Short Circuit Analysis

Theoretical Concepts

Electrical power systems composed of a wide range of equipment devoted to generating, transmitting, and distributing electrical power to various consumption centers. The very complexity of these systems suggests that failures are unavoidable, no matter how carefully these systems have been designed. Within the context of short-circuit analysis, system failures manifest themselves as insulation breakdowns that may lead to one of the following phenomena:

- Undesirable current flow patterns.
- Appearance of currents of excessive magnitudes that could lead to equipment damage and downtime.
- Excessive over voltages, of the transient and/or sustained nature, that compromise the integrity and reliability of various insulated parts.
- Voltage depressions in the vicinity of the fault that could adversely affect the operation of rotating equipment.
- Creation of system conditions that could prove hazardous to personnel.

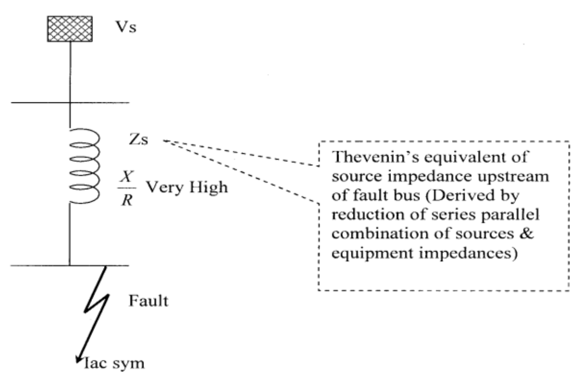
Because short circuits cannot always be prevented, we can only attempt to mitigate and to a certain extent contain their potentially damaging effects. One should aim to design the system so that the likelihood of the occurrence of short circuit becomes small. If a short circuit occurs, mitigating its effects consists of

- Managing the magnitude of undesirable fault currents.
- Isolating the smallest possible portion of the system around the area of mishap in order to retain service to the rest of the system.

The main reasons for performing short-circuit studies:

- Verification of the adequacy of existing interrupting equipment. The same type of studies will form the basis for the selection of the interrupting equipment for system planning purposes.
- Determination of the system protective device settings.
- Determination of the effects of the fault currents on various system components such as cables, lines, busways, transformers, and reactors during the time the fault persists.
- Assessment of the effect that different kinds of short circuits of varying severity may have on the overall system voltage profile.

Basic of AC & DC component of fault



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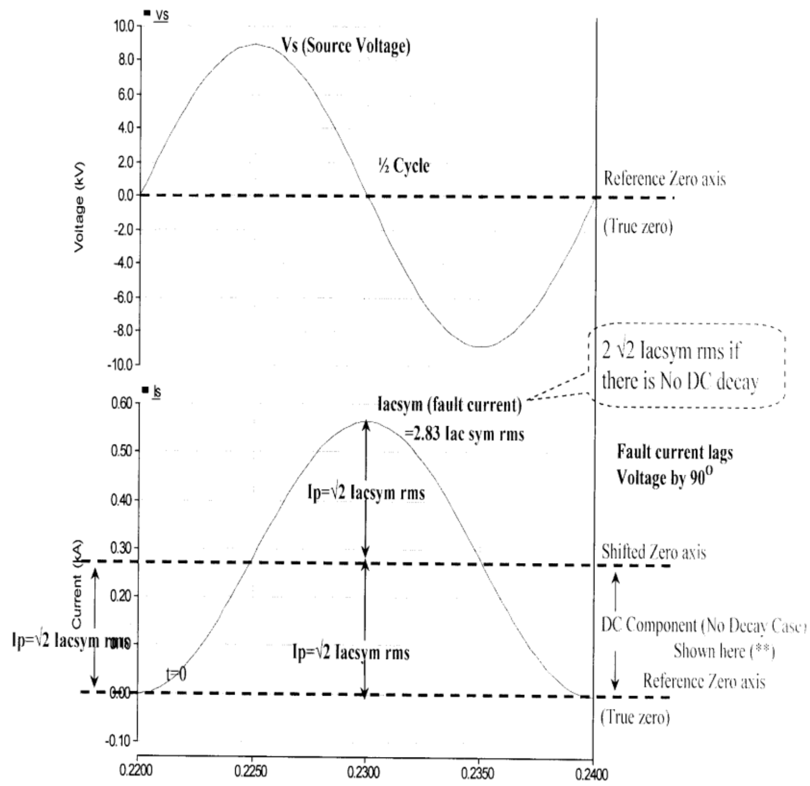
The DC component or shift in zero axis of current from reference or true zero (voltage zero axis) results from the necessity to satisfy two conflicting requirements:

a) Fault current wave must be maximum (-ve peak) when voltage wave is zero, because of highly inductive source fault impedance (X/R very high) 90 deg. lag of current.
b) The actual instantaneous fault current at fault is the value determined by the pre-fault network condition. It will be zero if fault occurs on unloaded circuit. So instantaneous fault current at t=0 should be zero.

To satisfy (a) and (b) above the AC current wave will have to be shifted by Ip = √2. Iacsymrms, when fault occurs at zero point of the voltage wave. The shifted current axis is DC component of fault.

FAULT CURRENT AT ZERO POINT OF VOLTAGE



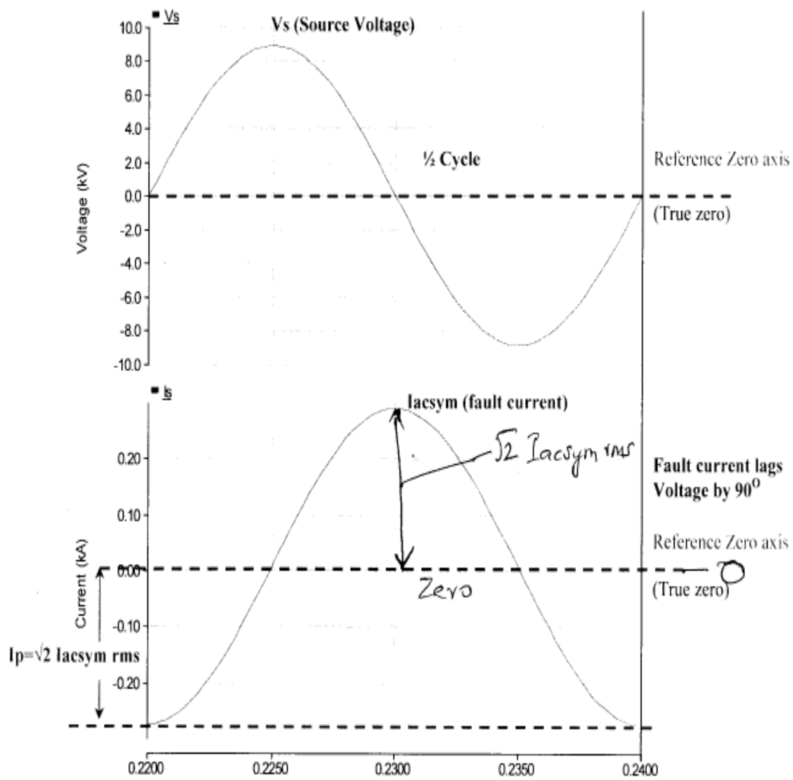
DC Current axis shift initially to √2. Iacsymrms.

Note: In actual practice DC will decay based on fault circuit time constant 'Taw'.

Short Circuit Analysis

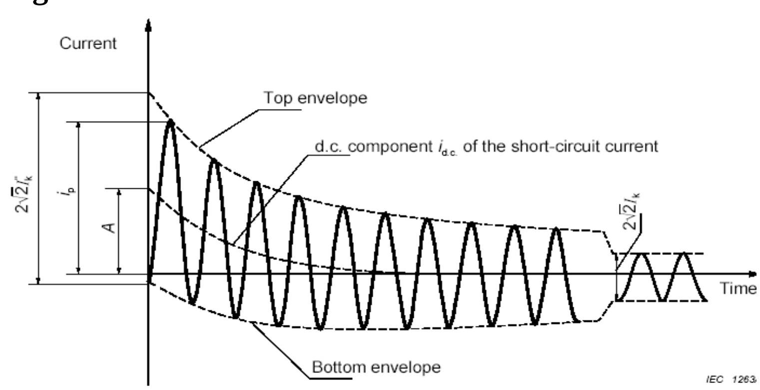
For fault occurring at peak point of voltage wave fault current is already zero (as required from (a) and (b) above) & Hence no current shift is required & Hence no DC component in fault current.

FAULT CURRENT AT PEAK POINT OF VOLTAGE



Here no DC current axis shift. Hence no DC component when fault current at voltage peak point in inductive circuit**.**

Short circuit near to generator



I_k'' = initial symmetrical short-circuit current

i_p = peak short-circuit current

I_k = steady-state short-circuit current

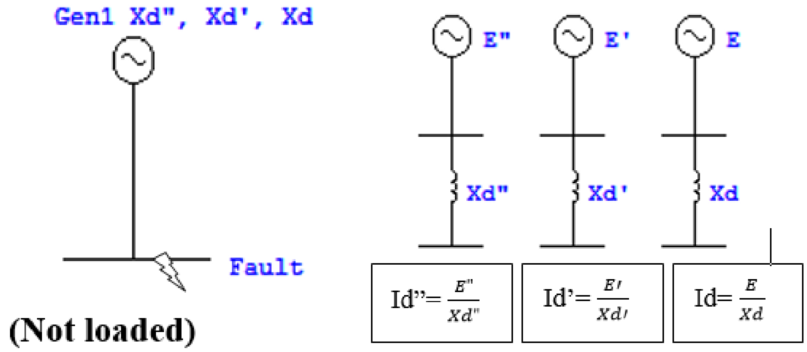
$i_{d.c.}$ = d.c. component of short-circuit current

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

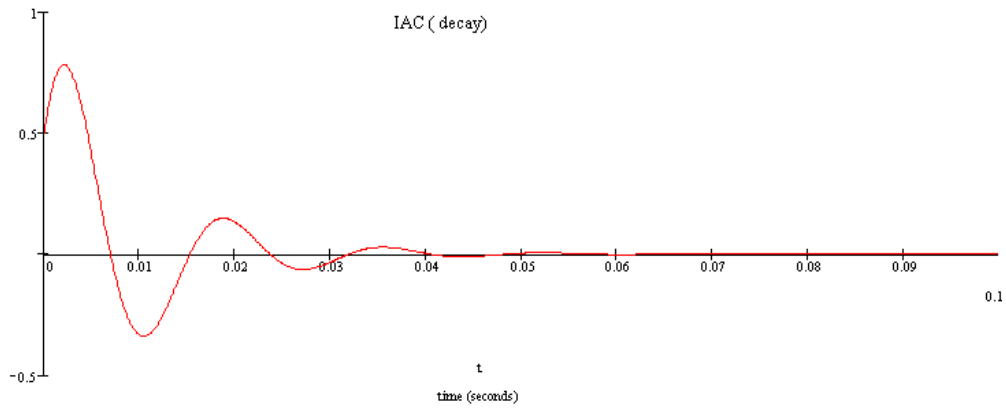
Short Circuit Analysis

Decay of AC component of fault

For fault close to generator, AC component of fault reduces from initial value as generator reactance varies from sub-transient to transient and then to steady state values (Xd'', Xd', Xd).

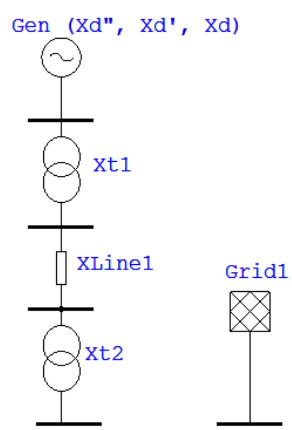


Fault close to generator, AC component will decay as shown in the below figure:



AC Decay

For fault at grid bus, AC component of fault does not decay since grid bus is considered to be remote from a generator (i.e. there are many other reactance components of equipment in series up to grid bus).



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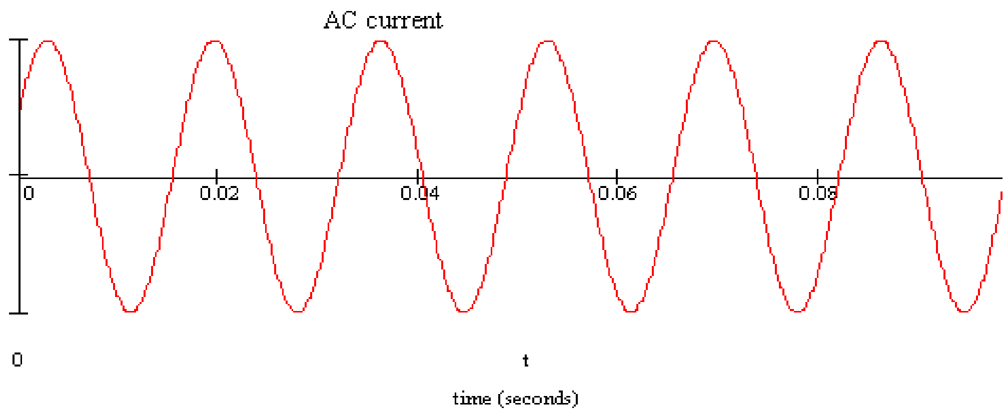
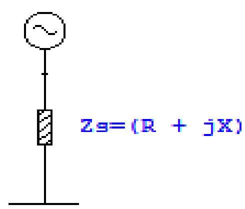
Here, $X_{t1} + X_{line1} + X_{t2}$ >>>> Xd''

Hence any change in Xd" to Xd' will not have a big change in net total X hence AC component of fault at grid bus does not decay.



Decay of DC component of fault

DC component of fault will decay based on L/R of the equivalent source circuit impedance (applies both to grid & to generator)



Thevenin's equivalent of all source impedance (series parallel combination).

Tau= $\frac{L}{R}$ of the source circuit in seconds.

Tau in terms $\frac{L}{R}$ will have to be converted in terms of $\frac{X}{R}$ as follows:

ω Tau= $\omega \frac{L}{R} = \frac{X}{R}$ (X= ω L)

ω Tau= $\frac{X}{R}$ (where Tau is in second and $\omega = 2\Pi f$)

(or) Tau = $\frac{(X/R)}{\omega}$

DC decay

DC component decay is given as

Idc (t) = Idc (t=0) × $e^{-t/Tau}$

Where,

Idc (t=0) = Peak of normal rms value of AC symmetrical fault current.

Idc (t=0) = $\sqrt{2} \times I_{ac\text{-}sym.rms}$

Hence, Idc (t) = $\sqrt{2} \times I_{ac\text{-}sym.rms} \times e^{-t/Tau}$

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Generator DC decay

Generator DC decay is based on 'Ta' of generator.
Where Ta = armature dc short circuit time given in seconds.
If Ta is given by vendor as 0.3 sec then for 50 Hz generator then,

ω Ta = $\frac{Xd''}{R}$ = 0.3 × 314.2 = 94

Note: In ETAP, $\frac{Xd''}{R}$ value needs to be entered, not Ta.

Asymmetrical break fault current of CB

Ib asym (kArms) at any instant of time't' which is CB breaking time from fault initiation is given as,

Ib asym (kArms) = $\sqrt{(I_{ac\text{-}sym\ rms}(t)^2 + Idc(t)^2)}$
$= \sqrt{(I_{ac\text{-}rms}(t)^2 + Idc(t)^2)}$

The system calculated asymmetrical break fault current should be less than selected CB's asymmetrical break fault current duty (kA_{rms}).

% DC component of fault

% DC component at any instant of time = $\frac{\mathrm{Idc(t)} \times 100}{\mathrm{Inp{-}ac(t)}}$

Inp-ac = Normal peak of ac symmetrical rms fault current for the cycle at "t" sec in kA_p.
$I_{dc}(t)$ = dc component of fault current decay at time "t" sec in kA.

Standard MV CB short circuit duty

Standard MV CB are type tested as per IEC 62271 with a fault dc decay circuit time constant of Tau = 45 milliseconds (i.e. 0.045 second) based on test generator (short circuit test on generator) having **'No AC fault decay'** (i.e. Xd" = Xd').

The ac & dc test fault current at any instant that a tested CB is subjected to short circuit rating of 25 kA ac sym rms for 50 Hz or 60 Hz are shown below.

Short Circuit Analysis

62271-100 © IEC:2001+A1:2002 – 75 –
+A2:2006

NOTE 1 The minimum opening time is the shortest opening time, which is expected by the manufacturer to cover the entire population of the circuit-breaker concerned under any operational conditions when breaking asymmetrical currents in accordance with this standard (terminal fault test-duty T100a). It should be chosen in such a manner that the d.c. component applied in test-duty T100a, which is based on this minimum opening time among others, is so large, that each circuit-breaker manufactured in the product life time will be covered by this test

The percentage value of the dc component (% dc) can be derived from figure 9 and is based on the time interval (T_{op} + T_r) and the time constant τ using the formula:

$$\% \text{ dc} = 100 \times e^{-\frac{T_{op}+T_r}{\tau}}$$

The graphs of the d.c. component against time given in figure 9 are based on:

a) standard time constant of 45 ms;

b) special case time constants, related to the rated voltage of the circuit-breaker:
   - 120 ms for rated voltages up to and including 52 kV;
   - 60 ms for rated voltages from 72,5 kV up to and including 420 kV;
   - 75 ms for rated voltages 550 kV and above.

These special case time constant values recognise that the standard value may be inadequate in some systems. They are provided as unified values for such special system needs, taking into account the characteristics of the different ranges of rated voltage, for example their particular system structures, design of lines, etc.

NOTE 2 In addition, some applications may require even higher values, for example if a circuit-breaker is close to a generator. In these circumstances, the required d.c. component and any additional test requirements should be specified in the enquiry.

NOTE 3 More detailed information on the use of the standard time constant and the special case time constants is given in the explanatory note in I.2.1.

Standards LV CB are tested as per IEC 60947. These CB's are tested at system short circuit power factor (i.e. System source short circuit impedance R/2 value).

Range of CB	Short circuit PF	Peak make factor
CB's > 50 kA	0.2	2.2
CB's between 20 to 50 kA, including 50 kA	0.25	2.1

4.3.5.3 Standard relationship between short-circuit making and breaking capacities and related power factor, for a.c. circuit-breakers

The standard relationship between short-circuit breaking capacity and short-circuit making capacity is given in table 2.

Table 2 – Ratio *n* between short-circuit making capacity and short-circuit breaking capacity and related power factor (for a.c. circuit-breakers)

Short-circuit breaking capacity I kA r.m.s.	Power factor	Minimum value required for n: $n = \frac{\text{short-circuit making capacity}}{\text{short-circuit breaking capacity}}$
4,5 ≤ I ≤ 6	0,7	1,5
6 < I ≤ 10	0,5	1,7
10 < I ≤ 20	0,3	2,0
20 < I ≤ 50	0,25	2,1
50 < I	0,2	2,2
NOTE – For values of breaking capacity lower than 4,5 kA, for certain applications, see table 11 for the power factor.		

The rated short-circuit making and breaking capacities are only valid when the circuit-breaker is operated in accordance with the requirements of 7.2.1.1 and 7.2.1.2.

For special requirements, the manufacturer may assign a value of rated short-circuit making capacity higher than that required by table 2. Tests to verify these rated values shall be the subject of agreement between manufacturer and user.

Short Circuit Analysis

IEC 62271-100 CB Test MODEL-HV CB (old standard was IEC 60056)

f =freq	50	hz	
ω	314.15927	omega = 2 pi.f rad/s	ω = Angular frequency in radian/sec
Tau	45	mill-sec	Type Test Circuit L/R For Standard HV CB
	0.045	sec	
X/R	14.137167		**ω x Tau = X/R where Tau should be in SECOND (Not Milli-sec in this formula)**
Iac sym rms	**25**	**kA ac sym rms**	**Rated Short Circuit Rating Reference kA Of MV or HV Switchgear/CB**

HV CB TYPE TESTED (TO STANDARD Tau) DC & AC FAULT CURRENT DUTY AT VARIOUS INSTANTS

cycle "c"	time in milli-sec t = (c/f)*1000	Iacsym = Iac rms	Ipn=Sqrt(2)*IacsymNormal Peak Of Ic rms		Idc (t)		**Ipm_rtd= Peak Make Value kA**	**Ipm_rtd_f = Peak Make Factor**		**Ibasym = Asymmetrical kA rms**	**Ibasym_f = Asymmetric Break Factor**	**% dc comp = 100*Idc(t)/Ipn(t)**
		TEST WITH NO AC DECAY										
Idc(t) = Idc inirial x e^ (-t/Tau) = Idc(t=0)I x e^ (-t/Tau) Where Idc(t=0) = Ipn=Sqrt(2)*Iacsym at t-0												
For above Idc(t) calculation t is in millli-sec, Tau should also be converted to millisec												
0	0	25	35.35533906		35.35534							100.0
0.5	**10**	**25**	**35.35533906**		**28.31034**		**63.665681**	**2.547**				80.1
1	20	25	35.35533906		22.66915					**33.747**	**1.350**	64.1
1.5	30	25	35.35533906		18.15204							51.3
2	**40**	**25**	**35.35533906**		**14.53501**					**28.918**	**1.157**	41.1
2.5	50	25	35.35533906		11.63873					**27.576**	**1.103**	32.9
3	60	25	35.35533906		9.319566					**26.681**	**1.067**	26.4
3.5	70	25	35.35533906		7.462525					**26.090**	**1.044**	21.1
4	80	25	35.35533906		5.975523					**25.704**	**1.028**	16.9
4.5	90	25	35.35533906		4.784825					**25.454**	**1.018**	13.5
5	100	25	35.35533906		3.831388					**25.292**	**1.012**	10.8

Ipmrtd_f= Peak Make Factor & Ibasym_f = Asymmetric Break Factor are values reffered to reference switchgear fault rating i.e AC Symmetrical rms fault current in kA

Forces prop Ipm_rtd ^2 x Lspan / d, where Lspan is span of supports and d is distance between phase conductor

Short Circuit Analysis

IEC 62271-100 CB Test MODEL-HV CB (old standard was IEC 60056)

f =freq	60	hz	
ω	376.99112	omega = 2 pi.f rad/s	ω = Angular frequency in radian/sec
Tau	45	mill-sec	Type Test Circuit L/R For Standard HV CB
	0.045	sec	
X/R	16.9646		**ω x Tau = X/R where Tau should be in SECOND (Not Milli-sec in this formula)**
Iac sym rms	**25**	**kA ac sym rms**	**Rated Short Circuit Rating Reference kA Of MV or HV Switchgear/CB**

HV CB TYPE TESTED (TO STANDARD Tau) DC & AC FAULT CURRENT DUTY AT VARIOUS INSTANTS

cycle "c"	time in milli-sec t = (c/f)*1000	Iacsym = Iac rms	Ipn=Sqrt(2)*IacsymNormal Peak Of Ic rms		Idc (t)		**Ipm_rtd= Peak Make Value kA**	**Ipm_rtd_f = Peak Make Factor**		**Ibasym = Asymmetrical kA rms**	**Ibasym_f = Asymmetric Break Factor**	**% dc comp = 100*Idc(t)/Ipn(t)**
		TEST WITH NO AC DECAY										
Idc(t) = Idc inirial x e^ (-t/Tau) = Idc(t=0)l x e^ (-t/Tau) Where Idc(t=0) = Ipn=Sqrt(2)*Iacsym at t-0												
For above Idc(t) calculation t is in millli-sec, Tau should also be converted to millisec												
0	0	25	35.35533906		35.35534							100.0
0.5	**8.333333333**	**25**	**35.35533906**		**29.37853**		**64.733872**	**2.589**				83.1
1	16.66666667	25	35.35533906		24.4121					**34.942**	**1.398**	69.0
1.5	25	25	35.35533906		20.28525							57.4
2	**33.33333333**	**25**	**35.35533906**		**16.85603**					**30.152**	**1.206**	47.7
2.5	41.66666667	25	35.35533906		14.00653					**28.656**	**1.146**	39.6
3	50	25	35.35533906		11.63873					**27.576**	**1.103**	32.9
3.5	58.33333333	25	35.35533906		9.671207					**26.805**	**1.072**	27.4
4	66.66666667	25	35.35533906		8.036293					**26.260**	**1.050**	22.7
4.5	75	25	35.35533906		6.677761					**25.876**	**1.035**	18.9
5	83.33333333	25	35.35533906		5.548888					**25.608**	**1.024**	15.7

Ipmrtd_f= Peak Make Factor & Ibasym_f = Asymmetric Break Factor are values reffered to reference switchgear fault rating i.e AC Symmetrical rms fault current in kA

Forces prop Ipm_rtd ^2 x Lspan / d, where Lspan is span of supports and d is distance between phase conductor

Short Circuit Analysis

Selection of short circuit rating of circuit breaker or Switchgear

Circuit breaker or switchgear should be selected to satisfy ‘MAKE’, ‘BREAK’ & ‘THERMAL’ short circuit duty.

MAKE (kAp) = Peak making duty (at ½ cycle).

This is maximum instantaneous fault current magnitude seen by CB/ switchgear during fault. Maximum value occurs at ½ cycle.

BREAK (kArms) = Asymmetrical break current in kArms at instant of break of a CB (opening time of CB + relay opening time).

THERMAL = 1 or 3 sec short circuit duty.

Time	Duty of CB/switchgear As per test HV- IEC 62271 LV- IEC 60947	Calculated fault as per IEC 60909.
½ cycle 10 msec at 50 Hz 8.33 msec at 60 Hz	Peak make duty as per IEC. In ANSI IEEE, it is also called as Momentary duty or Make duty or Close & latch duty “I_{pm_rtd}” (kAp)	Calculated instantaneous fault of system at a given bus “I_{pm_cal}” (kAp)
CB break time 40 or 50 or 60 in milliseconds	$I_{b\_asymm\_rtd}$ (kArms) $= \sqrt{(I_{acrms}^2 + I_{dc}^2)}$ at opening time As per IEC test Tau.	$I_{b\_asymm\_cal}$ (kArms).

Switchgear selection

Switchgear is ok if,

a) $I_{pm\_rtd} > I_{pm\_cal}$

b) $I_{b\_asymm\_rtd} > I_{b\_asymm\_cal}$ (at CB opening time)
(CB opening time in second should be entered in CB rating page for the calculation)

c) $I_{thermal\_rtd}$ (at 1 sec) > $I_{thermal\_cal}$ (at 1 sec)
If 3 sec then 3 sec values are compared for calculation. Thermal withstand needs to be entered in CB rating.

To select CB, use factors from next sheet. These factors are useful to select switchgear rating require for calculated system.

Short Circuit Analysis

Freq 50 Hz

CB Standard Test CB As Per IEC

CB	IEC Standard	Test Value As Per IEC	Tested Eq Tau	Test PF or R/Z	X/R at 50 Hz Derived From Tau or PF	Factor by which correspoding calculated fault kA needs to be divide to estimate switchgear/CB AC SYMM Fault Rating in kA acsym rms				
							Aymmetrical break at CB opening time			
						1/2 cycletime for peak make	40 milli-sec	50 milli-sec	60 milli-sec	70 milli-sec
HVCB	62271	Tau-45 milli-sec	Tau = 45 milli-sec	Short Circuit Pf = R/Z = 0.0705 (Derived)	14	2.5	1.157	1.103	1.047	1.044
LV CB with Icu i.e ac symm fault rating kA acsymm rms > 50 kA rms	60974	Short Circuit Pf = R/Z = 0.2	Tau = 15.59 milli-sec (Derived)	Short Circuit Pf = R/Z = 0.2	4.89	2.2	Almost 1.0			
LV CB with Icu i.e ac symm fault rating kA acsymm rms between 20 kA to equal to 50 kA rms	60974	Short Circuit Pf = R/Z = 0.25	Tau = 12.33 milli-sec (Derived)	Short Circuit Pf = R/Z = 0.25	3.87	2.1	Almost 1.0			

IEC calculation standards:

IEC 60909 provides guidance on the calculation of short circuit currents in a three phase ac system.
The standard produces fault current results for an unloaded network, that is the results do not include load current and the pre-fault conditions do not take account of tap positions.
To counter some of these assumptions, multipliers are applied to the driving voltage. The calculations from IEC 60909 lead to conservative results and it is possible that this method could result in over investment.
In order to ensure that an overtly conservative approach is not taken, that could increase equipment requirements leading to weight and space constraints on mobile or fixed offshore installations, IEC 61363 standard is also being used for short circuit studies in shipping and offshore industry as per the title of the IEC 61363 standard which is '**Electrical installations of ships and mobile and fixed offshore units – Part 1: Procedures for calculating short-circuit currents in three-phase a.c.'**
The IEC 61363 standard is known to evaluate short-circuit currents within sufficient accuracy that is suitable for practical applications after allowing for generator pre-loading and appropriate fault current attenuation based on actual data of generator impedance and time constants.
IEC 60909 is used for both meshed and unmeshed systems whereas IEC 61363 is applicable only for unmeshed systems.
Other standards such as IEC 61363 and UK Engineering Recommendation G74 are also used as practical standards for a computer-based derivation of fault currents.
To accurately determine the decay of the DC fault current component, the X/R ratio of the system under consideration has to be known.
This is not a problem for a simple single circuit radial system. However, in a complex, meshed network, there are several sources contributing to the total fault current via a number of branches with different X/R ratios.
The problem is thus to determine an equivalent X/R ratio to represent the entire system.
A number of methods that can be used to determine an equivalent X/R ratio will be briefly described below, at the hand of a practical example.
The so-called 'Method C described in IEC 60909 aims to improve the DC short circuit current calculation by using a variable X/R ratio.
A different X/R ratio is used for different time periods following the inception of the fault. Method C also known as the 'equivalent frequency method', works by scaling all reactance in the network to an equivalent frequency, fc.
The network is thus treated as if the system frequency is fc and not 50 Hz.

The ratio Xc/Rc is first calculated and scaled back to obtain the X/R ratio as below:

$$X/R = (50/f) * (Xc/fc)$$

Time Window (milli sec)	fc (Hz)
t < 10	20
10 < t < 20	13.5
20 < t < 50	7.5
50 < t < 100	4.6
100 < t < 250	2.75