ANSI Short-Circuit Calculation Methods

PowerStation provides two short-circuit calculation methods based on ANSI/IEEE and IEC standards. You can select the calculation method from the Short-Circuit Study Case Editor. This section describes the ANSI/IEEE standard method of calculation.

Standard Compliance

PowerStation short-circuit calculation per ANSI/IEEE standards fully complies with the latest ANSI/IEEE and UL standards, as listed below:

Standard	Pub. Year	Title
IEEE C37.04	1979 (1988)	Standard Rating Structure for AC High-Voltage Circuit Breakers
IEEE C37.04f	1990	Rated on a Symmetrical Current Basis and Supplements
IEEE C37.04g	1986	
IEEE C37.04h	1990	
IEEE C37.04i	1991	
IEEE C37.010	1979 (1988)	Standard Application Guide for AC High-Voltage Circuit Breakers
IEEE C37.010b	1985	Rated on a Symmetrical Current Basis and Supplements
IEEE C37.010e	1985	
IEEE C37.013	1997	Standard for AC High-Voltage Generator Circuit Breakers Rated on a Symmetrical Current Basis
IEEE C37.20.1	1993	Standard for Metal Enclosed Low-Voltage Power Circuit Breaker Switchgear
IEEE Std 399	1990	Power System Analysis -- the Brown Book
IEEE Std 141	1986	Electric Power Distribution for Industrial Plants -- the Red Book
IEEE Std 242	1986	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems – the Buff Book
UL 489_9	1996	Standard for Safety for Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures

General Description of Calculation Methodology

In ANSI/IEEE short-circuit calculations, an equivalent voltage source at the fault location, which equals the prefault voltage at the location, replaces all external voltage sources and machine internal voltage sources.

All machines are represented by their internal impedances. Line capacitances and static loads are neglected. Transformer taps can be set at either the nominal position or at the tapped position, and different schemes are available to correct transformer impedance and system voltages if off-nominal tap setting exists. It is assumed the fault is bolted, therefore, arc resistances are not considered. System impedances are assumed to be balanced three-phase, and the method of symmetrical components is used for unbalanced fault calculations.

Three different impedance networks are formed to calculate momentary, interrupting, and steady-state short-circuit currents, and corresponding duties for various protective devices. These networks are: ½ cycle network (subtransient network), 1.5-4 cycle network (transient network), and 30-cycle network (steady-state network).

ANSI/IEEE Standards recommend the use of separate R and X networks to calculate X/R values. An X/R ratio is obtained for each individual faulted bus and short-circuit current. This X/R ratio is then used to determine the multiplying factor to account for the system DC offset.

Using the ½ cycle and 1.5-4 cycle networks, the symmetrical rms value of the momentary and interrupting short-circuit currents are solved first. These values are then multiplied by appropriate multiplying factors to finally obtain the asymmetrical value of the momentary and interrupting short-circuit currents.

Definition of Terms

The following terms are helpful in understanding short-circuit calculations using ANSI/IEEE standards.

½ Cycle Network

This is the network used to calculate momentary short-circuit current and protective device duties at the ½ cycle after the fault. The following table shows the type of device and its associated duties using the ½ cycle network.

Type of Device	Duty
High voltage circuit breaker	Closing and latching capability
Low voltage circuit breaker	Interrupting capability
Fuse	Interrupting capability
Switchgear and MCC	Bus bracing
Relay	Instantaneous settings

½ Cycle Network

The ½ cycle network is also referred to as the subtransient network, primarily because all rotating machines are represented by their subtransient reactances, as shown in the following table:

Type of Machine	Xsc
Utility	X”d
Turbo generator	X”d
Hydro-generator with amortisseur winding	X”d
Hydro-generator without amortisseur winding	0.75 X’d
Condenser	X”d
Synchronous motor	X”d
Induction Machine	
> 1000 hp @ 1800 rpm or less	X”d
> 250 hp @ 3600 rpm	X”d
All other ≥ 50 hp	1.2 X”d
< 50 hp	1.67 X”d

½ Cycle Network Impedance
(X”d = 1/LRC for induction motors)

1½-4 Cycle Network

This network is used to calculate the interrupting short-circuit current and protective device duties 1.5-4 cycles after the fault. The following table shows the type of device and its associated duties using the 1.5-4 cycle network.

Type of Device	Duty
High voltage circuit breaker	Interrupting capability
Low voltage circuit breaker	N/A
Fuse	N/A
Switchgear and MCC	N/A
Relay	N/A

1 ½-4 Cycle Network

The 1.5-4 cycle network is also referred to as the transient network. The type of rotating machine and its representation is shown in the following table:

Type of Machine	**Xsc**
Utility	X”d
Turbo generator	X”d
Hydro-generator with amortisseur winding	X”d
Hydro-generator without amortisseur winding	0.75 X’d
Condenser	X”d
Synchronous motor	1.5 X”d
Induction machine	
> 1000 hp @ 1800 rpm or less	1.5 X”d
> 250 hp @ 3600 rpm	1.5 X”d
All other ≥ 50 hp	3.0 X”d
< 50 hp	Infinity

1 ½-4 Cycle Network Impedances
(X”d = 1/LRC for induction motors)

30 Cycle Network

This is the network used to calculate the steady-state short-circuit current and duties for some of the protective devices 30 cycles after the fault. The following table shows the type of device and its associated duties using the 1.5-4 cycle network:

Type of Device	**Duty**
High voltage circuit breaker	N/A
Low voltage circuit breaker	N/A
Fuse	N/A
Switchgear and MCC	N/A
Relay	Overcurrent settings

30 Cycle Network

The type of rotating machine and its representation in the 30-cycle network is shown in the following table. Note that induction machines, synchronous motors, and condensers are not considered in the 30-cycle fault calculation.

Type of Machine	**Xsc**
Utility	X”d
Turbo generator	X’d
Hydro-generator with amortisseur winding	X’d
Hydro-generator without amortisseur winding	X’d
Condenser	Infinity
Synchronous motor	Infinity
Induction machine	Infinity

30 Cycle Network Impedance

ANSI Multiplying Factor (MF)

The ANSI multiplying factor is determined by the equivalent system X/R ratio at a particular fault location. The X/R ratio is calculated by the separate R and X networks.

Local and Remote Contributions

A local contribution to a short-circuit current is the portion of the short-circuit current fed predominately from generators through no more than one transformation, or with external reactance in a series which is less than 1.5 times the generator subtransient reactance. Otherwise the contribution is defined as remote.

No AC Decay (NACD) Ratio

The NACD ratio is defined as the remote contributions to the total contributions for the short-circuit current at a given location.

$$NACD = \frac{I_{remote}}{I_{total}}$$

- Total short-circuit current $I_{total} = I_{remote} + I_{local}$
- NACD = 0 if all contributions are local.
- NACD = 1 if all contributions are remote.

Momentary (1/2 Cycle) Short-Circuit Current Calc. (Buses & HV CB)

The momentary short-circuit current at the ½ cycle represents the highest or maximum value of the short-circuit current (before its ac and dc components decay toward the steady-state value). Although, in reality, the highest or maximum short-circuit current actually occurs slightly before the ½ cycle, the ½ cycle network is used for this calculation.

The following procedure is used to calculate momentary short-circuit current:

1) Calculate the symmetrical rms value of momentary short-circuit current using the following formula:

$$I_{mom,rms,symm} = \frac{V_{pre-fault}}{\sqrt{3}Z_{eq}}$$

where Z_{eq} is the equivalent impedance at the faulted bus from the ½ cycle network.

2) Calculate the asymmetrical rms value of momentary short-circuit current using the following formula:

$$I_{mom,rms,asymm} = MF_m I_{mom,rms,symm}$$

where MF_m is the momentary multiplying factor, calculated from

$$MF_m = \sqrt{1 + 2e^{-\frac{2\pi}{X/R}}}$$

3) Calculate the peak value of momentary short-circuit current using the following formula:

$$I_{mom,peak} = MF_p I_{mom,rms,symm}$$

where MF_p is the peak multiplying factor, calculated from

$$MF_p = \sqrt{2}\left(1 + e^{-\frac{\pi}{X/R}}\right)$$

This value is the calculated Asymmetrical kA Crest printed in the Momentary Duty column of the Momentary Duty page in the output report.

In both equations for MF_m and MF_p calculation, X/R is the ratio of X to R at the fault location obtained from separate X and R networks at ½ cycle.

The value of the fault current calculated by this method can be used for the following purposes:

- Check closing and latching capabilities of high voltage circuit breakers
- Check bus bracing capabilities
- Adjust relay instantaneous settings
- Check interrupting capabilities of fuses and low voltage circuit breakers

High Voltage Circuit Breaker Interrupting Duty Calculation

The interrupting fault currents for high voltage circuit breakers correspond to the 1½-4 cycle short-circuit currents, i.e., the 1½-4 cycle network is used for this calculation.

The following procedure is used to calculate the interrupting short-circuit current for high voltage circuit breakers:

1) Calculate the symmetrical rms value of the interrupting short-circuit current using the following formula:

$$I_{\text{int},rms,symm} = \frac{V_{pre-fault}}{\sqrt{3}Z_{eq}}$$

where Z_{eq} is the equivalent impedance at the faulted bus from the 1½-4 cycle network.

2) Calculate the short-circuit current contributions to the fault location from the surrounding buses.
3) If the contribution is from a Remote bus, the symmetrical value is corrected by the factor of MF_r, calculated from

$$MF_r = \sqrt{1 + 2e^{-\frac{4\pi}{X/R}t}}$$

where t is the circuit breaker contact parting time in cycles, as shown in the following table:

Circuit Breaker Rating in Cycles	**Contact Parting Time in Cycles**
8	4
5	3
3	2
2	1.5

The following table shows the Multiplying Factors for Remote Contributions (MF_r).

X/R Ratio	**8 Cycle CB (4 cy CPT)**	**5 Cycle CB (3 cy CPT)**	**3 Cycle CB (2 cy CPT)**	**2 Cycle CB (1.5 cy CPT)**
100	1.487	1.540	1.599	1.63
90	1.464	1.522	1.585	1.619
80	1.438	1.499	1.569	1.606
70	1.405	1.472	1.548	1.59
60	1.366	1.438	1.522	1.569

50	1.316	1.393	1.487	1.54
45	1.286	1.366	1.464	1.255
40	1.253	1.334	1.438	1.499
35	1.215	1.297	1.405	1.472
30	1.172	1.253	1.366	1.438
25	1.126	1.201	1.316	1.393
20	1.078	1.142	1.253	1.334
18	1.059	1.116	1.223	1.305
16	1.042	1.091	1.190	1.271
14	1.027	1.066	1.154	1.233
12	1.015	1.042	1.116	1.190
10	1.007	1.023	1.078	1.142
9	1.004	1.015	1.059	1.116
8	1.002	1.009	1.042	1.091
7	1.001	1.005	1.027	1.066
6	1.000	1.002	1.015	1.042
5	1.000	1.00.	1.007	1.023
4	1.000	1.000	1.002	1.009
3	1.000	1.000	1.000	1.002
2	1.000	1.000	1.000	1.000
1	1.000	1.000	1.000	1.000

MFr, Remote Contributions Multiplying Factors; Total Current Basis CBs

If the contribution is from a **Local** generator, the symmetrical value is corrected by the factor of MF_l, which is obtained from: ANSI/IEEE C37.010-1979, Application Guide for AC High-Voltage.

X/R Ratio	**8 Cycle CB (4 cy CPT)**	**5 Cycle CB (3 cy CPT)**	**3 Cycle CB (2 cy CPT)**	**2 Cycle CB (1.5 cy CPT)**
100	1.252	1.351	1.443	1.512
90	1.239	1.340	1.441	1.511
80	1.222	1.324	1.435	1.508
70	1.201	1.304	1.422	1.504
60	1.175	1.276	1.403	1.496
50	1.141	1.241	1.376	1.482
45	1.121	1.220	1.358	1.473
40	1.098	1.196	1.337	1.461
35	1.072	1.169	1.313	1.446
30	1.044	1.136	1.283	1.427
25	1.013	1.099	1.247	1.403
20	1.000	1.057	1.201	1.371
18	1.000	1.039	1.180	1.356
16	1.000	1.021	1.155	1.339
14	1.000	1.003	1.129	1.320
12	1.000	1.000	1.099	1.299
10	1.000	1.000	1.067	1.276

9	1.000	1.000	1.051	1.263
8	1.000	1.000	1.035	1.250
7	1.000	1.000	1.019	1.236
6	1.000	1.000	1.005	1.221
5	1.000	1.000	1.000	1.205
4	1.000	1.000	1.000	1.188
3	1.000	1.000	1.000	1.170
2	1.000	1.000	1.000	1.152
1	1.000	1.000	1.000	1.132

MF_l, Local Contributions Multiplying Factors; Total Current Basis CBs

4) Calculate the total remote contributions and total local contribution, and thus the NACD ratio.

5) Determine the actual multiplying factor (AMF_i) from the NACD ratio and calculate the adjusted rms value of interrupting short-circuit current using the following formula.

$$I_{int,rms,adj} = AMF_i \, I_{int,rms,symm}$$

where

$$AMF_i = MF_l + NACD\,(MF_r - MF_l)$$

6) For symmetrically rated breakers, the adjusted rms value of interrupting short-circuit current is calculated using the following formula.

$$I_{int,rms,adj} = \frac{AMF_i \; I_{int,rms,symm}}{S}$$

where the correction factor S reflects an inherent capability of ac high voltage circuit breakers, which are rated on a symmetrical current basis, and its values are found in the following table.

Circuit Breaker Contact Parting Time (CPT)	**S Factor**
4	1.0
3	1.1
2	1.2
1.5	1.3

S Factor for AC High Voltage Circuit Breaker
Rated on a Symmetrical Current Basis

The value of this current is applied to check high voltage circuit breaker interrupting capabilities. The correction factor S is equal to 1.0 for ac high voltage circuit breakers rated on a total current basis.

Low Voltage Circuit Breaker Interrupting Duty Calculation

Due to the instantaneous action of low voltage circuit breakers at maximum short-circuit values, the ½ cycle network is used for calculating the interrupting short-circuit current.

The following procedure is used to calculate the interrupting short-circuit current for low voltage circuit breakers:

1) Calculate the symmetrical rms value of the interrupting short-circuit current from the following formula.

$$I_{\text{int},rms,symm} = \frac{V_{pre-fault}}{\sqrt{3}Z_{eq}}$$

where Z_{eq} is the equivalent impedance at the faulted bus from the ½ cycle network.

2) Calculate the adjusted asymmetrical rms value of the momentary short-circuit current duty using the following formula:

$$I_{\text{int},rms,adj} = MF I_{\text{int},rms,symm}$$

where MF is the multiplying factor, considering the system X/R ratio and the low voltage circuit breaker testing power factors, calculated from

$$MF = \frac{\sqrt{2}(1+e^{-\frac{\pi}{X/R}})}{\sqrt{2}(1+e^{-\frac{\pi}{(X/R)_{test}}})}$$ for unfused power breakers

or

$$MF = \frac{\sqrt{1+2e^{-\frac{2\pi}{X/R}}}}{\sqrt{1+2e^{-\frac{2\pi}{(X/R)_{test}}}}}$$ for fused power breakers and molded cases

where $(X/R)_{test}$ is calculated based on the test power factor entered from the Low Voltage Circuit Breaker Editor. The manufacturer maximum testing power factors given in the following table are used as the default values:

Circuit Breaker Type	**Max Design (Tested)**	
	% PF	**$(X/R)_{test}$**
Power Breaker (Unfused)	15	6.59
Power Breaker (Fused)	20	4.90
Molded Case (Rated Over 20,000 A)	20	4.90
Molded Case (Rated 10,001-20,000 A)	30	3.18
Molded Case (Rated 10,000 A)	50	1.73

Maximum Test PF for Low Voltage Circuit Breaker

The calculated duty value *Iint,rms,adj* can be applied to low voltage breaker interrupting capabilities.

Note that if the calculated multiplication factor is less than 1, it is set to 1 so that the symmetrical fault current is compared against the symmetrical rating of the device. If the symmetrical fault current is less than the symmetrical rating of the device, the checking on asymmetrical current will certainly pass.

Fuse Interrupting Short-Circuit Current Calculation

The procedures for calculating the fuse interrupting short-circuit current is the same as those for the **Circuit Breaker Interrupting Duty** calculation.

Comparison of Device Rating and Short-Circuit Duty

ETAP PowerStation compares the rating of protective devices and busbars with the fault duties of the bus. The comparison results are listed in the summary page of the output report. The device rating and fault duty used in the comparison are shown below.

Device Type	**Device Capability**	**Calculated Short-Circuit Duty**
Momentary Duty		
HV Bus Bracing	Asymm. KA rms	Asymm. KA rms
	Asymm. KA Crest	Asymm. KA Crest
LV Bus Bracing	Symm. KA rms	Symm. KA rms
	Asymm. KA rms	Asymm. KA rms
HV CB	C&L Capability kA rms	Asymm. KA rms
	C&L Capability kA Crest	Asymm. KA Crest
Momentary Duty		
HV CB	Interrupting kA***	Adjusted kA
LV CB	Rated Interrupting kA	Adjusted kA

Comparison of Device Rating and Short-Circuit Current Duty

***The interrupting capability of a high voltage circuit breaker is calculated based on the nominal kV of the connected bus and the prefault voltage (Vf) if the flag is set in the Short-Circuit Study Case, as shown below.

Interrupting kA = (Rated Int. kA) * (Rated Max. kV) / (Bus Nominal kV)

or

Interrupting kA = (Rated Int. kA) * (Rated Max. kV) / (Bus Nominal kV * Vf)

The calculated interrupting kA (as shown above) is then limited to the maximum interrupting kA of the circuit breaker.

Short-Circuit Analysis
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