TSEWG TP-6:   LOW-VOLTAGE BREAKER INTERRUPTING RATINGS

BREAKER CERTIFICATION PROCESS.

The short circuit interrupting rating defines a breaker's ability to interrupt the flow of fault current and to protect the conductors connected to the breaker. A breaker's interrupting rating depends on the rated voltage; the interrupting rating for a given design decreases as the applied voltage increases. A short circuit study is normally performed to determine the minimum required interrupting rating of breakers to be applied in a system. The manufacturer certifies an interrupting rating as the highest current at rated voltage that a breaker is intended to interrupt under standard test conditions. The interrupting rating of a breaker is one of its most important characteristics. Breakers applied beyond their rating (over duty) pose a personnel, equipment, and fire hazard concern.

Molded case circuit breakers (MCCBs) are tested per UL-489, Molded-Case Circuit Breakers and Circuit-Breaker Enclosures, to confirm their capability to interrupt rated short circuit current. Low voltage power breakers (LVPBs) are tested per C37.13, IEEE Standard for Low-Voltage AC Power Circuit Breakers Used in Enclosures.

An understanding of the breaker certification process is necessary to apply them properly. The power factor of the short circuit current applied in a certification test varies with the breaker rating or types as shown in Tables 1 and 2.

Table 1 UL-489 Test Circuit Power Factor for MCCBs

Breaker Interrupting Rating in Amperes	Test Circuit Power Factor	Equivalent Minimum X/R Ratio
10,000 or Less	0.45 to 0.50	1.73
10,001 to 20,000	0.25 to 0.30	3.18
Over 20,000	0.15 to 0.20	4.90

Table 2 C37.13 Test Circuit Power Factor for LVPBs

Breaker Type	Test Circuit Power Factor	Equivalent Minimum X/R Ratio
Unfused Breaker	0.15	6.60
Fused Breaker	0.20	4.90

As shown in Table 1, an MCCB with an interrupting rating of 7,500 amperes would be certified by UL test with a circuit power factor of 0.45 to 0.50, and an

MCCB with an interrupting rating of 35,000 amperes would be tested with a power factor of 0.15 to 0.20.

The net effect of the breaker certification process is that the tested power factor represents a qualification limit; the MCCB or LVPB rating must be adjusted if the power factor at the short circuit current location is less than the tested value. The following paragraphs explain the basis for this requirement.

Power factor (*pf*) is defined as the cosine of the phase angle (θ) between the voltage and the current, or

$$pf = cos\,\theta$$

When considering short circuit effects, power factor is often expressed in terms of the *X/R* ratio, where *X* is the reactance in the circuit and *R* is the resistance in the circuit. The ratio of reactance to resistance equals the tangent of the phase angle θ.

$$\frac{X}{R} = tan\,\theta$$

Therefore, power factor can be expressed in terms of *X* and *R* as follows:

$$pf = cos\left(\arctan\frac{X}{R}\right)$$

In a purely resistive circuit, the current and voltage are in phase and the power factor equals 1. In a purely reactive circuit, the current lags the voltage by 90° and the power factor equals 0. A circuit containing both resistance and reactance will have a power factor value between 0 and 1.

Tables 1 and 2 also show the corresponding minimum tested X/R ratio for different breaker ratings. Sometimes, it is more convenient to convert from a power factor to the X/R ratio as follows.

$$\frac{X}{R} = tan\left[\arccos(pf)\right]$$

The term *symmetrical current* refers to the shape of an alternating current in which the waveform is symmetric about the zero axis. An example of symmetrical current is shown in Figure 1.

Figure 1 Completely Symmetric or Asymmetric Current

Completely Symmetric

Zero Axis

Completely Asymmetric
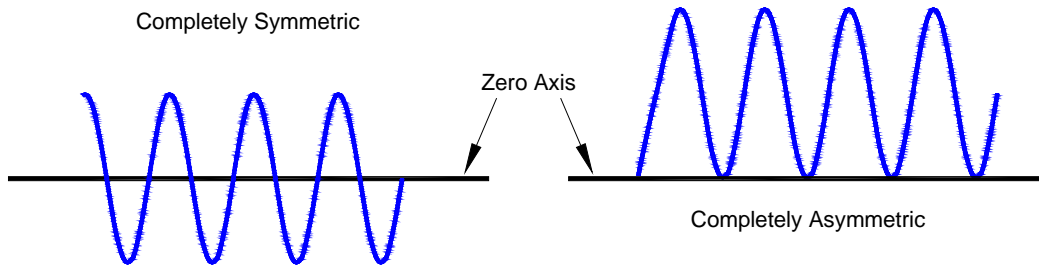
Short circuit currents are usually asymmetrical, or not symmetric, about the zero axis for the first few cycles. An example of an asymmetrical current is shown in Figure 2.

Figure 2 Typical Asymmetrical Short Circuit Behavior

Zero Axis
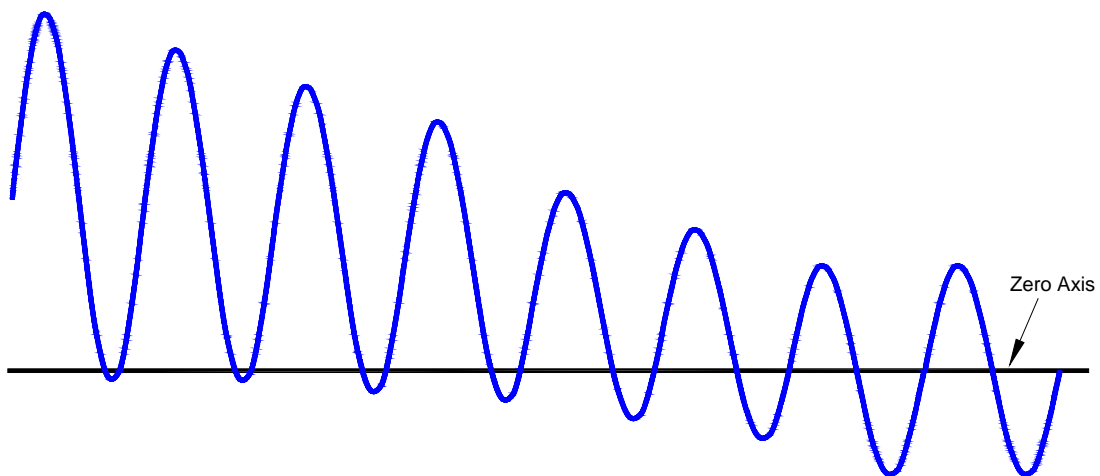
As shown in Figure 2, the asymmetrical current peaks on the first cycle after a short circuit occurs and gradually becomes symmetrical over the next few cycles. Short circuit current can be modeled as a symmetrical AC sinusoidal component that is varying about an exponentially decaying DC component. The DC component decreases to zero with a rate of decay inversely proportional to the X/R ratio at the point of fault. The rate of decay is more rapid for lower X/R ratios. Higher X/R ratios result in higher peak currents and slower decay rates, causing the breaker to be exposed to a higher current for a longer time.

When a breaker is tested at a specified power factor per UL-489 or C37.13, the breaker is subjected to a certain peak current and rate of decay from the peak

current down to a symmetric value about the zero axis. If the system short circuit current X/R ratio at a particular fault location is larger than this tested value, the breaker could be exposed to an asymmetric current greater than it has been certified to withstand. To account for this difference, the breaker is either 1) derated or 2) the symmetrical fault current is increased by a multiplying factor to account for the higher X/R ratio at the fault location. These multiplying factors are shown in Tables 3 and 4 for the different breaker interrupting ratings.

Table 3 MCCB X/R Multiplying Factors

System Power Factor	System X/R Ratio	Multiplying Factor as a Function of Interrupting Current Rating		
		≤10,000	10,001 - 20,000	>20,000
0.50	1.73	1.000	1.000	1.000
0.40	2.29	1.078	1.000	1.000
0.30	3.18	1.180	1.000	1.000
0.25	3.87	1.242	1.052	1.000
0.20	4.90	1.313	1.112	1.000
0.15	6.59	1.394	1.181	1.062
0.10	9.95	1.487	1.260	1.133
0.05	19.98	1.595	1.351	1.215

Table 4 C37.13 LVPB X/R Multiplying Factors

System Power Factor	System X/R Ratio	Multiplying Factor	
		Unfused Breaker	Fused Breaker
0.20	4.90	1.00	1.00
0.15	6.60	1.00	1.07
0.12	8.27	1.04	1.11
0.10	9.95	1.07	1.15
0.085	11.72	1.09	1.18
0.07	14.25	1.11	1.21
0.05	20.00	1.15	1.26

Notice that the multiplying factor is 1.000 for X/R ratios less than the tested value. A breaker interrupting rating can only be derated for higher X/R ratios; it can not be uprated for a higher fault current due to lower X/R ratios. The multiplying factors shown in Tables 3 and 4 are obtained by the following expression:

$$I_{Adjusted} = I_{Symmetrical} \times \frac{1 + e^{\left(-\frac{\pi}{actual\ X/R}\right)}}{1 + e^{\left(-\frac{\pi}{tested\ X/R}\right)}}$$

EXAMPLE BREAKER DERATING CALCULATION.

Table 3 shows a multiplying factor of 1.215 for an MCCB rated above 20,000 amperes when exposed to a short circuit current with a power factor of 0.05, or an X/R ratio of 19.98. This multiplying factor can be easily confirmed. Table 3 shows that the minimum allowed X/R ratio for UL certification testing is 4.90 for a test circuit power factor of 0.20. Thus, in accordance with the above equation, the multiplying factor is obtained as follows:

$$I_{Adjusted} = I_{Symmetrical} \times \frac{1 + e^{(-\frac{\pi}{19.98})}}{1 + e^{(-\frac{\pi}{4.90})}} = I_{Symmetrical} \times 1.215$$

For discussion purposes, assume the actual symmetrical fault current to which the breaker might be subjected is 23,500 A. The adjusted fault current is then:

$$I_{Adjusted} = I_{Symmetrical} \times 1.215 = 23{,}500 \times 1.215 = 28{,}553 \ A$$

The calculated adjusted symmetrical fault current can now be compared to the breaker's interrupting rating. The adjusted value of short circuit current should be less than the interrupting rating in order for the breaker to be applied properly. Electrical power analysis computer programs typically perform this calculation automatically.