Short-Circuit Analysis
IEC Standard

Purpose of Short-Circuit Studies

- A Short-Circuit Study can be used to determine any or all of the following:
  - Verify protective device close and latch capability
  - Verify protective device interrupting capability
  - Protect equipment from large mechanical forces (maximum fault kA)
  - I^2t protection for equipment (thermal stress)
  - Selecting ratings or settings for relay coordination

Types of Short-Circuit Faults

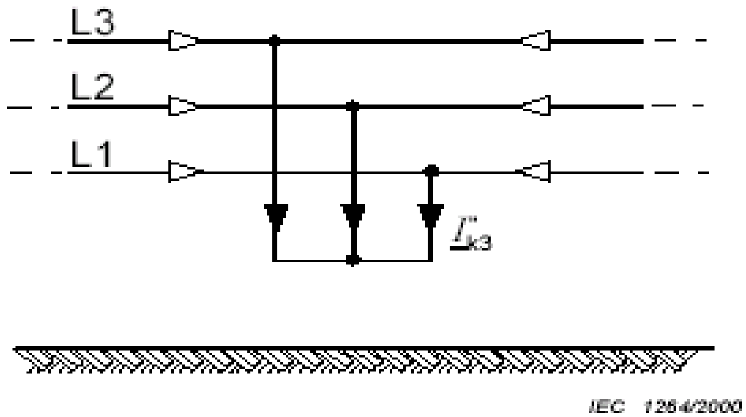


Figure 3a – Three-phase short circuit

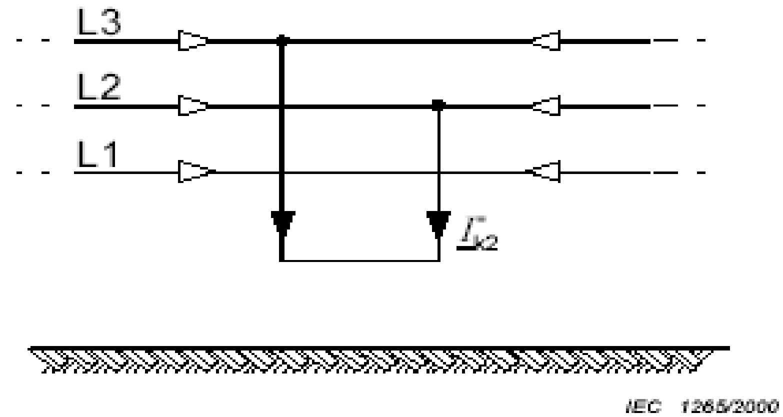
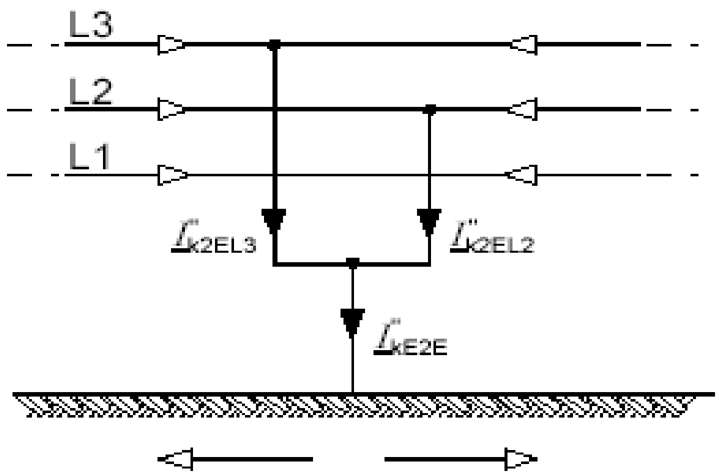
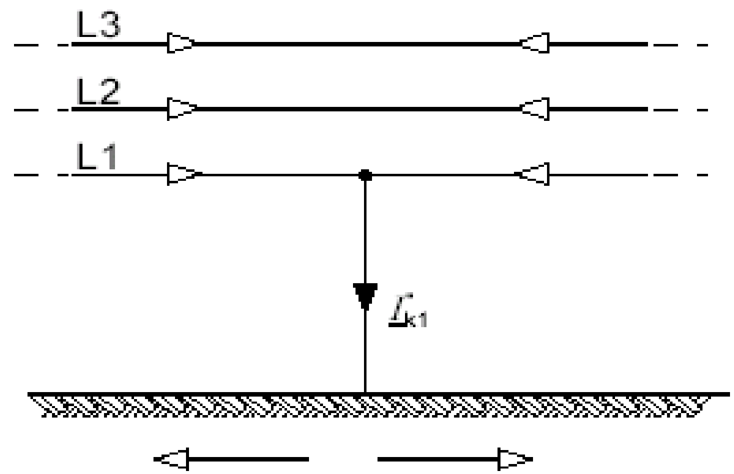


Figure 3b – Line-to-line short circuit

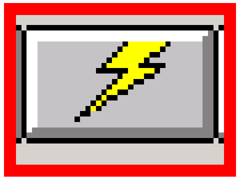




Short-circuit current

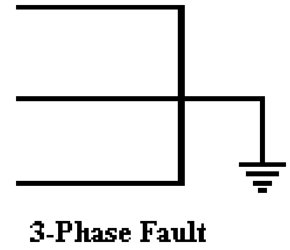
Partial short-circuit currents in conductors and earth return

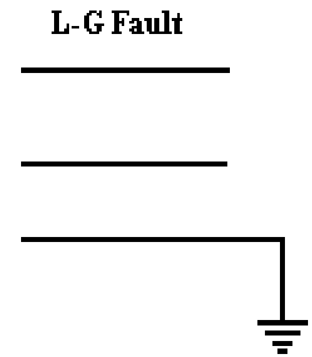
Types of Short-Circuit Faults



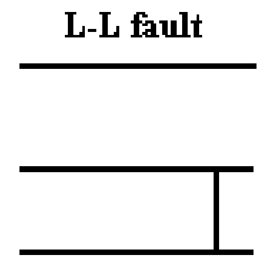
Types of SC Faults

- Three-Phase Ungrounded Fault
- Three-Phase Grounded Fault
- Phase to Phase Ungrounded Fault
- Phase to Phase Grounded Fault
- Phase to Ground Fault

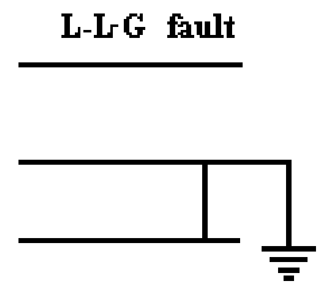




Fault Current

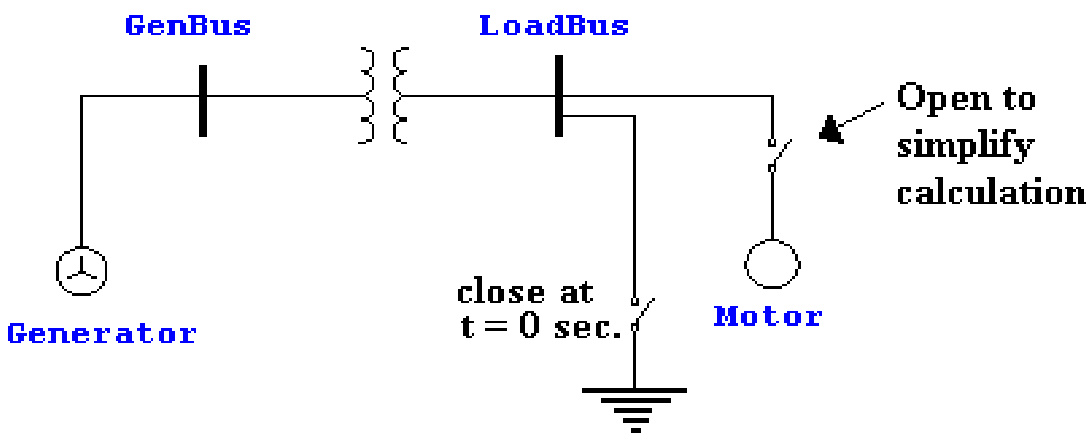


- $I_{L\text{-}G}$ can range in utility systems from a few percent to possibly 115 % (if $X_o < X_1$) of $I_{3\text{-phase}}$ (85% of all faults).
- In industrial systems the situation $I_{L\text{-}G} > I_{3\text{-phase}}$ is rare. Typically $I_{L\text{-}G} \cong .87 * I_{3\text{-phase}}$
- In an industrial system, the three-phase fault condition is frequently the only one considered, since this type of fault generally results in Maximum current.

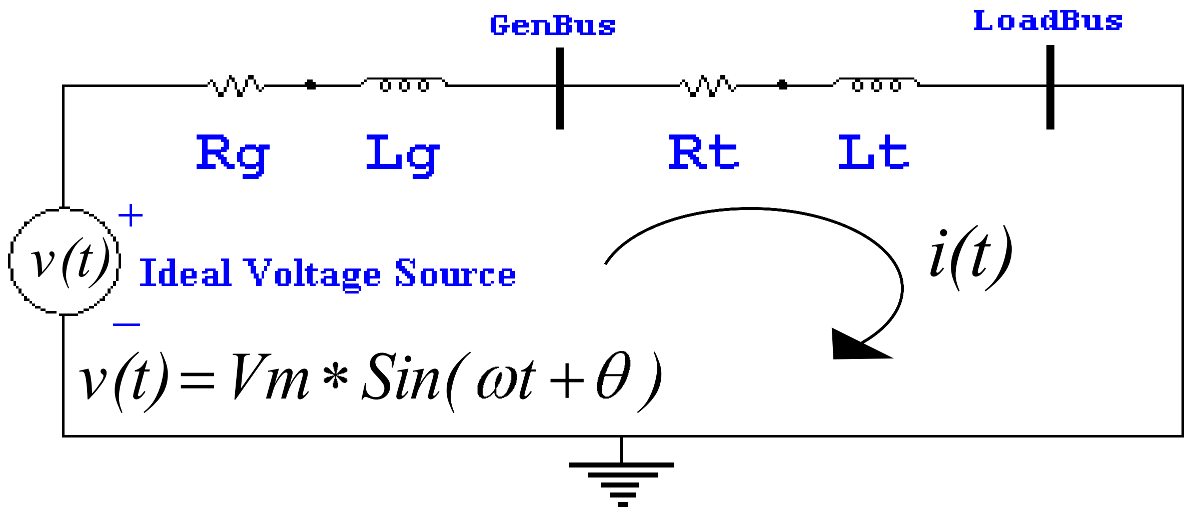


Short-Circuit Phenomenon

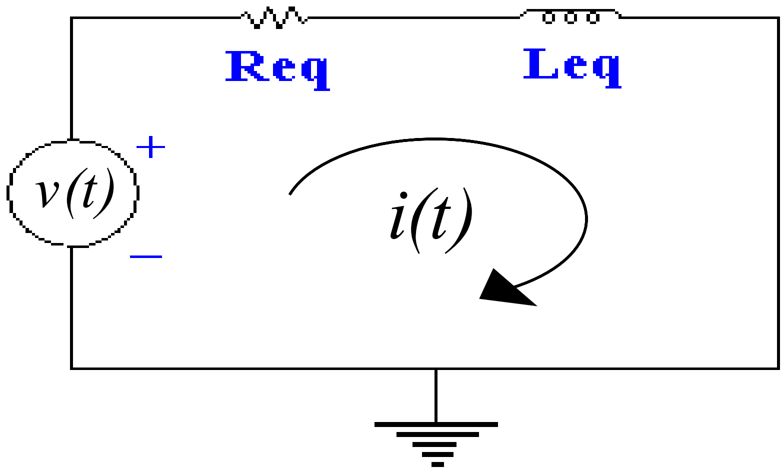
One-Line Diagram in PowerStation



Equivalent Impedance Diagram



Thevenin Equivalent

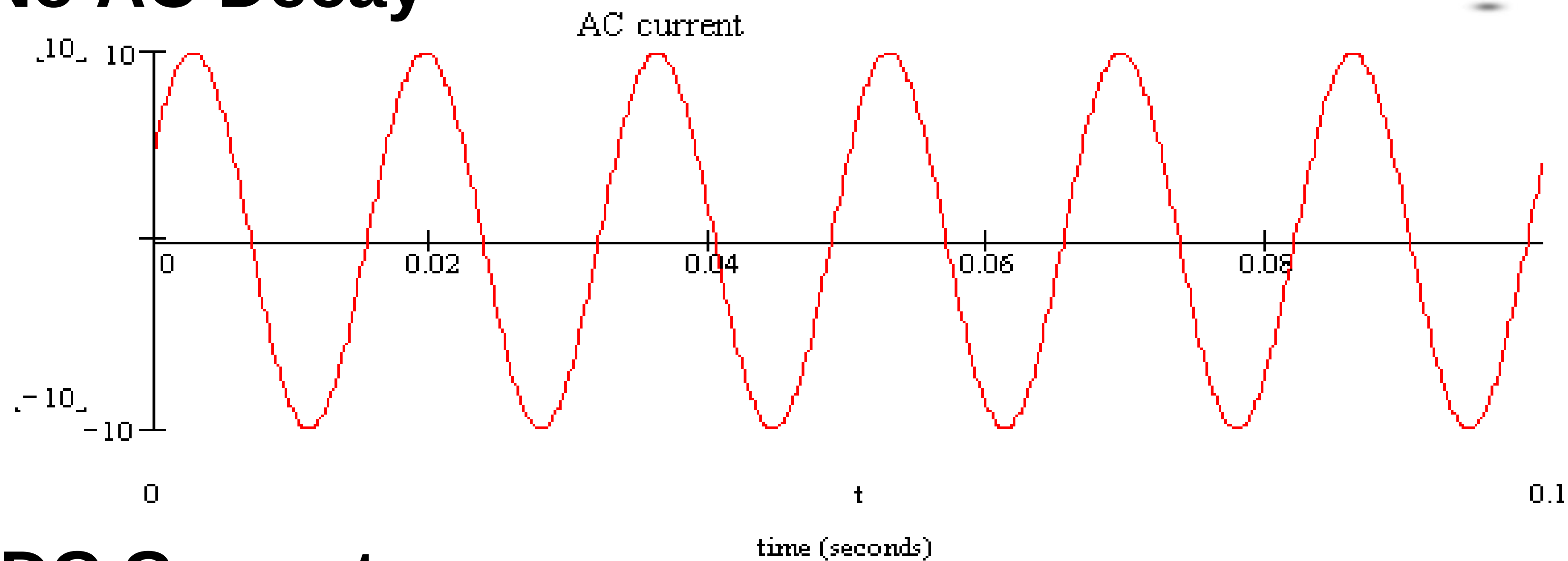


$$\mathbf{v(t) = Ri + L\frac{di}{dt} = Vm \times Sin(\omega t + \theta)} \qquad \mathbf{(1)}$$

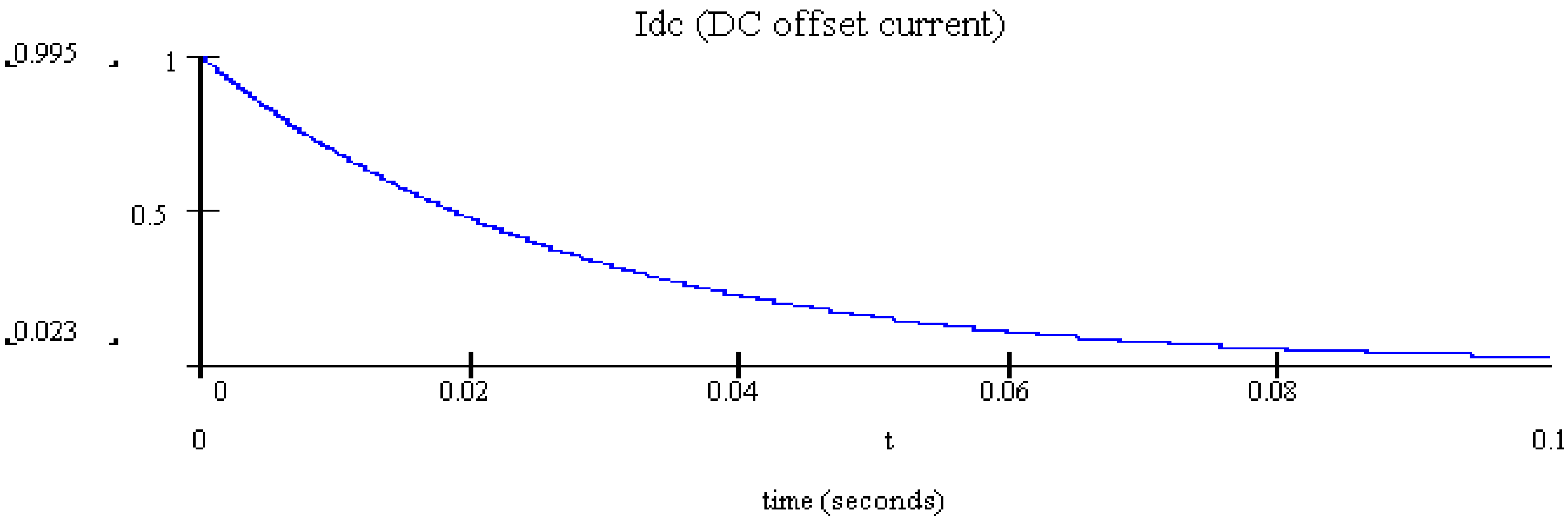
Solving equation 1 yields the following expression

$$\mathbf{i(t)} = \underbrace{\frac{\mathbf{Vm}}{|\mathbf{Z}|} \times \mathbf{sin}(\omega \mathbf{t} + \theta - \phi)}_{\textbf{Steady State}} + \underbrace{\frac{\mathbf{Vm}}{|\mathbf{Z}|} \times \mathbf{sin}(\theta - \phi) \times e^{-\frac{R}{L}\mathbf{t}}}_{\textbf{Transient (DC Offset)}}$$

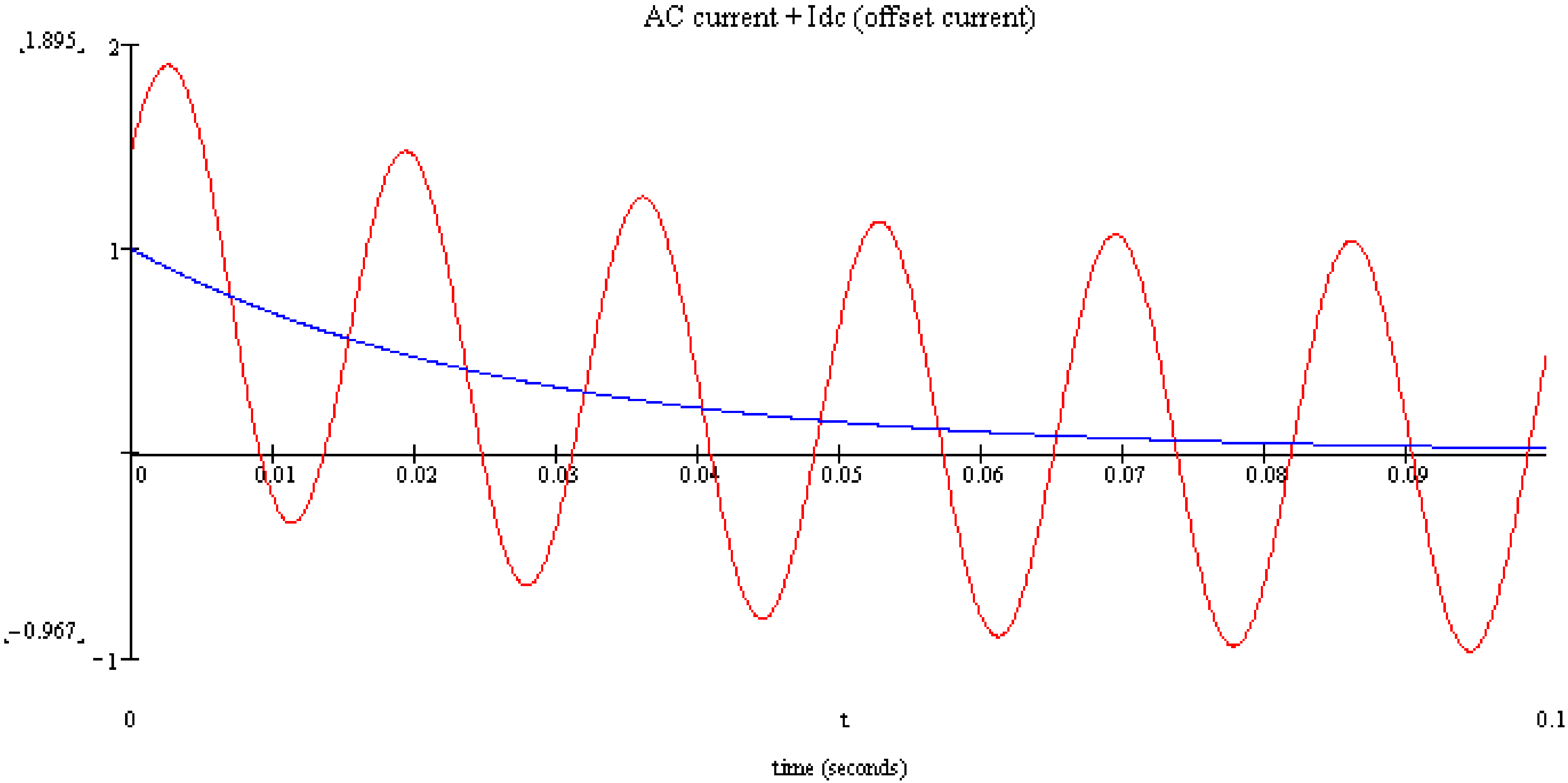
AC Current (Symmetrical) with No AC Decay



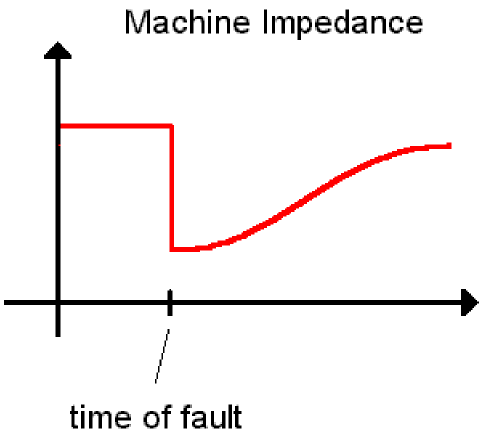
DC Current



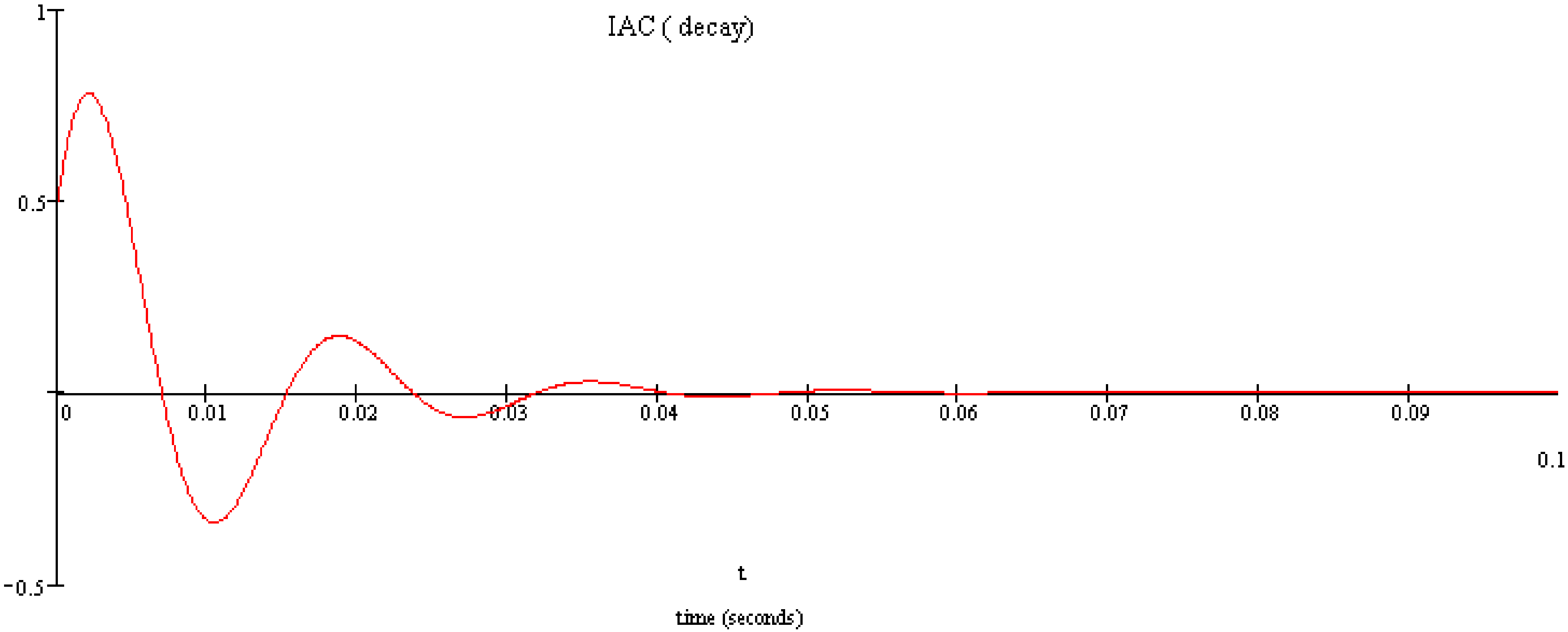
AC Fault Current Including the DC Offset (No AC Decay)



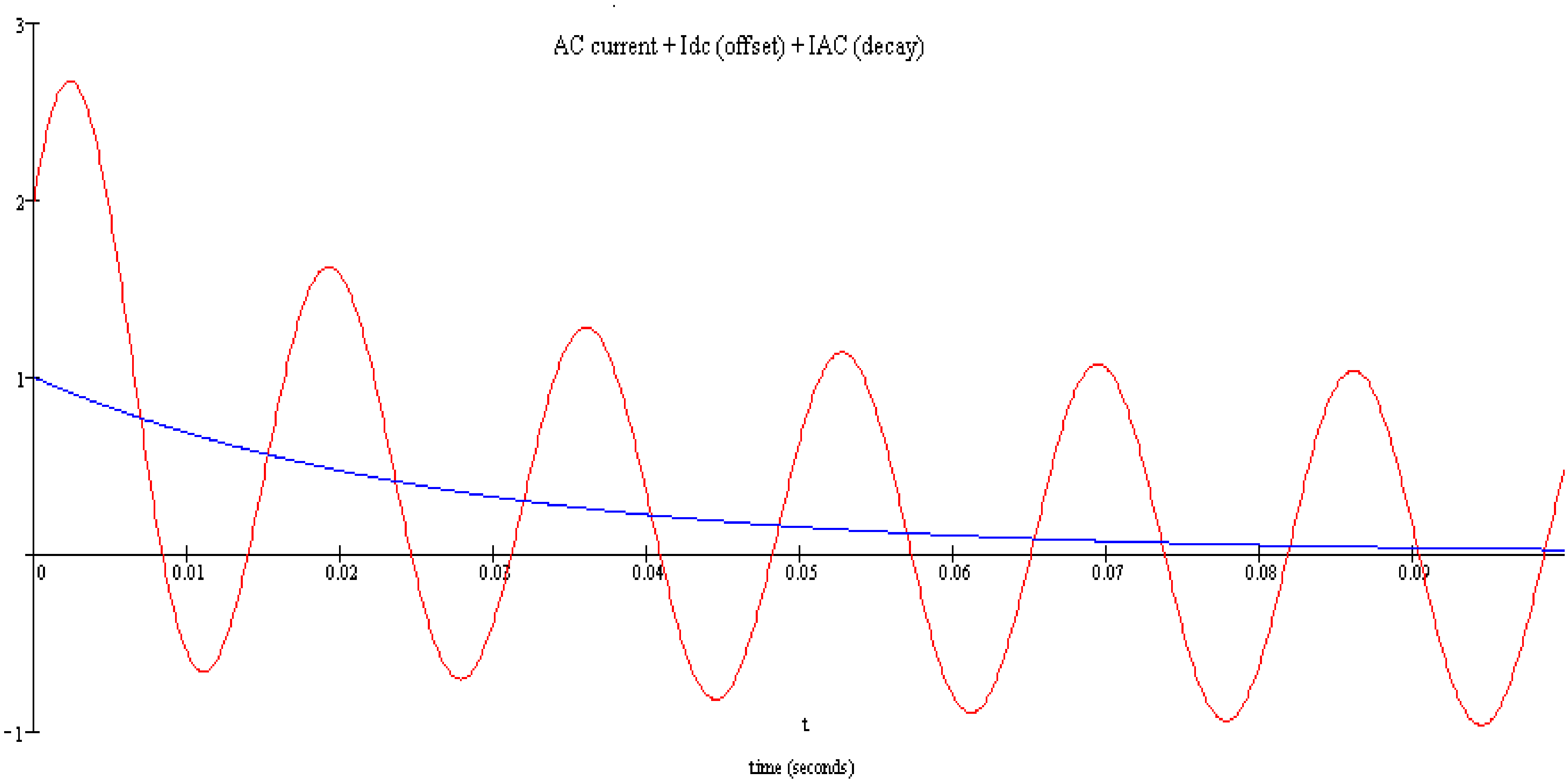
Machine Reactance (λ = L I)



AC Decay Current



Fault Current Including AC & DC Decay



IEC Short-Circuit Calculation (IEC 909)

- Initial Symmetrical Short-Circuit Current (I"k)
- Peak Short-Circuit Current (ip)
- Symmetrical Short-Circuit Breaking Current (Ib)
- Steady-State Short-Circuit Current (Ik)

IEC Short-Circuit Calculation Method

- Ik" = Equivalent V @ fault location divided by equivalent Z

- Equivalent V is based bus nominal kV and c factor

- XFMR and machine Z adjusted based on c_{max}, component Z & operating conditions

Transformer Z Adjustment

- K_T -- Network XFMR
- K_S,K_{SO} – Unit XFMR for faults on system side
- $K_{T,S}$,$K_{T,SO}$ – Unit XFMR for faults in auxiliary system, not between Gen & XFMR
- K=1 – Unit XFMR for faults between Gen & XFMR

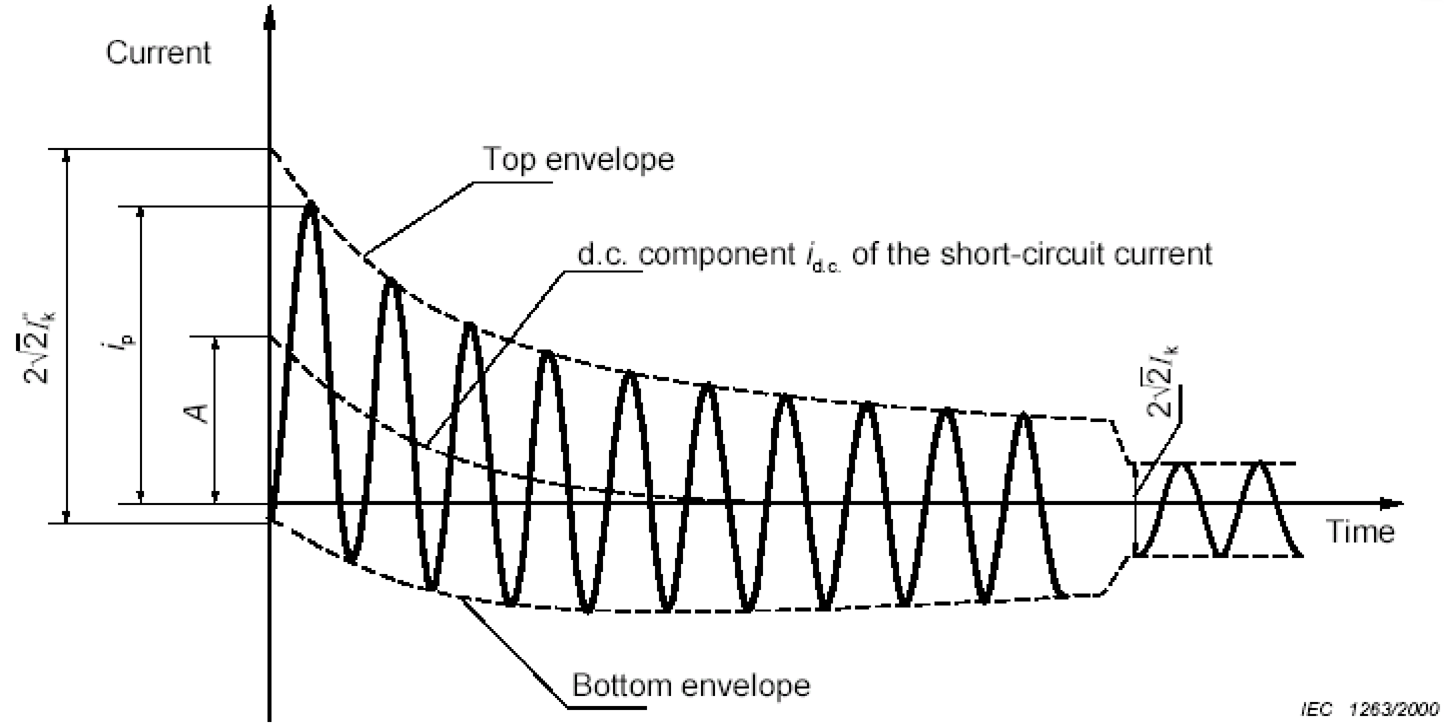
Syn Machine Z Adjustment

- K_G – Synchronous machine w/o unit XFMR
- K_S,K_{SO} – With unit XFMR for faults on system side
- $K_{G,S}$,$K_{G,SO}$ – With unit XFMR for faults in auxiliary system, including points between Gen & XFMR

Types of Short-Circuits

- Near-To-Generator Short-Circuit
  - This is a short-circuit condition to which at least one synchronous machine contributes a prospective initial short-circuit current which is more than twice the generator's rated current, or a short-circuit condition to which synchronous and asynchronous motors contribute more than 5% of the initial symmetrical short-circuit current (I"k) without motors.

Near-To-Generator Short-Circu



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

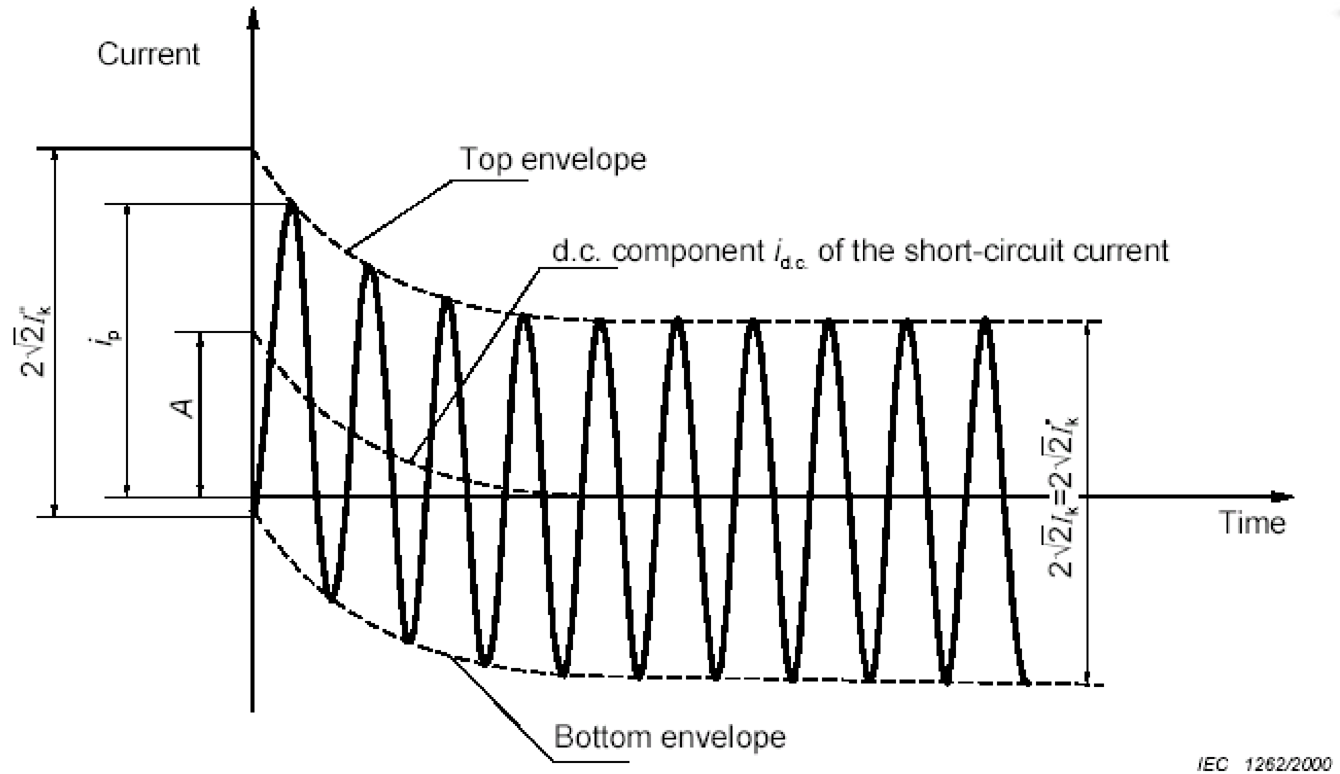
A = initial value of the d.c. component $i_{d.c.}$

Figure 2 – Short-circuit current of a near-to-generator short circuit with decaying a.c. component (schematic diagram)

Types of Short-Circuits

- Far-From-Generator Short-Circuit
  - This is a short-circuit condition during which the magnitude of the symmetrical ac component of available short-circuit current remains essentially constant.

Far-From-Generator Short-Circuit



I''_k = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

$i_{d.c.}$ = d.c. component of short-circuit current

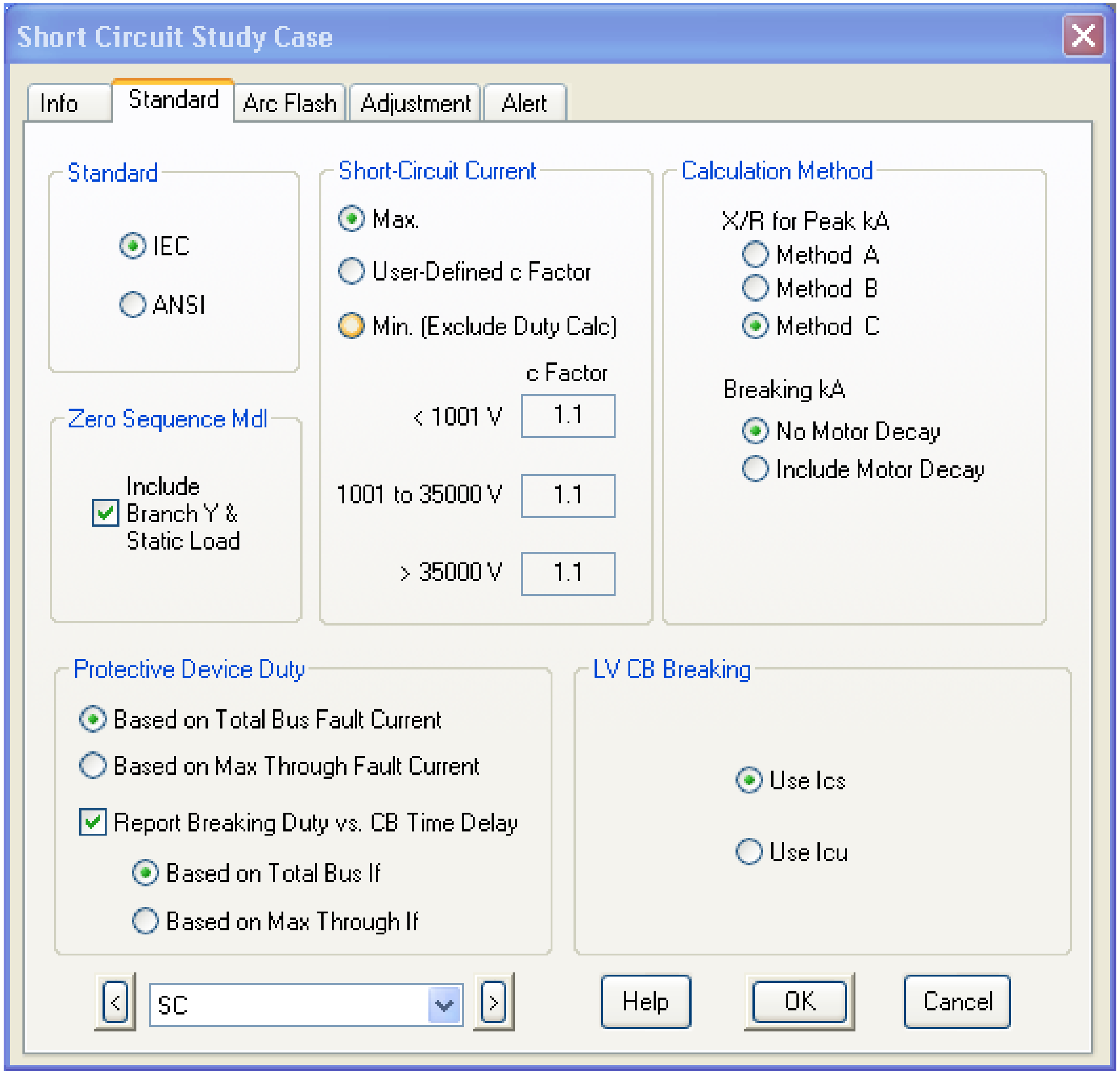
A = initial value of the d.c. component $i_{d.c.}$

Figure 1 – Short-circuit current of a far-from-generator short circuit

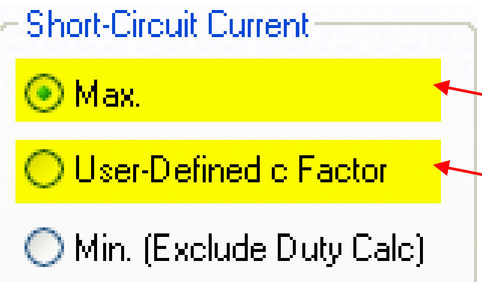
Factors Used in I_f Calc

- κ – calc i_p based on I_k"
- μ – calc i_b for near-to-gen & not meshed network
- q – calc induction machine i_b for near-to-gen & not meshed network
- Equation (75) of Std 60909-0, adjusting Ik for near-to-gen & meshed network
- λ_{min} & λ_{max} – calc i_k

IEC Short-Circuit Study Case



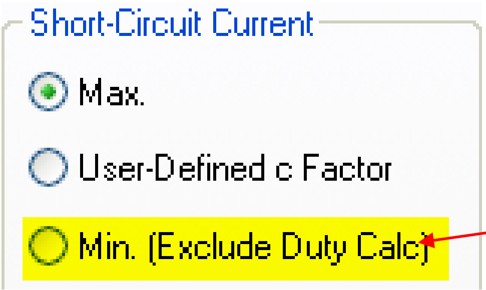
Types of Short-Circuits



When these options are selected

- Maximum voltage factor is used
- Minimum impedance is used (all negative tolerances are applied and minimum resistance temperature is considered)

Types of Short-Circuits

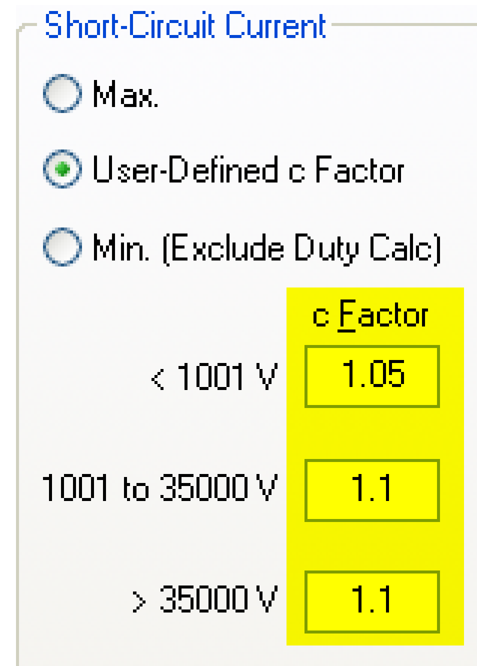


When this option is selected

- Minimum voltage factor is used
- Maximum impedance is used (all positive tolerances are applied and maximum resistance temperature is considered)

Voltage Factor (c)

- Ratio between equivalent voltage & nominal voltage
- Required to account for:
  - Variations due to time & place
  - Transformer taps
  - Static loads & capacitances
  - Generator & motor subtransient behavior

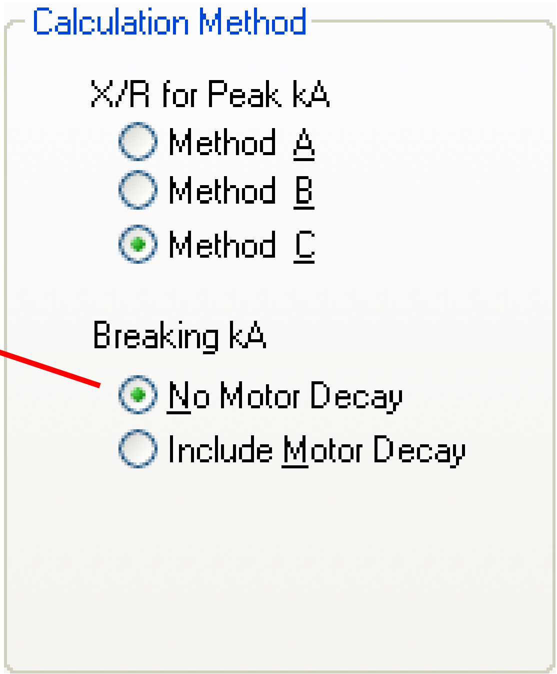


Calculation Method

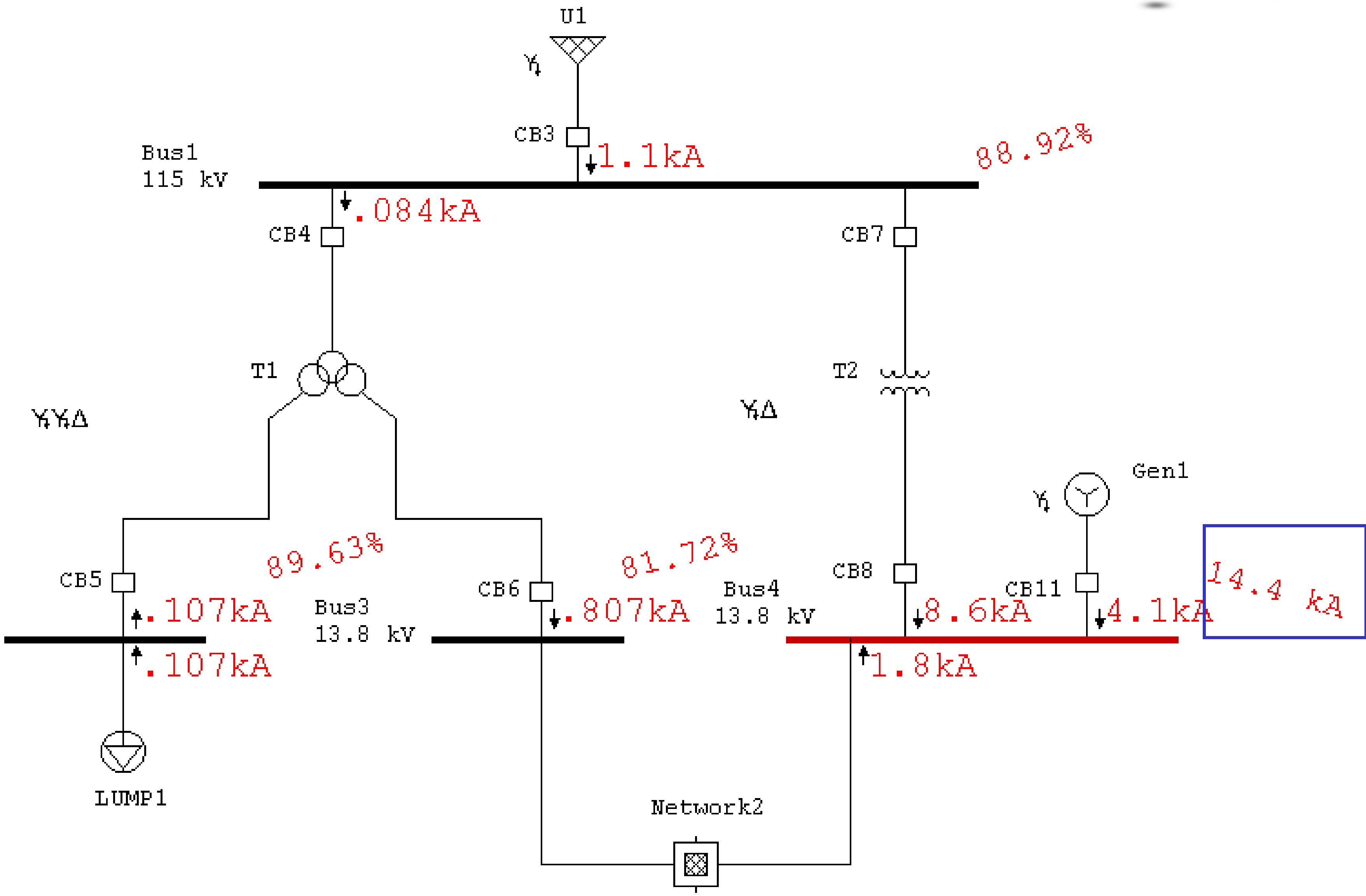
X/R for Peak Current

- **Method A** – Using the uniform ratio X/R in calculating the peak current
- **Method B** – Using the X/R ratio at the short-circuit location in calculating the peak current
- **Method C** – Using equivalent frequency in calculating the peak current

- Breaking kA is more conservative if the option No Motor Decay is selected



IEC SC 909 Calculation



Device Duty Comparison

Element	Current Rating	Duty
Bus	Making	i_p
HV CP	Symmetrical Breaking	$I_{b,sym}$
	Asymmetrical Breaking	$I_{b,asym}$
	Making	i_p
	DC Component (%)	I_{dc}
LV CP	Symmetrical Breaking	$I_{b,sym}$
	Asymmetrical Breaking	$I_{b,asym}$
	Making	i_p
Fuse	Symmetrical Breaking	$I_{b,sym}$
	Asymmetrical Breaking	$I_{b,asym}$

Mesh & Non-Mesh I_f

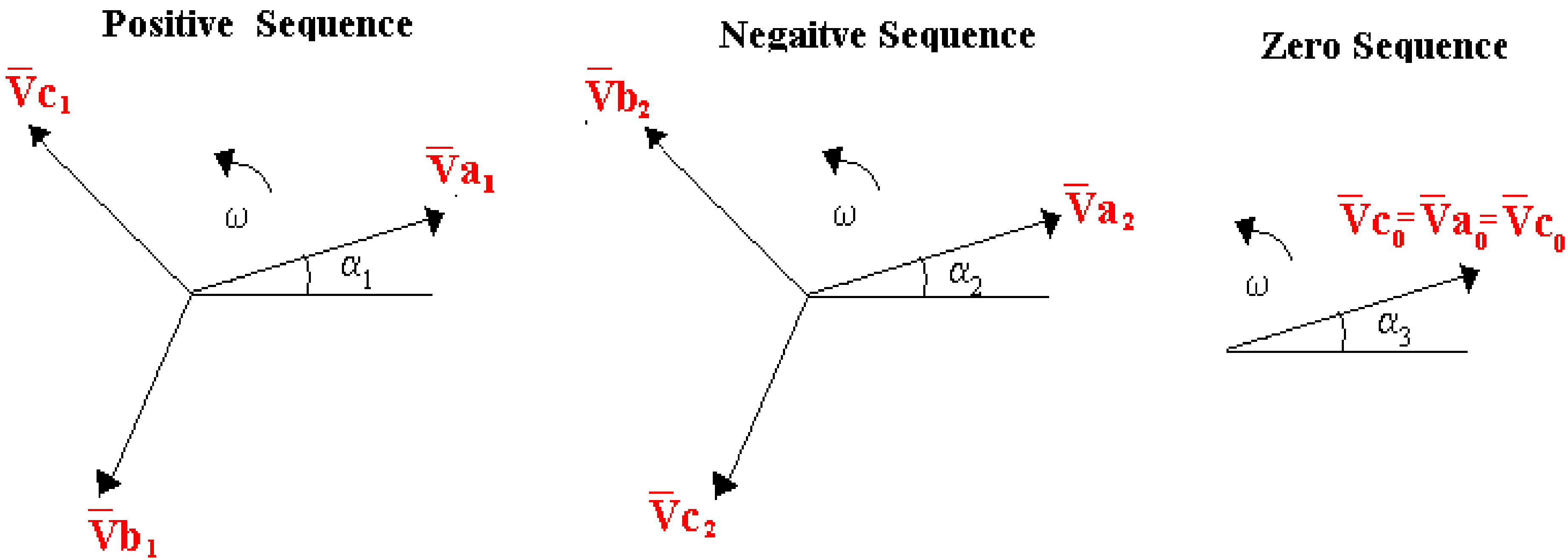
- ETAP automatically determines mesh & non-meshed contributions according to individual contributions

- IEC Short Circuit Mesh Determination Method – 0, 1, or 2 (default)

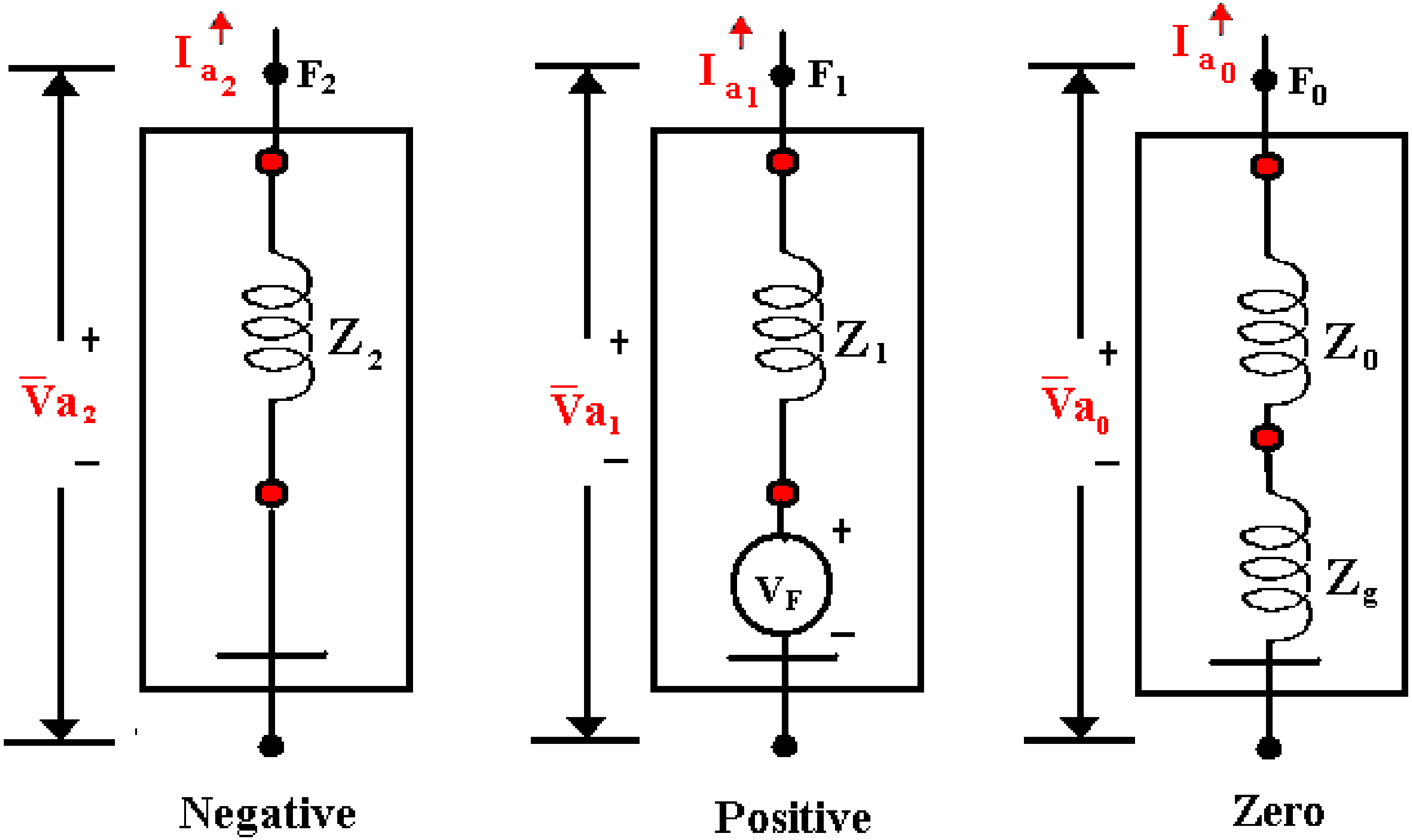
L-G Faults

L-G Faults

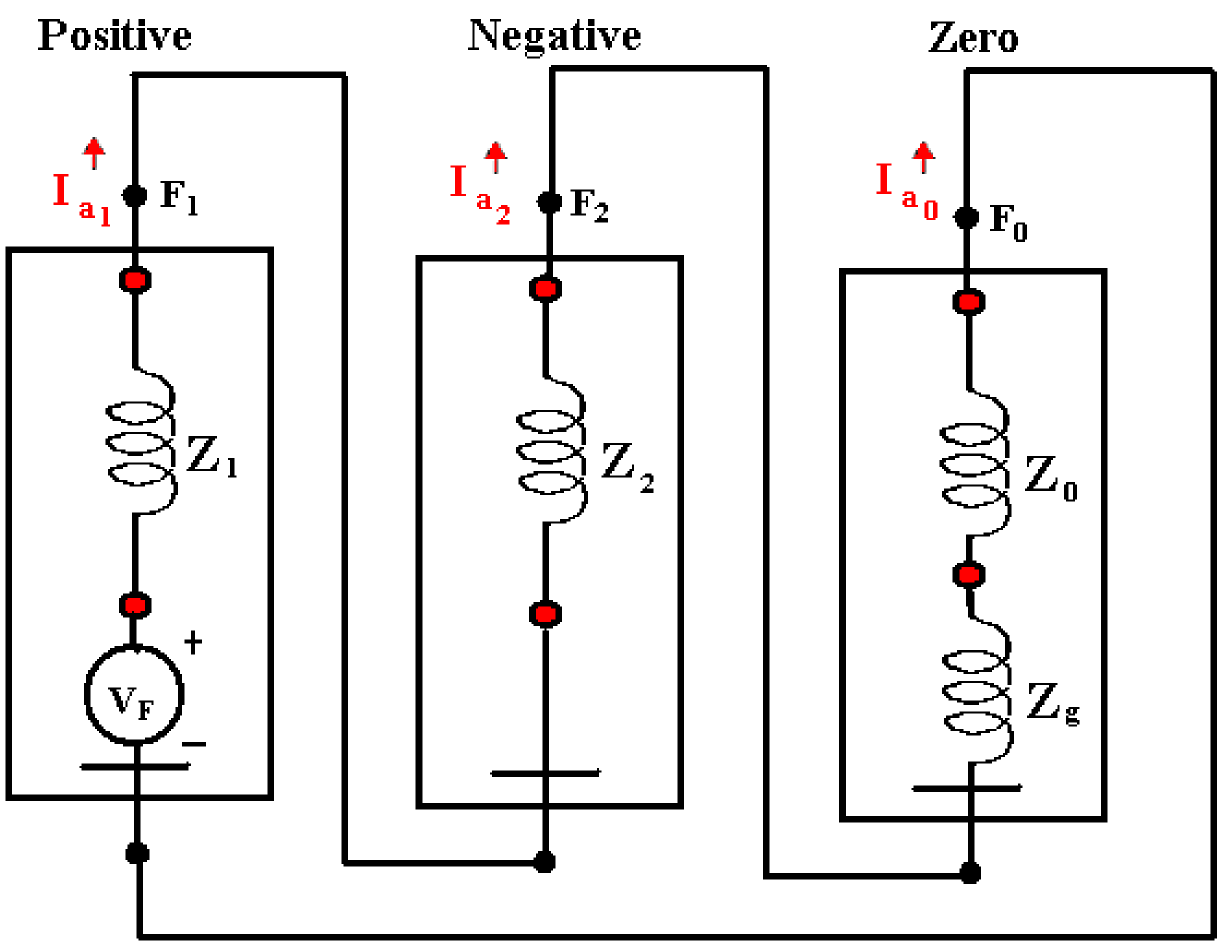
Symmetrical Components



Sequence Networks



L-G Fault Sequence Network Connections

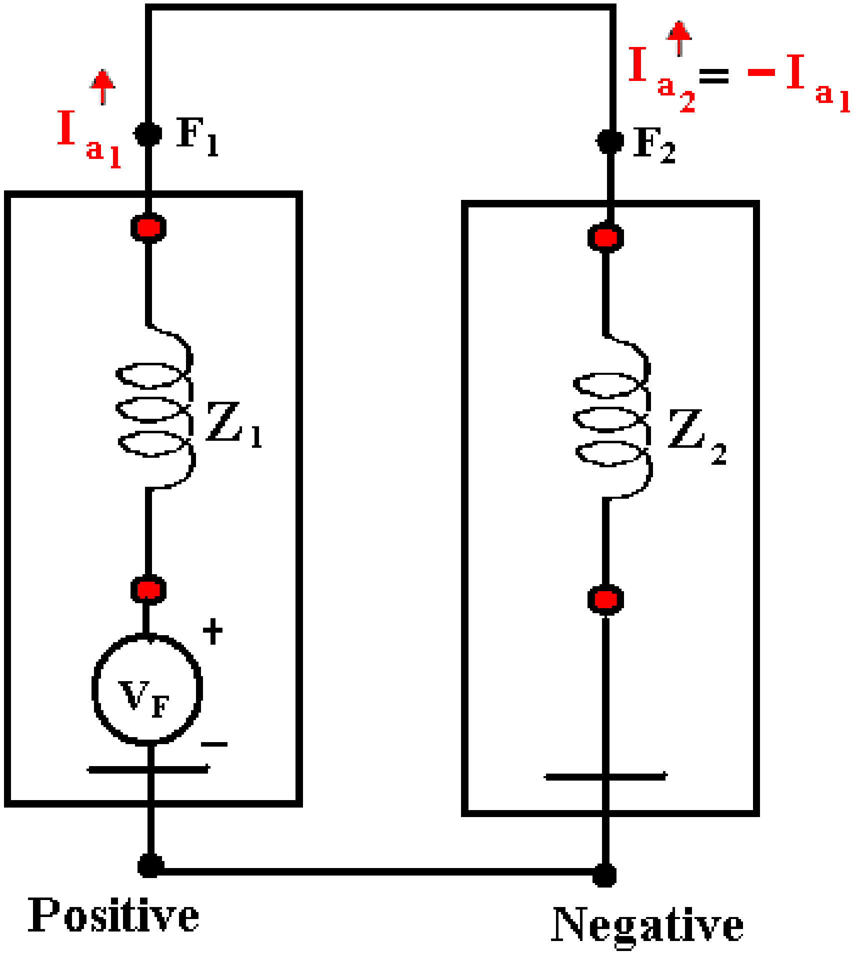


$$I_f = 3 \times I_{a_0}$$

$$I_f = \frac{3 \times V_{Prefault}}{Z_1 + Z_2 + Z_0}$$

$$\text{if } Z_g = 0$$

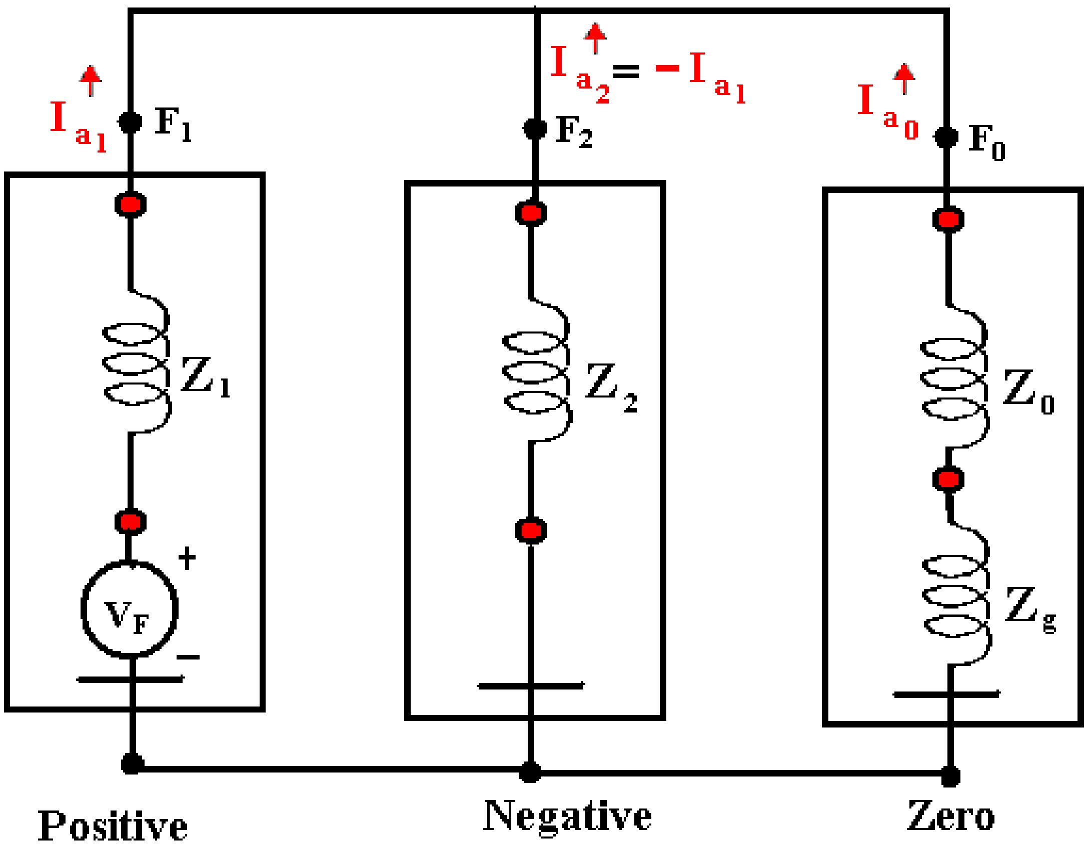
L-L Fault Sequence Network Connections



$$I_{a_2} = -I_{a_1}$$

$$I_f = \frac{\sqrt{3} \times V_{Prefault}}{Z_1 + Z_2}$$

L-L-G Fault Sequence Network Connections

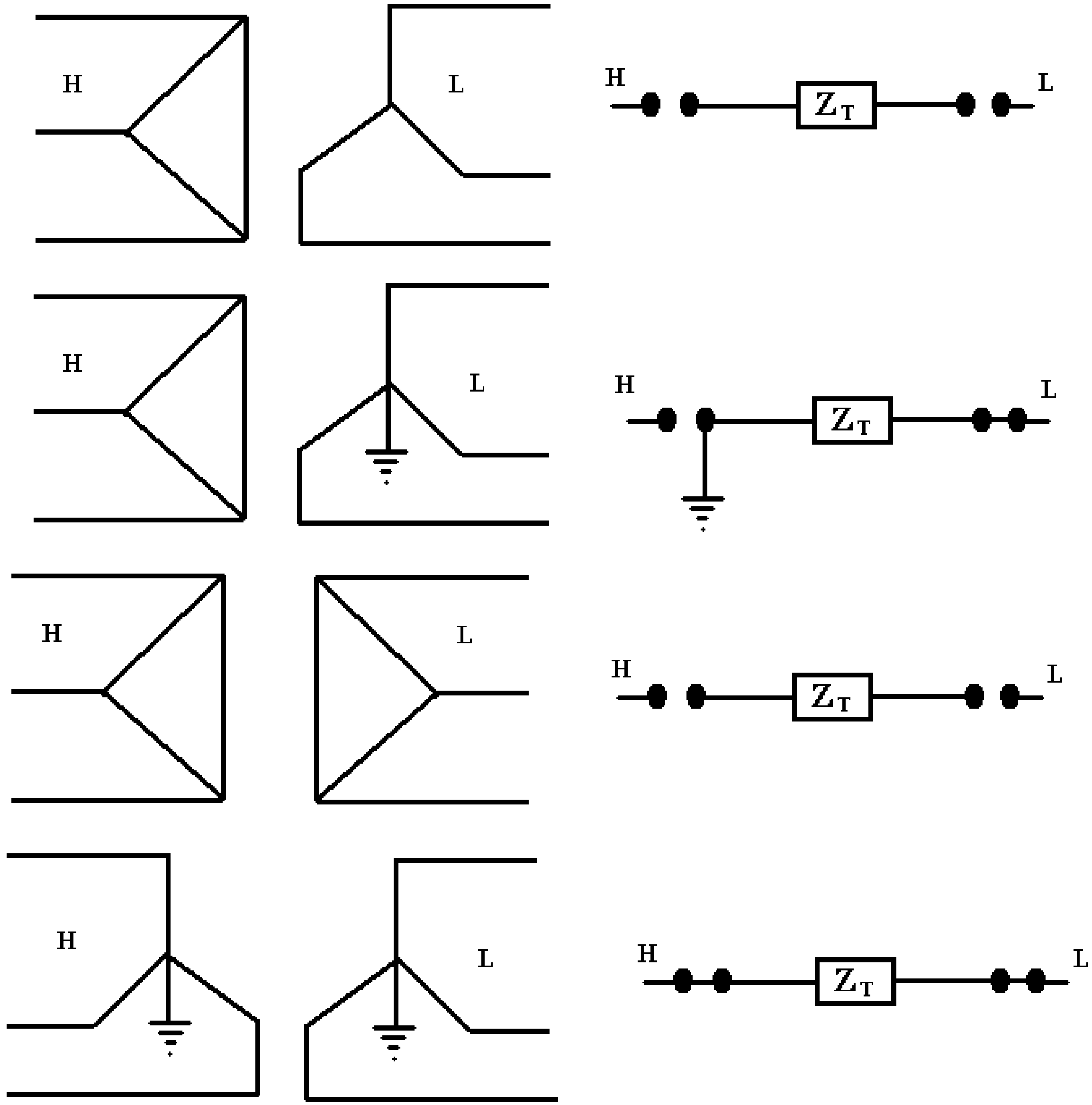


$$I_{a_2} + I_{a_1} + I_{a_0} = 0 = I_a$$

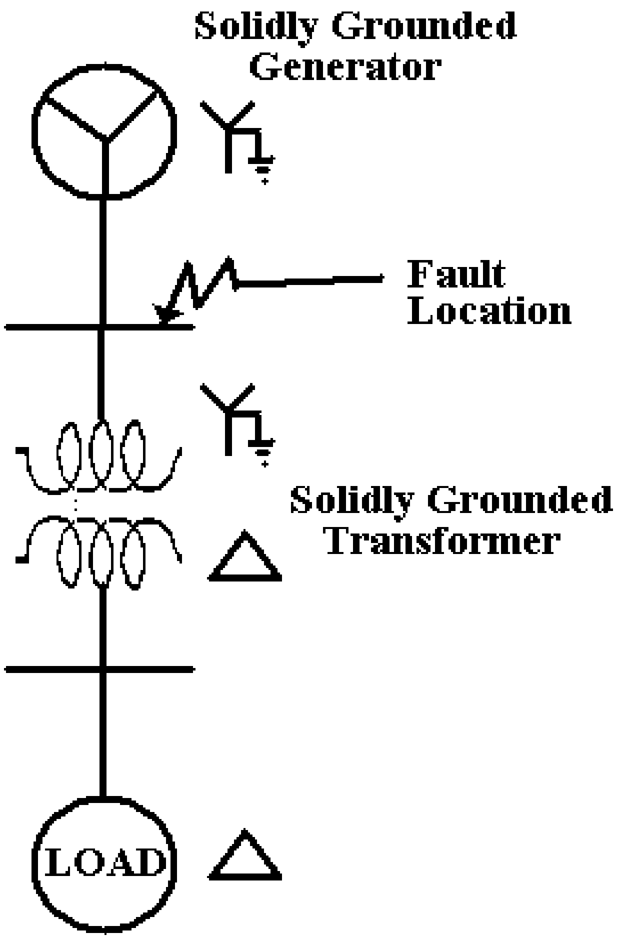
$$I_f = \frac{V_{Prefault}}{Z_1 + \left(\frac{Z_0 Z_2}{Z_0 + Z_2}\right)}$$

$$\text{if } Z_g = 0$$

Transformer Zero Sequence Connections



Solid Grounded Devices and L-G Faults



Generally a 3-phase fault is the most severe case. L-G faults can be greater if :

$$Z_1 = Z_2 \ \& \ Z_0 < Z_1$$

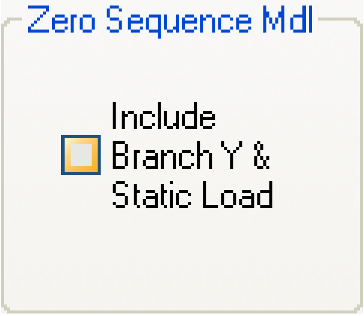
If this conditions are true then :

$$I_{f3\phi} < I_{f1\phi}$$

This may be the case if Generators or Y/Δ Connected transformer are solidly grounded.

Zero Sequence Model

- Branch susceptances and static loads including capacitors will be considered when this option is checked
- Recommended by IEC for systems with isolated neutral, resonant earthed neutrals & earthed neutrals with earth fault factor > 1.4



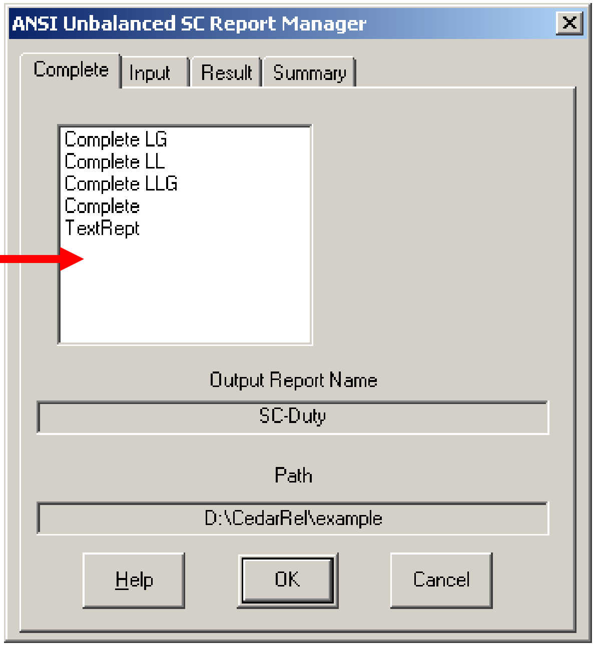
Unbalanced Faults Display & Reports

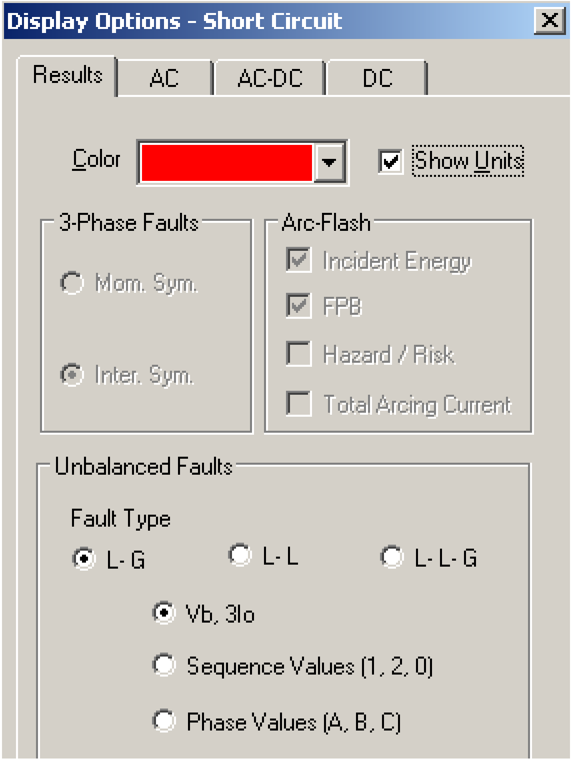
Complete reports that include individual branch contributions for:

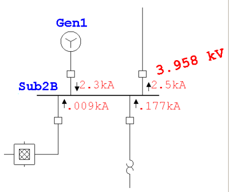
•L-G Faults

•L-L-G Faults

•L-L Faults







One-line diagram displayed results that include:

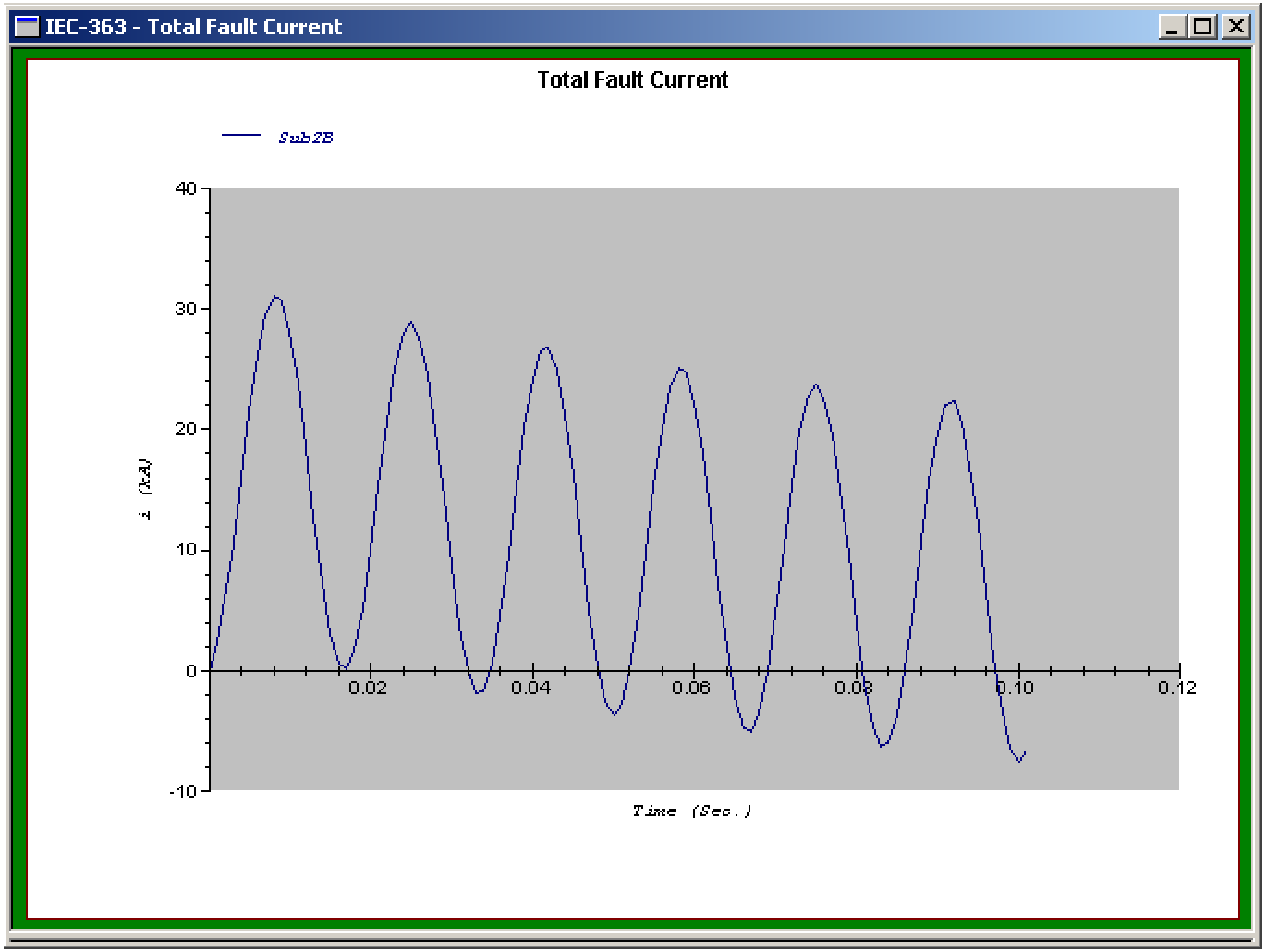
•L-G/L-L-G/L-L fault current contributions

•Sequence voltage and currents

•Phase Voltages

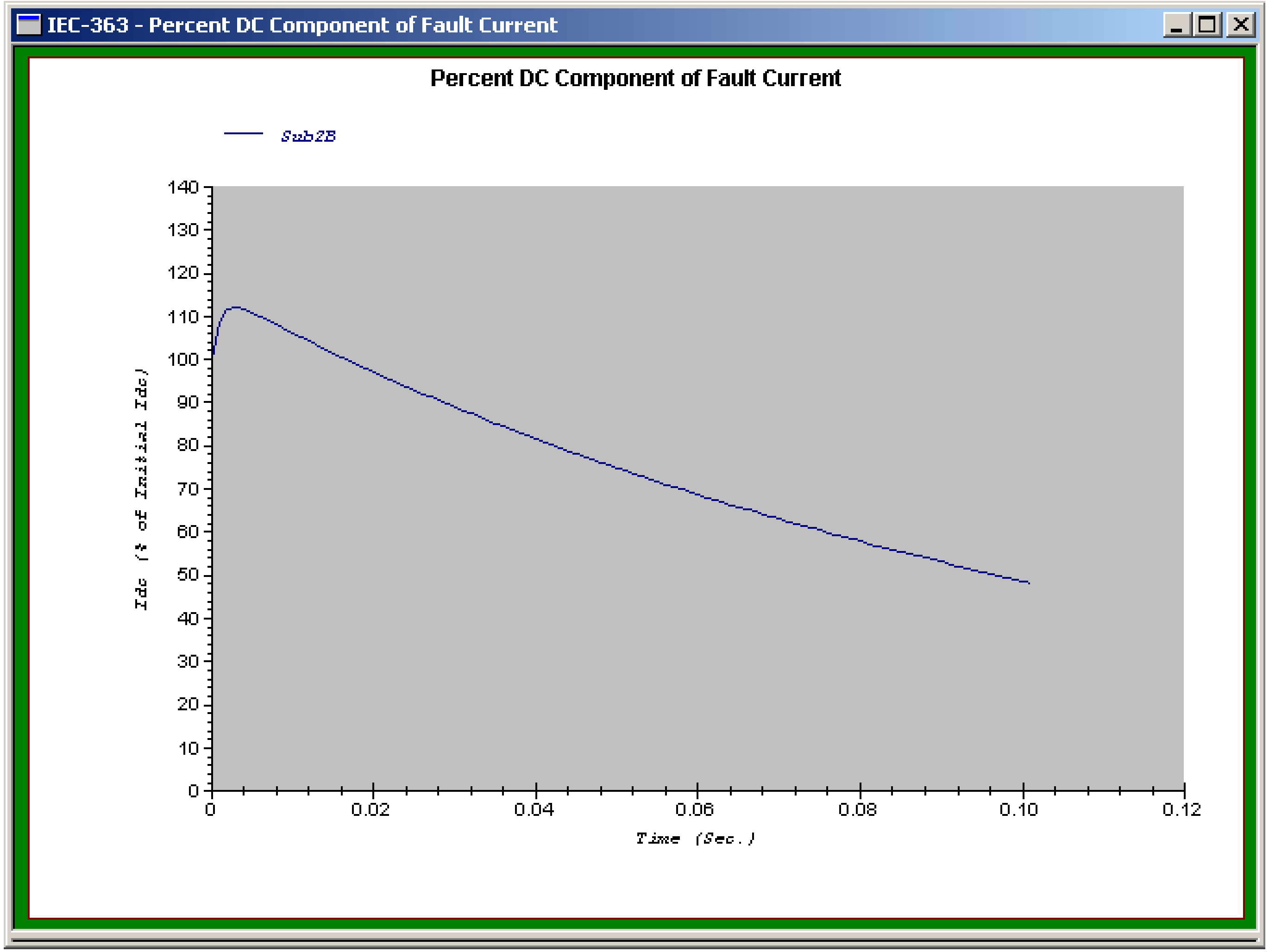
Transient Fault Current Calculation (IEC 61363)

Total Fault Current Waveform



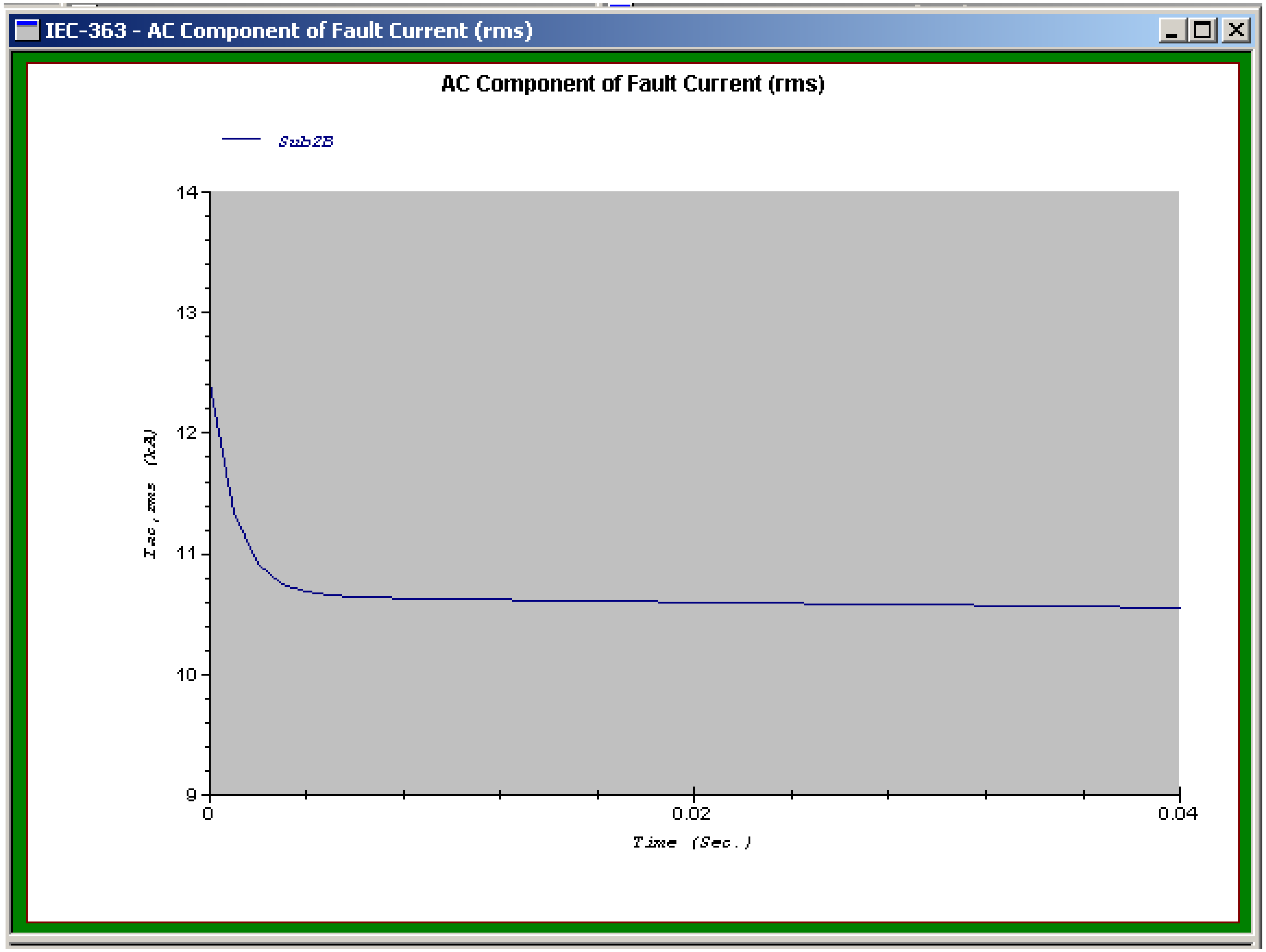
Transient Fault Current Calculation (IEC 61363)

Percent DC Current Waveform



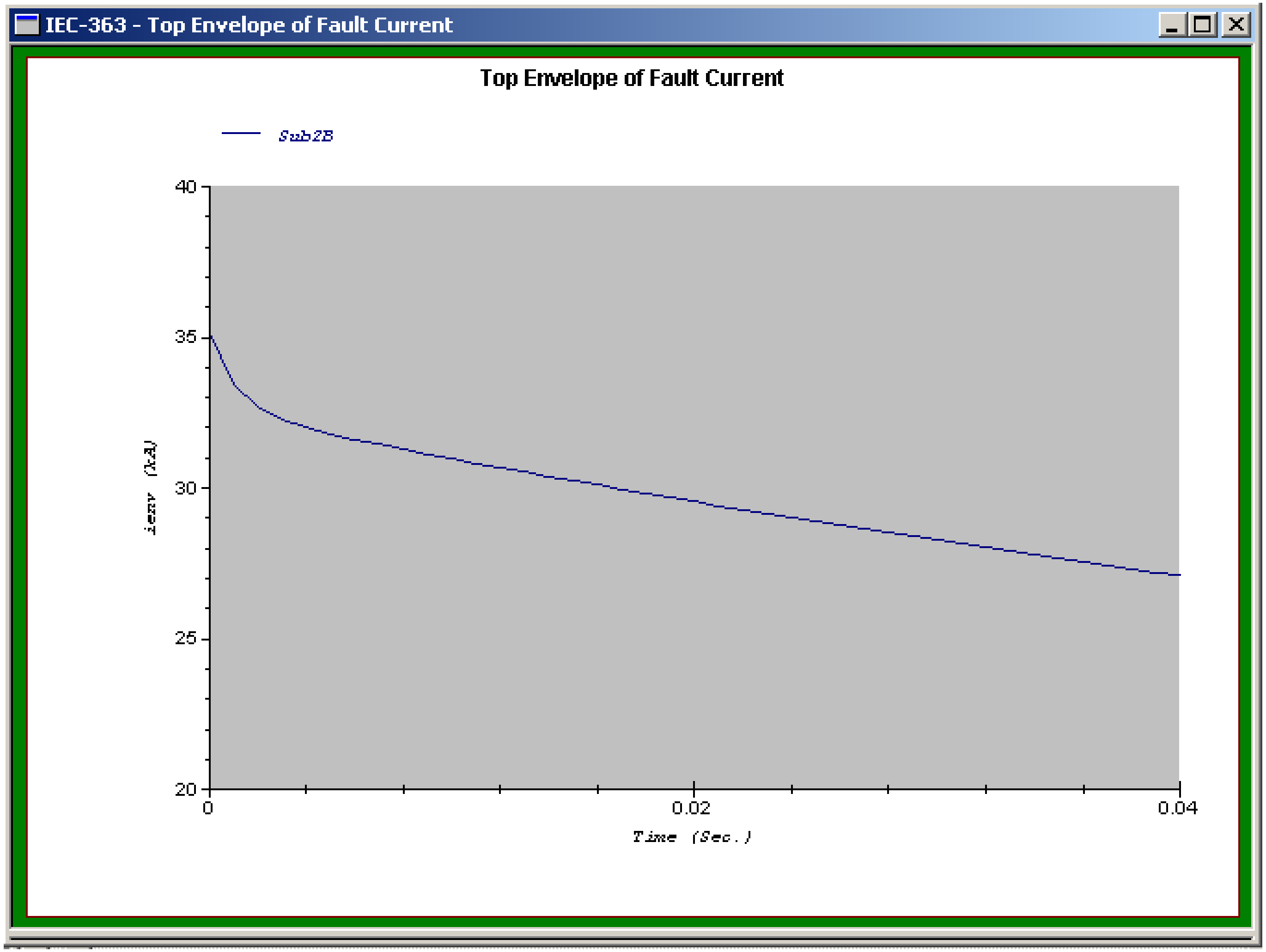
Transient Fault Current Calculation (IEC 61363)

AC Component of Fault Current Waveform



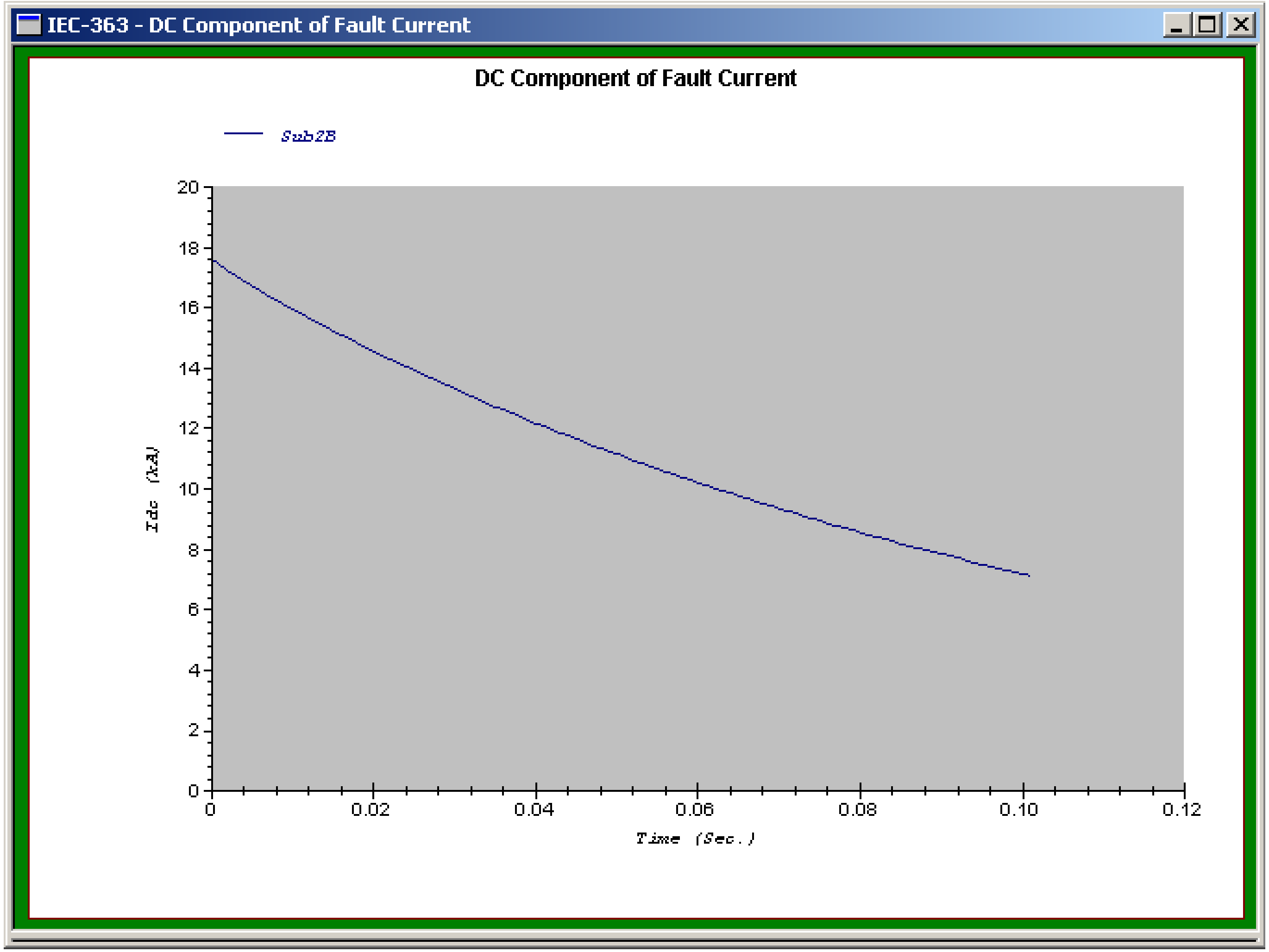
Transient Fault Current Calculation (IEC 61363)

Top Envelope of Fault Current Waveform

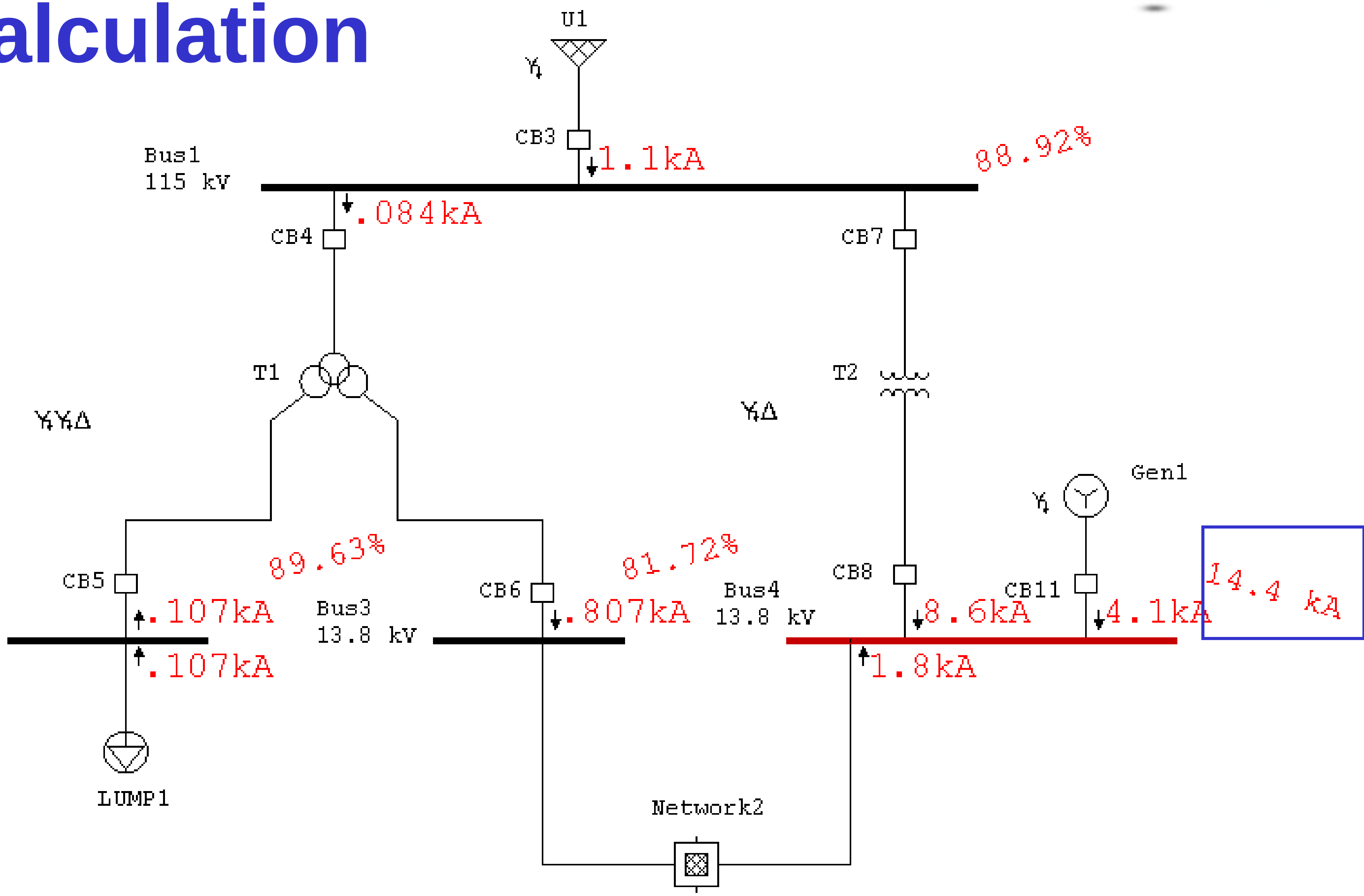


Transient Fault Current Calculation (IEC 61363)

Top Envelope of Fault Current Waveform



IEC Transient Fault Current Calculation



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•L-L-G Faults

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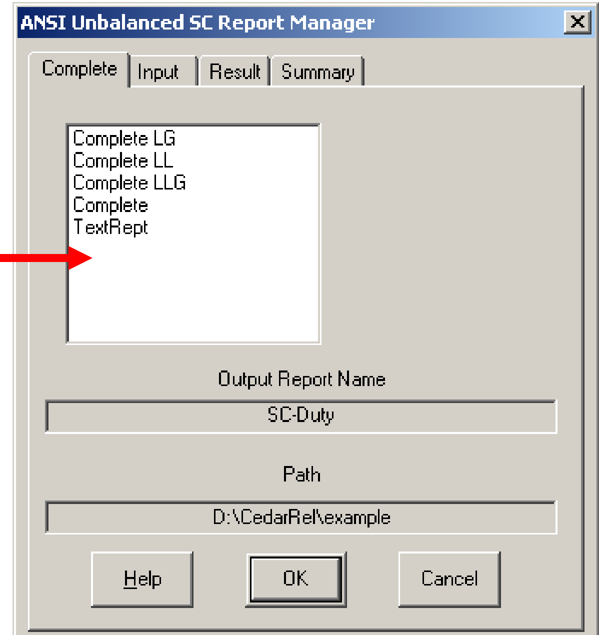

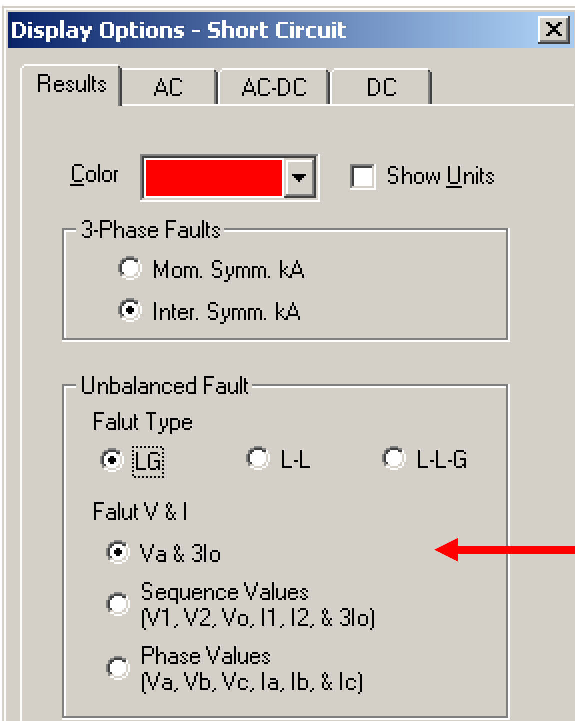

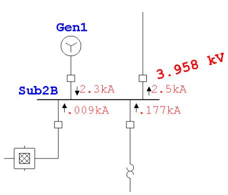

One-line diagram displayed results that include:

•L-G/L-L-G/L-L fault current contributions

•Sequence voltage and currents

•Phase Voltages

Line-To-Ground Fault

% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA		
Va		Vb		Vc		Ia		Ib		Ic				
Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1	I2	I0
0.00	179.1	1.00	-114.5	1.00	114.5	30.939	-88.7	0.000	0.0	0.000	0.0	10.313	10.313	10.
65.65	-55.0	65.78	-124.9	107.69	90.0	0.372	-87.2	0.186	92.8	0.186	92.8	0.186	0.186	0.
67.80	-50.7	67.87	-129.3	105.00	90.0	1.730	-88.5	0.582	-88.6	0.582	-88.6	0.382	0.382	0.
2.61	8.1	100.44	-114.9	100.13	115.0	0.090	-80.5	0.028	100.8	0.028	102.0	0.039	0.039	0.
105.00	0.0	105.00	-120.0	105.00	120.0	28.748	-88.7	0.369	90.0	0.369	89.9	9.706	9.706	9.

Line-To-Line Fault

% Voltage at From Bus						Current at From Bus (kA)						Sequence Current (kA)		
Va		Vb		Vc		Ia		Ib		Ic				
Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1	I2	I0
105.00	0.0	52.50	180.0	52.50	180.0	0.000	0.0	24.254	-178.7	24.254	1.3	14.003	14.003	0.000
9387.80	-6.3	9377.51	-173.7	2053.52	90.3	0.000	-65.6	0.438	-177.2	0.438	2.8	0.253	0.253	0.000
9216.89	-9.3	9211.61	-170.7	2977.94	90.1	0.000	-68.2	0.899	-178.5	0.899	1.5	0.519	0.519	0.000
10498.58	0.0	5215.94	-177.1	5296.05	177.1	0.000	112.9	0.092	-169.9	0.092	9.8	0.053	0.054	0.000
10500.00	0.0	10500.00	-120.0	10500.00	120.0	0.000	-67.1	22.826	-178.7	22.826	1.3	13.179	13.178	0.000

Line-To-Line-To-Ground Fault

% Voltage at From Bus						Current at From Bus (kA)								
Va		Vb		Vc		Ia		Ib		Ic		Sequence Current (kA)		
Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	Mag.	Ang.	I1	I2	I0
92.72	0.0	0.00	-129.8	0.00	129.8	0.000	0.0	29.772	145.9	29.787	36.8	19.763	8.244	0.000
6310.16	-9.3	6301.67	-170.6	2053.52	90.3	0.208	-87.3	0.450	169.4	0.450	16.1	0.357	0.149	0.000
6586.22	-13.0	6582.50	-166.9	2977.94	90.1	0.651	91.4	1.573	126.3	1.575	56.6	0.733	0.306	0.000
9359.59	0.1	283.76	-102.1	288.33	118.9	0.031	-78.8	0.098	169.3	0.099	30.3	0.075	0.031	0.000
10500.00	0.0	10500.00	-120.0	10500.00	120.0	0.413	-90.0	27.790	146.5	27.788	36.0	18.599	7.758	0.000