Contact Erosion in Circuit Breaker Vacuum Interrupters

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The majority of high-voltage vacuum circuit breaker (VCB) specifications require the circuit breakers be equipped with an easily visible and/or measurable indication of interrupter main contact erosion.

Prior to the advent of VCBs becoming the predominant choice for 5 and 15kV drawout circuit breakers the market was served mostly by air-magnetic circuit breakers. Running the risk of oversimplification, air-magnetic circuit breakers worked by opening main and arcing contacts sequentially in air. The main current-carrying contacts parted first. The arcing contacts parted after the main contacts. True to their name, the arcing contacts were responsible for initiating and maintaining the arc until it extinguished. As such, the arcing contacts were exposed to literally all of the arcing energy, melting and vaporization that occurs during arc interruption. This served two purposes. The primary purpose of course was to carry the arcing current. The second purpose was to protect the main current carrying contacts from the deleterious effects of arcing such as burning and pitting that would negatively affect the ability to carry normal load currents within the rated thermal limits. The arcing contacts were considered sacrificial and were a normal maintenance item. Because the contacts were in air, they were relatively easy to visually inspect and replace when worn.

VCB interrupters have only one set of contacts to control the arcing and carry load currents. They are hermetically sealed in an opaque evacuated envelope, or “tube”, which is one of the few external parts visible to the naked eye. This configuration obviously prevents a visual indication of the continued serviceability of the contacts.

It is desirable to be able to physically determine the remaining life of vacuum interrupters. Perhaps in no small part due to the legacy of the air-magnetic circuit breakers, equipment users want a way to physically measure *something*.

But is an external physical displacement measurement a true indicator of the remaining life of a VCB? In my opinion, the answer is perhaps surprisingly and emphatically “No.”

Why? Because it is misleading. External physical displacement indicators, wherein a measurement is taken between two external reference surfaces, disregards several important factors. The first is simply measurement error due to the relatively small distances of vacuum interrupter contact travel and specified contact erosion limits. Both of those limits are specified by the vacuum interrupter manufacturer. The specifications are determined under very controlled conditions for the interrupter itself and do not take into account the elasticity of typical VCB operating, support and insulating structures. It’s left up to the VCB manufacturer to address those variables. Due to the nature of those variables, the method chosen normally utilizes some sort of adjustment to “zero” the reading when the VI is new. Designing in the ability to make mechanical adjustments can lead to measurement drift over time, leading to inaccurate contact erosion indication.

Is there a better way to determine remaining VCB interrupter main contact life? I believe the answer is “yes”.

Again running the risk of oversimplification, a brief explanation of what happens to arcing contacts, both in air and in vacuum, is needed.

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During an energized opening operation of a circuit breaker an arc is formed between the separated contacts. Due to the intense heat of the arc, the contact material melts, boils, and vaporizes. After the arc is extinguished the vapor condenses and solidifies. The process is basically the same for air magnetic and vacuum interrupters. However, in an air magnetic design the contact material vapor condenses mostly on the linings of the arc chutes. In a vacuum interrupter the vapor condenses mostly on the metal vapor shield or back onto the main contacts. In one sense an air magnetic design could loosely be considered a non-self-restoring process in which the arcing contact condensate is lost to all future use. In that same sense, a vacuum interrupter could be considered more of a self-restoring process in that some of the condensate ends up back on the main contacts.

In many designs of power circuit breaker vacuum interrupters the metal vapor shield is made from the same material as the contacts; often a mixture of copper and chromium. This is significant because sometimes during periods of very high-current arcing the arc actually impinges on or transfers to the shield causing it to become vapor. The vapor from the shield then condenses either back on the shield or the main contacts. The additional contact material vapor from the shield that condenses on the main contacts actually adds contact material back to the main contacts. Since this entire process occurs in a highly evacuated contaminate-free environment, the redeposited material is equivalent to “new” contact material in both electrical and mechanical properties.

The vapor deposition process along with the melting, solidification and reshaping of the main contact touch points during interruption explains the observation that in many cases the external contact erosion indication measurements show the contacts are “better than new” after a complete short-circuit interrupting test sequence. I have personally experienced this after numerous test sequences over the years.

So why are field measurements indicating that an interrupter is “worn out” being reported? In most, if not all, cases it’s simply mechanical creep and/or drift of the indication means or due to field adjustments to other areas of the circuit breaker structure that were not accounted for or recorded properly.

A much better method of determining contact erosion is to record and analyze the amount of actual current that has been switched by an interrupter over time. Many modern digital protection relays contain this capability. This measurement of the cumulative total current switched can be compared either manually or digitally to the published electrical life switching curve for a particular interrupter rating and style.

Powell can supply curves similar to the curve shown below for all ratings of circuit breakers we manufacture. This particular curve is for a 15kV, 25kA, 1200A circuit breaker. Although it’s not recommended by Powell, it is worth noting that the curve shows the interrupter is actually cable of interrupting full load current during the entire 10,000 operation mechanical life of the circuit breaker or the full rated short-circuit current up to 20 times. Powell does not recommend adherence to the curve for replacement. Why? Because the curve is generated for symmetrical currents at a system X/R ratio of 17. The current IEEE standard requires that the electrical endurance capability of an interrupter is 800% or 8 times the rated short-circuit current of the circuit breaker. During the normal course of performing design tests on a VCB, it is not uncommon to accumulate 12 or more times the rated short-circuit current on a test sample. To err on the conservative side, Powell recommends that the vacuum interrupters be considered for replacement after accumulation 800% or 8 times the rated short circuit current.

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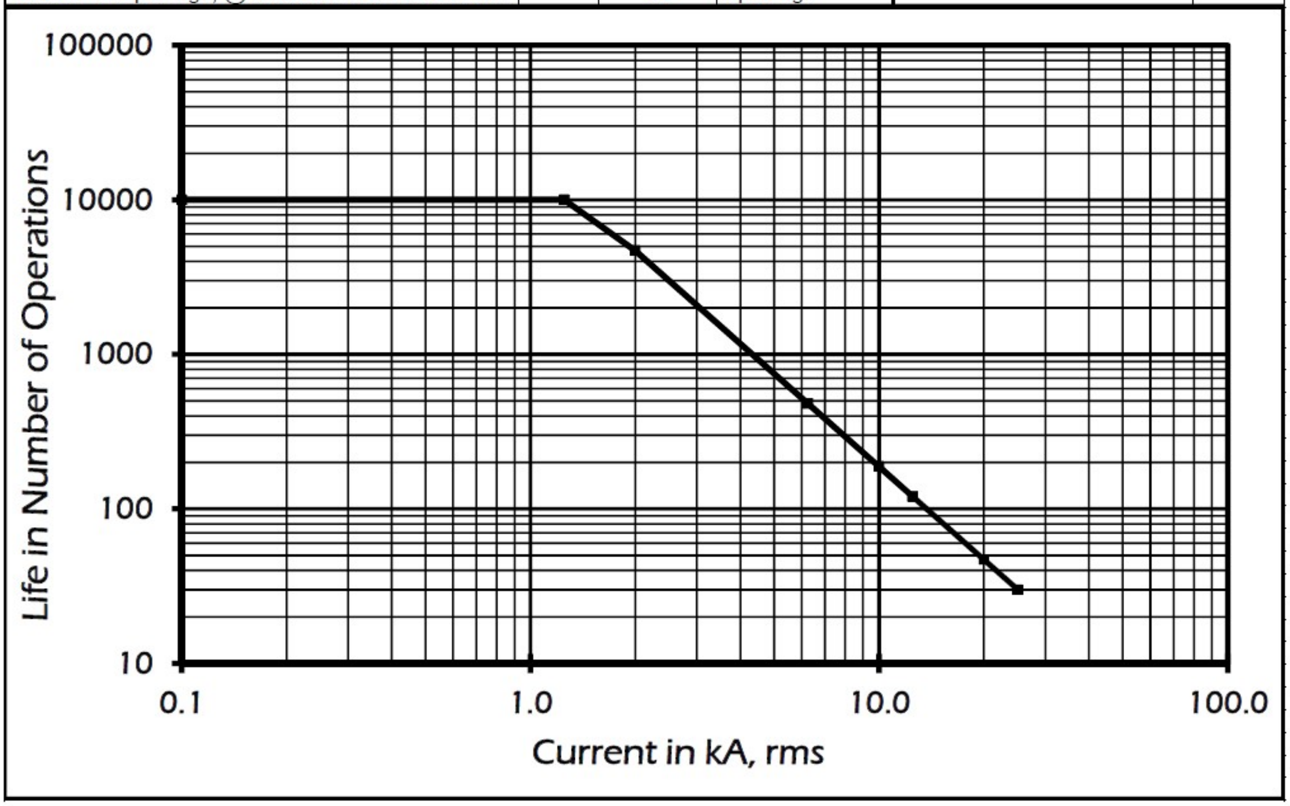
Electrical Switching Life of a Vacuum Interrupter

Rated Voltage:	15	kV,rms
Rated Short Circuit Current:	25	kA, rms
Rated Continuous Current:	1200	Amps,rms
Number of Openings, @ Max Short Circuit Current:	30	Openings



In summary, using a mechanical means only such as visual and measurable contact erosion indicators to determine the remaining electrical switching life of a VCB is simply not the best way to approach it. A regimen of recording, storing and accumulating current switching history in conjunction with routine dielectric and circuit breaker primary current path resistance tests will positively ensure the circuit breaker will interrupt when called upon to do so, while avoiding the unnecessary expense of prematurely replacing vacuum interrupters.

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