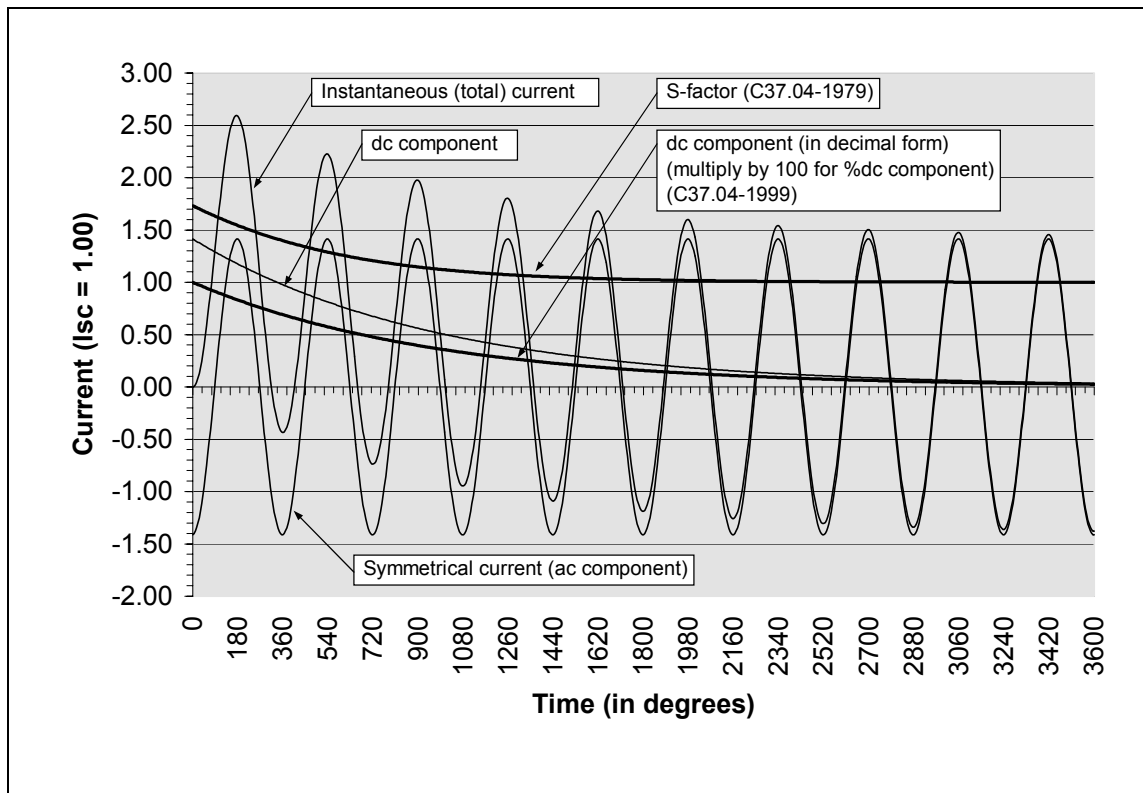


TechTopics Topic: Anatomy of a Short-Circuit

This issue of TechTopics discusses a short-circuit current waveform, and more specifically, the fully-offset asymmetrical short-circuit. This is the worst-case short-circuit considered in the standards for metal-clad switchgear (ANSI/IEEE C37.20.2) and circuit breakers (ANSI/IEEE C37.04) as it imposes the highest mechanical forces on the conductors and their supports.

The fully-offset asymmetrical short-circuit current wave is shown below.



The figure is constructed with a symmetrical rms current value of 1.00A as the base to allow direct comparison to the ratios given in the standards for other variables such as the closing & latching current.

Initially, we assume that the pre-fault current is zero. When a short-circuit occurs, the current changes over time from the initial value to the value that would exist under steady-state short-circuit conditions. This value is the “symmetrical current” in the figure, also referred to as the “ac component” of the short-circuit current. In the ideal case, where the circuit resistance is zero and the current is limited only by the circuit inductance,

the short-circuit current and the system voltage would be out of phase by 90°. Thus, the worst-case instant for initiating the short-circuit current would be when the system voltage is zero.

In the real world, the circuit resistance is non-zero. Thus, the worst case does not occur when the system voltage is zero. Rather, it occurs a few degrees from zero voltage, but we'll ignore that nicety in this discussion.

By definition, the short-circuit current is limited only by the circuit inductance. The current in an inductor cannot change instantaneously from the initial value (zero) to the steady state value (in the figure, -1.414A, the peak value of a symmetrical current of 1.00A). To achieve a current balance at the instant of short-circuit initiation, we consider that the short-circuit current consists of an ac component (the symmetrical component) and a dc component, which accounts for the difference between the steady-state short-circuit current at the instant of fault initiation and the initial zero value. In the figure above, the dc component must be equal in magnitude to the instantaneous value of the symmetrical steady-state current at time 0. Thus, the dc component at time 0 must be 1.414A, and is opposite in sign to the instantaneous value of the symmetrical short-circuit current at time 0.

The dc component of the short-circuit declines exponentially from the initial value, with a time constant that is determined by the values of the circuit inductance (X) and resistance (R). In both the ANSI/IEEE and the IEC standards, the time constant of dc decay is standardized at 45msec, which corresponds to an X/R ratio of 17 for a 60 Hz system. The dc component is expressed as the %dc component, and is calculated from the following:

$$\%dc = 100e^{-(t/\tau)}$$

$$\tau = (X / R) / 2\pi f$$

Where

- %dc = dc component expressed in percent
- e = e, the base of the natural (Naperian) logarithms, approximately 2.71828 18284 59045
- t = the instant of time, in ms, for which the %dc component is desired
- τ = time constant of dc decay, in ms
- X = system inductance to the point of the fault, in ohms
- R = system resistance to the point of the fault, in ohms
- f = system frequency, in hertz

The actual dc component of the fully-offset asymmetrical short-circuit current wave is shown in the figure, and is 1.414A at time 0, declining exponentially, approaching zero after about 10 cycles. The dc component, in decimal form, is also shown, and the data from the figure must be multiplied by 100 to convert it to %dc component. The %dc component is also referred to as the % asymmetry in older standards.

The total short-circuit current, labeled as the instantaneous (total) current in the diagram, is the sum of the symmetrical current (ac component) and the actual dc component.

The %dc component concept underlies the requirements contained in the 1999 revisions to the major circuit breaker standards, including ANSI/IEEE C37.04, C37.06, C37.09, and C37.010. In the 1979 versions of these standards, the dc component was accounted for by an S-factor, the ratio of the asymmetrical (total) current (expressed in rms current) and the symmetrical rms current. The concept of S-factor and %dc component are mathematically equivalent, even though they express the concept in different ways. The S-factor at any instant of time is shown in the diagram for comparison to the modern %dc component parameter.

The S-factor and the %dc component are related by the expression:

$$S = \frac{I_{total}}{I_{symmetrical}} = \sqrt{1 + 2(\%dc / 100)}$$

The S-factor curve allows us to make an observation about the asymmetrical (total) current. Notice that the S-factor declines from its maximum value, 1.707 at time zero, approaching 1.00 after only about 5 cycles. Since an S-factor of 1.00 is equivalent to a symmetrical current, the S-factor indicates that a fully-offset asymmetrical current declines to a symmetrical current in only a few cycles.

TechTopics No. 21, "Bus Bracing in Metal-Clad Switchgear", discussed the concept of "bus bracing", and listed various current values corresponding to parameters given in the standards. To tie the anatomy of a short-circuit to the factors discussed in TechTopics No. 21, let's look at the factors in TechTopics No. 21 and see where they come from on the waveform of the fully-offset asymmetrical short-circuit current.

Current parameters	Comments
Short-circuit (interrupting) rating	This is the symmetrical current (ac component) in the diagram. The symmetrical current is assumed to remain constant. The current waveform shown has an rms value of 1.000A, with a peak magnitude of 1.414A.
Close & latch current (for circuit breakers) Or Peak withstand current (for switchgear) (in peak amperes)	This is the value of the first peak of the fully-offset asymmetrical current, taken from the "instantaneous current" curve in the diagram. The value of the first peak for a 60Hz system is 2.60, and is measured at 1/2 cycle of power frequency (180 electrical degrees). The first peak produces the most severe mechanical forces between conductors, and therefore is the critical mechanical value for bus bars and their supports.
Momentary current (in rms amperes)	This is the rms value corresponding to the peak withstand current discussed above. The rms value is not shown in the diagram, but it is easily seen as the basis of the diagram is an rms symmetrical current of 1.000A. Because the whole diagram is referenced to 1.000A, the value of the momentary current is equal to the S-factor. The S-factor at 1/2 cycle (180 electrical degrees) is 1.55.
%dc component	%dc component is initially 100% at time 0. At 1/2 cycle (180 electrical degrees), it is 83%.

The factors listed above relate to the "bus bracing" discussion in TechTopics No. 21, and so relate to the mechanical capability of the equipment to withstand the forces during short-circuits.

A different issue is that of the actual current to be interrupted by a circuit breaker when the fully-offset asymmetrical short-circuit current occurs.

To evaluate this, we must know when the time of contact part, since this determines the amount of dc offset that the circuit breaker has to handle. In TechTopics No. 6, "3-Cycle vs. 5-Cycle Interrupting Time", the opening time for the type GMI circuit breaker is given. The nominal opening time is 33ms, with a range of 25ms to 41ms for production circuit breakers. To this time, we must add an allowance for relay operating time, which is assumed to be 1/2 cycle (8.3ms) in the standards. This gives us a contact part time of 41.3ms nominal, with a range of 33.3ms to 49.3ms.

In testing of the product, we have to be concerned with the worst case. The worst case is the shortest possible contact part time, which is 33.3ms (2 cycles, or 720 electrical degrees) for the type GMI circuit breaker. By examination of the diagram, the values of interest at contact part are:

%dc component	47.6%
S-factor	1.206

And, since the diagram is referenced to a symmetrical current of 1.000A rms, the rms asymmetrical (total) current is given by the S-factor, 1.206A

To this point, the entire discussion has been referenced to a symmetrical current of 1.000A rms. This makes it easy to calculate the various currents for a "real" short-circuit current rating. For our example, let us consider a rated short-circuit interrupting current of 50kA, which yields the following "real" values for the various parameters:

Parameter	Value from diagram	Calculated value
Short-circuit interrupting current	1.000	50.0kA rms
Peak withstand current	2.600	130.0kA peak
Momentary current (rms)	1.550	77.5kA rms
dc component at contact part	0.476	23.8kA instantaneous
rms asymmetrical (total) current at contact part	1.206	60.3kA rms

The purpose of this issue of TechTopics is to try to explain, in simple terms, the characteristics of the short-circuit current and how these characteristics relate to the parameters established in the relevant standards. Unfortunately, the standards can be difficult to understand as they are not intended to be tutorial. As a result, the standards use jargon which obscures the basic physics involved.

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