

TechTopics No. 65

Arc furnace transformer switching applications are very specialized. The special issues of interest for arc furnace applications are:

1. High number of mechanical operations
2. Resonant voltage phenomena.

High number of mechanical operations

Under normal operation of the arc furnace, the electrodes are usually withdrawn from the furnace when the need for heat decreases. Thus, the switching operation for the circuit breaker is a no-load or light-load operation and, accordingly, contact erosion is not typically an issue. Even if the mill chooses to switch the circuit breaker before the electrodes are withdrawn, the contact erosion is still minimal.

However, the number of operations per day is very high. It is not unusual for an arc furnace switching circuit breaker to experience 30 to 50 operations per day with exceptional cases approaching 150 operations per day.

This number of operations is far beyond the mechanical endurance required by ANSI/IEEE C37.06 for "general purpose" circuit breakers. For example, the rated mechanical endurance for a 38 kV indoor circuit breaker in accordance with ANSI/IEEE C37.06-2000 is 1,500 operations. An arc furnace application would reach the ANSI mechanical endurance limit for a general purpose 38 kV circuit breaker in only 30 to 50 days. Similarly, the ANSI limit for 15 kV class circuit breakers is 10,000 operations for most circuit breakers (up to 31.5 kA interrupting) and 5,000 for 15 kV 50 kA circuit breakers. Even with a circuit breaker having a mechanical endurance capability of 10,000 operations, an arc furnace application reaches the circuit breaker endurance in about six to 10 months.

Of course, it is easy to maintain a spare drawout circuit breaker element and swap the active circuit breaker for the spare circuit breaker when maintenance or overhaul is needed. However, this is expensive and takes care of the circuit breaker, but ignores the circuit breaker compartment in the switchgear structure. Sliding primary disconnect contacts have a limited endurance as do structure-mounted mechanism-operated cell (MOC) switches. By ANSI standards, a MOC switch has a mechanical endurance limit of 1,500 (for 38 kV) or 10,000 (most 15 kV ratings) or 5,000 (15 kV 50 kA) operations to match the ANSI requirement for the circuit breaker.

Arc furnace switching applications

Answers for energy.

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Several points should be clear from this discussion of the number of operations:

- A general purpose circuit breaker is not intended for the high number of operations involved with arc furnace switching
- If a drawout circuit breaker is used, the associated switchgear should not be equipped with stationary structure-mounted MOC switches.

Accordingly, a special purpose, fixed-mounted circuit breaker should be used to perform routine switching of the arc furnace transformer. Our type 3AH4 circuit breakers have been designed specifically for such duty. The type 3AH4 circuit breaker is available in ratings of 31.5 kA or 40 kA interrupting at up to 38 kV and is designed for a total operating life of 120,000 operations under typical operating conditions with overhauls performed at intervals of 30,000 operations. Periodic maintenance, consisting primarily of cleaning and lubrication, is required at intervals of 10,000 operations. Overhaul, at intervals of 30,000 operations, requires replacement of the vacuum interrupters and several other elements, such as the spring charging motor, auxiliary switches, close and trip coils, and similar items.

The type 3AH4 circuit breaker is designed, rated and tested in accordance with IEC 62271-100 (formerly IEC 60056) standard for circuit breakers. These circuit breakers are available only in a fixed-mount configuration and not in a drawout form.

Resonant voltage phenomena

Transient voltage phenomena present a second major issue that must be considered.

The arc furnace transformer should be installed in a vault adjacent to the arc furnace. The connections between the primary equipment in the transformer vault are normally open bus and are mounted on generously sized standoff insulators.

The transformer represents a huge inductance with extremely small phase-ground capacitance. If a switching transient occurs, it will cause a voltage transient between the circuit breaker and the terminals of the transformer. The transient magnitude is a function of the magnetic energy trapped in the transformer core, the inductance of the transformer, together with the capacitance between the circuit breaker and the transformer.

The magnetic energy trapped in the transformer core will be very large. The amount of capacitance between the circuit breaker and the transformer is very low. When the magnetic energy trapped in the transformer core (inductance) transfers to the capacitance between the circuit breaker and the transformer, the resulting voltage on the capacitance will have to be very, very high in order to match the trapped energy. Since the magnitude of inductance is very high and the magnitude of capacitance is extremely low, the natural frequency of the energy interchange between the inductance and the capacitance will be very high.

Transformers do not like to be subjected to voltage transients with extremely fast rise times, so the transformer insulation on the first couple of turns will be stressed, likely beyond its design capabilities.

A large arc furnace transformer can be represented as a network with distributed capacitances and distributed inductances. When the primary circuit breaker (the arc furnace circuit breaker) is switched on (closed), a prestrike closing transient will be initiated as the circuit breaker contacts approach the point of contact touch. When the contact gap becomes small enough (less than 2 mm in a vacuum interrupter), the voltage across the contacts will exceed the dielectric withstand of the contact gap and an arc will be initiated between the contacts before actual contact-touch. This prestrike closing transient is characteristic of all switching technologies, whether air magnetic, oil, SF₆ or vacuum.

The prestrike closing transient includes high-frequency components. If one of the frequencies in the prestrike closing transient happens to coincide with a resonant frequency of the transformer capacitive-inductive network, a resonant voltage wave will result. As this wave travels through the transformer winding, it may expose particular areas of the winding to voltage stresses that exceed the capabilities of the design. Transformer failure is the probable consequence.

Arc furnace transformers are **major** investments, and great care should be exercised to manage voltage transients so as to prevent transformer failure.

The voltage transient that can occur is a result of the interaction between the prestrike closing transient and the transformer capacitance-inductance network (and, to a degree, with the system). The susceptibility to resonant voltage phenomena depends on the length of cables and their characteristics (arrangement of the phase conductors, type of insulation, cross-section, method of shield grounding, etc.).

In order to protect the system from resonant voltage phenomena, we recommend that the services of a firm competent to perform high frequency voltage transient studies be employed. The voltage transient study must model the conductor arrangement between the circuit breaker and the transformer to correctly reflect the capacitance elements. We emphasize the need for competence in performing high-frequency voltage transient studies, as our experience is that many firms advertise such capability but few actually have the expertise. Siemens Metals & Mining Technologies group has extensive experience in performing these kinds of studies and can determine the types, ratings and locations of voltage transient mitigation elements.

Several points must be emphasized in this discussion of resonant voltage phenomena:

- The circuit breaker should be located as close to the arc furnace transformer as possible, preferably in the transformer vault itself. It is preferred that the connections between the circuit breaker and the arc furnace transformer be made using open bus in air rather than using shielded cables. This places the high inductance transformer, voltage transient mitigation devices and the circuit breaker all in close proximity and minimizes the influence of more remote components
- For arc furnace switching applications, regardless of the switching technology employed, a transient voltage study is needed to determine the types, ratings and location of protective elements (such as surge arresters, high-frequency ground bus and/or R-C elements) necessary to mitigate voltage transient problems


- Since the circuit breaker for the routine switching of the arc furnace transformer should be located directly adjacent to the arc furnace transformer, the cables that connect from the arc furnace circuit breaker to the upstream source should be protected by a conventional drawout circuit breaker or an outdoor circuit breaker, such as our type SDV6. This upstream circuit breaker should be used only to energize and de-energize the cables to the arc furnace circuit breaker and not to energize and de-energize the arc furnace transformer itself. The protection at the upstream circuit breaker should be set to provide short-circuit protection for the cables and backup overcurrent protection for the arc furnace transformer and associated directly connected arc furnace transformer circuit breaker.

Arc furnace summary and recommendations

Considering the preceding discussions relevant to arc furnace applications, we recommend the following:

- The arc furnace transformer feeder circuit breaker at the switchgear should be a conventional drawout circuit breaker or an outdoor circuit breaker, used for backup protection of the arc furnace and its associated dedicated circuit breaker and not for routine switching of the arc furnace
- The arc furnace transformer should be switched routinely by a dedicated fixed-mounted special purpose circuit breaker, such as our type 3AH4, located in the transformer vault
- The connections between the arc furnace transformer and its associated routine switching circuit breaker should be by means of open bus bars to minimize capacitance

- A transient voltage study should be performed by an organization that is competent to perform high-frequency transient voltage studies. This study must determine the exposure to transient voltage phenomena, including resonant voltage exposure, and, in turn, the type, ratings and location of appropriate voltage transient mitigation elements (R-C network, high-frequency ground bus and/or surge arresters).



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