

TechTopics No. 72

Generator circuit breaker applications - delayed current zeroes

TechTopics No. 71 discussed the major issues that make a circuit breaker application for a large generator quite different from a normal circuit breaker application. For convenience, a normal circuit breaker application will be referred to as a “distribution application,” but this can include transformer applications, motor feeders, bus tie applications, capacitor switching and others. This issue of TechTopics explores the aspect of delayed current zeroes for generator circuit breaker applications in more detail.

The premise of an ordinary distribution short-circuit application is that the system symmetrical short-circuit current has a constant value. Therefore, the symmetrical current does not decay over time. Of course, if time goes on long enough, this is not correct, but for the relatively short time increments that are relative, the assumption is both conservative and sufficiently accurate. We can think of this situation as one with an infinite time constant of decay of the ac component (the symmetrical current) of the short-circuit current.

The dc component of the short-circuit current, on the other hand, is a function of the circuit conditions at the time of fault inception. The instantaneous value of the symmetrical current that would exist in the steady state condition determines the value of the dc component.

The dc component is equal to the value of the instantaneous ac steady-state current at the instant of fault inception, and is of opposite polarity so the ac component and the dc component cancel each other at this instant and the short-circuit current thus starts at an instantaneous value of zero current.

If the dc component had no decay, the peak value of short-circuit current for a fully offset asymmetrical fault would be twice the peak of the ac component, or $2 \times 1.414 \times I_{ac}$, where I_{ac} is the rms value of the symmetrical current.

However, the dc component has a rate of decay, determined by the values of the system elements, reactance (X) and resistance (R). The system X/R ratio determines the time constant (τ) of decay of the dc component. 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 (reactance) (X) and resistance (R). The time constant is calculated from the following:

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

where

τ = time constant of dc decay, in seconds

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 (Hz).

In both the ANSI/IEEE and the IEC standards, the time constant of dc decay for distribution applications is standardized at 45 ms, which corresponds to a X/R ratio of 17 for a 60 Hz system. This subject is explored in more detail in TechTopics No. 44.

However, for applications for large generators, the situation is different, for two reasons. The X/R ratio of the system is typically higher than in distribution applications, with X/R ratios of 50 and higher not uncommon. In fact, in IEEE C37.013, the time constant for generator circuit breakers is set at 133 ms, corresponding to an X/R ratio of 50 in a 60 Hz system. In a generator application, the system is typically dominated by a very large step-up transformer and by a large generator. Both are highly inductive, which results in a very high X/R ratio.

For a generator source fault the inertia of the machine is limited, and this is the factor that results in a rate of decay of the ac component of short-circuit output current of the machine into a fault. Particularly for gas turbine machines, the rate of decay of the symmetrical current from the machine (a function of the inertia, among other factors) can be significantly faster than the decay of the dc component (a function of the generator X/R ratio).

If the fault current consists of a decaying ac wave superimposed on a relatively more constant dc component, the result will be a wave that lacks current zeroes for an extended period. The fault current shown in Figure 1 exhibits this type of behavior, with the first current zero occurring just prior to 100 ms.

IEEE C37.013-1997 contains a more extreme example of a current waveform with the first current zero delayed by a very long time, approximately 133 ms (reference Figure A.2 in IEEE C37.013-1997).

While intuitively interesting, such extreme mathematical examples are not of practical significance due to the nature of generator connections and system grounding. The fault representation shows only one phase, and in a grounded distribution system the single phase-to-ground fault would be possible and likely, which would be the worst-case condition. However, almost no large generators are operated in solidly grounded mode, but rather are resistance grounded to limit damage to the machine in the event of a single phase-to-ground fault. Thus, any real fault would be a three-phase fault, of which only one phase could be fully offset. The other two phases would not be heavily offset, and both of the other two phases would have non-delay current zeroes.

When interruption occurs at a current zero in one of these two phases, the remaining fault is a two-phase fault and will also have current zeroes. Thus, in the real world, we have to worry about a delayed current zero in a single phase, but do not have to worry about extremely long delays while we wait for the current to exhibit a zero crossing.

Now we understand the phenomenon of delayed current zeroes. What does it mean for a generator circuit breaker? And, how do we deal with this issue in the short-circuit laboratory?

First, if the application is subject to delayed current zeroes, we need to conduct tests to explore the ability of the circuit breaker to withstand some level of delay in the arrival of the first current zero. In practice, the manner in which this capability is demonstrated is to set up a circuit that has delayed current zeroes and then progressively increase the amount of delay until the limits of the laboratory are reached.

The following curve is an excerpt of a report on one of our type GMSG-GCB generator circuit breakers, successfully interrupting after a delayed current zero interval of over 39 ms, measured from contact part (shown by the vertical line). Thus, the arcing time for this interruption is over 39 ms, well over two cycles on a 60 Hz system.

Future issues of TechTopics will discuss other matters that make application of circuit breakers for large generators more challenging than normal distribution applications.

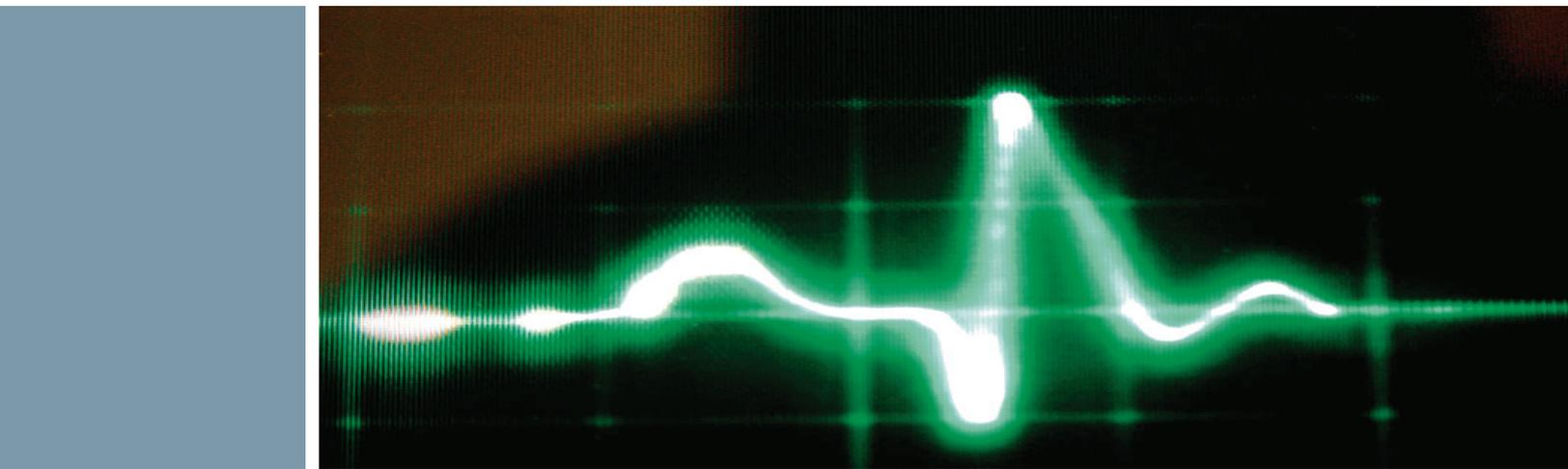


Figure 1: Offset fault current, I, delayed current zero

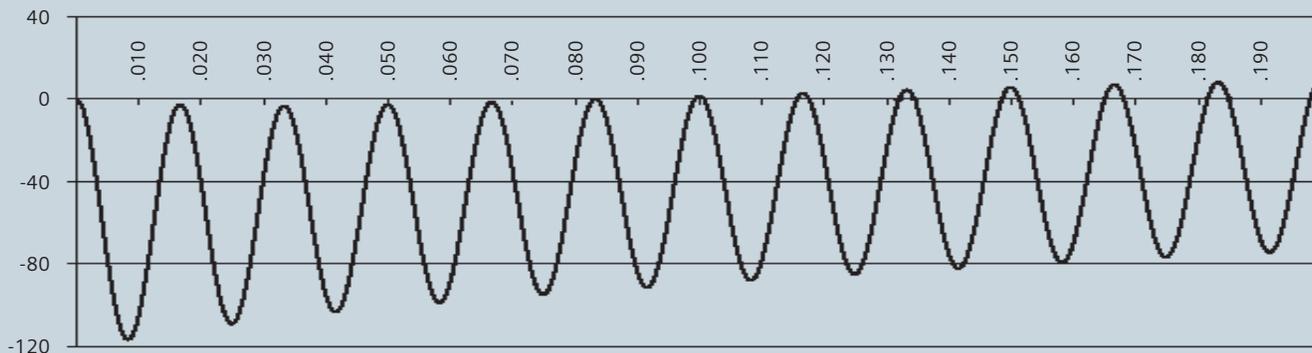
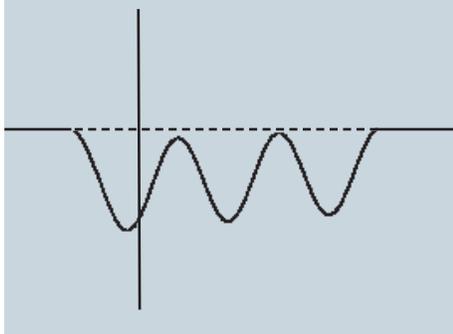


Figure 2: Test of GMSG-GCB generator circuit breaker with current zero occurring 39 ms after contact part



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