Effects of DC Components on Circuit Breaker

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Abstract: ***Whenever fault occurs in a system the current becomes asymmetrical and has two components AC and DC. Here in this concept of DC component and its effects on the circuit breaker are discussed. The focus of this paper is to analyze the criticality of the operation of breaker at the various % of the D.C. component with respect to its operation time and decay time constant.***

Keywords: DC Component, Circuit Breaker, Closing Time, Opening Time.

1. Introduction

Right after a fault occurs in the current waveform is no longer a sine wave. Instead, it can be represented by the sum of a sine wave and a decaying exponential**.** The decaying exponential added to the sine wave causes the current to reach a much larger value than that of the sine wave alone.
The waveform that equals the sum of the sine wave and the decaying exponential is called the asymmetrical current because the waveform does not have symmetry above and below the time axis.

The initial value of the DC component is dependent on the exact time within a cycle at which the fault takes place and the value of current at that time. At the initiation of a fault, the current in any system inductance cannot instantly change from its value at fault inception to that of its steady state fault value. To compensate for this, a DC component is introduced. The DC component is equal to the value of the instantaneous AC current at fault inception and of opposite polarity.

Maximum asymmetry occurs when short circuit takes place. Maximum asymmetry occurs when short circuit takes place at zero voltage.

Let us consider the effects of Short-Circuit Current on the power system.

1) At Short Circuit location arcing or burning can occur.
2) Short-circuit current flows from various sources to short circuit location.
3) Voltage drops in the system are proportional to the magnitude of current and components carrying short-circuit current will undergo higher thermal and mechanical stress.

The peak value of a symmetrical current is to be achieved and hence to balance current at the instant of short-circuit initiation, consider that the short-circuit current consists of an AC component and a DC component. Small currents are tend to be cut off before the current falls to zero because of the higher dielectric strength of vacuum. The DC component must be equal in magnitude to the instantaneous value of the symmetrical steady-state current at time zero.

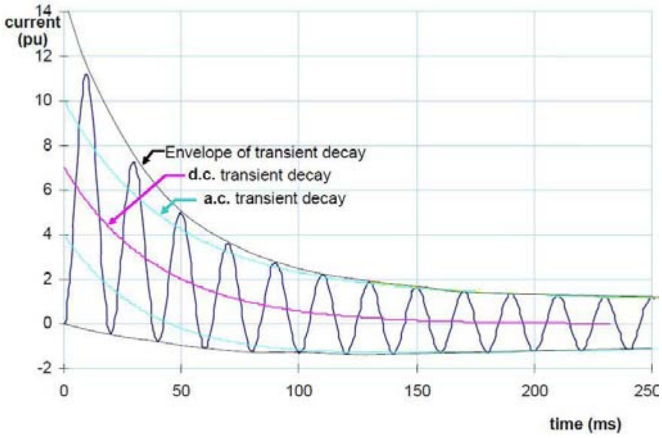


Figure 1: Asymmetrical Current with AC- DC components.

2. Explanation of DC Component

Magnitude of the dc component is dependent on location of the fault inception.

In the worse case, the initial dc offset will be √2 times the symmetrical short circuit value (RMS).

Rated Interrupting time of a breaker is defined as maximum permissible time interval between energization of trip circuit and interruption of current in main circuit in all 3 phase.

The dc component is expressed as the %dc component and is calculated from the following:

$i_{d.c.} = \sqrt{2}\, i'' e^{(-t/\tau)}$ $\tau = (X / R) / 2\pi f$

Where
i dc - in percent dc component expressed.
e - The base of the natural (Naperian) logarithms.
t - The instant of time, in ms, for which the %dc component is desired.
τ - Dc decay time constant, in ms.
X - System inductance to the point of the fault, in ohm. R - System resistance to the point of the fault in ohms. f - System frequency, in hertz.

3. X/R and τ

Impedance of a rotating machine consists primarily of the reactance and is not one simple value like reactance of transformer or cable. Initially current starts at a high value and decays to a steady state value after the time is elapsed. During this short duration the field excitation voltage and speed assumed constant the change in current value is explained by Reactance.

Therefore three values of reactance are assigned to motors and generators. These values are called sub-transient reactance, transient reactance and synchronous reactance.

Sub-transient reactance (X”d) is apparent reactance of the stator winding at the instant of short circuit occurrence. Transient reactance (X’d) is the reactance effective up to one-half second or longer depending on machine design. Synchronous Reactance (Xd) is the reactance of the machine after it reaches the steady state. Xd is not effective until several seconds after short circuit.

Interrupting current ratings for circuit-breakers rated on symmetrical basis are defined under the ANSI standard C37.06-1979. The circuit breaker must have a calculated interrupting duty equal to or greater than this current.

Most of the cases short-circuit calculation is a simple E/X (E is circuit operating voltage and X is reactance) computation if X/R is 15 or less or if E/X does not exceed 80% of symmetrical interrupting capability of breaker. If these conditions are not met then calculation is carried out according to the Section 5.3.2 of ANSI Standard 37.010-1979.

A time constant of 45 ms is adequate for the majority of actual cases. Special case time constants, related to the rated voltage of the circuit-breaker, shall cover such cases where the standard time constant 45 ms is not sufficient.

4. Higher X/R ratio

Special case time constants can be defined for higher X/R ratio for lines or some medium voltage systems with radial structure or to any systems with particular system structure or line characteristics.

In all there can be Higher X/R ratio or Lower X/R ratio. In case of Lower X/R ratio the criticality is very less compared to Higher ones. Thus while operating breakers at higher X/R ratio IEC and IEEE has mentioned few constraints while using the circuit breakers of higher X/R i.e. mostly the Generator Circuit Breaker.

This X/R rating of a breaker can be simply defined as the X/R ratio of the equipment situated next to it. For example in case of GCB the X/R ratio that breaker should withstand is the X/R ratio of generator.

Few Important points regarding Higher X/R ratio

1) The time constants referred to in this standard are only valid for three-phase fault currents. For maximum asymmetrical current, the initiation of the short-circuit current has to take place at system voltage zero in at least one phase.
2) The time constant is related to the maximum rated short-circuit current of the circuit breaker. If, for example, higher time constants than 45 ms are expected but with a lower short circuit current rating.
3) The time constant of a complete system is a time-dependent parameter considered to be an equivalent constant derived from the decay of the short-circuit currents in the various branches of that system.
4) Various methods for the calculation of the D.C. time constant are in use, the results of which may differ considerably. Caution should be taken in choosing the right method.
5) When choosing a special case time constant, it has to be kept in mind, that the circuit breaker is stressed by the asymmetrical current after contact separation. The time instant of contact separation corresponds to the opening time of the circuit-breaker and the reaction time of the protection relay. In this standard this relay time is one half-cycle of power frequency. If the protection time is longer this should be taken into account.

Table 1:

TYPE OF ROTATING MACHINE	MOMENTARY FIRST CYCLE	INTERRUPTING H.V. BREAK (1.5-4 CYCLES)
All turbine generators, condensers	1.00 X”d	1.00X”d
All hydro-generators	0.75 X’d	0.75X’d
All Synchronous motors	1.00 X”d	1.50 X”d
Induction Motors		
Above 1000 horsepower@ 1800 r/min	1.00 X”d	1.50 X”d
Above 250 horsepower @3600 r/min	1.00 X”d	1.50 X”d
All others, 50 horsepower and above	1.20 X”d	3.00 X”d
All smaller than 50 horsepower	Neglect	Neglect

Rotating machine reactance according to IEEE C.37.5-1979

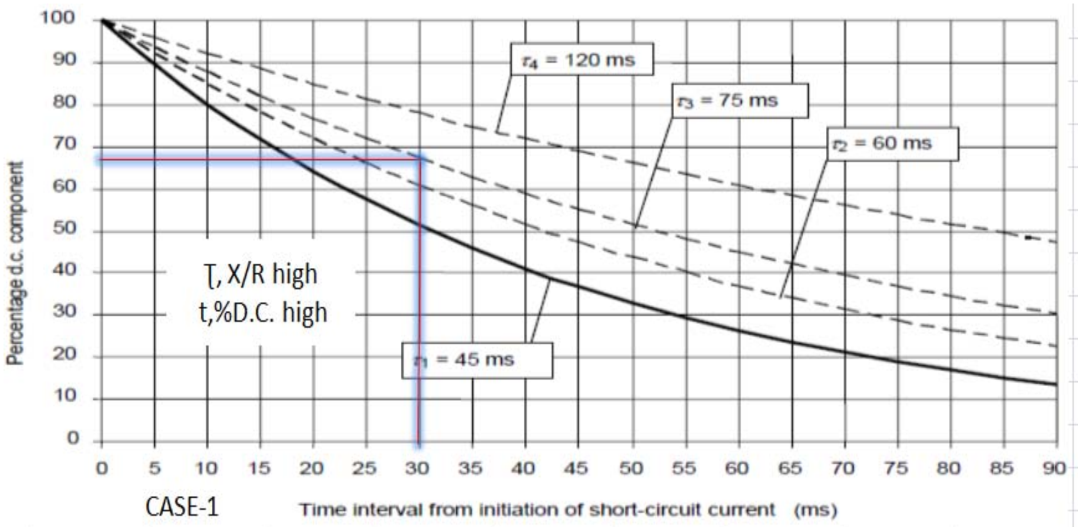
5. Special Case Studies

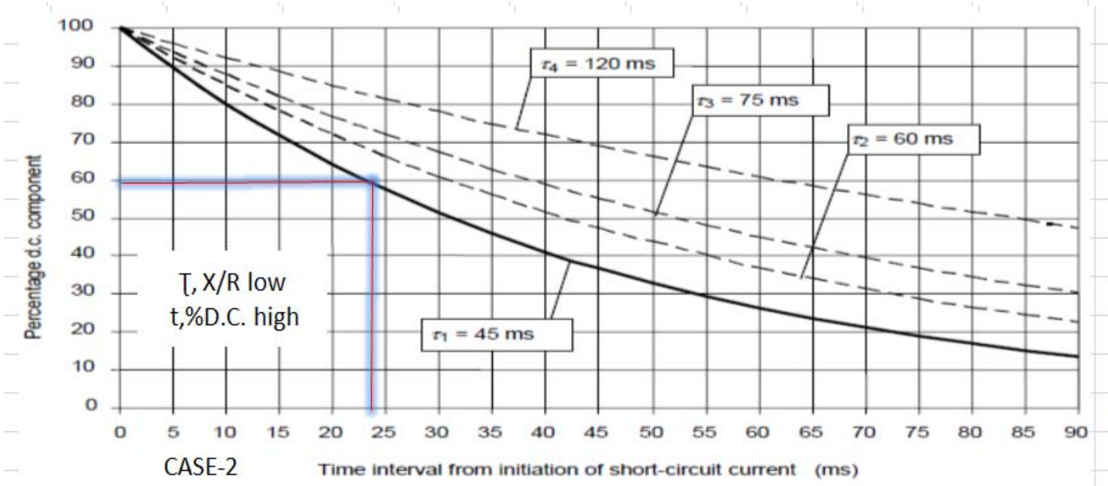
1) When value of time constant, X/R ratio, operating time and %DC component is high there are more possibilities that the contacts of the circuit breaker interrupter may restrike back. Contacts will re-strike back because the current to be interrupt will be very high and due to which the force of repulsion faced while breaking operation will be more and might happen that the contacts might not open completely and restrike back and not interrupt the fault at required instance.
2) When value of time constant and X/R ratio is low and %DC component and operating time is high. Here we can see from the graphs that time constant is less and time of

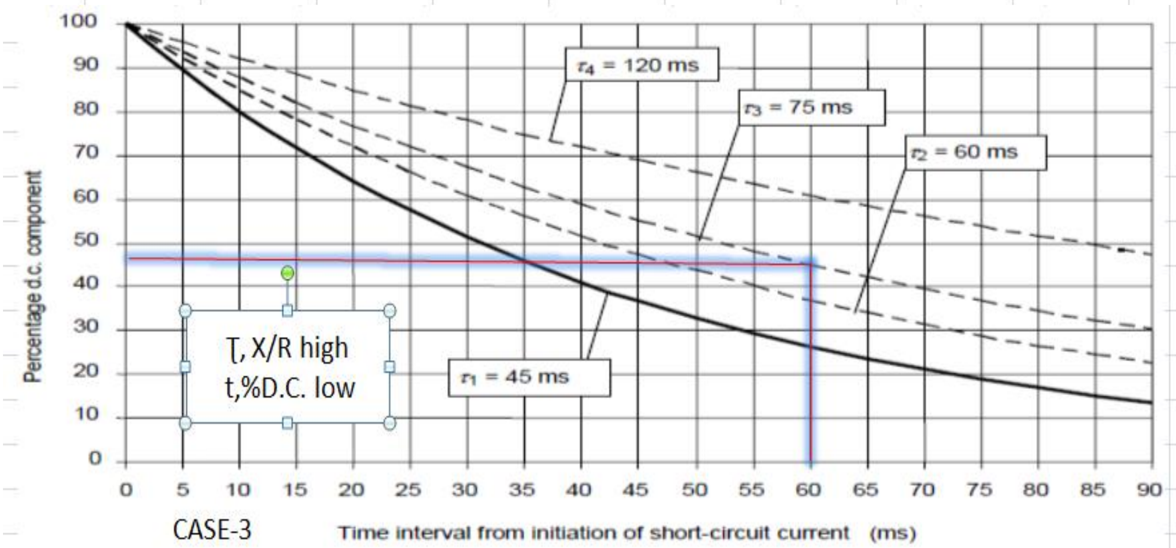
operation is high the breaker has to operate at higher DC component but this DC component value would be lower than the case I. So here there are chances of re-striking but not as high as in case of case I.

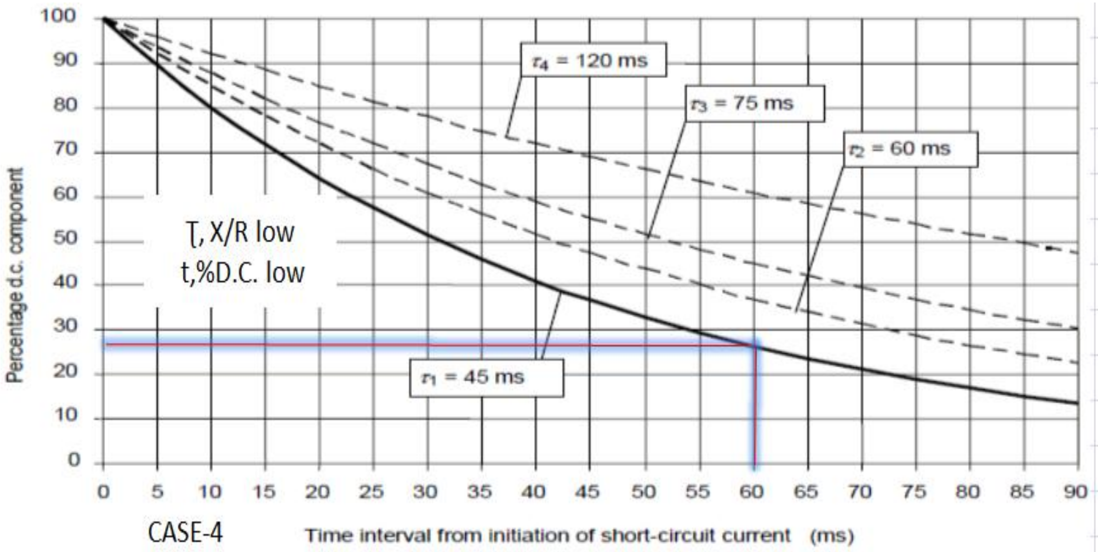
3) When value of time constant and X\R ratio is high and operation time and %DC component is low circuit breaker contact has to withstand higher value of short circuited current having higher DC component for longer duration and due to this there are chances of erosion of contacts or there might be welding of contacts if the quenching methodology is not sufficient enough.

4) When value of time constant, X\R ratio, operation time and %DC component are low the circuit breaker contact will have to withstand lower DC component for longer time duration and this will definitely affect the contact surface and there are maximum chances of contact welding. Moreover in this case the fault current will persist in the system for a longer duration of time thus it might damage the others components of the system and might end up in complete loss of equipments if no backup protection provided.









6. Conclusion

Listed Below is the few conclusions that are drawn on the basis of the study made on effect of DC component on circuit breaker.

1) 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.
2) The DC component makes the symmetrical current become asymmetrical and DC component is non periodic and decays exponentially with a time constant L/R where L/R is proportional to X/R.
3) 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.
4) 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.
5) Contact material of vacuum interrupter plays an important role in determining fundamental electrical performance of vacuum interrupters such as interruption capacity and dielectric strength. Current peak value and major loop duration are controlled by the value of X/R.
6) When circuit has an inherently high X/R interrupting time must still meet interruption rating of breaker however, arcing time will increase due to large major current loop.
7) Circuit has increased time between consecutive current zeros and will also have a higher peak current. Major changes are required to be made to the profile of the vacuum contacts and even there will be change in the diameter of the contacts.

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