FAULT LEVEL CALCULATIONS
WHAT IS FAULT LEVEL?

Fault level at any given point of the electric power supply network is the maximum current that would flow in case of a short circuit fault at that point.
PURPOSE OF FAULT LEVEL CALCULATIONS

- FOR SELECTING SHORT CIRCUIT PROTECTIVE DEVICES OF ADEQUATE SHORT CIRCUIT BREAKING CAPACITY.

- FOR SELECTING CIRCUIT BREAKERS & SWITCHES OF ADEQUATE SHORT CIRCUIT MAKING CAPACITY.

- FOR SELECTING BUSBARS, BUSBAR SUPPORTS, CABLE & SWITCHGEAR, DESIGNED TO WITHSTAND THERMAL & MECHANICAL STRESSES BECAUSE OF SHORT CIRCUIT.

- TO DO CURRENT BASED DISCRIMINATION BETWEEN CIRCUIT BREAKERS.
TYPES OF SHORT CIRCUITS

- L – E  (SINGLE LINE TO EARTH)
- L – L  (LINE TO LINE)
- L – L – E  (LINE TO LINE TO EARTH)
- L – L – L  (THREE PHASE)
SOURCES OF SHORT CIRCUIT CURRENTS

- IN-HOUSE SYNCHRONOUS GENERATORS
- SYNCHRONOUS MOTORS & SYNCHRONOUS CONDENSERS
- ASYNCHRONOUS INDUCTION MOTORS
- ELECTRIC UTILITY SYSTEM THROUGH THE TRANSFORMER
NATURE OF SHORT CIRCUIT CURRENT

SOURCE: UTILITY SYSTEM

THE SHORT CIRCUIT CURRENT WILL CONSIST OF FOLLOWING COMPONENTS:

1. THE AC COMPONENT WITH CONSTANT AMPLITUDE

2. THE DECAYING DC COMPONENT
NATURE OF SHORT CIRCUIT CURRENT

SOURCE: SYNCHRONOUS GENERATORS & MOTORS / INDUCTION MOTORS

THE SHORT CIRCUIT CURRENT WILL CONSIST OF FOLLOWING COMPONENTS:

1. THE AC COMPONENT WITH DECAYING AMPLITUDE

2. THE DECAYING DC COMPONENT
NATURE OF SHORT CIRCUIT CURRENT

WAVEFORM

- TOP ENVELOPE
- DECAYING DC COMPONENT
- BOTTOM ENVELOPE

CURRENT

\[ 2\sqrt{2} I_k \]

\[ i_p \]

\[ A \]

\[ 2\sqrt{2} I_k = 2\sqrt{2} I_k \]

TIME
NATURE OF SHORT CIRCUIT CURRENT

SYMBOLS USED

\[ I''_K = \text{INITIAL SYMMETRICAL RMS S/C CURRENT} \]

\[ I_K = \text{STEADY STATE RMS S/C CURRENT} \]

\[ i_p = \text{PEAK S/C CURRENT} \]

\[ A = \text{INITIAL VALUE OF DECAYING DC COMPONENT} \]

Note: FOR S/C FAR FROM GENERATOR (e.g. L.V. SYSTEM GETTING POWER FROM UTILITY THROUGH TRANSFORMERS) : \[ I''_K = I_K \]
CALCULATION ASSUMPTIONS

WHY?

- SIMPLIFIES CALCULATION
- ACCURACY IS NOT MUCH AFFECTED
- CALCULATED VALUES WILL BE HIGHER THAN ACTUAL & HENCE SAFE
CALCULATION ASSUMPTIONS

WHAT?

- TYPE OF SHORT CIRCUIT: THREE PHASE BOLTED SHORT CIRCUIT
- IMPEDANCES OF BUSBAR/SWITCHGEAR/C.T./JOINTS ARE NEGLECTED
- FAULT CURRENT FROM THE TRANSFORMER WOULD BE LIMITED BY THE SOURCE FAULT LEVEL
- TRANSFORMER TAP IS IN THE MAIN POSITION
- SHORT CIRCUIT CURRENT WAVEFORM IS A PURE SINE WAVE
- DISCHARGE CURRENT OF CAPACITORS ARE NEGLECTED
CALCULATION METHODS

* DIRECT METHOD

* PER UNIT METHOD
ADVANTAGES OF DIRECT METHOD

# USES SYSTEM SINGLE LINE DIAGRAM DIRECTLY
# USES SYSTEM & EQUIPMENT DATA DIRECTLY
# USES BASIC ELECTRICAL EQUATIONS DIRECTLY
# EASIER TO COMPREHEND
THE FAULT LEVEL CALCULATION PROCEDURE FOLLOWED IN THIS PRESENTATION IS AS GIVEN IN IS 13234 – 1992 (Indian Standard Guide for Calculating Short Circuit Currents in AC Electrical Networks up to 220kV)
Fault Level Calculations – Direct Method – A Step by Step Approach

Step 1: Prepare a single line diagram of the electrical power supply and distribution network, clearly indicating all the significant network elements, fault current contributors, short circuit protective devices, etc.
Step 2: Get the following data:

i) Transformer rated kVA, rated secondary voltage of the transformer (U_{rT}), %R & %X values.

ii) Generator rated kVA, rated voltage (U_{rG}), rated sub-transient reactance (%x''_d) & rated Power factor (Cos \varphi_{rG}).
FAULT LEVEL CALCULATIONS – DIRECT METHOD – A STEP BY STEP APPROACH

Step 2: Get the following data:

iii) Cable Resistance ($R_C$) & Cable Reactance ($X_C$) per unit length and the actual length of the cable used.

iv) Motors’ rated voltages ($U_{rM}$), rated currents ($I_{rM}$) and locked rotor currents ($I_{LR}$).
Fault Level Calculations – Direct Method – A step by step approach

Step 3: Convert %R into Ohmic values, to obtain $R_T$.

$$10 \times (%R) \times (kV)^2$$

$$R_T \text{ (in } \Omega) = \frac{\text{-------------------}}{\text{kVA}}$$
FAULT LEVEL CALCULATIONS – DIRECT METHOD – A STEP BY STEP APPROACH

Step 4: Similarly, convert %X into Ohmic values, to obtain $X_T$.

$$X_T \text{ (in } \Omega) = \frac{10 \times (%X) \times (kV)^2}{kVA}$$
Step 5: Similarly, convert \( \%x''_d \) of the generator into Ohmic values, to obtain \( X_G \).

\[
X_G \ (\text{in } \Omega) = \frac{10 \times (\%x''_d) \times (\text{kV})^2}{\text{kVA}}
\]
Fault Level Calculations – Direct Method – A Step by Step Approach

Step 6: Now, the resistance of the generator, $R_G$’ is normally given as a % of $X_G$. For LV Generators, it is:

$$R_G \text{ (in } \Omega) = 0.15 \times X_G$$
Fault Level Calculations – Direct Method – A Step by Step Approach

Step 7: Calculate a correction factor ‘$K_G$’.

$$K_G = \frac{U_n}{U_{rG}} \frac{c}{1 + [(x_d^\prime) (\sin \phi_{rG})]}$$

where,
FAULT LEVEL CALCULATIONS – DIRECT METHOD – A STEP BY STEP APPROACH

\[ K_G = \text{Generator Correction Factor} \]
\[ U_n = \text{Nominal System Voltage, in Volts} \]
\[ U_{RG} = \text{Generator Rated Voltage, in Volts} \]
\[ c = \text{Voltage Correction Factor} = 1.05 \]
\[ x''_d = \text{Sub-transient Reactance of the Generator, in p.u. form} \]
\[ \sin \phi_{rG} = \sqrt{1 - \cos^2 \phi_{rG}} \]
\[ \cos \phi_{rG} = \text{Rated Power Factor of the Generator} \]
Step 8: Now find out the Corrected Generator Resistance ($R_{GK}$) & the Corrected Generator Reactance ($X_{GK}$):

\[ R_{GK} = K_G \times R_G \]

\[ X_{GK} = K_G \times X_G \]
Step 9: Now find out the cable resistance & reactance for the actual length of cable used up to the point of fault:

\[
\begin{align*}
R_L &= R_C \times L_C \\
X_L &= X_C \times L_C
\end{align*}
\]
Fault Level Calculations – Direct Method – A step by step approach

where,

\[ R_L \]
\[ X_L \]
\[ R_C \]
\[ X_C \]
\[ L_C \]

- \( R_L \) = Line or Lead Resistance, in \( \Omega \)
- \( X_L \) = Line or Lead Reactance, in \( \Omega \)
- \( R_C \) = Cable Resistance per km, in \( \Omega \)
- \( X_C \) = Cable Reactance per km, in \( \Omega \)
- \( L_C \) = Actual length of cable up to the point of fault, in m
FAULT LEVEL CALCULATIONS – DIRECT METHOD – A STEP BY STEP APPROACH

Step 10: Now add all ‘R’ & all ‘X’ values; find out ‘Z_k’.

\[ Z_k = \sqrt{(R_e)^2 + (X_e)^2} \]

\[ R_e = R_T \text{ or } R_{GK} + R_L \]

\[ X_e = X_T \text{ or } X_{GK} + X_L \]
Step 11: Now find out the initial symmetrical short circuit current, $I''_k$:

$$I''_k = \frac{c \ U_n}{\sqrt{3} \ Z_k}$$
Fault Level Calculations – Direct Method – A Step by Step Approach

where,

\[ I''_k = \text{Initial Symmetrical short circuit current, in Amperes} \]
\[ U_n = \text{Nominal System Voltage, in volts} \]
\[ c = \text{Voltage Correction factor} = 1.05 \text{ for LV (for HV it is 1.10)} \]
\[ Z_k = \text{Equivalent Impedance up to the point of fault, in } \Omega \]
Fault Level Calculations – Direct Method – A Step by Step Approach

Step 12: Determine the ‘X’/’R’ ratio up to the point of fault.

Step 13: Calculate the Asymmetry Factor ‘χ’ (pronounced as ‘KHI’).

\[ \chi = (1.02 + 0.98 e^{-3R/X}) \]
FAULT LEVEL CALCULATIONS – DIRECT METHOD – A STEP BY STEP APPROACH

Step 14: Now, calculate the peak current,

\[ i_p = \chi \sqrt{2} I_k \]

Step 15: Calculate the aggregate of the rated full load currents of all the motors at a particular location (\( \Sigma I_{rM} \)).
Step 16: If $(\Sigma I_{rM})$ at a particular location is less than 1% of the short circuit current contributed by other sources for a fault at that particular location, then contribution to the short circuit, from the motors in that particular group, need not be considered. Or else, the motors’ contribution to short circuit has to be calculated.
Step 17: Assuming that the motors’ contribution has to be considered, the R.M.S. Current contribution to the short circuit, from the group of motors will be:

$$I''_{kM} = c \ 6 \ \Sigma I_{rM}, \text{ if the S/C is at the motor terminals}$$

$$I''_{kM} = c \ 5 \ \Sigma I_{rM}, \text{ if the S/C is away from the motor terminals, involving a cable}$$
Step 18: And, the peak current contribution from the motor group would be:

\[ i_{PM} = \chi_M \sqrt{2} I''_{KM} \]

where,
\[ \chi_M = 1.3 \text{ for an R/X ratio of 0.42, as in the case of LV Induction motors} \]
Step 19: Now, calculate the total fault level, both R.M.S. ($I''_{KT}$) and the Peak ($i_{pT}$) at the fault location:

$$I''_{KT} = I''_K + I''_{KM}$$

and

$$i_{pT} = i_p + i_{pM}$$
What if the transformer’s ‘%R’ & ‘%X’ values are not known?

Need not worry! However, one can get to know the transformer’s ‘%Z’ from the name plate. Now, convert this ‘%Z’, into $Z_T$ in $\Omega$, using the same formula:

$[Z_T = \{(10 \times \%Z \times kV^2)/(kVA)\}]$. 
Fault Level Calculations – Direct Method – a few ‘ifs’ and ‘buts’.

The resistance of the transformer in Ω ($R_T$), can be got from one of the following ways:

i) From the manufacturer’s test certificate

ii) By actual measurements, using either a low resistance measuring meter or a Kelvin’s Double Bridge
iii) Or from the formula:

\[ R_T = \frac{P_{krT}}{3I_{rT}^2} \]

where,

- \( P_{krT} \) = Transformer Full Load Copper Loss, in Watts
- \( I_{rT} \) = Rated full load secondary current of the transformer, in amperes
Fault Level Calculations – Direct Method – a few ‘ifs’ and ‘butts’.

Once you know $Z_T$ & $R_T$, $X_T$ can be easily calculated by:

$$X_T = \sqrt{[Z_T]^2 - [R_T]^2}.$$
Fault Level Calculations – Direct Method – A Few ‘ifs’ and ‘buts’.

What if I don’t have any of the above data regarding $R_T$?

Transformer manufacturers give guidance values of the no-load loss, the full load loss & % impedance for a wide range of transformers in their catalogues. They can be taken as a guide for the calculations.
Fault Level Calculations – Direct Method – A Few ‘ifs’ and ‘buts’.

For example, the following data is got from a leading transformer manufacturer.

<table>
<thead>
<tr>
<th>kVA</th>
<th>NLL (W)</th>
<th>FLL (W)</th>
<th>%Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>450</td>
<td>3000</td>
<td>4.75</td>
</tr>
<tr>
<td>200</td>
<td>540</td>
<td>3200</td>
<td>4.75</td>
</tr>
<tr>
<td>250</td>
<td>630</td>
<td>3800</td>
<td>4.75</td>
</tr>
<tr>
<td>315</td>
<td>725</td>
<td>4400</td>
<td>5</td>
</tr>
<tr>
<td>400</td>
<td>850</td>
<td>5500</td>
<td>5</td>
</tr>
<tr>
<td>500</td>
<td>1040</td>
<td>6500</td>
<td>5</td>
</tr>
</tbody>
</table>
### Fault Level Calculations – Direct Method – A Few ‘ifs’ and ‘buts’.

<table>
<thead>
<tr>
<th>kVA</th>
<th>NLL (W)</th>
<th>FLL (W)</th>
<th>%Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>630</td>
<td>1200</td>
<td>8000</td>
<td>5</td>
</tr>
<tr>
<td>800</td>
<td>1450</td>
<td>9500</td>
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</tr>
<tr>
<td>1000</td>
<td>1800</td>
<td>11500</td>
<td>5</td>
</tr>
<tr>
<td>1250</td>
<td>1900</td>
<td>13500</td>
<td>6.25</td>
</tr>
<tr>
<td>1600</td>
<td>2300</td>
<td>17000</td>
<td>6.25</td>
</tr>
</tbody>
</table>
FAULT LEVEL CALCULATIONS
- A CASE STUDY
STEP 2 : SYSTEM DATA

TRANSFORMER : 11/0.433kV
1600kVA
%R = 0.94
%X = 5.46
%Z = 5.54

STANDBY GENERATOR : $U_r = 415V$
1250kVA
%X''d = 20
Cos $\phi_r = 0.8$
$U_n = 415V$
STEP 2 : SYSTEM DATA

CABLE : \( R = 0.062 \, \Omega/kM \)
\( X = 0.079 \, \Omega/kM \)

LENGTH OF CABLE, 21 TO 31= 100M

INDUCTION MOTORS :

\( M_1, I_{rM} = 70A \)
\( M_2, I_{rM} = 135A \)
\( M_3, I_{rM} = 40A \)
\( M_4, I_{rM} = 200A \)

\( U_{rM} = 415V; \, I_{LR} = 6 \, I_{rM} \)