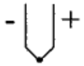
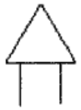
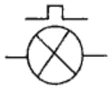
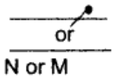
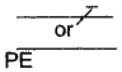
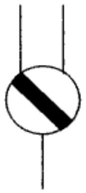
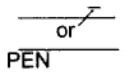
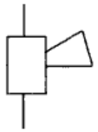
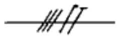
Graphical Symbols (IEC 617)

Symbol and description	Symbol	Symbol and description	Symbol
Reactive Power Meter		Bell	
Thermocouple, shown with polarity symbols		Siren	
Lamp, general symbol signal lamp, general symbol		Buzzer	
Signal lamp, flashing type		Neutral conductor	
Indicator, electro-mechanical Annunciator element		Protective conductor	
Electromechanical position indicator with one de-energized (shown) and two operated positions		Combined protective and neutral conductor	
Horn		Three-phase wiring with neutral conductor and protective conductor	
Star Delta Starter		DOL starter	

Fault Level Calculations

(I.S. 13234 - 1992, IEC 60909 - 1988)

EQUATIONS AND SYMBOLS

Z_Q - Source impedance $= \dfrac{c\,U^2_{nQ}}{S''_{kQ}}\ \Omega$

Z_Q - Source complex impedance.

c - Voltage factor. Low voltage 230/400 Volts $c = 1$
For all other low voltages $c = 1.05$
Medium and high voltages >1kV to 230 kV, $c = 1.1$

U_{nQ} - Nominal source voltage, line to line (r.m.s.) in V

S''_{KQ} - Initial symmetrical short circuit apparent power at feeder connection point Q in VA.

R_Q - Source resistance $= 0.1\ X_Q$ Ohm

X_Q - Source reactance $= 0.995\ Z_Q$ Ohm

R'_L - Resistance of overhead line $= \dfrac{\rho \times 1000}{q_n}\ \Omega/\text{km}$

ρ - Resistivity of conductor.

$\dfrac{1}{54}\Omega\ \dfrac{mm^2}{m}$ for copper

$\dfrac{1}{34}\Omega\ \dfrac{mm^2}{m}$ for aluminium

$\dfrac{1}{31}\Omega\ \dfrac{mm^2}{m}$ for aluminium alloy

q_n - Area of cross section of conductor in mm^2

X'_L - Reactance of overhead line $= 0.0628\left(\dfrac{0.25}{n} + \ln\dfrac{d}{r}\right)\Omega/\text{km}$

n - Number of conductors per phase

d - Spacing of overhead line conductors in mtr r - Mean radius of conductor $= \frac{1.14}{1000}\sqrt{\frac{q_n}{\pi}}$ mtr

Z_T - Transformer impedence $= \frac{U_{kr}}{100} \cdot \frac{U_{rT}^2}{S_{rT}}$ Ω

u_{kr} - Percentage impedence of transformer.

U_{rT} - Rated voltage of transformer on the high voltage or low voltage side in volts.

S_{rT} - Rated apparent power of the transformer in VA

R_T - Transformer resistance $= \frac{P_{krT}}{3.I_{rT}^2}$ Ohm

P_{krT} - Full load loss of transformer in Watts.

I_{rT} - Full load current of transformer on high voltage or low voltage side in amps.

X_T - Transformer reactance $= \sqrt{Z_T^2 - R_T^2}$ Ω

I''_K - Initial symmetrical short circuit current $= \frac{c \cdot U_n}{\sqrt{3} \cdot Z_k}$ A

U_n - Nominal voltage, line to line, of the system in volts (r.m.s)

Z_k - Short circuit impedance upto the fault point in Ω

i_p - Peak short circuit current $= \sqrt{2}\,\chi . I''_K$ A

$\chi = 1.02 + 0.98\, e^{-3.R_k/X_k}$

R_k - Short circuit resistance upto the fault point in Ω

X_k - Short circuit reactance upto the fault point in Ω

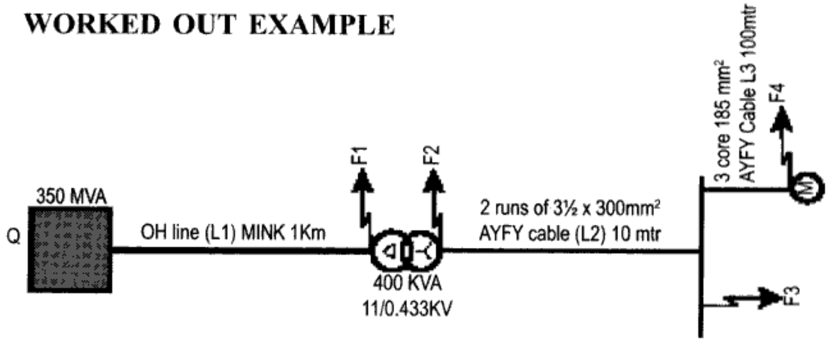
Z_{kt} - Short circuit impedance of high voltage side referred to low voltage side $= Z_k \cdot \frac{1}{t_r^2}$ Ω

R_{kt} - Short circuit resistence of high voltage side reffered to low voltage side $= R_k \cdot \frac{1}{t_r^2}$ Ω

X_{kt} - Short circuit reactance of high voltage side reffered to low voltage side $= X_k \cdot \frac{1}{t_r^2}$ Ω

t_r - Transformation ratio of transformer.

WORKED OUT EXAMPLE



U_{nQ} - 11000 Volts

S''_{KQ} - 350×10^6 VA

q_n - 95mm² (MINK conductor area)

d - 1.2 mtr

S_{rT} - 400 x 1000 VA

t_r - 11000/433

U_{rT} - 11000 V - High voltage and 433 volts - low voltage

u_{kr} - 5%

P_{krT} - 4600 watts - Data collected from manufacturer.

R'_{L2} - Resistance of 3½ × 300mm² cable = 0.1 /km

X'_{L2} - Reactance of 3½ × 300mm² cable = 0.071 /km

R'_{L3} - Resistance of 3 × 185mm² cable = 0.211 /km

X'_{L3} - Reactance of 3 × 185mm² cable = 0.074 /km

(R'_{L2}, X'_{L2}, R'_{L3}, X'_{L3} are collected from manufacturers catalogues)

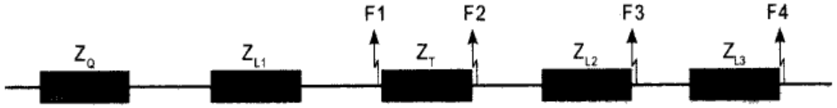
L_1 - Length of OH line - 1 km.

L_2 - Length of 300mm² cable = 10 m

L_3 - Length of 185mm² cable = 100 m

CALCULATIONS

Fault Location F1



Z_Q - Source impedance = $\dfrac{cU^2_{nQ}}{S''_{kQ}}\,\Omega \;=\dfrac{1.1\times 11000^2}{350\times 10^6}=0.38\;\Omega$

X_Q - Source reactance $= 0.995\times Z_Q = 0.995\times 0.38 = 0.3781\ \Omega$

R_Q - Source resistance $= 0.1\times X_Q = 0.1\times 0.3781 = 0.03781\ \Omega$

R'_{L1} - $\dfrac{\rho\times 1000}{q_n}\ \Omega/\text{km} = \dfrac{1\times 1000}{34\times 95} = 0.3096\,\Omega/\text{km}$

R_{L1} - $R'_{L1}\times L_1 = 0.3096 \quad 1\text{km} = 0.3096\ \Omega$

r - $\dfrac{1.14}{1000}\times\sqrt{\dfrac{q_n}{\pi}} = \dfrac{1.14}{1000}\times\sqrt{\dfrac{95}{\pi}} = 0.0063\ \text{m}$

(Since conductors are stranded, to get mean radius multiply by 1.14)

n - 1 (Since only one conductor per phase)

X'_{L1} - $0.0628\left(\dfrac{0.25}{n}+l_n.\dfrac{d}{r}\right)\Omega/\text{km}$

$= 0.0628\left(\dfrac{0.25}{1}+l_n.\dfrac{1.2}{0.0063}\right) = 0.3454\,\Omega/\text{k m}$

X_{L1} - $X'_{L1}\times L_1 = 0.3454\times 1 = 0.3454\,\Omega/\text{km}$

R_{K1} - Short circuit resistance upto fault F1,

$R_Q + R_{L1} = 0.03781 + 0.3096\,\Omega = 0.34741\,\Omega$

X_{K1} - Short circuit reactance upto fault F1,

$X_Q + X_{L1} = 0.3781 + 0.3454 = 0.7235\,\Omega$

Z_{K1} - Short circuit impedence upto fault point F1 =

$\sqrt{R^2_{K1}+X^2_{K1}} = \sqrt{0.34741^2+0.7235^2} = 0.8086\,\Omega$

I''_{kF1} - Initial symmetrical short ciruit current at

$$\text{F1}= \frac{c\times U_n}{\sqrt{3}\times Z_{k1}} = \frac{1.1\times 11000}{\sqrt{3}\times 0.8026} = 8704\text{amps} = 8.704\ \text{kA}$$

χ_1 - $1.02+0.98\times e^{-3\times R_{k1}/X_{k1}} = 1.02+0.98\,e^{-3\,(0.34741/0.7235)} = 1.2521$

i_{pF1} - Peak short circuit current at fault

F1= $\chi_1\sqrt{2}\ I''_{kF1} = 1.2521\times\sqrt{2}\times 8.704 = 15.412\,\text{kA}$

Fault Location F2

R_{k1t} - Short circuit resistance upto F1 transferred to low voltage side of transformer = $R_{k1}\dfrac{1}{t_r^2} = \dfrac{0.34741\times 433^2}{11000^2} = 0.00054\,\Omega$

X_{k1t} - Short circuit reactance upto F1 transffered to low voltage side of transformer = $X_{k1}\dfrac{1}{t_r^2} = \dfrac{0.7235\times 433^2}{11000^2} = 0.00112\,\Omega$

Z_T - $\dfrac{u_{kr}\,U^2_{rT}}{100\,S_{rT}} = \dfrac{5\times 433^2}{100\times 400\times 1000} = 0.0234\,\Omega$

R_T - $\dfrac{P_{krT}}{3I^2_{rT}} = \dfrac{4600}{3\times 533^2} = 0.0054\,\Omega$ (Full load current of 400KVA tansformer is 533 amps)

X_T - $\sqrt{Z_T^2-R_T^2} = \sqrt{0.0234^2-0.0054^2} = 0.0228\,\Omega$

R_{k2} - Short circuit resistance upto fault point F2

$= R_{k1t}+R_T = 0.00054 + 0.0054 = 0.00594\ \Omega$

X_{k2} - Short circuit reactance upto fault point F2

$= X_{k1t}+X_T = 0.00112 + 0.0228 = 0.02392\ \Omega$

Z_{k2} - Short circuit impedance upto fault point F2

$= \sqrt{R^2_{k2}+X^2_{k2}} = \sqrt{0.00594^2+0.02392^2} = 0.0246\,\Omega$

I''_{kF2} - Initial symmetrical short circuit current at location F2

$$= \frac{cU_n}{\sqrt{3} \times Z_{k2}} = \frac{1.05 \times 433}{\sqrt{3} \times 0.0246} = 10.671 \text{ kA}$$

χ_2 - $1.02 + 0.98e^{-3 R_{K2}/X_{K2}} = 1.02 + 0.98e^{-3(0.00594/0.02392)} = 1.49$

i_{pF2} - Peak short circuit current at location

$$F2 = \chi_2 \times \sqrt{2} \times I''_{kF2} = 1.49 \times \sqrt{2} \times 10.671 = 22.49 \text{ kA}$$

Fault Location F3

R_{L2}(Single run) - $R'_{L2} \times L_2 = \frac{0.1 \times 10}{1000} = 0.001\,\Omega$

X_{L2}(Single run) - $X'_{L2} \times L_2 = \frac{0.071 \times 10}{1000} = 0.00071\,\Omega$

As two cables are connected in parallel

R_{L2}(2 run) - $\frac{R_{L2}(\text{Single run})}{2} = 0.0005\,\Omega$

X_{L2}(2 run) - $\frac{X_{L2}(\text{Single run})}{2} = 0.000355\,\Omega$

R_{k3} - Short circuit resistance upto fault point F3

$= R_{k2} + R_{L2}(2 \text{ runs}) = 0.00594 + 0.0005 = 0.00644\,\Omega$

X_{k3} - Short circuit reactance upto fault point

$F3 = X_{k2} + X_{L2}(2 \text{ runs}) = 0.02392 + 0.000355 = 0.0243\,\Omega$

Z_{k3} - Short circuit impedance upto fault point

$$F3 = \sqrt{R_{k3}^2 + X_{k3}^2} = \sqrt{0.00644^2 + 0.0243^2} = 0.02514\,\Omega$$

I''_{kF3} - Initial symmetrical short circuit current at location

$$F3 = \frac{cU_n}{\sqrt{3} \times Z_{k3}} = \frac{1.05 \times 433}{\sqrt{3} \times 0.02514} = 10.441 \text{ kA}$$

χ_3 - $1.02 + 0.98 \times e^{-3 \times R_{k3}/X_{k3}} = 1.02 + 0.98e^{-3(0.00644/0.0243)} = 1.46$

i_{pF3} - Peak short circuit current at location

$$F3 = \chi_3 \times \sqrt{2} \times I''_{kF3} = 1.46 \times \sqrt{2} \times 10.441 = 21.56 \text{ kA}$$

Fault Location F4

R_{L3} - $R'_{L3} \times L_3 = \frac{0.211 \times 100}{1000} = 0.0211\,\Omega$

X_{L3} - $X'_{L3} \times L_3 = \frac{0.074 \times 100}{1000} = 0.0074\,\Omega$

R_{k4} - Short circuit resistance upto fault point F4

$= R_{k3} + R_{L3} = 0.00644 + 0.0211 = 0.02754\,\Omega$

X_{k4} - Short circuit reactance upto fault point F4

$= X_{k3} + X_{L3} = 0.0243 + 0.0074 = 0.0317\,\Omega$

Z_{k4} - Short circuit impedance upto fault point F4

$$= \sqrt{R_{k4}^2 + X_{k4}^2} = \sqrt{0.02754^2 + 0.0317^2} = 0.042\,\Omega$$

I''_{kF4} - Initial symmetrical short circuit current at location F4

$$= \frac{cU_n}{\sqrt{3} \times Z_{k4}} = \frac{1.05 \times 433}{\sqrt{3} \times 0.042} = 6.25 \text{ kA}$$

χ_4 - $1.02 + 0.98 \times e^{-3 \cdot R_{k4}/X_{k4}} = 1.02 + 0.98\,e^{-3(0.02754/0.0317)} = 1.09$

i_{pF4} - Peak short circuit current at location F4

$$= \chi_4 \times \sqrt{2} \times I''_{kF4} = 1.09 \times \sqrt{2} \times 6.25 = 9.63 \text{ kA}$$

Fault locations	*Initial symmetrical short ciruit current I''_k*	*Peak short circuit current i_p*
F1	8.704 kA	15.412 kA
F2	10.671 kA	22.49 kA
F3	10.441 kA	21.56 kA
F4	6.25 kA	9.63 kA

Note (1) I''_k is to be considered for cable size, breaking capacity of circuit breaker, earthing design etc. (2) i_p is to be considered for ascertaining making capacity of circuit breakers, dynamic effect due to short circuit on bus bars etc.