SIEMENS

www.usa.siemens.com/techtopics

TechTopics No. 95

Tie circuit breakers and out-of-phase applications

The application of circuit breakers in a bus-tie configuration is common in any large electrical installation, whether at low voltages (e.g., 480 volts) or at medium-voltage levels (2,400 volts and above). This application is so common that many specifying engineers do not think about the application limits that apply to use of a circuit breaker to tie together two different electrical systems.

IEEE C37.010, the application guide for high-voltage circuit breakers, has for many years indicated that application of circuit breakers to normally-open tie circuits should be discussed with the manufacturer.

Fundamental to understanding the limitations associated with bus-tie circuit breaker applications is an understanding of how circuit breakers are tested. Medium-voltage circuit breakers are designed and tested on the basis of a balanced three-phase system, in which the maximum continuous operating phase-ground voltage is 58 percent ($1/\sqrt{3}$) of the maximum continuous operating phase-phase voltage. This is the basis of the dielectric-system design, and also is the basis for demonstrating interrupting performance during short-circuit tests.

For normal feeder circuit breaker applications, when the circuit breaker is opened, the load-side circuit is disconnected from any voltage sources, which means that the load-side conductors are at or near ground potential. Thus, the dielectric stress across the open circuit breaker contacts is equal to the phase-ground voltage.

The insulation (dielectric) structure of the circuit breaker is designed on the same basis, that the maximum continuous voltage from line side to load side of an open circuit breaker will be equal to the phase-ground voltage. The dielectric-system design for circuit breakers is intended to be free of partial discharge (often incorrectly referred to as corona) at voltages reasonably in excess of the phase-ground voltage. Historically, designs were based on freedom from partial discharges up to 110 percent of system phase-ground voltage, and more recently up to about 120 percent of system phase-ground voltage.

The interrupting performance of the circuit breaker is validated during design short-circuit tests, which are similarly conducted on the basis of system phase-ground voltage. The circuit breaker must successfully interrupt with the system- (source-) side voltage maintained at the system rated phase-ground voltage, and with transient-recovery voltage across the open contacts that is a function of parameters that include the system phase-ground voltage. This condition applies for all of the interrupting design tests performed on a standard general purpose medium-voltage circuit breaker.

How does this affect the application of a circuit breaker in a bus-tie situation? In most cases, there is no issue. However, if the application is such that the voltage across the open contacts can be higher than system phase-ground voltage for long periods, the circuit breaker can be exposed to conditions for which it is not designed. The existing design tests in the standards do not cover the increased voltage levels possible under this scenario.

Consider the voltage across the open contacts of a circuit breaker. As discussed, the premise of the standards is that when the circuit breaker is open, the voltage across the contacts will be no higher than 100 percent of system phase-ground voltage. If both sides of the circuit breaker are energized, the voltage across the open contacts will be (ignoring differences in voltage magnitude between the two systems) a function of the phase relationship between the sources as indicated in the following table:

Out-of-phase condition	Voltage across open contacts - % of phase-ground voltage
0° (in phase)	0%
30°	51.8%
60°	100%
75°	121.8%
90°	141.4%
120°	173.2%
180°	200%

From this, the circuit breaker is able to withstand an out-of-phase condition of up to 60 electrical degrees continuously, as this would be the same condition that would exist with one side energized and the other side of the circuit breaker de-energized. So, the concern arises when the phase difference exceeds 60°. In the worst case situation of 180° out-of-phase, the insulation from one side of the circuit breaker to the other will likely be subject to partial discharges continually, with subsequent deterioration of the dielectric capabilities over time.

However, this discussion only relates to the voltage across the open contacts. Next, consider the problem of short-circuit current interruption.

If there is a normally-open tie circuit breaker, with the two voltage sources out-of-phase by more than a small amount, when the command is given to close the tie circuit breaker, there will be a significant transient current between the two sources. If the two systems have high short-circuit current available, then the resulting overcurrent may persist for a long time, and will likely initiate tripping due to overcurrent. With the two sources out-of-phase, the voltage across the contacts immediately following the last current zero will be higher than normal, and the current may also exceed the capability of the circuit breaker to interrupt out-of-phase currents. IEEE Standards regard out-of-phase switching capability as an abnormal situation, so do not impose a mandatory requirement for out-of-phase switching tests.

If a manufacturer chooses to perform out-of-phase switching tests (as Siemens does), the preferred rating in IEEE Std. C37.04 is 25 percent of the short-circuit rating of the circuit breaker. So, it is quite possible that the interrupting capability of the circuit breaker will be exceeded if the circuit breaker attempts to open with significantly out-of-phase sources.

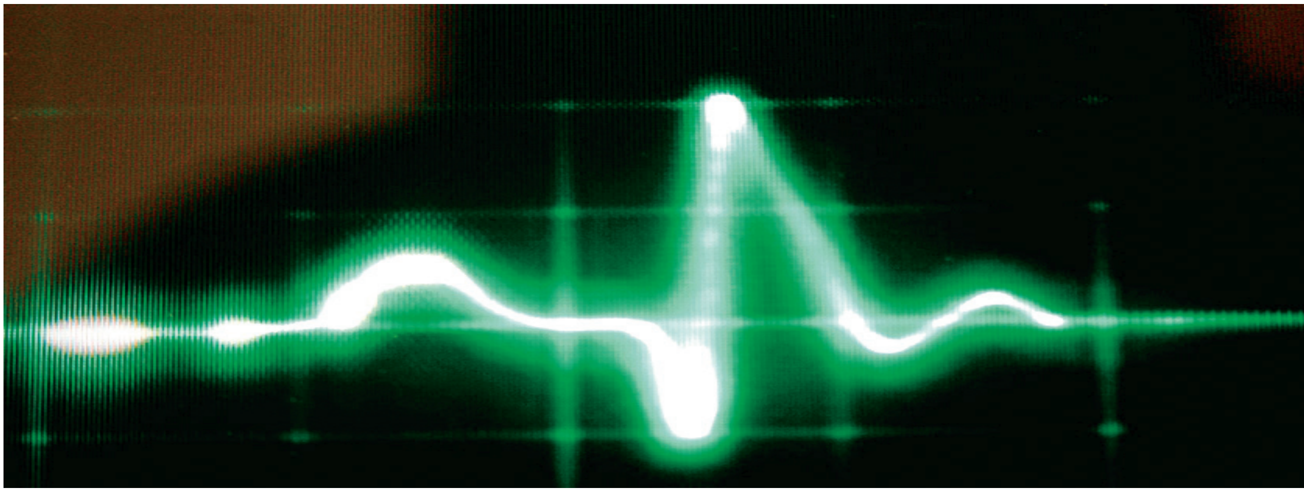
Beyond this, the impact on the overall system is undesirable, posing a significant risk of mechanical damage to rotating machines and their driven loads.

For this reason, the closing of a tie circuit breaker between two sources that may be out-of-phase should be supervised by a synchronism check relay (device 25) to prevent closing of the tie circuit breaker if the sources are out-of-phase by more than a nominal amount.

One approach to dealing with the out-of-phase situation is to use two tie circuit breakers in series, and operate with both tie circuit breakers normally open. Under this condition, and assuming reasonably balanced conditions, each circuit breaker sees no more than phase-ground voltage across the open contacts. This is an approach adopted by a number of firms, especially in certain continuous process industries. It is very commonly used in installations where the buses are in physically separate lineups of switchgear, connected together with metal-enclosed bus duct or other conductors (e.g., cables in conduit) external to the switchgear.

In addition to solving the problem of a higher voltage condition across the open contacts of the circuit breaker than the circuit breaker is designed for, this creates a very substantial operational advantage to the user, as it facilitates maintenance.

In a "normal" tie circuit breaker application, when a user wishes to perform system maintenance, one side (call it bus A) of the installation is typically de-energized for maintenance and the tie circuit breaker is opened. Then when bus A has been maintained, bus A is re-energized, and the other side (call it bus B) is de-energized to perform maintenance. This allows maintenance of both buses A and B but it does not allow maintenance of the tie circuit breaker compartment itself. In order to maintain and clean the primary disconnects in the compartment with reasonable safety, both bus A and bus B must be de-energized. This is typically not feasible in continuous process plants, so maintenance of the tie circuit breaker compartment is often neglected, which can have very adverse consequences.



In contrast, if there are two tie circuit breakers in series, both tie circuit breakers can be open and maintenance can safely be conducted on each bus and on the tie bus, without need for a complete plant shutdown. The user must consider appropriate PPE requirements when performing maintenance whenever the equipment is not fully de-energized. For example, with two lineups facing each other across a common maintenance aisle, if one lineup is energized while the other lineup is undergoing maintenance, the maintenance personnel must have PPE with ratings appropriate to the hazards.

Thus, Siemens recommends that when the application involves two sources that can be significantly out-of-phase on a continuous basis, two tie circuit breakers in series should be used. Both tie circuit breakers should be operated as normally open, avoiding issues of excess voltage across the open contacts. If the two sources are essentially in-phase (no significant phase difference between sources, some users prefer to keep one of the two tie circuit breakers closed so that the tie bus remains energized continuously.

One might ask how the situation described is similar to, or differs from the situation of a generator circuit breaker. When a generator is being brought on line, the generator source and the system source are often out-of-phase as well as having different voltages. This is not really similar to the situation in which the sources are out-of-phase on a continuous basis, as in the generator situation, the process of bringing the machine on line only takes a short time. Typically, the machine is brought up to speed, and when desired speed is reached, the field excitation is applied. From this point, the process of synchronizing the machine with the system only takes a very short time, seldom more than a few minutes. Thus, the voltage stress on the circuit breaker exists only for a short duration, not continuously.

Siemens Industry, Inc.
7000 Siemens Road
Wendell, NC 27591

Subject to change without prior notice.
Order No.: IC1000-F320-A176-X-4A00

For more information, contact: +1 (800) 347-6659

www.usa.siemens.com/techtopics