Proper Polarity Short Circuit Conditions in Double Break Designed Circuits

Scope:

This paper addresses two (2) aspects of proper polarity hot shorts as they relate to the potential for fire-induced spurious operation of solenoids and relays in DC and AC circuits with a double break design:

- The first aspect is whether a reversal of polarity, i.e., negative connection above the coil and positive connection below the coil versus positive connection above the coil and negative connection below the coil, will affect the coil's ability to operate when the applied voltage is from a compatible power source, i.e., an AC circuit interfacing with an AC target device, or a DC circuit interfacing with a DC target device.

- The second aspect is whether a device designed for an AC application will operate if the applied voltage is from a DC circuit and, conversely, whether a device designed for a DC application will operate if the applied voltage is from an AC circuit.

Summary of Results:

The following results are derived from the information provided in this paper:

<u>Reversal of polarity:</u>

AC and DC solenoids and relays used in double break control circuits should be assumed "polarity insensitive," unless specific manufacturer's technical data indicates the device is "polarity sensitive". "Polarity insensitive" means that the coil will operate regardless of the orientation of the applied positive and negative voltage to the coil.

<u>AC devices interfacing with DC circuits:</u>

- AC solenoids used in double break control circuits should be assumed capable of being operated by a DC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the plant conditions found.

- AC relays used in double break control circuits should be assumed capable of being operated by a DC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific relay will not operate under the plant conditions found.

DC devices interfacing with AC circuits:

- DC solenoids used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the plant conditions found.

- DC relays used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific relay will not operate under the plant conditions found.

Background:

Several portions of this report refer to "proper polarity" hot shorts as a particular mode of circuit failure, and thus this phrase deserves some discussion and clarification. The term "proper polarity" indicates that, in order for a spurious operation to occur, two concurrent hot shorts of opposite polarity must occur. Further, these two concurrent hot shorts must involve both polarities of an aggressor power source such that a suitable voltage is impressed across the target end device, thereby creating a complete path for actuating current to flow. Depending on the specific characteristics of the circuit designs, i.e., both the target and aggressor circuits, the potential for the spurious operation could be supplied through either a GFEHS or, even a ground as is the case for a grounded AC aggressor circuit. The term proper polarity hot short is used in this discussion to represent all of these circuit failure mode interactions. The proper polarity hot short failure mode generally requires special consideration for double-break circuit designs; that is, circuits where connections to the end device (e.g., a solenoid valve or relay) are opened on both polarities of the end device as part of the control or isolation design. Double break designs include:

- Control switches or relays that open two sets of contacts in the control circuit, one set in each leg of the end device circuit.
- Fuses pulled from both legs of a single break control circuit. (This is a pseudo-double break design.)
- Two-pole circuit breaker opens both legs of the control circuit. (This is a pseudo-double break design.)

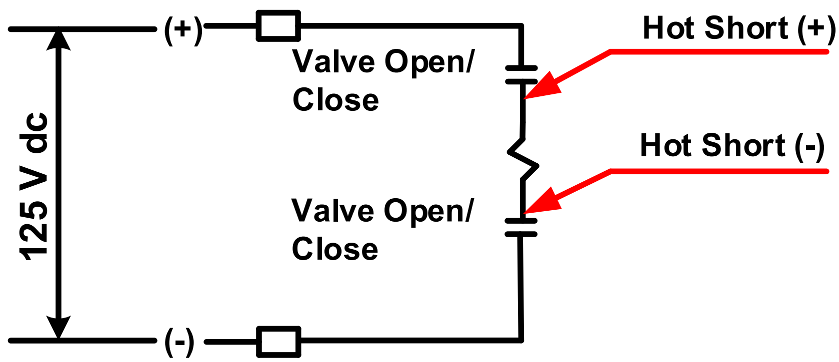
A proper polarity hot short can result when aggressor conductors (source conductors) of each polarity concurrently make contact with their respective conductor for the end device. This case, as shown in the figures below, represents the most often visualized case for the proper polarity hot short failure mode.

Discussion:

- Proper Polarity Aspect #1: [AC circuits to AC Devices; DC circuits to DC devices]

Based on a review of the manufacturer's literature on solenoids, neither AC nor DC solenoids and relays are polarity sensitive, i.e., the coil will operate regardless of the orientation of the applied positive and negative voltage to the coil. [Reference: ASCO "Engineering Principles" and "installation" literature]. This is an inherent characteristic of the principle coil design. In some special cases, DC solenoids are, however, designed to be "polarity sensitive." This type construction is generally limited to very low DC voltage designs that incorporate voltage suppressors for basic circuit protection against transients. From readily available manufacturers' literature, this design feature appears to be used only for solenoids rated 24 VDC or below.

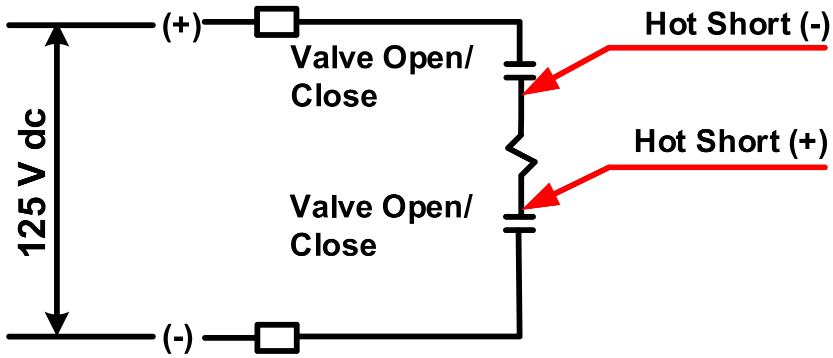
Hence, proper polarity shorts can also occur from a pair of hot shorts whose polarity is reversed from that normally anticipated for the end device under normal operating conditions.



Proper Polarity [Normally Anticipated Configuration]

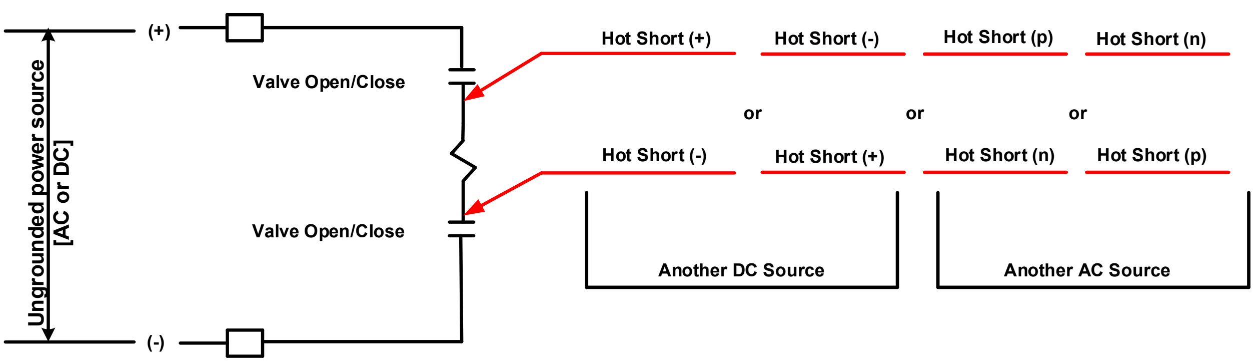
This reverse polarity configuration, as shown below, will still be considered "proper polarity" since it has the same functional impact of producing a spurious operation.

Proper Polarity Short Circuit Conditions in Double Break Designed Circuits



Proper Polarity [Reverse Polarity Configuration]

The illustrations shown above are for a 125 VDC ungrounded circuit, but the principles could also apply to other circuit types, e.g., ungrounded AC from a CPT, or distributed ungrounded AC as shown generically below.



Generic Proper Polarity Potential Configurations

- Proper Polarity Aspect #2: [DC circuits to AC Devices; AC circuits to DC Devices]

AC and DC solenoids are electrically engineered to operate under specific voltage conditions. Given the somewhat random and inconsistent conditions caused by fire-induced circuit failures, it is highly unlikely that the conditions produced in a fire environment can duplicate, with any predictability, the specific design conditions for which these devices are designed. In addition to the design differences between AC and DC solenoids or relays as discussed below, there are other secondary effects between AC and DC voltage that reduce the likelihood of a spurious operation of the coil. Inrush currents and opening transients are very different between AC and DC coils due to the inductive effect of AC. The air gap between coil and central core also has an impact on operating performance. Finally, DC voltage can cause residual magnetism in AC coils, which can lead to improper operation during switching.

Most basically, however, AC and DC solenoids are designed differently to account for the different impedance characteristics exhibited by the coil when AC and DC voltage is applied. Under AC voltage, a coil has both a resistive and inductive element ($Z = Xj + R$); under

DC voltage the exhibited impedance is only the resistive element (Z = R). Thus, DC voltage will produce much higher current flow over the equivalent AC voltage (i.e., same voltage with very different impedances). Since the force produced in the magnetic field is a function of current, DC voltage will produce a greater force than equivalent AC voltage, i.e. lower coil impedance under DC voltage produces higher current, which in turn produces greater force ($P = I^2 R$).

Based on the above principle, a coil designed for a DC application would require a higher applied AC voltage to produce an equivalent force. Depending on the solenoid design and the counter force produced by the reset spring, an equivalent AC voltage may or may not be able to overcome the spring force. From available documentation, it appears that an AC voltage will typically not be able to overcome spring force in a DC solenoid of the same voltage class (e.g., a 120 VAC hot short is not likely to cause a 125 VDC solenoid to pick up). Despite this, it is possible for higher AC Voltages to be present, e.g., 208 VAC; 277 VAC. Although these higher voltages do not, by any means, guarantee a 125 VDC solenoid will operate should it come into contact with a conductor from one of these higher voltage circuits, they do present the possibility that spurious operation could occur. Operation of a DC solenoid by a conductor from an AC circuit requires a coincidental combination of a sufficient number of factors that, although theoretically possible, it is considered to be of low likelihood. Some of the coincidental factors required for the interaction described above to occur include considerations such as: (1) sufficient fire damage to the conductors feeding the DC solenoid to allow an interaction with conductors of one or more adjacent cables; (2) the presence of conductors of an adjacent cable(s) at a voltage level complimentary to the required power characteristics of the solenoid; (3) sufficient fire damage to the conductors of the adjacent cable(s) that allow it to interface with the conductors supplying the solenoid without first going to ground; (4) insulation resistance characteristics at the interface between the fire damaged conductors that provide a current transfer path consistent with the characteristics required for the operation of the device. Despite the low likelihood of these conditions occurring, due to the wide range of available DC solenoids available, the occurrence cannot be ruled out. As such, operation of a DC solenoid by a conductor from an AC circuit should be assumed unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the identified plant conditions.

Based on the above principle, a solenoid designed for AC application would require a much lower applied DC voltage to produce equivalent force. In the case of equivalent DC voltage applied to an AC solenoid, the likely failure mode is that the significantly higher current flow for equivalent DC voltage will cause an over temperature condition that will burn out the coil, in some cases rather quickly. Although coil burnout under the conditions postulated could occur, factors such as the timing of the burnout and insulation resistance of the fire-induced short on the postulated aggressor conductor make it impossible to predict that coil burnout in a prescribed period of time is assured. Furthermore, the fire induced short impedance could lower the DC voltage applied to the coil, making the coil burnout less likely. Thus, it must be assumed that DC voltage applied to an AC solenoid will cause it to energize. Accordingly, operation of an AC solenoid by a conductor from a DC circuit must be assumed unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the identified plant conditions.

The recommendations provided above for AC and DC solenoids are also applicable to AC and DC relays used in control circuits for safe shutdown components in operating nuclear power facilities.

When operating a DC relay from an AC source the alternating current decreases to zero every half cycle, which results in the relay armature releasing every half cycle. This continual movement of the armature not only causes a "buzz," but will result in the contacts rapidly opening and closing (i.e., relay chatter) as the armature moves. Depending on the characteristics of the device being operated and the circuit itself, this relay chatter could result in the spurious operation of the device. Should the device be a latching device, a permanent change of state could occur. Additionally, if the relay manufacturer uses a shading ring (or shading coil) on the top of the relay core, the shading ring could compensate for the cycling effect described above. When a shading ring is used an AC source could be capable of operating a DC relay coil. Based on these considerations, for any safe shutdown components using DC relays, the construction of the DC relays, the characteristics of the device to be operated, and the circuit characteristics itself should be reviewed to assure that the AC source is incapable of operating the DC relay. In the absence of this review, it should be assumed that an AC source can operate the DC relay.

Similarly to the AC solenoid discussion above, sustained operation of an AC relay from a DC source is impractical without reducing the DC voltage to a level less than the AC rating of the relay. For similar reasons to those cited for an AC solenoid, however, it should be assumed that operation of an AC relay by a conductor from a DC circuit can occur unless a specific engineering analysis, factoring in bounding values for the appropriate plant specific parameters, is documented and/or testing has been performed showing that the specific relay will not operate under the plant conditions found.

Conclusions:

The following conclusions can be drawn from the discussion documented above. The accuracy of these conclusions has been verified by discussion with a Technical Representative from, at least, one component manufacturer. The Technical Representative advised that, based on the wide range of component products available, definitively ruling out any of the occurrences discussed above is not possible and, in fact, depending on the product being tested, these types of occurrence have been observed during bench testing of components.

Reversal of polarity:

AC and DC solenoids and relays used in double break control circuits should be assumed to be "polarity insensitive," unless specific manufacturer's technical data indicates the device is "polarity sensitive". "Polarity insensitive" means that the coil will operate regardless of the orientation of the applied positive and negative voltage to the coil.

AC devices interfacing with DC circuits:

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DC devices interfacing with AC circuits:

- DC solenoids used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific solenoid will not operate under the plant conditions found.

DC relays used in double break control circuits should be assumed capable of being operated by an AC source, unless a specific engineering analysis, factoring in bounding values for all of the appropriate plant specific parameters, is documented and/or testing is conducted showing that the specific relay will not operate under the plant conditions found.