-symmetric transmission-line faults are shown in figure. We show the faults with zero impedance, but in general, nonzero impedances must also be considered. In addition, there are faults on generator and other equipment.

The most common type of fault by far is the single line-to-ground (SLG) fault, followed in frequency of occurrence by line-to-line (LL) faults, double line-to-ground (DLG) faults, and balanced three-phase (3Φ) faults. Faults are triggered by lighting strokes, high winds topple towers, tree across a line, and fog or salt spray on dirty insulators.

Much less common are faults on cables, circuit breakers, generators, motors, and transformer.



重疊定理(Superposition Principle) 正.負.零序皆為線性

The superposition principle states that the voltage across (or current through) an element in a linear circuit is the algebraic sum of the voltage across (or current through) that element due to each independent source acting alone.

We consider one independent source at a time while all other independent sources are turned off. This implies that we replace every voltage source by 0V (or a short circuit), and every current source by 0A (or an open circuit). This way we obtain a simpler and more manageable circuit.

Dependent sources are left intact because they are controlled by circuit variables.

Step1: Turn off all independent sources except one source. Find the output (voltage or current) due to that active source using the Kirchhoff's Voltage and Current Laws (KVL and KCL).

Step2: Repeat step 1 for each of the other independent sources.

Step3: Find the total contribution by adding algebraically all the contributions due to the independent sources.

13.1對稱分量(Symmetrical Components)

Represent I_a, I_b, and I_c in terms of nine symmetrical components , zero sequence set ($I^0_a = I^0_b = I^0_c$), positive (abc) sequence set, and negative (acb) sequence set. ($I^0_a, I^+_a, I^-_a, I^0_b, I^+_b, I^-_b, I^0_c, I^+_c, I^-_c$)

(13.1) $I_a = I^0_a + I^+_a + I^-_a$, $I_b = I^0_b + I^+_b + I^-_b$, $I_c = I^0_c + I^+_c + I^-_c$,

Define $\alpha = e^{j2\pi/3} = 1\angle 120^\circ, \alpha^2 = e^{j4\pi/3} = 1\angle 240^\circ = 1\angle -120^\circ, \alpha^* = \alpha^2$, $1+\alpha+\alpha^2 = 0$

(13.5) $[I_a\ I_b\ I_c] = A[I^0_a\ I^+_a\ I^-_a]$, (13.6) $A = [1\ 1\ 1; 1\ \alpha^2\ \alpha; 1\ \alpha\ \alpha^2]$

A is symmetrical components transformation matrix.

(13.8) $A^{-1} = (1/3)\,[1\ 1\ 1; 1\ \alpha\ \alpha^2; 1\ \alpha^2\ \alpha]$,

(13.9) $[I^0_a\ I^+_a\ I^-_a] = A^{-1}\,[I_a\ I_b\ I_c]$,

Balanced Positive Sequence $V_a = 1\angle 0^\circ$, $V_b = 1\angle -120^\circ$, $V_c = 1\angle 120^\circ$,

$[V^0_a\ V^+_a\ V^-_a] = A^{-1}\,[V_a\ V_b\ V_c] = [0\ \ 1\angle 0^\circ\ \ 0]$

Balanced Negative Sequence $V_a = 1\angle 0^\circ$, $V_b = 1\angle 120^\circ$, $V_c = 1\angle -120^\circ$,

$[V^0_a\ V^+_a\ V^-_a] = A^{-1}\,[V_a\ V_b\ V_c] = [0\ \ 0\ \ 1\angle 0^\circ]$

Unbalanced line-line voltages, V_{ab} , V_{bc} , and V_{ca} . Zero-sequence is zero.

$V^0 = (V_{ab} + V_{bc} + V_{ca})/3 = [(V_a - V_b)+(V_b - V_c)+(V_c - V_a)]/3 = 0$

Ex13.1 Finding Symmetrical Components ($\theta = \omega t$)

$V_a = 1\angle 0^\circ$, $V_b = 1\angle -90^\circ$, $V_c = 2\angle 135^\circ$,

Define $\alpha = e^{j2\pi/3} = 1\angle 120^\circ$, $\alpha^2 = e^{j4\pi/3} = 1\angle 240^\circ = 1\angle -120^\circ$

$A^{-1} = (1/3)\,[1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$, $[V^0_a\ V^+_a\ V^-_a] = A^{-1}\,[V_a\ V_b\ V_c]$,

$[V^0_a\ V^+_a\ V^-_a] = [0.195\angle 135^\circ\quad 1.311\angle 15^\circ\quad 0.494\angle -105^\circ]$

$V^0_a = 0.195\angle 135^\circ = 0.195\cos(\omega t + 135^\circ)$

Zero Sequence: $V^0_a = V^0_b = V^0_c = 0.195\angle 135^\circ$

$V^+_a = 1.311\angle 15^\circ = 1.311\cos(\omega t + 15^\circ)$

Positive Sequence: $1.311\angle 15^\circ$, $1.311\angle(15^\circ - 120^\circ)$, $1.311\angle(15^\circ + 120^\circ)$

$V^-_a = 0.494\angle -105^\circ = 0.494\cos(\omega t - 105^\circ)$

Negative Sequence: $0.494\angle -105^\circ$, $0.494\angle(-105^\circ + 120^\circ)$, $0.494\angle(-105^\circ - 120^\circ)$

$V_a = 1\angle 0^\circ = V^0_a + V^+_a + V^-_a = 0.195\angle 135^\circ + 1.311\angle 15^\circ + 0.494\angle -105^\circ$

$V_b = 1\angle -90^\circ = V^0_b + V^+_b + V^-_b = V^0_a + \alpha^2 V^+_a + \alpha V^-_a$

$= 0.195\angle 135^\circ + 1.311\angle(15^\circ - 120^\circ) + 0.494\angle(-105^\circ + 120^\circ)$

$V_c = 2\angle 135^\circ = V^0_c + V^+_c + V^-_c = V^0_a + \alpha V^+_a + \alpha^2 V^-_a$

$= 0.195\angle 135^\circ + 1.311\angle(15^\circ + 120^\circ) + 0.494\angle(-105^\circ + 240^\circ)$

Ex13.2 Finding symmetrical components of single line-to-ground faults currents

Fault current: $I^f = [I_{af}\ I_{bf}\ I_{cf}] = [I^f\ \ 0\ \ 0]$

$A^{-1} = (1/3)\ [1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$,

$[I^0_{af}\ \ I^+_{af}\ \ I^-_{af}\ ] = A^{-1}\ [I^f\ \ 0\ \ 0] = (I^f/3)[1\ \ 1\ \ 1]$,

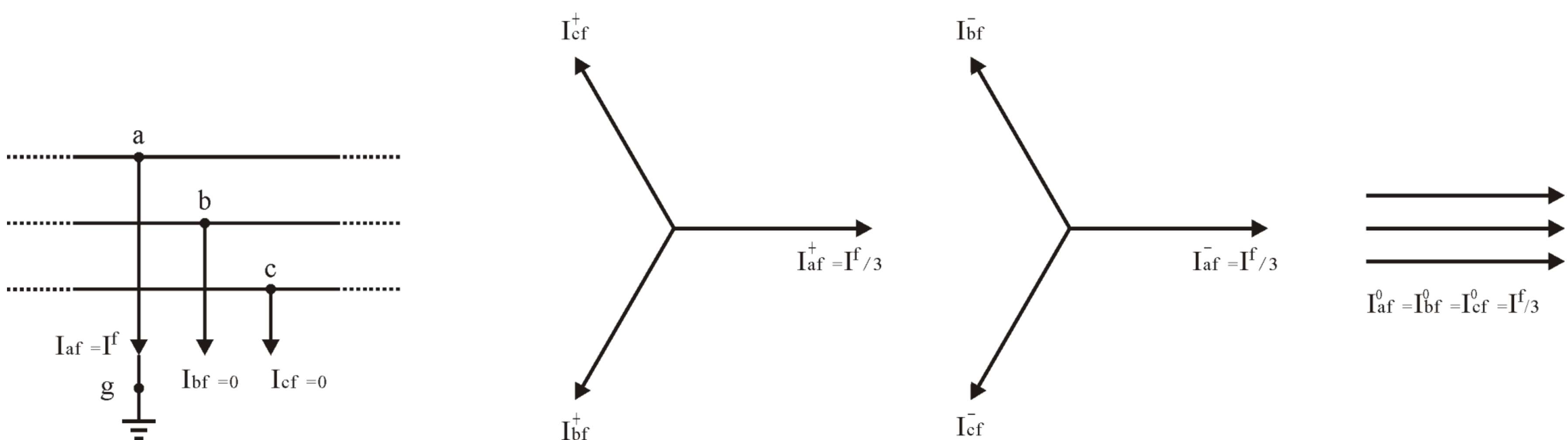
$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$

(13.5) $[I_{af}\ I_{bf}\ I_{cf}] = A[I^0_{af}\ I^+_{af}\ I^-_{af}\ ]$, (13.6) $A = [1\ 1\ 1; 1\ \alpha^2\ \alpha;\ 1\ \alpha\ \alpha^2]$

$I_{af} = I^0_{af} + I^+_{af} + I^-_{af} = I^f$,

$I_{bf} = I^0_{bf} + I^+_{bf} + I^-_{bf} = (I^f/3)[1\ \ \alpha^2\ \ \alpha] = 0$,

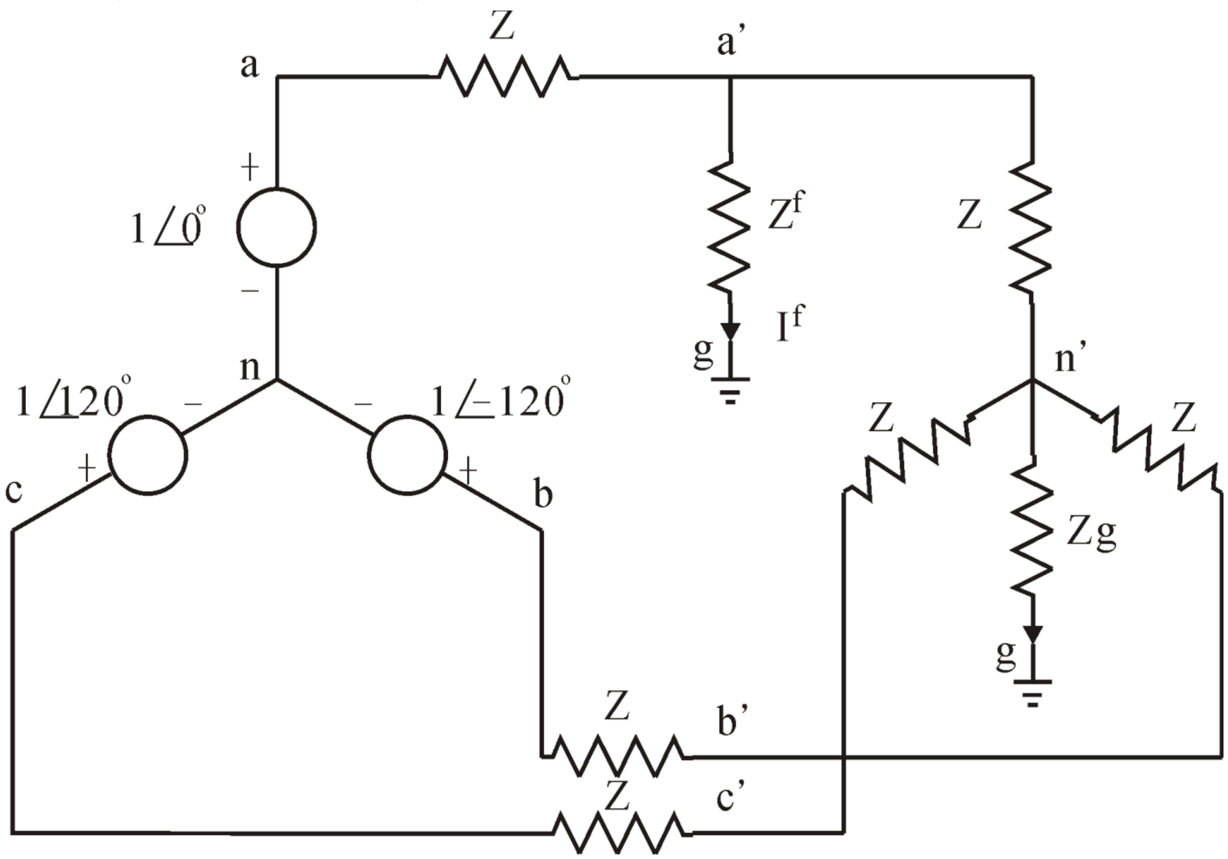
$I_{cf} = I^0_{cf} + I^+_{cf} + I^-_{cf} = (I^f/3)[1\ \ \alpha\ \ \alpha^2] = 0$,



13.2使用對稱分量做故障分析(Use of Symmetrical Components for Fault Analysis)

Find the fault current, can not solve the problem by per phase analysis because the faulted network does not have the required three-phase symmetry. We can replace the unbalanced fault current by the sum of a (3Φ) zero-sequence source, a (3Φ) positive-sequence source, and a (3Φ) negative-sequence source, and then using the principle of superposition.

Find $V_{a'g}$, $V_{b'g}$, $V_{c'g}$, and I^f. $V_{a'g} = Z^f I^f$. Voltage sources are positive sequence.



Single line-to-ground faults currents

(13.5) $[I_{af}\ I_{bf}\ I_{cf}]=A[I^0_{af}\ I^+_{af}\ I^-_{af}]$, (13.6) $A=[1\ 1\ 1;1\ \alpha^2\ \alpha;\ 1\ \alpha\ \alpha^2]$

Fault current: $I^f = [I_{af}\ I_{bf}\ I_{cf}] = [I^f\ \ 0\ \ 0]$, $I_{af} = I^0_{af} + I^+_{af} + I^-_{af} = I^f$,

$I_{bf} = I^0_{bf} + I^+_{bf} + I^-_{bf} = (I^f/3)[1\ \ \alpha^2\ \ \alpha]=0$, $I_{cf} = I^0_{cf} + I^+_{cf} + I^-_{cf} = (I^f/3)[1\ \ \alpha\ \ \alpha^2]=0$

$A^{-1} = (1/3)\ [1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$,

$$[I^0_{af}\ \ I^+_{af}\ \ I^-_{af}] = A^{-1}\ [I^f\ \ 0\ \ 0] = (I^f/3)[1\ \ 1\ \ 1]$$

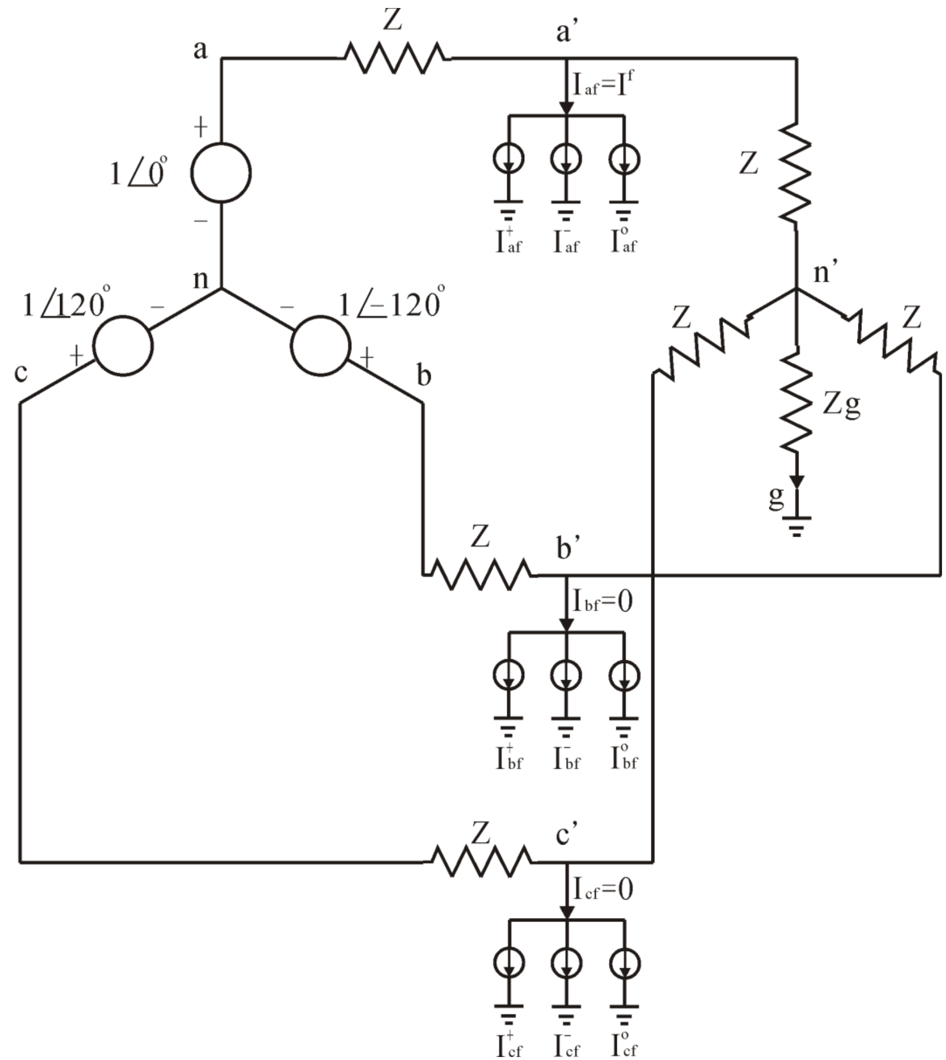
$$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$$

Using Superposition:

Positive Sequence

Negative Sequence

Zero Sequence



Single line-to-ground faults currents: Positive Sequence

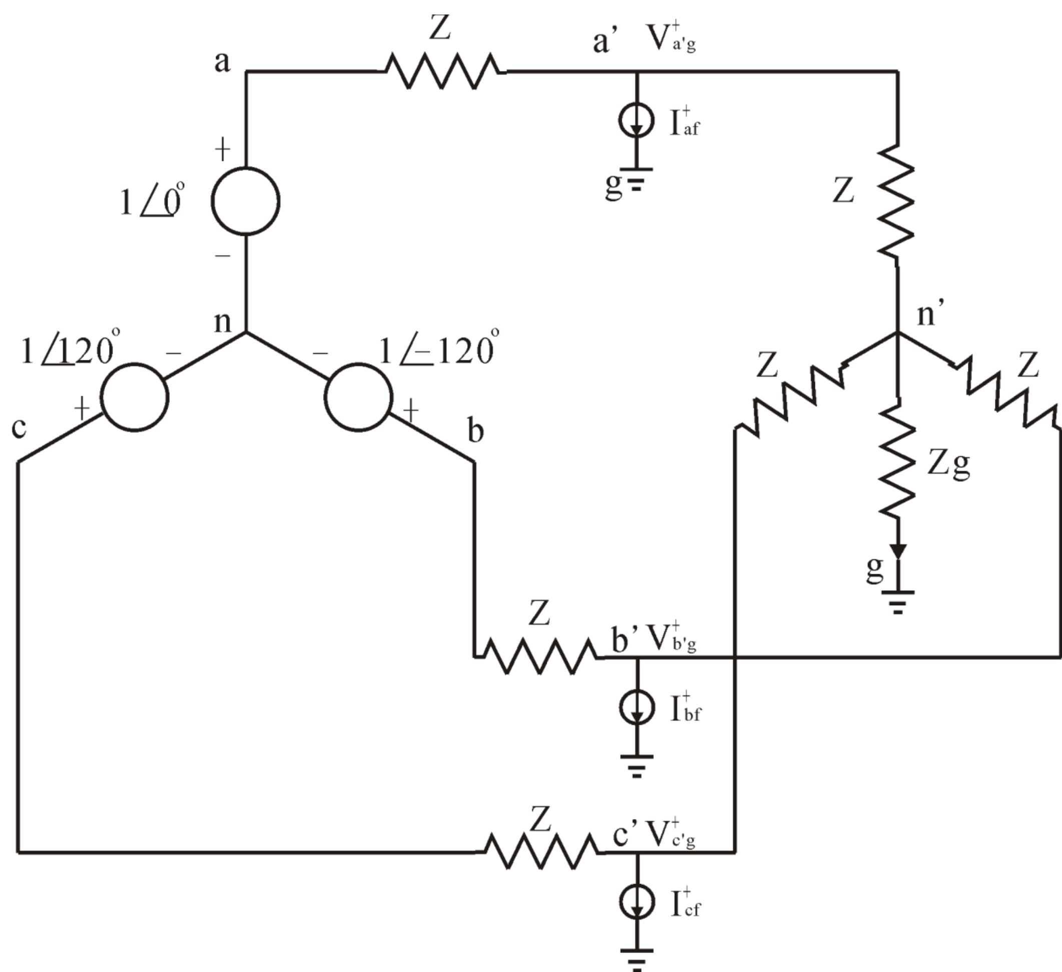
$A^{-1} = (1/3)\,[1\ \ 1\ \ 1;\ 1\ \ \alpha\ \ \alpha^2;\ 1\ \ \alpha^2\ \ \alpha]$,

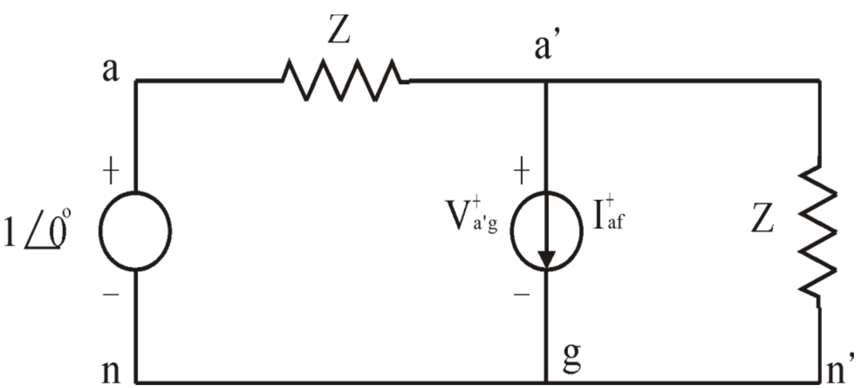
$[I^0_{af}\ \ I^+_{af}\ \ I^-_{af}] = A^{-1}\,[I^f\ \ 0\ \ 0] = (I^f/3)[1\ \ 1\ \ 1]$

$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$

Using Superposition:

$V^+_{a'g} = (1/2) - (1/2) Z I^+_{af}$,





Single line-to-ground faults currents: Negative Sequence

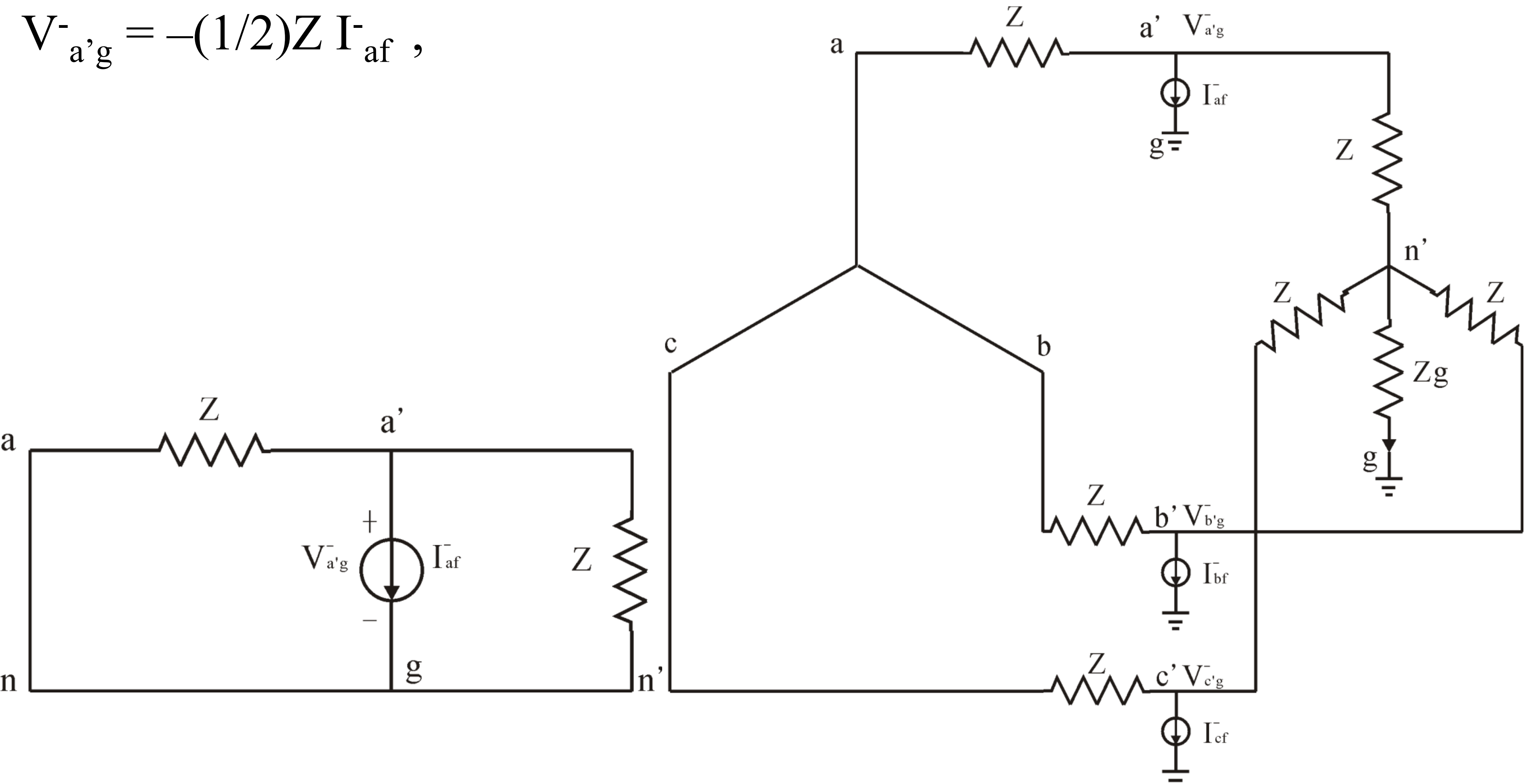
$A^{-1} = (1/3)\,[1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$,

$[I^0_{af}\ \ I^+_{af}\ \ I^-_{af}\,] = A^{-1}\,[I^f\ \ 0\ \ 0] = (I^f/3)[1\ \ 1\ \ 1]$

$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$

Using Superposition:

$V^-_{a'g} = -(1/2)Z\,I^-_{af}$,



Single line-to-ground faults currents: Zero Sequence

(For n) $I^0_a = I^0_b = I^0_c$, and $I^0_a + I^0_b + I^0_c = 0$, => $I^0_a = I^0_b = I^0_c = 0$

(For n') $I^0_{a'} = I^0_{b'} = I^0_{c'}$,

$A^{-1} = (1/3)\ [1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$,

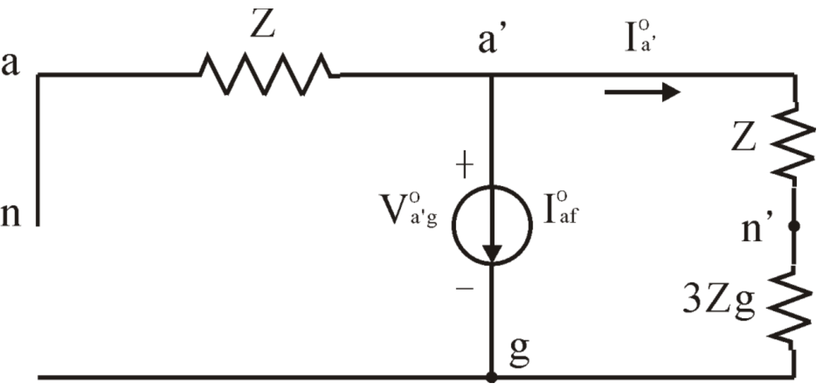
$[I^0_{af}\ \ I^+_{af}\ \ I^-_{af}] = A^{-1}\ [I^f\ \ 0\ \ 0] = (I^f/3)[1\ \ 1\ \ 1]$

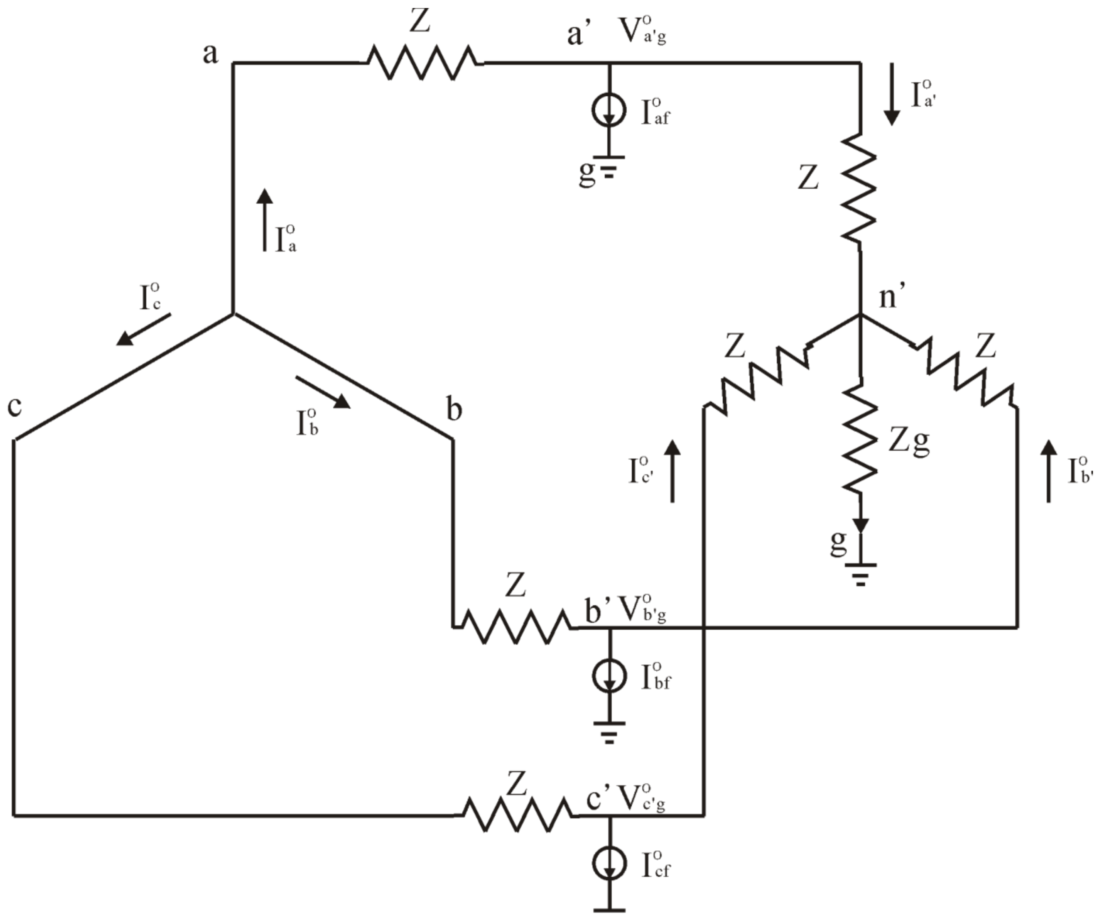
$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$

(For a'-n'-g)($n \neq n' \neq g$)

$V^0_{a'g} = ZI^0_{a'} + 3Z_g\ I^0_{a'}$,

$I^0_{a'} = -I^0_{af}$





Single line-to-ground faults currents: Superposition

$I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3),\ I^0_{a'} = -\, I^0_{af}\,,$

$V_{a'g} = V^+_{a'g} + V^-_{a'g} + V^0_{a'g} = (0.5 - 0.5Z\, I^+_{af}) + (-0.5Z\, I^-_{af}) + (ZI^0_{a'} + 3Z_g\, I^0_{a'})$

$\quad = (0.5 - 0.5Z\, I^f/3) + (-0.5Z\, I^f/3) + (-ZI^f/3 - 3Z_g\, I^f/3)$

$\quad = 0.5 - (2/3)Z\, I^f - Z_g\, I^f$

Because $V_{a'g} = Z^f I^f$, $(= 0.5 - (2/3)Z\, I^f - Z_g\, I^f)$,

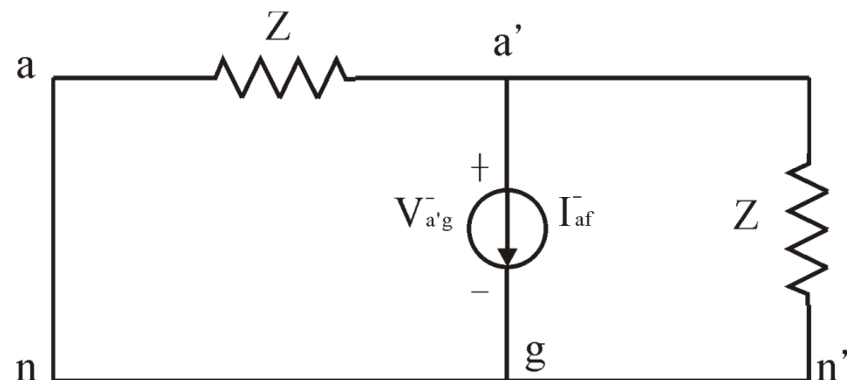
So $I^f = 0.5 / [Z^f + (2/3)Z + Z_g]$

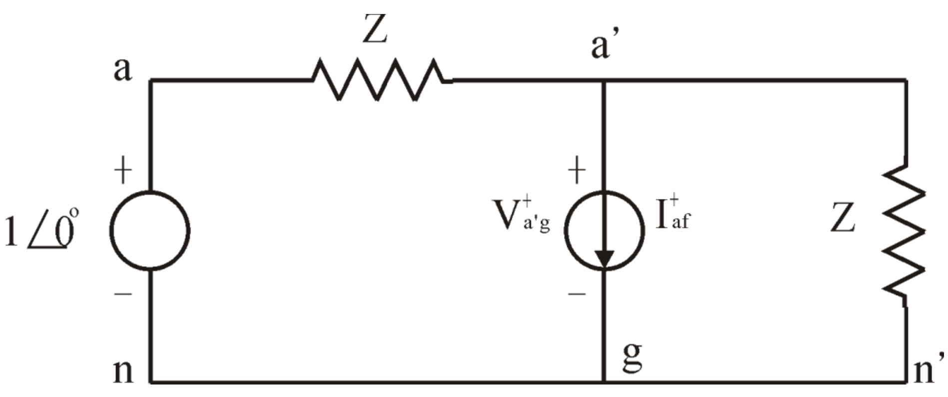
$V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g}$

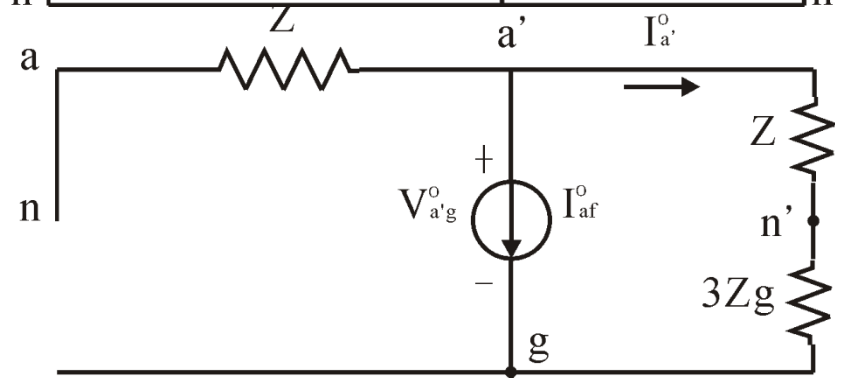
$V_{b'g} = V^0_{b'g} + V^+_{b'g} + V^-_{b'g}$

$V_{c'g} = V^0_{c'g} + V^+_{c'g} + V^-_{c'g}$

$[V_{a'g}\ V_{b'g}\ V_{c'g}] = A[V^0_{a'g}\ V^+_{a'g}\ V^-_{a'g}]$







13.3單線接地故障的序網路連接(Single Line-ground Fault Sequence Networks)

(13.13) $V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g}$

(13.16) $I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$,

(13.17) $V_{a'g} = Z^f I^f = (3Z^f)(I^f/3)$

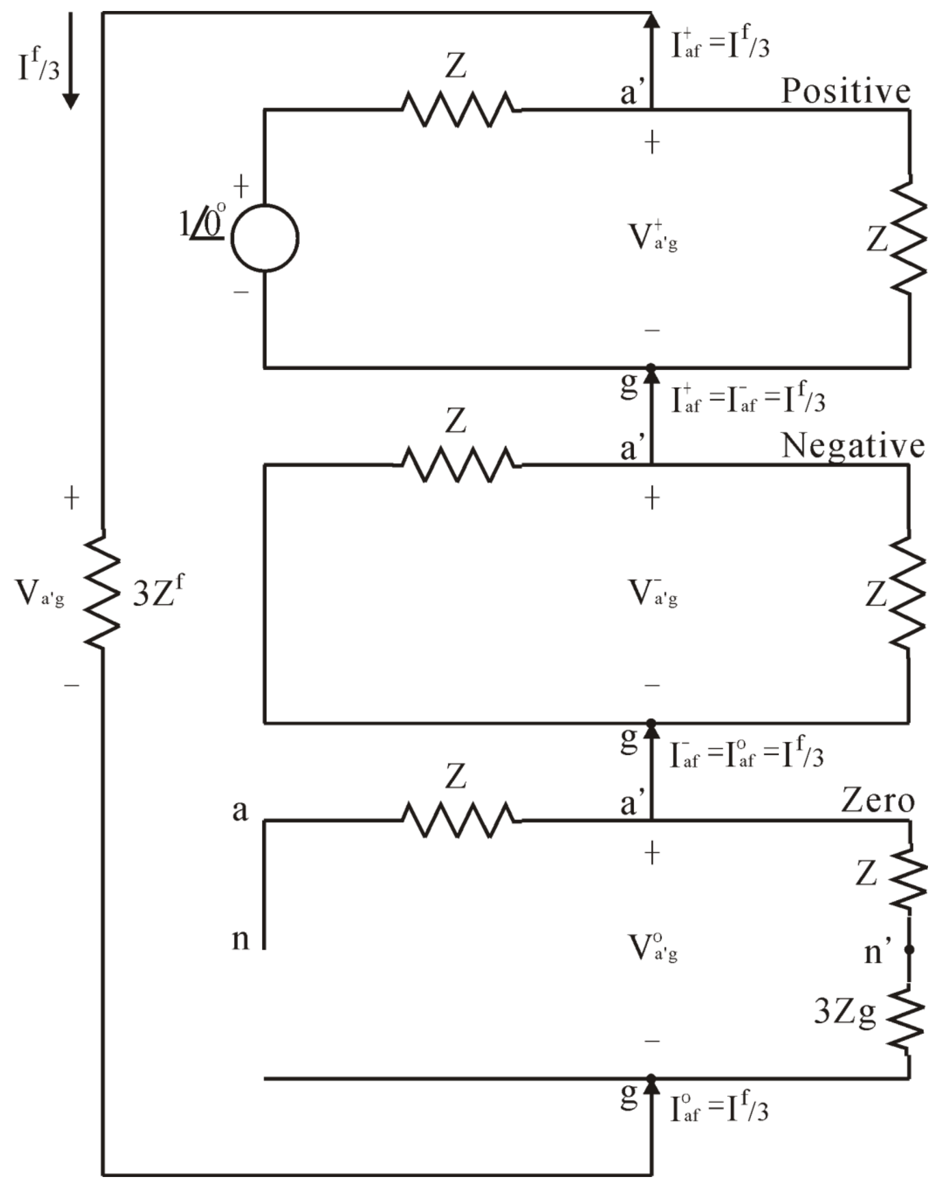
In Positive and Negative Sequence

(n = n' = g)

In Zero Sequence

(n ≠ n' ≠ g)

If $Z^f = \infty \Rightarrow I^f = 0$, No Fault



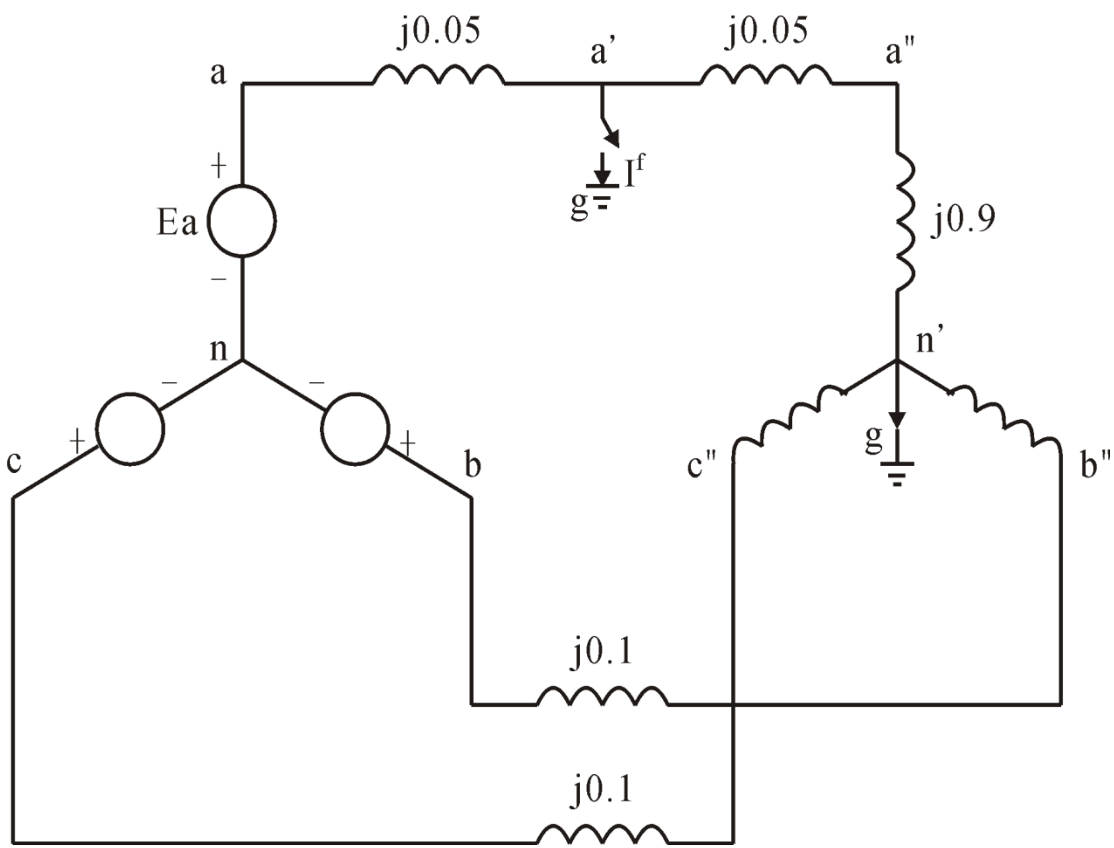
Ex13.3單線接地故障的序網路連接(Single Line-ground Fault Sequence Networks)

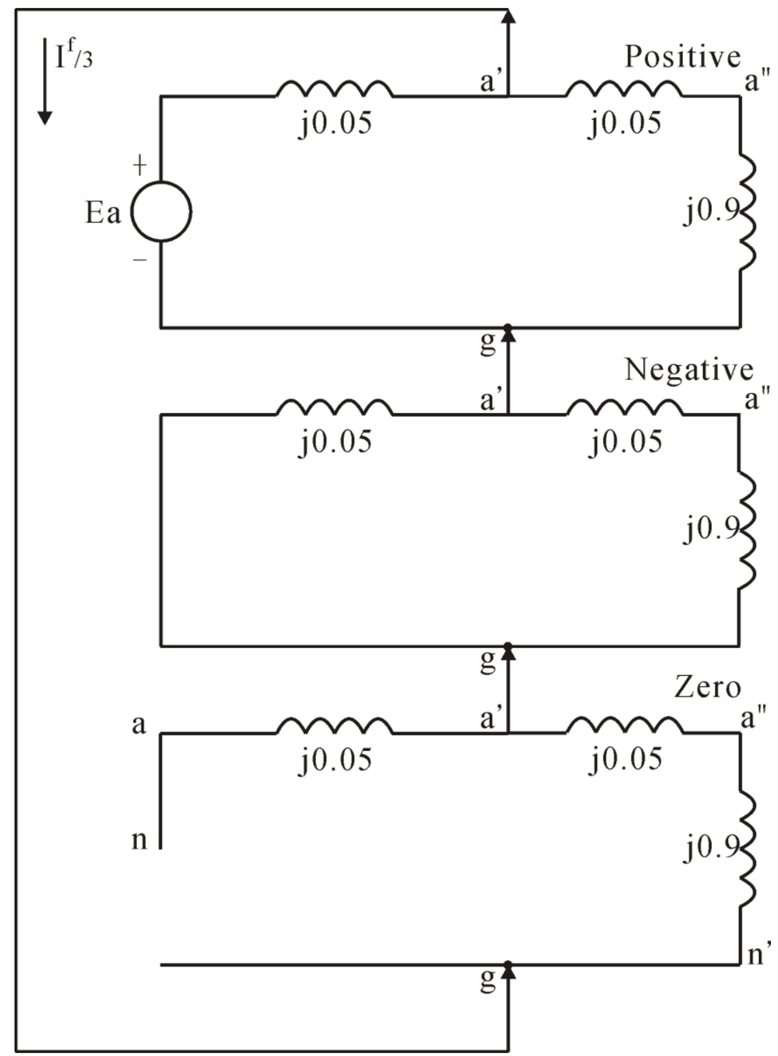
Series inductance X_L =j0.1 =j0.05 +j0.05, Before fault: $V_{a'n} = V_{a'g} = 1$,

After fault: Find I^f, $V_{a'g}$, $V_{a''g}$, and $V_{b''g}$.

(13.13) $V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g}$

(13.16) $I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$,





Ex13.3單線接地故障的序網路連接(Single Line-ground Fault Sequence Networks)(戴維寧定理 Thevenin's Theorem)

Series inductance X_L =j0.1 =j0.05 +j0.05, Before fault: $V_{a'n} = V_{a'g} = 1$,

After fault:Find I^f , $V_{a'g}$, $V_{a''g}$, and $V_{b''g}$

(13.13) $V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g}$

(13.16) $I^+_{af} = I^-_{af} = I^0_{af} = (I^f/3)$,

$(j0.05 \times j0.95)/(j0.05+j0.95) = j0.0475$

$I^f/3 = 1\angle 0^\circ/(j0.0475 + j0.0475 + j0.95)$

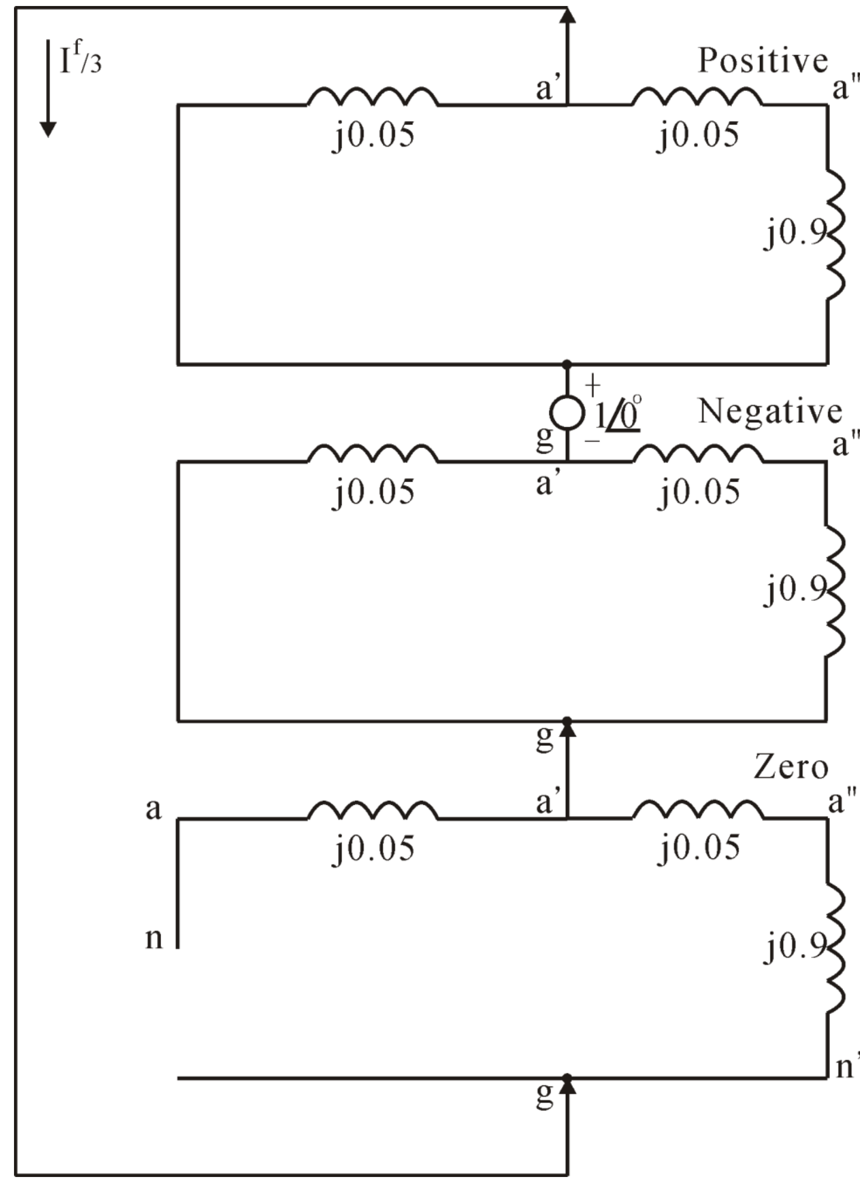
$= -j0.957 \Rightarrow I^f = -j2.87$

$V^+_{a'g} = 1 + j0.957 \times j0.0475 = 0.9545$

$V^-_{a'g} = j0.957 \times j0.0475 = -0.0455$

$V^0_{a'g} = j0.957 \times j0.95 = -0.9091$

$V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g} = 0$



Ex13.3單線接地故障的序網路連接(Single Line-ground Fault Sequence Networks)

$I^f/3 = 1\angle 0^\circ/(j0.0475+j0.0475+j0.95)$

$= -j0.957 \Rightarrow I^f = -j2.87$

$V^+_{a'g} = 1+j0.957\times j0.0475 = 0.9545$

$V^-_{a'g} = j0.957\times j0.0475 = -0.0455$

$V^0_{a'g} = j0.957\times j0.95 = -0.9091$

$V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g} = 0$

$V^+_{a''g} = (0.9/0.95)V^+_{a'g} = 0.9043$

$V^-_{a''g} = (0.9/0.95)V^-_{a'g} = -0.0431$

$V^0_{a''g} = (0.9/0.95)V^0_{a'g} = -0.8612$

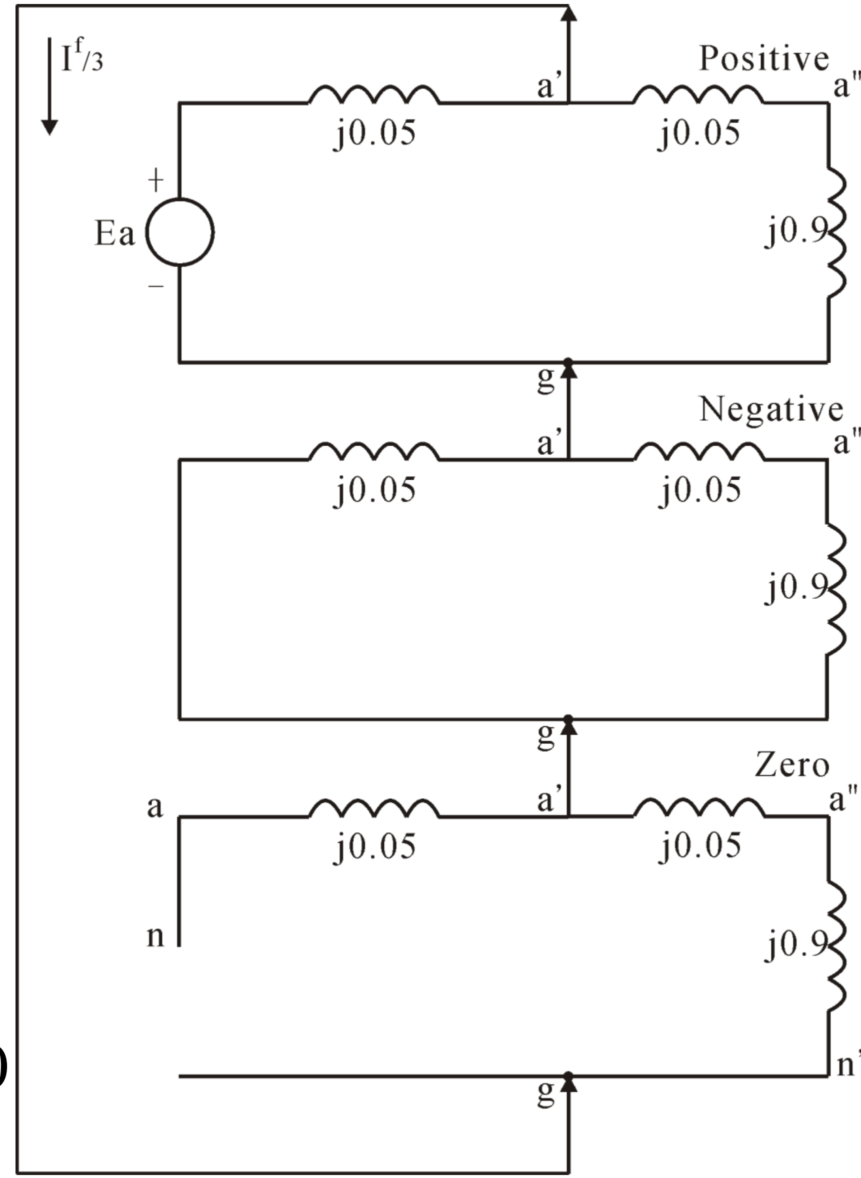
$V_{a''g} = V^0_{a''g} + V^+_{a''g} + V^-_{a''g} = 0$

$V_{b''g} = V^0_{b''g} + V^+_{b''g} + V^-_{b''g}$

$= V^0_{a''g} + \alpha^2 V^+_{a''g} + \alpha V^-_{a''g}$

$= -0.8613+0.9043\angle -120^\circ -0.0431\angle 120$

$= 1.77 \angle -136.8^\circ$



(13.26) $S_{3\Phi} = 3(V^0_{a''g} I^0_a{}^* + V^+_{a''g} I^+_a{}^* + V^-_{a''g} I^-_a{}^*) = 3[V^0_{a''g}(V^0_{a''g}/j0.9)^* + V^+_{a''g}(V^+_{a''g}/j0.9)^* + V^-_{a''g}(V^-_{a''g}/j0.9)^*]$

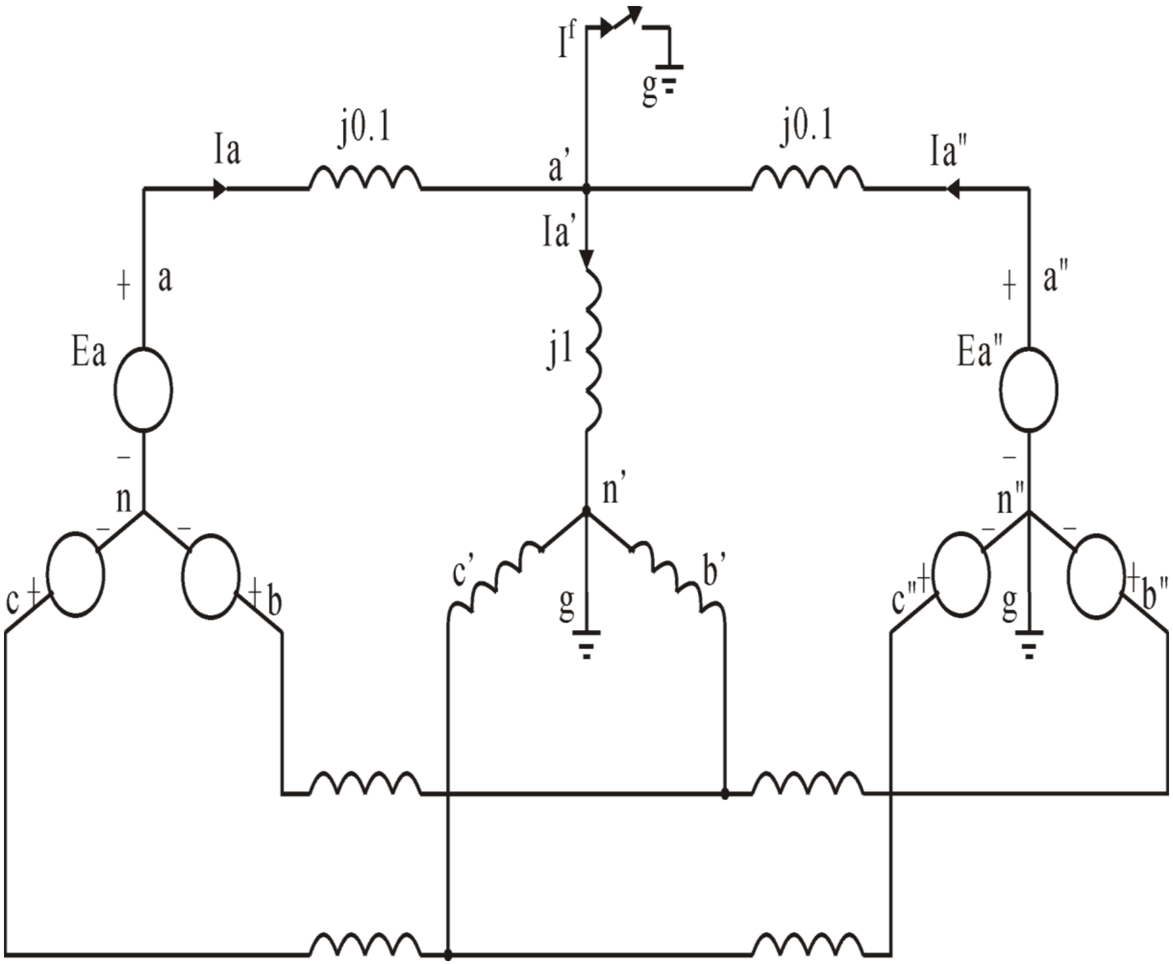
$= (3/-j0.9)[(0.9043)^2 + (0.0431)^2 + (0.8613)^2] = j5.2$

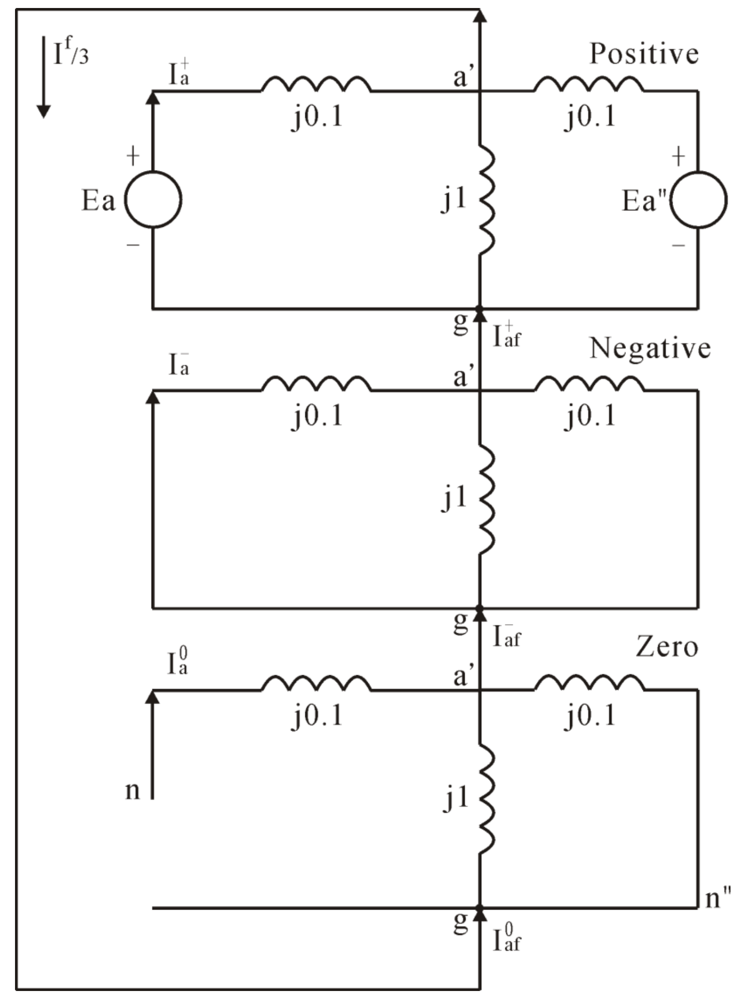
13.4使用角形網路做故障計算(Ex13.4Before fault: $I_a=1$, $I_{a'}=-j$, $I_{a''}=-1-j$, $V_{a'n}=V_{a'g}=1$, Find these value after fault, and find I^f, I_b, and $V_{b'g}$)

使用戴維寧定理 Thevenin's Theorem

$1/j0.0476 = 1/j0.1 + 1/j0.1 + 1/j$; $j0.0909 = (j \times j0.1)/(j + j0.1)$

$I^f/3 = 1\angle 0^\circ/(j0.0476 + j0.0476 + j0.0909) = -j5.372 \Rightarrow I^f = -j16.116$





Ex13.4 Before fault: $I^{pf}_{a}=1$, $I^{pf}_{a'} = -j$, $I^{pf}_{a''} = -1-j$, $V_{a'n} = V_{a'g} = 1$, Find these value after fault, and find I^f , I_b , and $V_{b'g}$)

使用戴維寧定理 Thevenin's Theorem

$1/j0.0476 = 1/j0.1 + 1/j0.1 + 1/j$; $j0.0909 = (j \times j0.1)/(j + j0.1)$

$I^f/3 = 1\angle 0^\circ/(j0.0476+ j0.0476+j0.0909) = -j5.372 \Rightarrow I^f = -j16.116$

$\Delta I^0_a = 0$, $\Delta I^+_a = \Delta I^-_a = (j0.0476/j0.1)(-j5.372) = -j2.558$

$\Delta I_a = \Delta I^0_a + \Delta I^+_a + \Delta I^-_a = -j5.116$

$\Delta I^+_{a''} = \Delta I^-_{a''} = (j0.0476/j0.1)(-j5.372) = -j2.558$

$\Delta I^0_{a''} = (j0.0909/j0.1)(-j5.372) = -j4.884$

$\Delta I_{a''} = \Delta I^0_{a''} + \Delta I^+_{a''} + \Delta I^-_{a''} = -j10$

$\Delta I^+_{a'} = \Delta I^-_{a'} = -(j0.0476/j1)(-j5.372) = j0.2558$

$\Delta I^0_{a'} = -(j0.0909/j1)(-j5.372) = j0.4884$

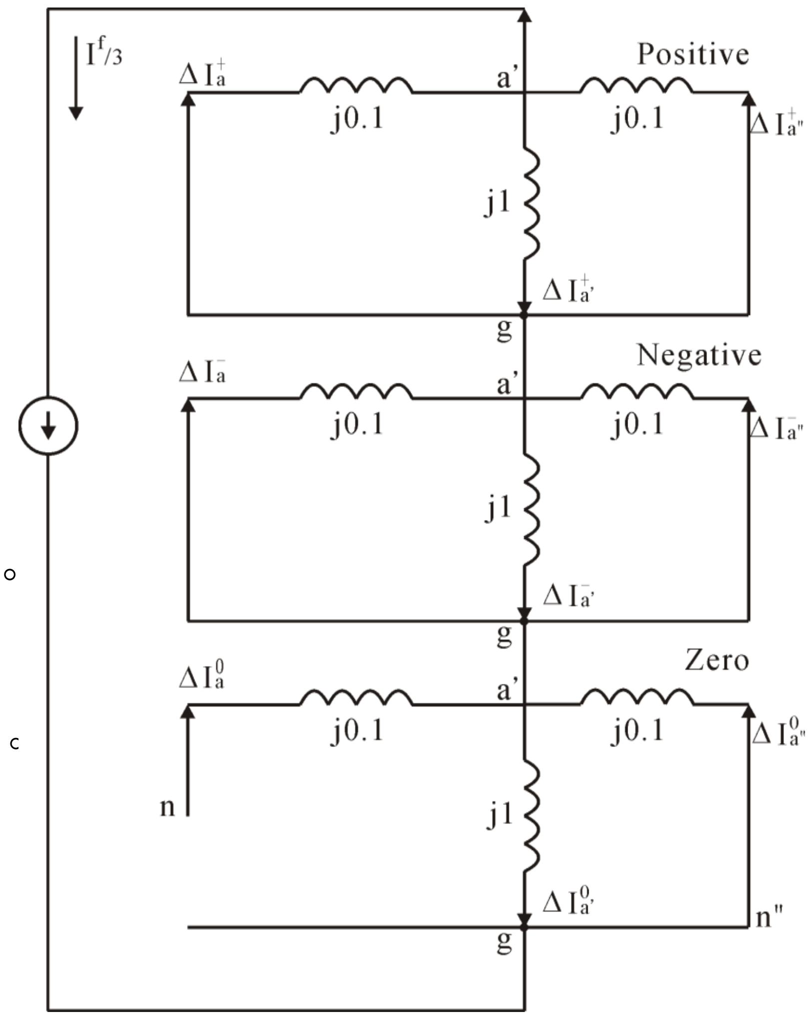
$\Delta I_{a'} = \Delta I^0_{a'} + \Delta I^+_{a'} + \Delta I^-_{a'} = j$

$I_a = I^{pf}_a + \Delta I_a = 1-j5.116 = 5.2128\angle -78.94^\circ$

$I_{a'} = I^{pf}_{a'} + \Delta I_{a'} = -j+j = 0$

$I_{a''} = I^{pf}_{a''} + \Delta I_{a''} = -1-j-j10 = 11.0454\angle -95.19^\circ$

$I^f = I_a - I_{a'} + I_{a''} = -j16.116$



Ex13.4 Before fault: $I^{pf}_{a}=1$, $I^{pf}_{a'} = -j$, $I^{pf}_{a''} = -1-j$, $V^{pf}_{a'n} = V^{pf}_{a'g} = 1$, Find these value after fault, and find I^{f} , I_b , and $V_{b'g}$)

$1/j0.0476 = 1/j0.1 + 1/j0.1 + 1/j$; $j0.0909 = (j \times j0.1)/(j + j0.1)$

$I^f/3 = 1\angle 0^\circ/(j0.0476 + j0.0476 + j0.0909) = -j5.372 \Rightarrow I^f = -j16.116$

$\Delta I^0_a = 0 = \Delta I^0_b$, $\Delta I^+_a = \Delta I^-_a = (j0.0476/j0.1)(-j5.372) = -j2.558$

$\Delta I^+_b = \Delta I^+_a \angle -120^\circ$, $\Delta I^-_b = \Delta I^-_a \angle 120^\circ$

$\Delta I_b = \Delta I^0_b + \Delta I^+_b + \Delta I^-_b$

$I_b = I^{pf}_b + \Delta I_b = 1.76\angle 106.5^\circ$

$= 1\angle -120^\circ - j2.558(1\angle -120^\circ + 1\angle 120^\circ)$

$V^{pf}_{b'g} = V^{pf}_{a'g} \angle -120^\circ = 1\angle -120^\circ$

$\Delta V_{b'g} = \Delta V^0_{b'g} + \Delta V^+_{b'g} + \Delta V^-_{b'g}$

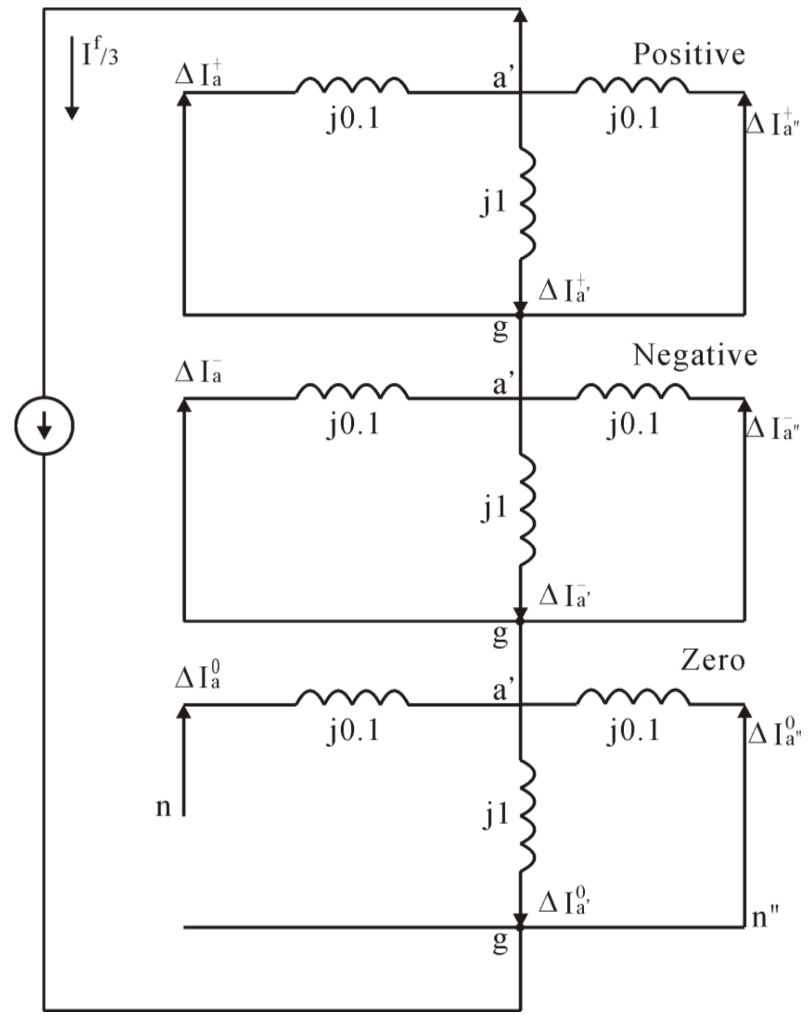
$\Delta V^0_{b'g} = \Delta V^0_{a'g} = j0.0909 \times j5.372 = -0.4883$

$\Delta V^+_{a'g} = \Delta V^-_{a'g} = j0.0476 \times j5.372 = -0.2557$

$V_{a'g} = V^{pf}_{a'g} + \Delta V_{a'g} = 0$

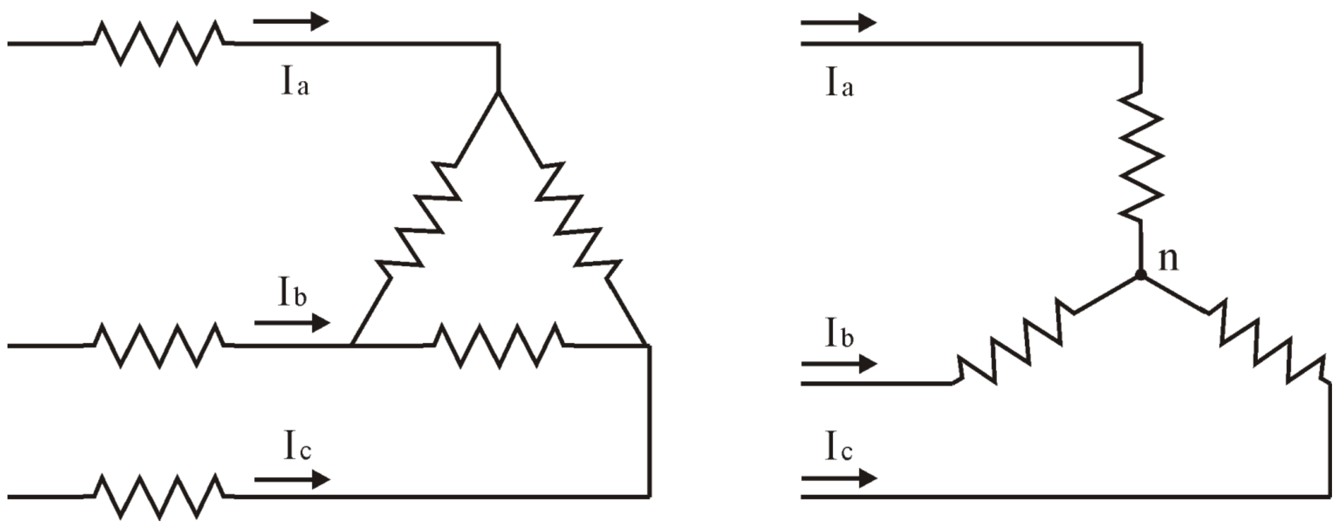
$V_{b'g} = V^{pf}_{b'g} + \Delta V_{b'g} = 1.134\angle -130^\circ$

$= 1\angle -120^\circ - 0.4883 - 0.2557(1\angle -120^\circ + 1\angle 120^\circ)$



13.5零序網路(Zero Sequence Networks)

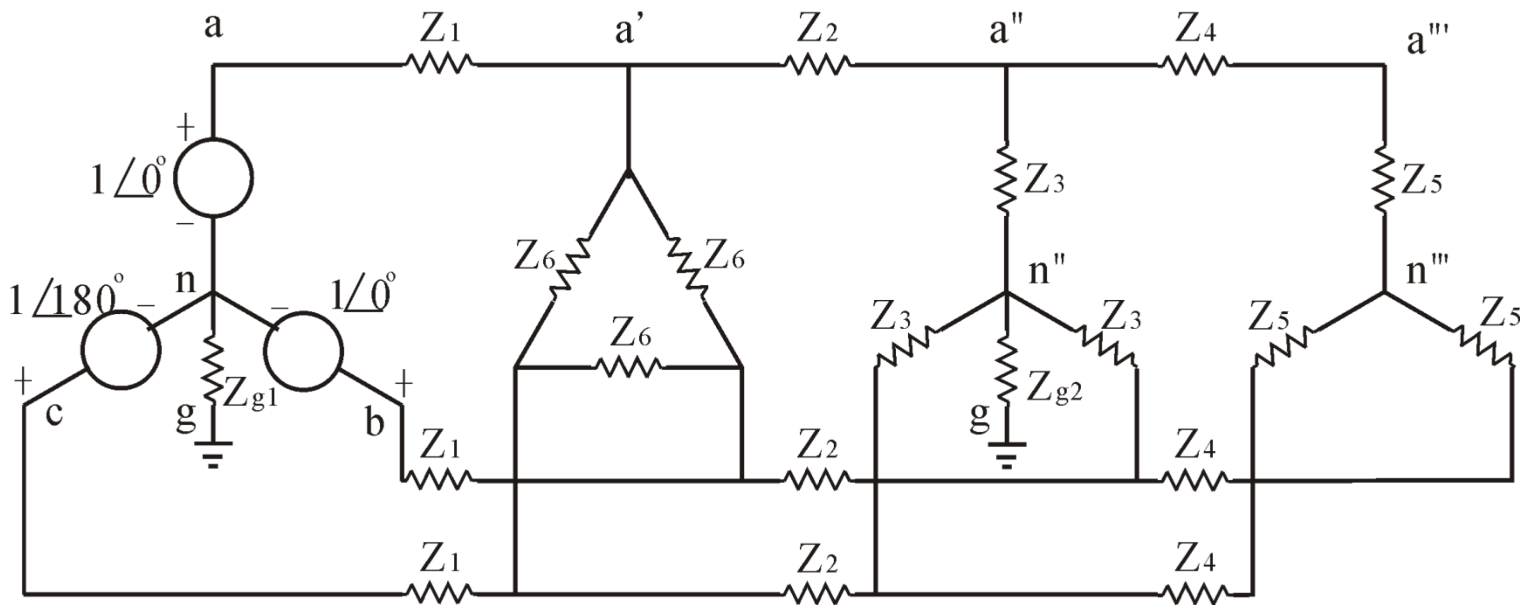
Delta or Y type networks without ground connected and then without zero Sequence current.

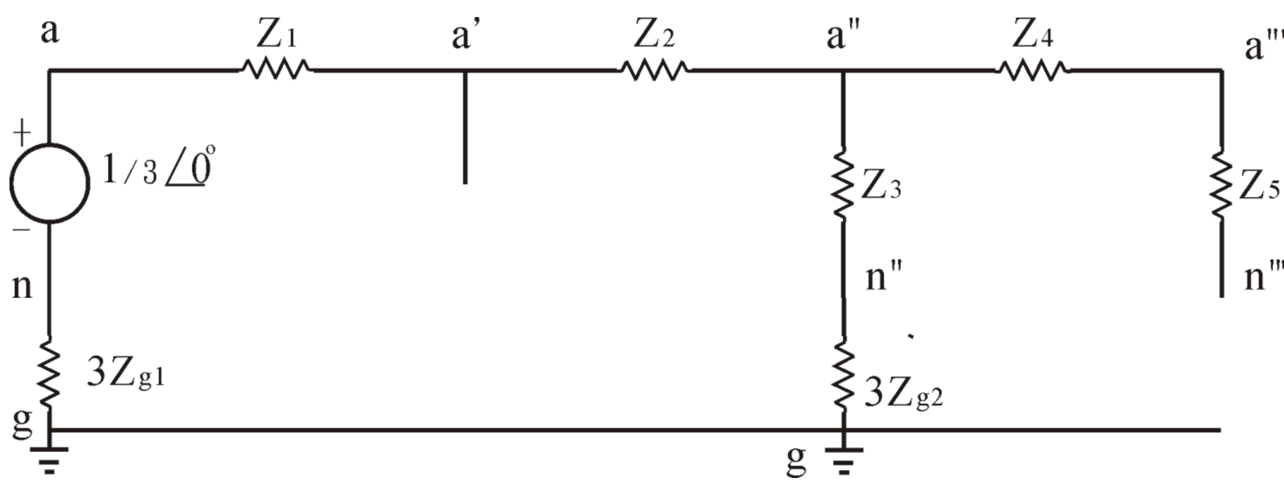


Ex 13.5找零序網路(Find zero sequence networks)

Unbalanced voltage sources:

$E^0_{an} = E^0_{bn} = E^0_{cn} = (1\angle 0^\circ + 1\angle 0^\circ + 1\angle 180^\circ)/3 = (1/3)\angle 0^\circ$





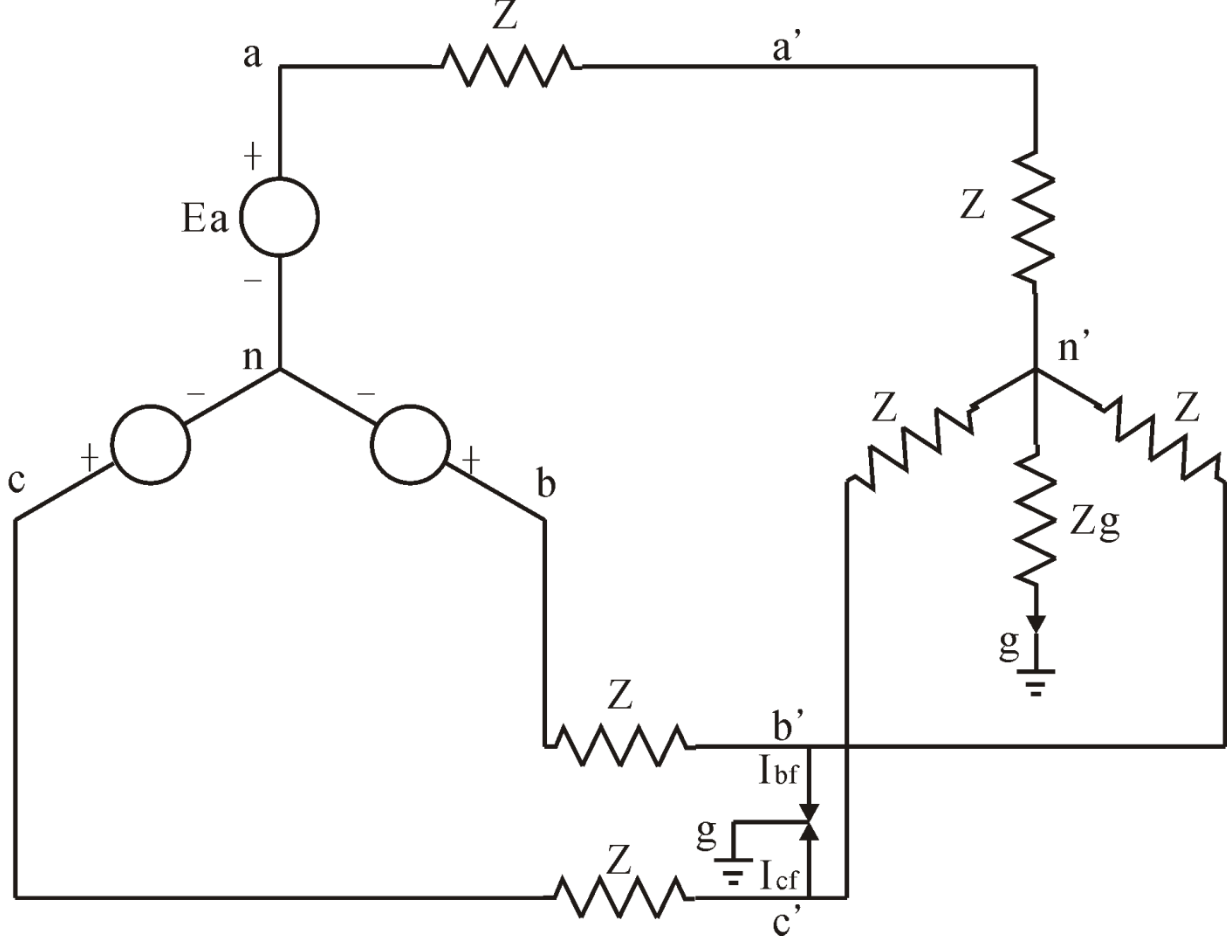
13.6雙線接地故障的序網路連接(Double Line-ground Fault Sequence Networks)

DLG Fault : $I_{af}=0$, $I_{bf}\neq 0$, $I_{cf}\neq 0$, $V_{b'g}=0$, $V_{c'g}=0$

Define $\alpha=e^{j2\pi/3}=1\angle 120^{\circ}$,$\alpha^2=e^{j4\pi/3}=1\angle 240^{\circ}=1\angle -120^{\circ}$

$A^{-1}=(1/3)\,[1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$, $[V^0_{a'g}\ V^+_{a'g}\ V^-_{a'g}]=A^{-1}\,[V_{a'g}\ \ 0\ \ 0]$

(13.18) $V^0_{a'g}=V^+_{a'g}=V^-_{a'g}$, (13.19) $I_{af}=I^0_{af}+I^+_{af}+I^-_{af}=0$,



13.6雙線接地故障的序網路連接(Double Line-ground Fault Sequence Networks)($V^0_{a'g} = V^0_{ag} = V^0_{ng} = V^0_{bg} = V^0_{cg}$)

DLG Fault : $I_{af}=0$, $I_{bf}\neq 0$, $I_{cf}\neq 0$, $V_{b'g}=0$, $V_{c'g}=0$,$\alpha=e^{j2\pi/3}=1\angle 120^\circ$,

$A^{-1} = (1/3)\ [1\ 1\ 1;\ 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$, $[V^0_{a'g}\ V^+_{a'g}\ V^-_{a'g}] = A^{-1}\ [V_{a'g}\ \ 0\ \ 0]$

(13.18) $V^0_{a'g} = V^+_{a'g} = V^-_{a'g}$, (13.19) $I_{af} = I^0_{af} + I^+_{af} + I^-_{af} = 0$,

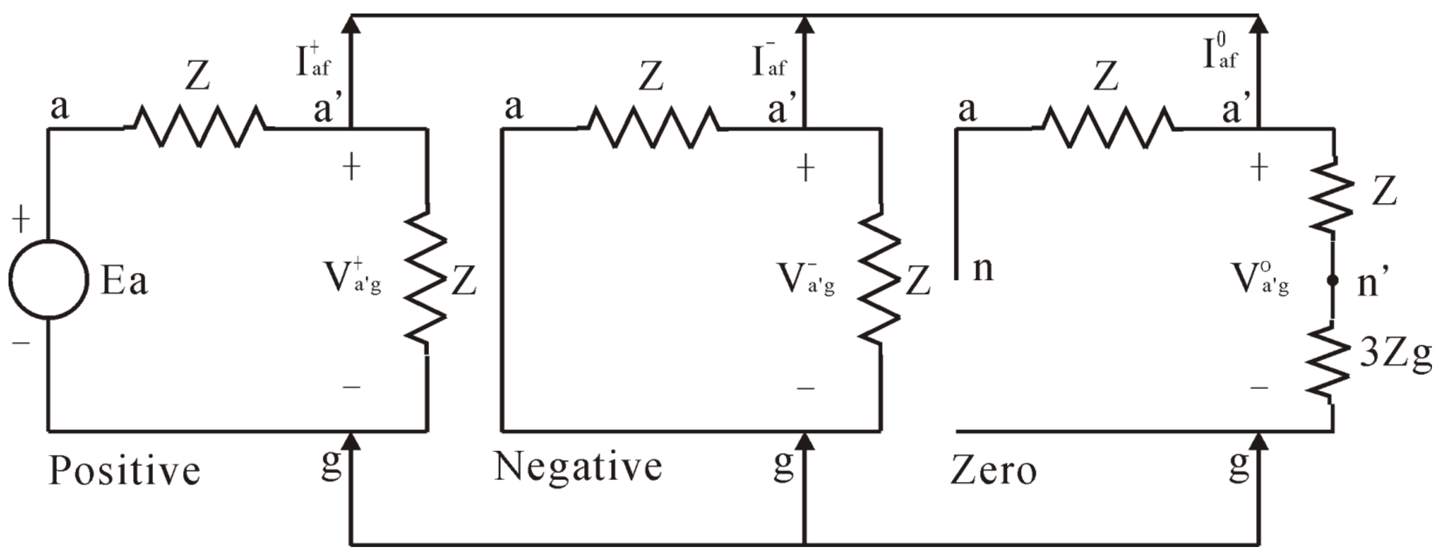
$I_{bf} = I^0_{bf} + I^+_{bf} + I^-_{bf} = I^0_{af} + \alpha^2 I^+_{af} + \alpha I^-_{af}$,

$I_{cf} = I^0_{cf} + I^+_{cf} + I^-_{cf} = I^0_{af} + \alpha I^+_{af} + \alpha^2 I^-_{af}$,

$V_{a'g} = V^0_{a'g} + V^+_{a'g} + V^-_{a'g} = 3V^+_{a'g}$,

$V_{ag} = V^0_{ag} + V^+_{ag} + V^-_{ag} = V^0_{a'g} + E_a + 0$,

$V_{bg} = V^0_{bg} + V^+_{bg} + V^-_{bg} = V^0_{a'g} + E_a\angle -120^\circ + 0$,



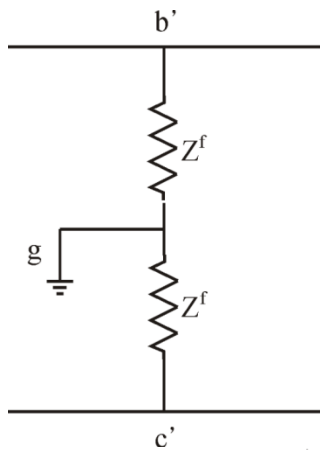
Ex 13.6雙線經電阻接地故障(Double Line-ground Fault with resistance)

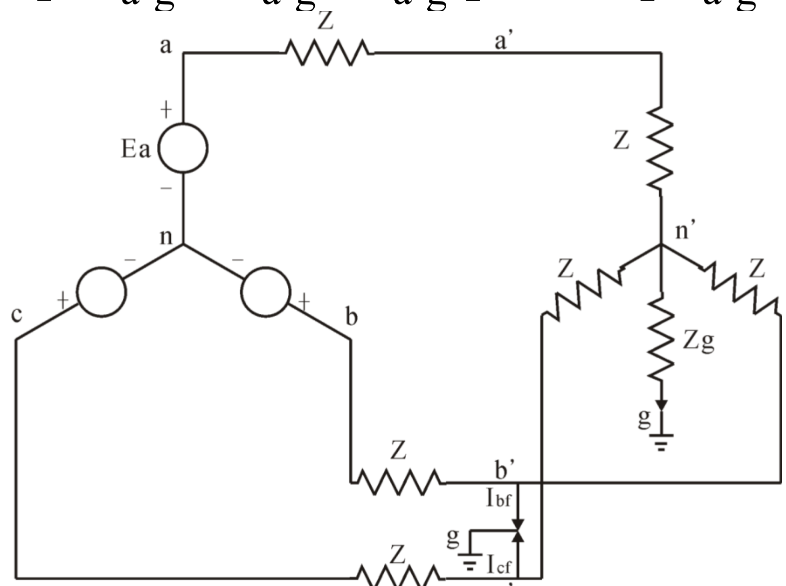
DLG Fault : $I_{af} = I_{a'f} = 0$, $I_{bf} \neq 0$, $I_{cf} \neq 0$, $V_{b'g} = I_{b'f} Z^f$, $V_{c'g} = I_{c'f} Z^f$

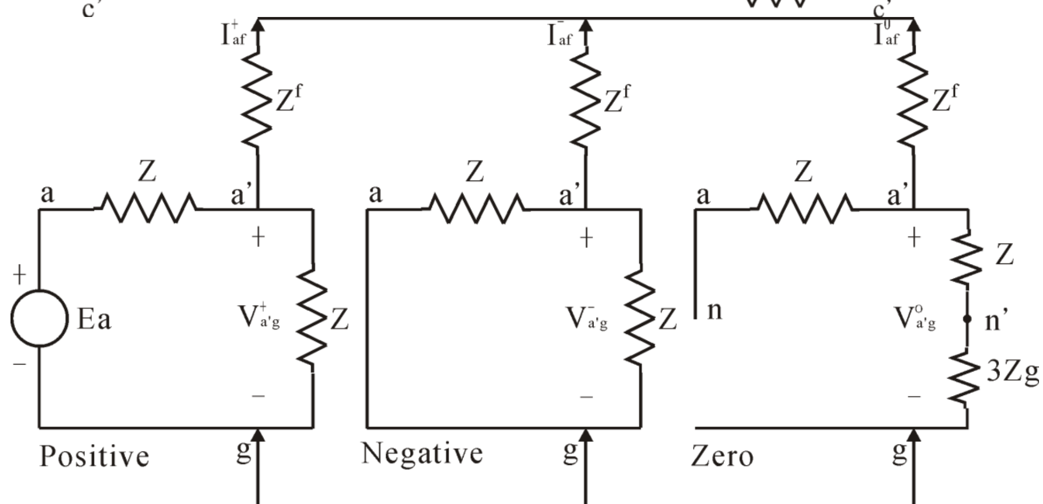
Define $\alpha = e^{j2\pi/3} = 1\angle 120^\circ$, $\alpha^2 = e^{j4\pi/3} = 1\angle 240^\circ = 1\angle -120^\circ$

$A^{-1} = (1/3)[1\ 1\ 1; 1\ \alpha\ \alpha^2;\ 1\ \alpha^2\ \alpha]$, $[V^0_{a'g}\ V^+_{a'g}\ V^-_{a'g}] = A^{-1}[V_{a'g}\ V_{b'g}\ V_{c'g}]$

(13.19) $I_{af} = I^0_{af} + I^+_{af} + I^-_{af} = 0$,







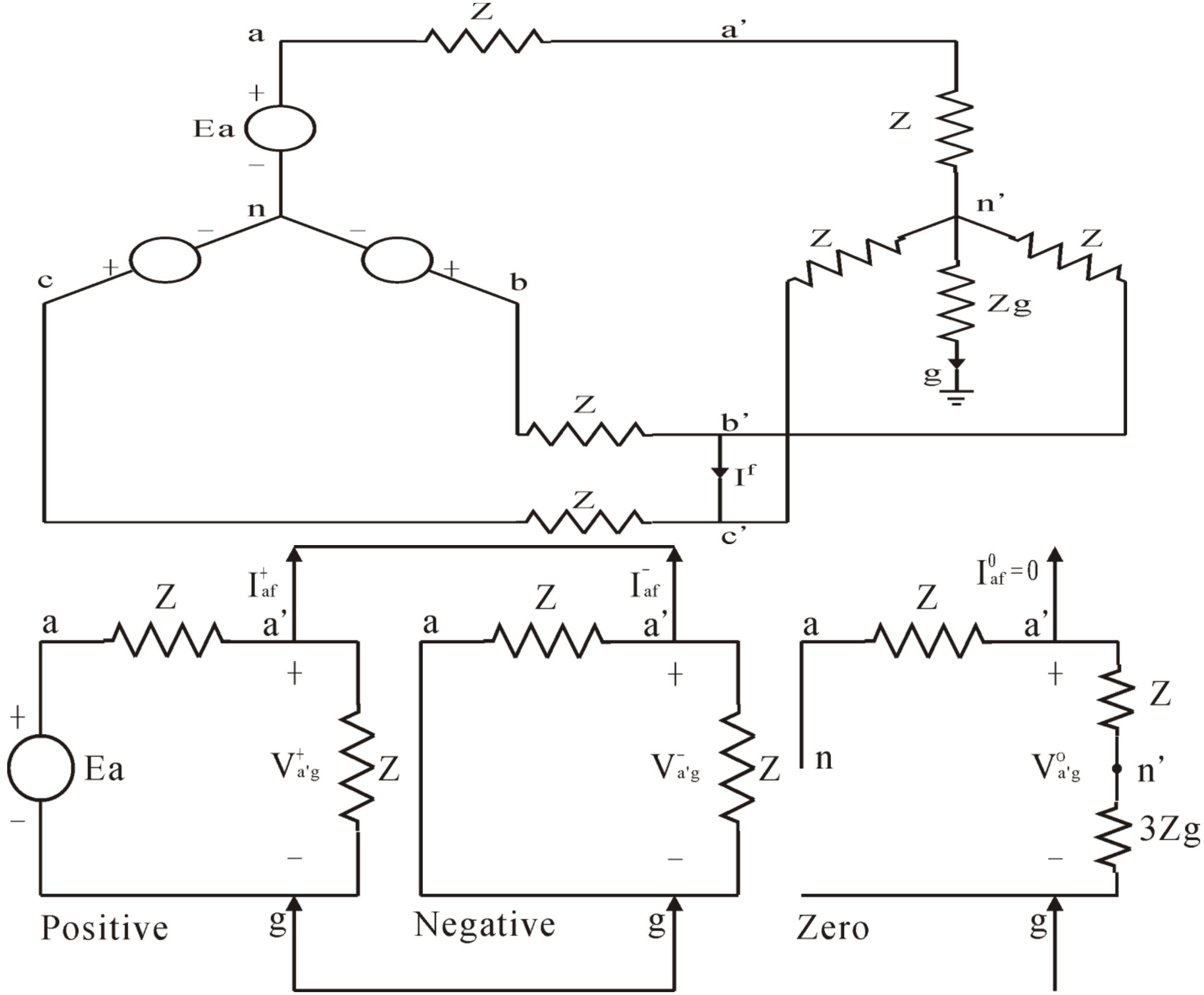
13.7線間故障的序網路連接(Sequence Networks Connections for Line-line Fault)

LL Fault : $I_{af} = I_{a'f} = 0$, $I_{bf} = I^f$, $I_{cf} = -I^f$, $V_{b'g} = V_{c'g}$

$\alpha = e^{j2\pi/3} = 1\angle 120^\circ$, $\alpha^2 = e^{j4\pi/3} = 1\angle 240^\circ$, $A^{-1} = (1/3)[1\ 1\ 1; 1\ \alpha\ \alpha^2; 1\ \alpha^2\ \alpha]$

$[V^0_{a'g}\ V^+_{a'g}\ V^-_{a'g}] = A^{-1}\,[V_{a'g}\ V_{b'g}\ V_{b'g}]$, (13.20) $V^+_{a'g} = V^-_{a'g}$,

$[I^0_{af}\ I^+_{af}\ I^-_{af}] = A^{-1}[I_{af}\ I_{bf}\ I_{cf}] = A^{-1}[0\ I^f\ -I^f]$,(13.21) $I^+_{af} = -I^-_{af} = jI^f/\sqrt{3}$, $I^0_{af} = 0 \Rightarrow V^0_{a'g} = 0$



13.8一般故障電路分析(More General Fault Circuit Analysis)

General Procedure

1. Find the positive-, negative-, and zero-sequence networks.
2. Attach terminal pairs at g and the point of fault.
3. Connect the networks in accordance with the type of fault.
4. Using circuit analysis, find the required a phase symmetrical components; using $[I^0_{af}\ I^+_{af}\ I^-_{af}]=A^{-1}[I_{af}\ I_{bf}\ I_{cf}]$, we find the corresponding triples of phase a, b, c variables.

A few comments on the general procedure follow.

a. Regarding item 1, we still need to introduce realistic models for generator, transformer, and transmission lines.

b. Regarding item 3, our catalog of faults covers the most important cases but is not extensive. More complete listings, inclding the case of open conductors, may be found in standard references.

c. Regarding item 4, for all but the simplest cases, circuit analysis will involve the use of the sequence network Z matrices.

d. In practice, certain simplifying assumptions are usually made.

13.9序變數的功率(Power from Sequence Variables)

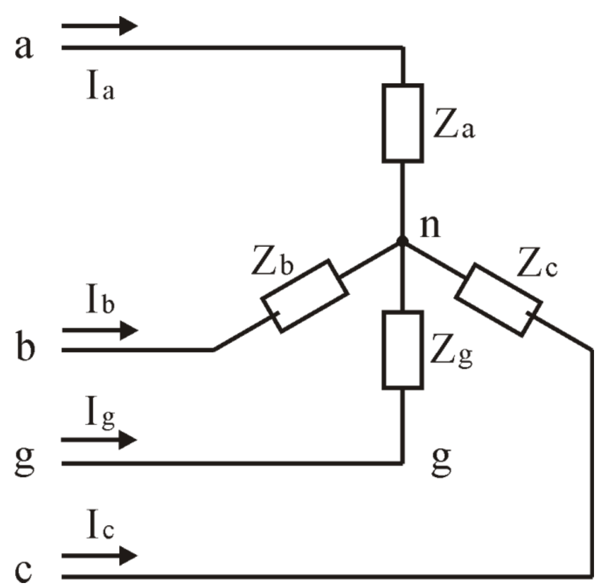
Balanced case with $V_{ag} = V_{an}$, (13.24) $S_{3\Phi} = 3V_{an}\, I^*_a$

Unbalanced case, (13.23) $S_{3\Phi} = V_{ag}\, I^*_a + V_{bg}\, I^*_b + V_{cg}\, I^*_c$

$I=[I_a \;\; I_b \;\; I_c]$, $V=[V_{ag} \;\; V_{bg} \;\; V_{cg}]$, (13.25) $S_{3\Phi} = I^*V$

Express I and V in terms of symmetrical components (A*A= 3 identity matrix),

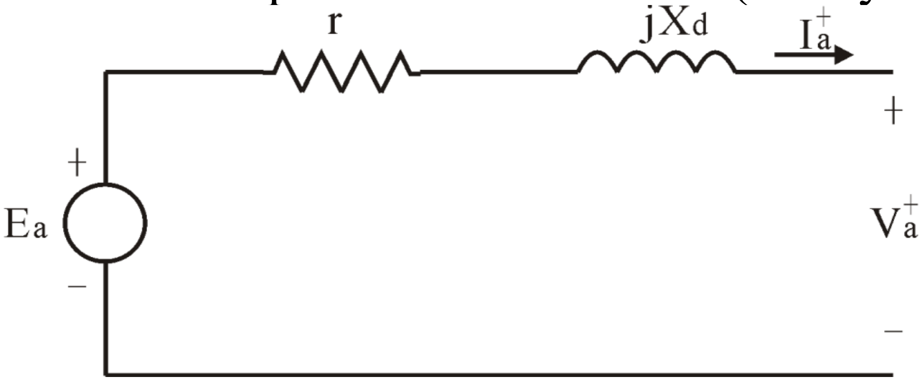
(13.26) $S_{3\Phi} =(AI_s)^*AV_s =I_s^*A^*AV_s=3I_s^*V_s =3(V^0_{ag}\, I^0_a{}^*+V^+_{ag}\, I^+_a{}^*+V^-_{ag}\, I^-_a{}^*)$

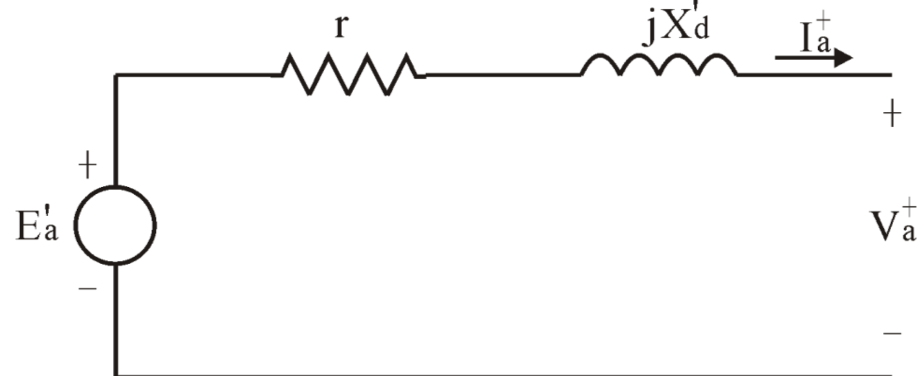


13.10序網路的發電機模型(Generator Models for Sequence Networks)

Positive Sequence Generator Model:

Positive Sequence Circuit Model (steady state) (transient)





Negative Sequence Generator Model ($jX^{-} = jX''_d$)

Zero Sequence Generator Model ($jX^0 = jX_l$)

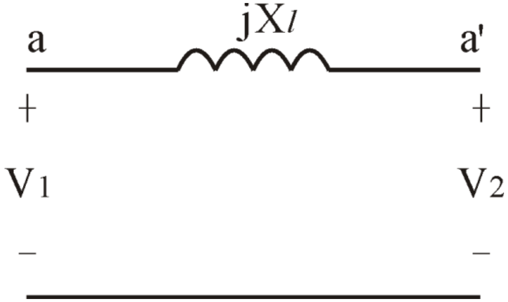
Table 13.1 Typical Synchronous Machine Reactances (Turbine-Generators two-pole)

	*Conventionally-cooled	Conductor-cooled	Salient-pole Generators with dampers
X_d	1.20	1.80	1.25
X_q	1.16	1.75	0.70
X'_d	0.15	0.30	0.30
X''_d	0.09	0.22	0.20
X^{-}	0.09	0.22	0.20
X^0	0.03	0.12	0.18

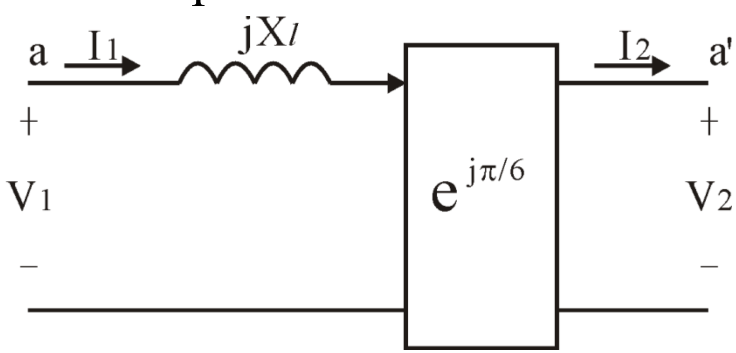
*Reactances are representative of smaller air-cooled and hydrogen-cooled machines

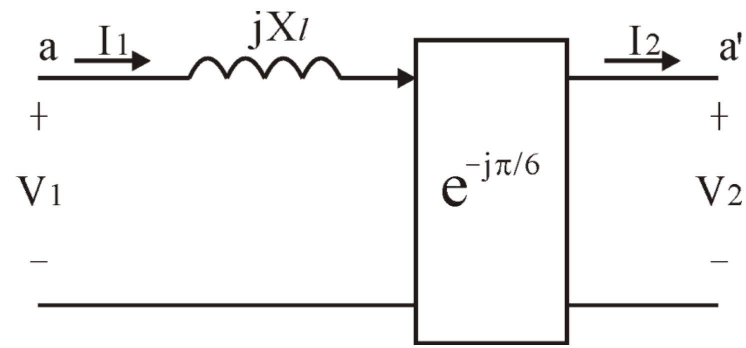
13.11序網路的變壓器模型(Transformer Models for Sequence Networks)

Positive- or negative-sequence simplified circuit of three-phase transformer bank

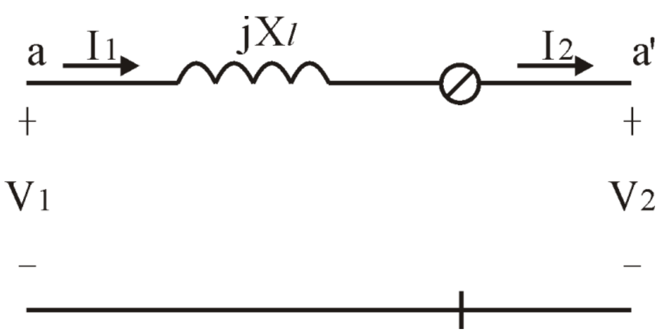


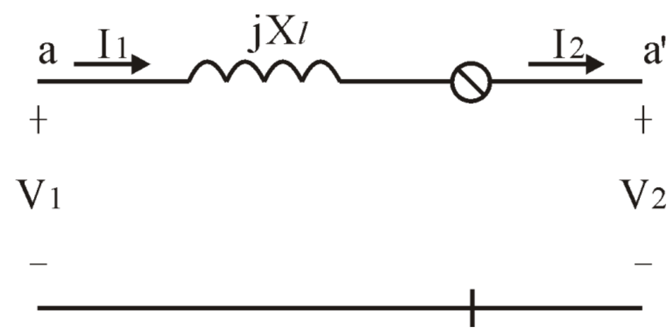
More complete circuit models



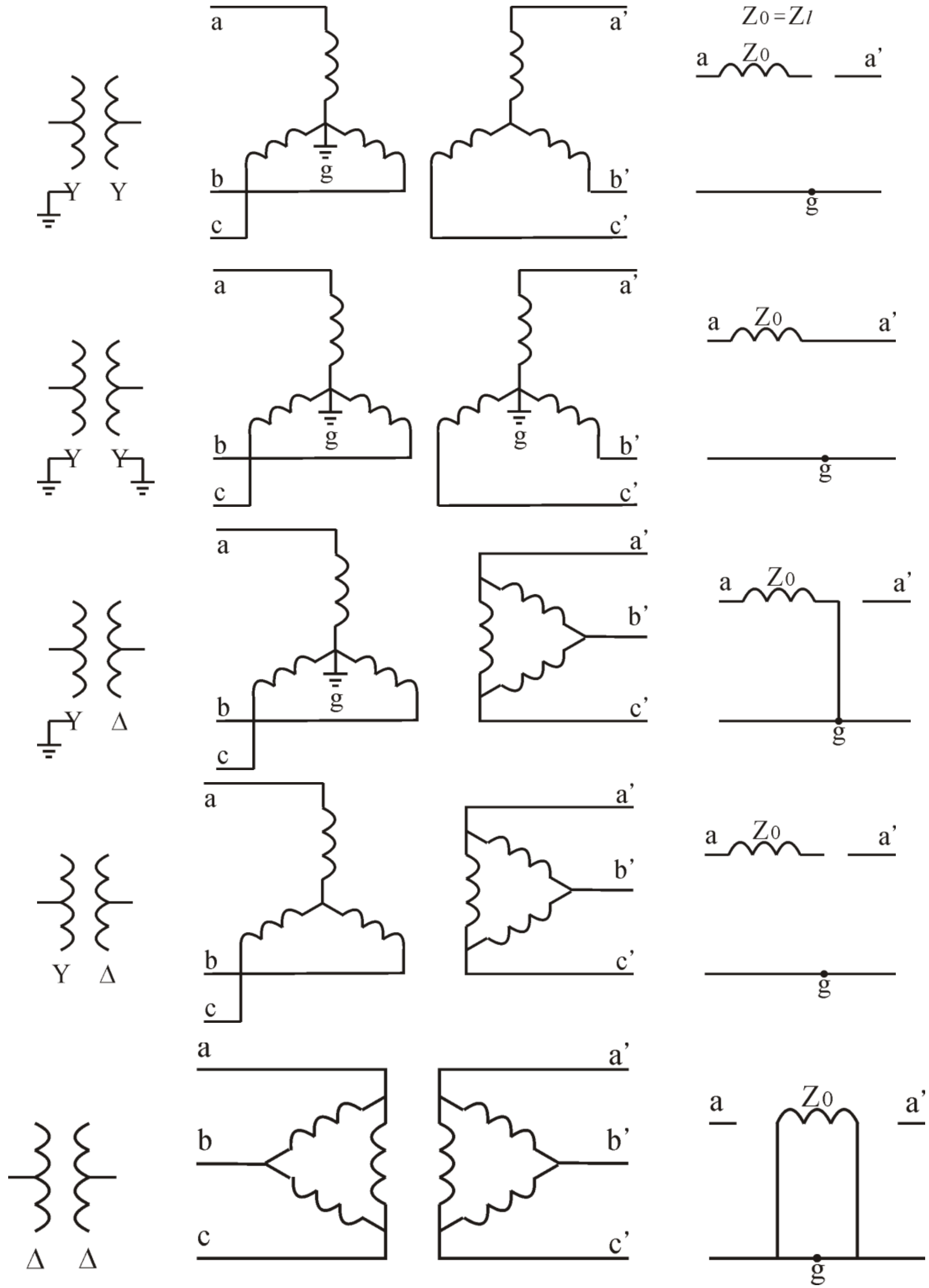


Positive-sequence circuit of Δ-Y or Y-Δ ; Negative-sequence circuit of Δ-Y or Y-Δ





零序等效電路(Zero Sequence Equivalent Circuit)



Ex13.7零序等效電路(Zero Sequence Equivalent Circuit)

$V_{2a} = V_{2b} = V_{2c} = 0$ => Primary side voltages are zero => $Va = jX_l I^0_a$

$V_a = jX_l I^0_a + (n1/n2)\, V_{2a}$

$V_b = jX_l I^0_b + (n1/n2)\, V_{2b}$

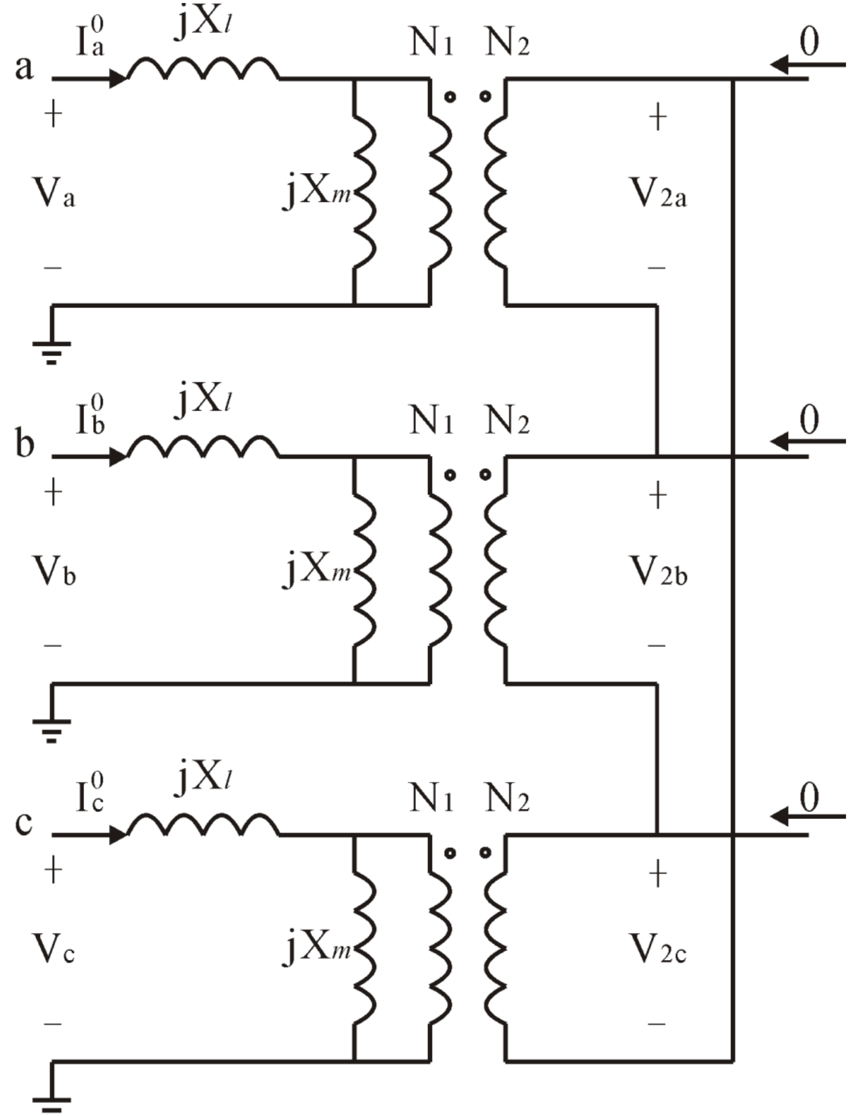
$V_c = jX_l I^0_c + (n1/n2)\, V_{2c}$

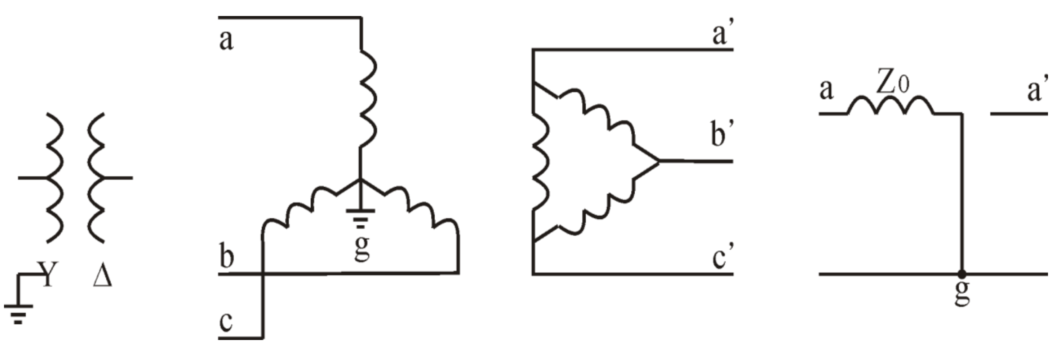
$V^0_a = (V_a + V_b + V_c)/3 = jX_l I^0_a$

$I^0_a = I^0_b = I^0_c$, $V_{2a} + V_{2b} + V_{2c} = 0$

Looking in from the left, the zero sequence impedance is $Z^0 = jX_l$.

Looking in from the right, we see an open circuit because there is no return Path for the zero sequence currents.





13.12序網路的輸電線模型(Sequence Representation of Transmission Line)

Single phase transmission line impedance : $Z_L = R_L + jX_L$, $R_L = 0$

Balanced case: $i_a + i_b + i_c = 0$, Unbalanced case: $i_a + i_b + i_c \neq 0$,

Ex13.8 Calculating zero sequence impedance

$i_r = i^0_a + i^0_b + i^0_c = 3i^0_a$

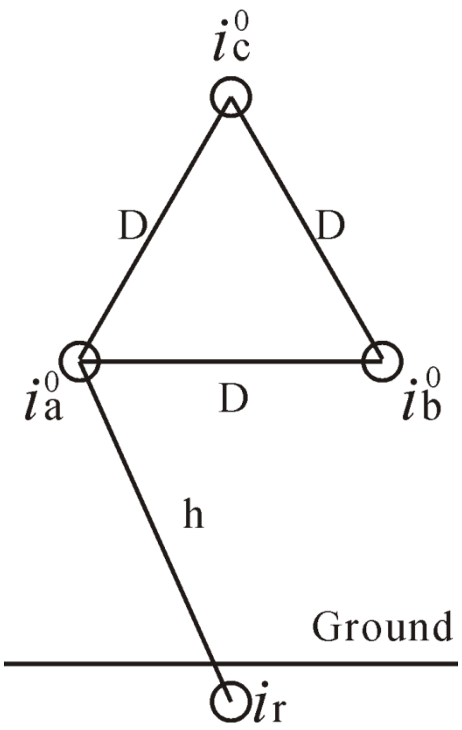
$l^0_a = \lambda^0_a / i^0_a = (\mu_0 /2\pi)[\ln(1/r') + \ln(1/d) + \ln(1/d) - 3\ln(1/h)]$

$= (\mu_0 /2\pi) \ln(h^3 / r'd^2) = (\mu_0 /2\pi) \ln(dh^3 / r'd^3)$

$= (\mu_0 /2\pi) [\ln(d/r') + 3\ln(h /d)]$

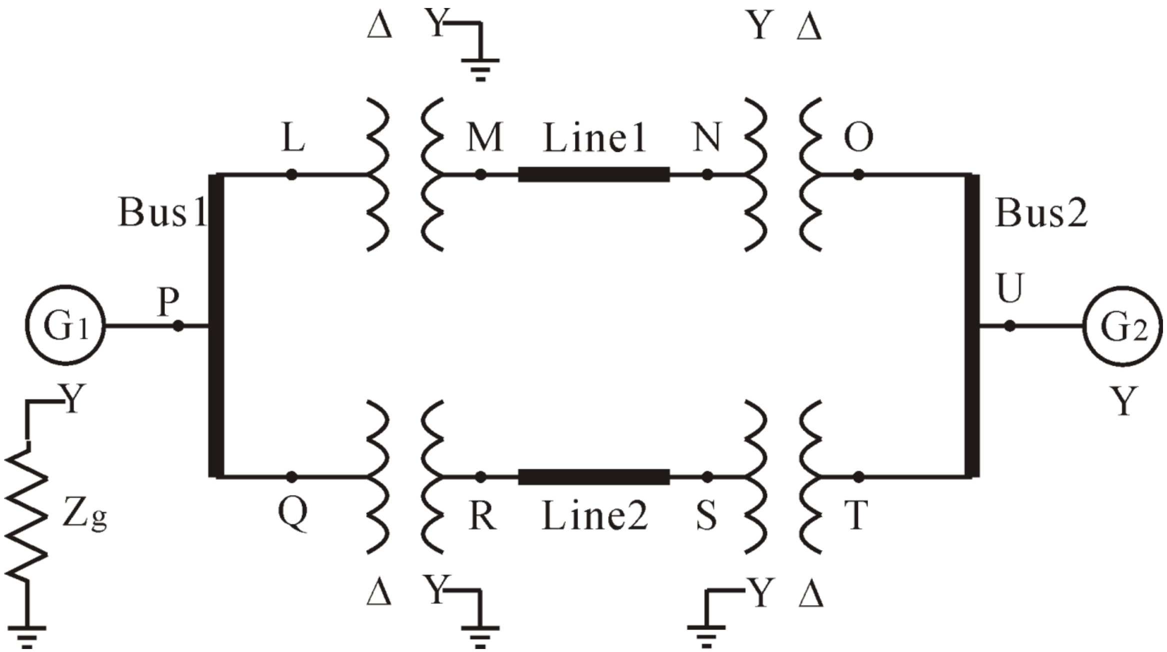
Balanced Positive or Negative Sequence

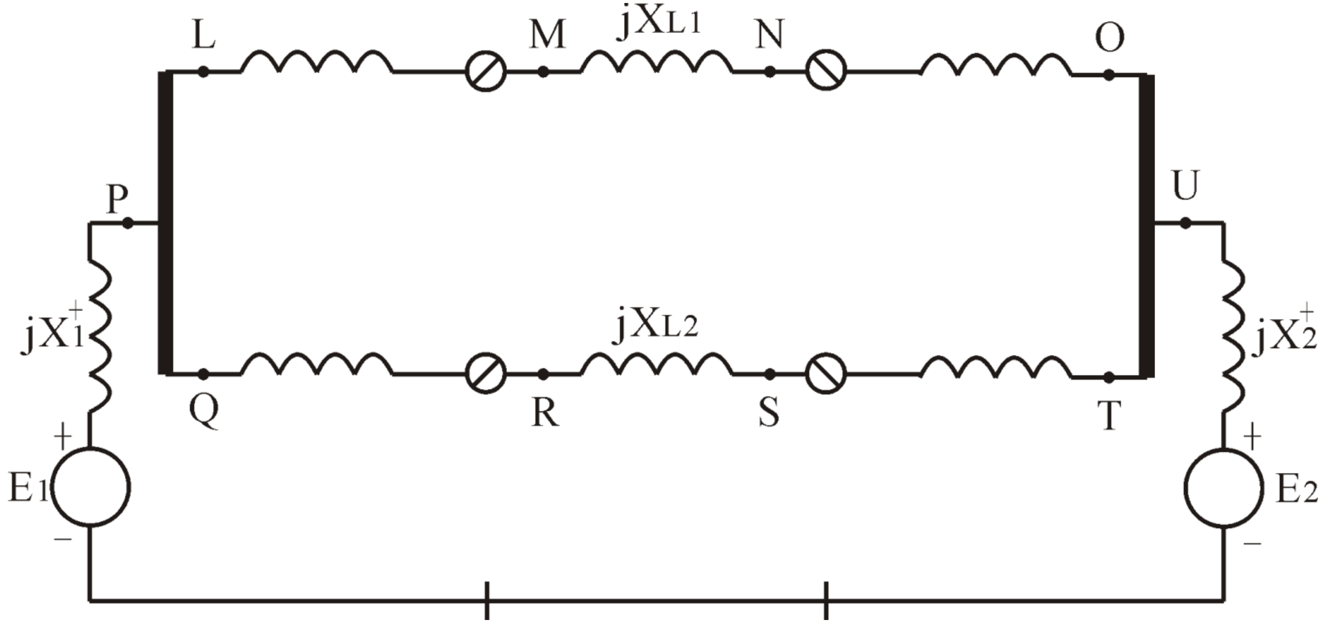
$l^+_a = \lambda^+_a / i^+_a = (\mu_0 /2\pi) \ln(d/r')$, $h/d > 1 \Rightarrow l^0_a > l^+_a$



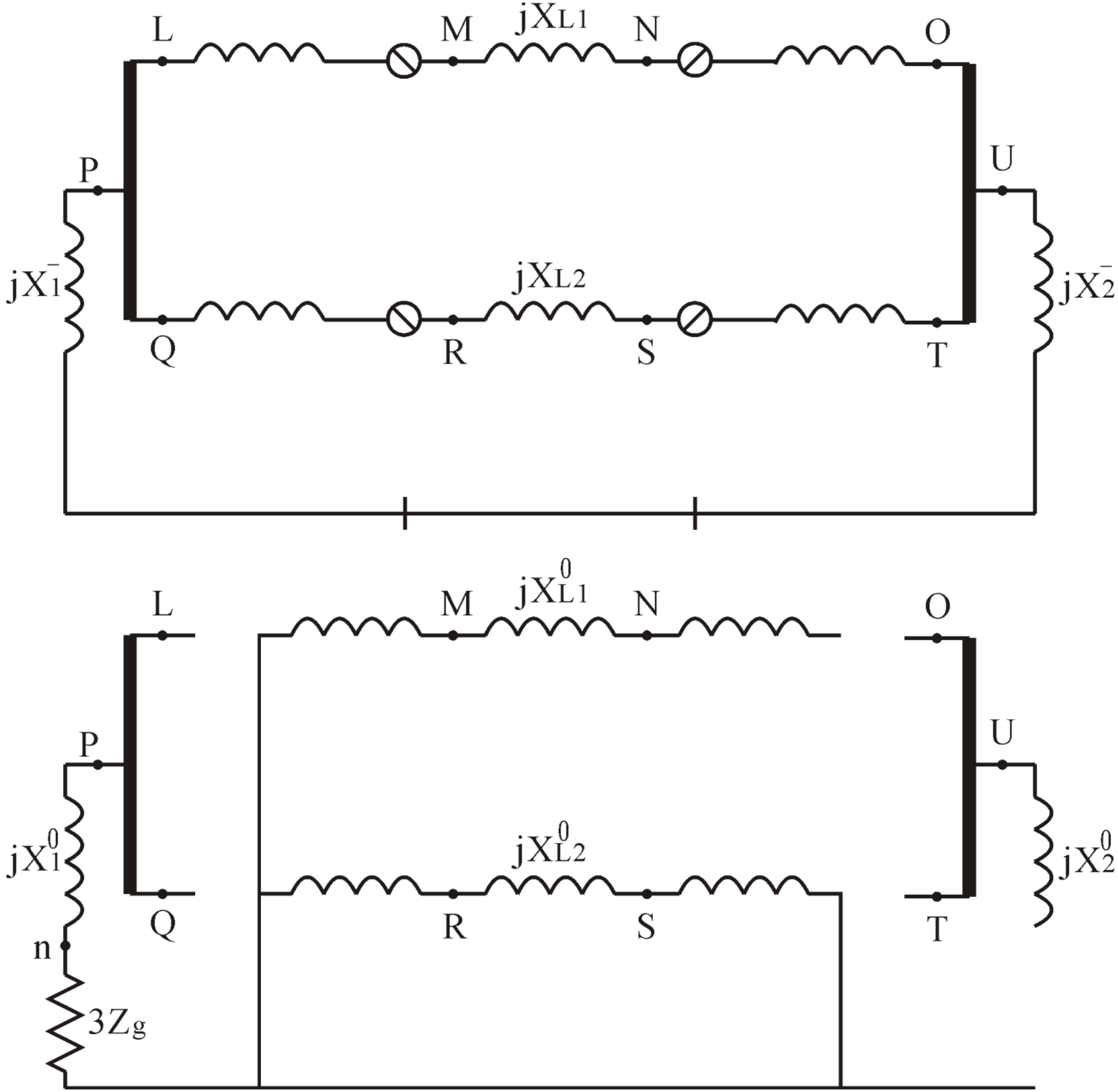
Zero sequence impedance is determined by test result ,and is 3 times of positive or negative sequence impedance

13.13序網路的組合(Assembly of Sequence Networks)





Assembly of Sequence Networks



13.14問題的形成(Formulation of Problem)

Formulation of Problem

13.15矩陣法(Matrix Methods)

Matrix Methods

13.16 Z矩陣的計算(Z Matrix Calculation)

Z Matrix Calculation

13.17結論與習題(Summary)

Fault are responsible for unbalanced conditions in power systems.

Normal power flow may be interrupted, and possible destructive currents may flow.

To design and monitor a system protection scheme, it is necessary to analyze a power system operating under unbalanced conditions.

The method of symmetrical components provides such a method.