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
- $I_{L-G}$ can range in utility systems from a few percent to possibly 115% (if $X_0 < X_1$) of $I_{3-phase}$ (85% of all faults).
- In industrial systems the situation $I_{L-G} > I_{3-phase}$ is rare. Typically $I_{L-G} \approx 0.87 \times I_{3-phase}$
- 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

$$v(t) = Vm \times \sin(\omega t + \theta)$$
\[ v(t) = Ri + L \frac{di}{dt} = Vm \times \sin(\omega t + \theta) \quad (1) \]

Solving equation 1 yields the following expression

\[
i(t) = \frac{Vm}{|Z|} \times \sin(\omega t + \theta - \phi) + \frac{Vm}{|Z|} \times \sin(\theta - \phi) \times e^{-\frac{R}{L}t}
\]

\[ \text{Steady State} \] \[ \text{Transient (DC Offset)} \]
AC Current (Symmetrical) with No AC Decay

DC Current
AC Fault Current Including the DC Offset (No AC Decay)
Machine Reactance \( (\lambda = LI) \)

AC Decay Current

Machine Impedance

time of fault

IAC (decay)

\[ t \]  
\[ \text{time (seconds)} \]
Fault Current Including AC & DC Decay

\[ \text{AC current} + I_{dc \ (offset)} + I_{AC \ (decay)} \]
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

• $I_k'' =$ 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-Circuit

\[ I_k^* = \text{initial symmetrical short-circuit current} \]
\[ i_p = \text{peak short-circuit current} \]
\[ I_k = \text{steady-state short-circuit current} \]
\[ i_{d.c.} = \text{d.c. component of short-circuit current} \]
\[ A = \text{initial value of the d.c. component } i_{d.c.} \]

**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

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

\[ I''_k = \text{initial symmetrical short-circuit current} \]
\[ i_p = \text{peak short-circuit current} \]
\[ I_k = \text{steady-state short-circuit current} \]
\[ i_{\text{d.c.}} = \text{d.c. component of short-circuit current} \]
\[ A = \text{initial value of the d.c. component} \]
Factors Used in $I_f$ Calc

- $\kappa$ – calc $i_p$ based on $I_k$

- $\mu$ – 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 $I_k$ for near-to-gen & meshed network

- $\lambda_{min} & \lambda_{max}$ – calc $i_k$
IEC Short-Circuit Study Case

- **Standard**
  - IEC
  - ANSI

- **Short-Circuit Current**
  - Max.
  - User-Defined c Factor
  - Min. (Exclude Duty Calc)
  - c Factor
    - < 1001 V: 1.1
    - 1001 to 35000 V: 1.1
    - > 35000 V: 1.1

- **Calculation Method**
  - \( X/R \) for Peak kA
    - Method A
    - Method B
    - Method C
  - Breaking kA
    - No Motor Decay
    - Include Motor Decay

- **Zero Sequence Model**
  - Include
    - Branch Y & Static Load

- **Protective Device Duty**
  - Based on Total Bus Fault Current
  - Based on Max Through Fault Current
  - Report Breaking Duty vs. CB Time Delay
    - Based on Total Bus If
    - Based on Max Through If

- **LV CB Breaking**
  - Use Ics
  - Use Icu
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
# Device Duty Comparison

<table>
<thead>
<tr>
<th>Element</th>
<th>Current Rating</th>
<th>Duty</th>
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<tbody>
<tr>
<td>Bus</td>
<td>Making</td>
<td>$i_p$</td>
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<tr>
<td>HV CP</td>
<td>Symmetrical Breaking</td>
<td>$I_{b,sym}$</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical Breaking</td>
<td>$I_{b,asym}$</td>
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<tr>
<td></td>
<td>Making</td>
<td>$i_p$</td>
</tr>
<tr>
<td></td>
<td>DC Component (%)</td>
<td>$I_{dc}$</td>
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<tr>
<td>LV CP</td>
<td>Symmetrical Breaking</td>
<td>$I_{b,sym}$</td>
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<tr>
<td></td>
<td>Asymmetrical Breaking</td>
<td>$I_{b,asym}$</td>
</tr>
<tr>
<td></td>
<td>Making</td>
<td>$i_p$</td>
</tr>
<tr>
<td>Fuse</td>
<td>Symmetrical Breaking</td>
<td>$I_{b,sym}$</td>
</tr>
<tr>
<td></td>
<td>Asymmetrical Breaking</td>
<td>$I_{b,asym}$</td>
</tr>
</tbody>
</table>
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

Positive Sequence

$\bar{V}_{c_1}$

$\bar{V}_{b_1}$

$\omega$

$\alpha_1$

Negative Sequence

$\bar{V}_{b_2}$

$\bar{V}_{a_2}$

$\omega$

$\alpha_2$

Zero Sequence

$\bar{V}_{c_0} = \bar{V}_{a_0} = \bar{V}_{c_0}$

$\omega$

$\alpha_3$
Sequence Networks

Negative

Positive

Zero

$V_{a_2}$ $I_{a_2}$ $F_2$

$V_{a_1}$ $I_{a_1}$ $F_1$

$V_{a_0}$ $I_{a_0}$ $F_0$

$Z_2$ $V_F$ $Z_1$

$Z_0$ $Z_g$
L-G Fault Sequence Network Connections

Positive

Negative

Zero

\[ I_f = 3 \times I_{a0} \]

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

if \( Z_g = 0 \)
L-L Fault Sequence Network Connections

\[ I_{a2} = -I_{a1} \]

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

Diagram showing fault sequence connections with symbols for \( I_{a1}, I_{a2} \), and \( V_F \).
L-L-G Fault Sequence Network Connections

![Diagram of L-L-G Fault Sequence Network Connections]

\[ I_{a_2} + I_{a_1} + I_{a_0} = 0 = I_a \]

\[ I_f = \frac{V_{Prefault}}{Z_1 + \left( \frac{Z_0Z_2}{Z_0 + Z_2} \right)} \]

if \( Z_g = 0 \)
Transformer Zero Sequence Connections

<table>
<thead>
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<th>L</th>
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<tr>
<td>H</td>
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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:

\[ I_{f3} < I_{f1} \]

This may be the case if Generators or Y/Δ Connected transformers 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

![Graph showing the percent DC component of fault current over time](slide39.png)
Transient Fault Current Calculation (IEC 61363)

AC Component of Fault Current Waveform

![Graph of AC Component of Fault Current (rms)]
Transient Fault Current Calculation (IEC 61363)

Top Envelope of Fault Current Waveform
Transient Fault Current Calculation (IEC 61363)

Top Envelope of Fault Current Waveform

![Graph showing the DC component of fault current over time. The graph plots the fault current in kiloamperes (kA) against time in seconds, with the waveform decaying over time. The waveform is labeled as SubIE.](image)
Unbalanced Faults Display & Reports

Complete reports that include individual branch contributions for:

- L-G Faults
- L-L-G Faults
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### Line-To-Ground Fault

<table>
<thead>
<tr>
<th>% Voltage at From Bus</th>
<th>Current at From Bus (kA)</th>
<th>Sequence Current (kA)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Va</td>
<td>Vb</td>
</tr>
<tr>
<td>0.00</td>
<td>179.1</td>
<td>1.00</td>
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<tr>
<td>65.65</td>
<td>-55.0</td>
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<td>67.80</td>
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<tr>
<td>2.61</td>
<td>8.1</td>
<td>100.44</td>
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<tr>
<td>105.00</td>
<td>0.0</td>
<td>105.00</td>
</tr>
</tbody>
</table>

### Line-To-Line Fault

<table>
<thead>
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</thead>
<tbody>
<tr>
<td></td>
<td>Va</td>
<td>Vb</td>
</tr>
<tr>
<td>105.00</td>
<td>0.0</td>
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<td>9387.80</td>
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<tr>
<td>10498.58</td>
<td>0.0</td>
<td>5215.94</td>
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<tr>
<td>10500.00</td>
<td>0.0</td>
<td>10500.00</td>
</tr>
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</table>
### Line-To-Line-To-Ground Fault

<table>
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<th>Current at From Bus (kA)</th>
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</tr>
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<tbody>
<tr>
<td>92.72 0.0 0.00 -129.8 0.00 129.8</td>
<td>0.000 0.0 29.772 145.9 29.787 36.8</td>
<td>19.763 8.244 0.000</td>
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<tr>
<td>6310.16 -9.3 6301.67 -170.6 2053.52 90.3</td>
<td>0.208 -87.3 0.450 169.4 0.450 16.1</td>
<td>0.357 0.149 0.000</td>
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<tr>
<td>6586.22 -13.0 6582.50 -166.9 2977.94 90.1</td>
<td>0.651 91.4 1.573 126.3 1.575 56.6</td>
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<tr>
<td>9359.59 0.1 283.76 -102.1 288.33 118.9</td>
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<td>0.075 0.031 0.000</td>
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<tr>
<td>10500.00 0.0 10500.00 -120.0 10500.00 120.0</td>
<td>0.413 -90.0 27.790 146.5 27.788 36.0</td>
<td>18.599 7.758 0.000</td>
</tr>
</tbody>
</table>

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**Diagram:**

- **Gen1** connected to **Sub2B**
- **Sub2B** shows current flows: 2.3kA, 0.09kA, 0.177kA, 2.5kA, 3.958 kV