Role of X/R Ratio in Circuit Breaker Short Circuit Duty Evaluation

Circuit breaker nameplates sometimes indicate only rating on symmetrical short circuit current. In such cases, the rating only reflects the AC component of the short circuit current. A common misinterpretation occurs when one compares the symmetrical short circuit current against the symmetrical short circuit current rating of the circuit breaker for the purposes of circuit breaker duty evaluation. This article provides pointers to avoid making the mistake.

Why is X/R Ratio Important?

Short circuit analysis is a critical piece of the engineering study for a power system. This analysis determines the maximum available fault current in the system, and hence the maximum level that the electrical equipment should be able to withstand.

When a short circuit occurs, the total short circuit current consists of:

- AC component (varies sinusoidally with time), also known as symmetrical current.
- DC component (non-periodic and decays exponentially with a time constant L/R; L/R is proportional to X/R)
- The DC component makes the symmetrical current become asymmetrical.

The X/R ratio affects the dc component, and therefore, also the total current. The higher the X/R ratio of a circuit, the longer the dc component will take to decay (longer time constant).

To illustrate, two circuits are shown in Figure 1. Both circuits have the same impedance of 0.4 ohms but with significantly different X/R ratio, 50 versus 5.

Figure 1 Sample simple circuits with different X/R ratios

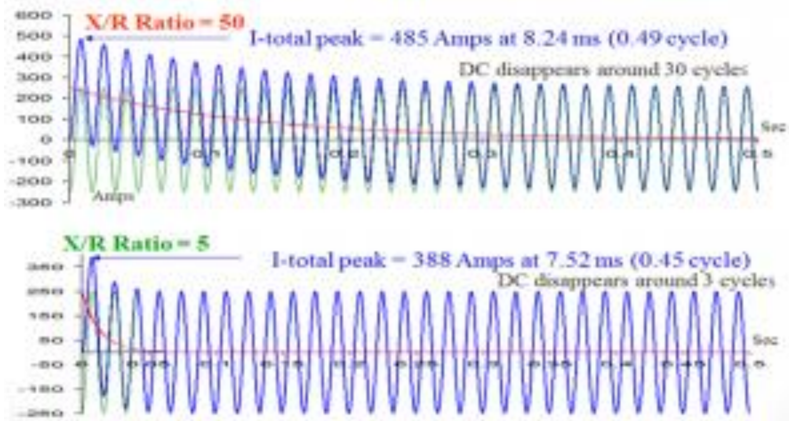

Figure 2 Short Circuit Plot with AC and DC Components for the First 30 Cycles

For both circuits, the symmetrical short circuit current is the same (100V/0.4 ohm = 250 amps). However, as shown in Figure 2 the circuit with X/R ratio of 50 will have a peak current about 485 amps while the circuit with X/R ratio of 5 will show peak current of about 388 amps. The higher the X/R ratio, the higher the peak short circuit current will be.

In addition, the DC component has a rate of decay which is determined by X/R ratio. This indicates the time the asymmetrical fault current decays to become symmetrical. As shown in Figure 3, the DC component for the circuit with X/R ratio of 50 is more prolonged: 30 cycles for X/R ratio of 50 as compared to 3 cycles in the circuit with X/R ratio of 5. The higher the X/R ratio, the slower the DC component decays.

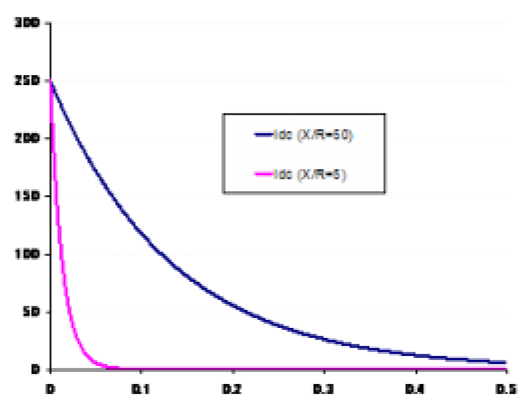

Figure 3 Short Circuit Plots showing DC Component Only

Considerations for Circuit Breaker Evaluation

Based on the above example, it is very clear that in short circuit studies, the X/R ratio should not be ignored because it determines the peak asymmetrical fault current. When comparing the short circuit current from the studies against circuit breaker name plate, one should know at what X/R ratio the circuit breaker was tested. The following rule of thumb can be used to determine if circuit breaker is properly rated:

1. Symmetrical short circuit current is less than symmetrical rating of the circuit breaker, and
2. X/R of the circuit is less than circuit breaker test X/R ratio

If the first item is met but the second is not, then the process of circuit breaker evaluation requires further calculation.

To provide a better understanding, let's consider short-circuit current of 19 kA with X/R ratio of 15 with low voltage circuit breaker (LVCB) symmetrical rating of 20 kA RMS as in Figure 4 below.

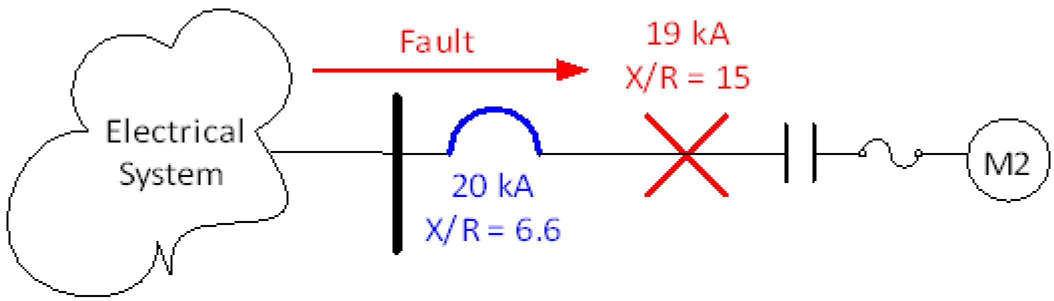

Figure 4 Sample short circuit for a low voltage circuit breaker

The LVCB was tested at X/R of 6.6 (0.15 power factor). This test X/R ratio is not provided on the circuit breaker nameplate. (For reference, high voltage circuit breakers are typically tested at X/R ratio of 17. Special purpose generator circuit breakers are typically tested at X/R ratio of 50.)

Comparing the fault symmetrical current and symmetrical rating of the breaker: symmetrical fault current is within the withstand capability defined by the symmetrical rating of the breaker. The assessment does not end here, but must continue to the next step. The fault X/R ratio is higher than breaker's test X/R ratio (15 versus 6.6), hence a more detailed examination for adequacy is required.

Given the symmetrical rating and test X/R ratio, we can find the LVCB's maximum peak capability. The LVPCB max peak capability is then compared with max peak fault current. The peak current, I_{peak}, is a function of the RMS current, I_{RMS}, and the X/R ratio per the following:

$$I_{peak} = \sqrt{2} * I_{ac(RMS)} * \left(1 + e^{\frac{-2\pi\tau}{X/R}}\right)$$

$$\tau = 0.49 - 0.1 * e^{\frac{-X/R}{3}}$$

A multiplication factor can be extracted from the above defined as:

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

$$\tau = 0.49 - 0.1 * e^{\frac{-X/R}{3}}$$

Using data from the sample LVCB:

Peak MF as tested = 2.31 for X/R = 6.6

Peak MF of fault = 2.57 for X/R = 15

From the above, the rated and short circuit maximum peak values are:

Tested Peak Capability = 2.31 * 20 = 46.2 kA

Fault Peak Capability = 2.57*19 = 48.83 kA.

The fault peak capability is higher than the tested peak capability, thus the sample LVCB is overduty. The magnitude of overduty is 6% from [(48.83/46.2)-1].

Summary

Comparing only symmetrical short circuit current against symmetrical short circuit rating of a circuit breaker is not sufficient to assess circuit breaker adequacy. This comparison only considers the ac component of the current. In fact, the short circuit current will comprise of ac and dc components.

The circuit breaker nameplate may only indicate short circuit symmetrical current which could lead to incorrect assessment if the assumed X/R ratio is less than the test X/R ratio. However, circuit breakers are typically tested at certain X/R ratio, depending on type of application. If the test X/R ratio of the breaker is not available from the manufacturer, the typically test ratio is available from IEEE standard C37 series.

The X/R ratio of a circuit would dictate the magnitude of dc component. The higher the X/R ratio, the higher the short circuit current is. If the X/R ratio is less than the circuit breaker test X/R ratio, we could directly verify the circuit breaker symmetrical rating with the symmetrical short circuit current. On the other hand, if the X/R ratio is higher than the circuit breaker test X/R ratio, a multiplication factor must be considered to “de-rate” the circuit breaker.

Electrical Engineers need to know the importance of X/R ratio in doing fault calculations. This ratio can actually determine the peak asymmetrical fault current. Accordingly, the asymmetrical fault current can be way higher than the symmetrical fault current.

The Importance of X/R Ratio

The equipment like transformer, motor, generator and transmission lines are inherently inductive which gives a small value of X/R ratio. When there is a short circuit in the system, the RMS value of the symmetrical fault current is determined by the system source voltage and the total system impedance to the point of fault. However, almost all faults involve significant asymmetry in at least one phase. This asymmetry is treated in analysis as a dc component, which must be combined with the ac symmetrical component to give a new current value, the RMS asymmetrical value. It is the value of the RMS asymmetrical current at the moment of contact part which a circuit breaker must interrupt.

It is important to note that the dc component of the fault current decays rather rapidly, reaching an insignificant value in a matter of 3 to 5 cycles of the power frequency. In this process, the rate of decay is determined by the X/R ratio of the circuit at the point of fault. That means, if the value of the ratio is higher then the DC component decay is slower which prolongs the danger as a result of the fault.

Modern circuit breakers are tested with a prescribed standard values of X/R. For example, the circuit breakers are both low and high voltage, the ANSI standards require this X/R ratio to be 6.6 or higher, corresponding to a power factor of 15% or less. For a given level of symmetrical fault current and a given circuit breaker contact part time, this X/R ratio establishes the value of asymmetrical fault current the breaker is required to interrupt. A higher X/R ratio, with its slower decay rate, will result in a higher asymmetrical fault current at contact part time. If the X/R ratio is too high, the asymmetrical fault current may exceed the breaker's interrupting capability.