U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Module II – Circuit Analysis

Cable and Circuit Failure Modes

Joint EPRI/NRC-RES Fire PRA Workshop
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A Collaboration of the Electric Power Research Institute (EPRI) & U.S. NRC Office of Nuclear Regulatory Research (RES)

CABLE AND CIRCUIT FAILURE MODES

Objectives

- Review circuit design parameters that influence cable/circuit failure modes and resultant equipment functional impacts
- Review fire-induced cable failures and the manifestation of different failures for various circuit types
- Review the concepts and engineering principles behind fire-induced cable failures
- Identify credible and non-credible failure modes based on NUREG/CR-7150 results, including new Volume 3
- Discuss practical aspects of performing circuit analysis for the wide variety of possible failure modes
- Focus on hot-short induced spurious operations

CABLE AND CIRCUIT FAILURE MODES

What are we going to cover?

- Definitions
- Circuit Design Parameters and Conventions
- Grounding Configurations
- Cable Fault Modes
- Circuit Failure Modes - Control Circuit
- Circuit Failure Modes - Special Cases
- Influence Parameters
  - Spurious Operation Likelihood
  - Spurious Operation Duration
- Complex Applications

CABLE AND CIRCUIT FAILURE MODES

Definitions

- Precise use of definitions is important to avoid misinterpretations and misapplications
- Surprisingly high number of people that still carry misconceptions and legacy issues
- Need to have clear understanding of key definitions to make full use of this course
- NUREG/CR-7150, Vol. 3 introduces some new terms

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

Available Short-Circuit Current – The maximum current that the power system can deliver through a given circuit point to any negligible impedance short circuit applied at the given point, or at any other point that will cause the highest current to flow through the given point.

Bolted Fault – The highest magnitude short circuit current for a particular fault location. The impedance at the fault location is typically very low or zero for a bolted fault.

Cable Fire Damage – If a cable is exposed to a fire (i.e., in the form of a plume, hot gas layer, flame, and/or radiant heating), damage to the cable may occur progressively from a base state of initial heating up to an end state of complete cable burn up.

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Cable Failure Modes – The mode by which a conductor or cable fails due to a fire. The following are general circuit failure modes of interest:

- **Open Circuit** – A fire-induced break in a conductor resulting in a loss of circuit continuity.

  Note: NUREG/CR-6850 does not require consideration of open circuits as a primary cable failure mode. However, DC testing places this position in question. It is also beneficial to consider open circuits for consistency with the Appendix R circuit analyses criteria

- **Short-to-Ground** – A fire-induced breakdown of a cable's insulation system resulting in the potential of a conductor being applied to a grounded medium. The grounding medium refers to any conduction path associated with the reference ground of the circuit or earth ground. This might include structural elements (tray, conduit, enclosures, metal beams, etc.) or intentionally grounded conductors of the circuit (neutral conductor). Ground may be either earth ground or reference ground. Note that for ungrounded systems, a single short to earth ground will not cause fault current to flow. For grounded circuits, reference ground and earth ground are one in the same.

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

- **Hot Short** – A fire-induced insulation breakdown between conductors of the same cable, a different cable or from some other external source resulting in a compatible but undesired impressed voltage or signal from one conductor (source conductor) to one or more different conductors (target conductor). Within the context of fire-induced faults, the target conductor is assumed to be an ungrounded conductor.

  Note: A hot short is characterized by an abnormal connection between conductors that does not produce a high fault current because of inherent impedance in the connection path attributable to circuit components. A defining characteristic of a hot short is that it is not detectable by normal circuit protective devices and thus will not trigger an overcurrent protective action. A hot short has the potential to cause undesired energization of components connected to the target conductor (i.e., spurious operation); however, the term hot short is not synonymous with the term spurious operation.

- NUREG/CR-7150 – Fire-induced hot shorts: Individual conductors of the same or different cables that come in contact with each other and that may result in an impressed voltage or current on the circuit being analyzed (definition per Regulatory Guide 1.189)

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

- **High Impedance Fault** – A fire induced partial breakdown of a cable's insulation resulting in an abnormal but high resistance short-circuit between two or more conductors in which ground may or may not be involved. This failure more results in partial diversion of the available electrical energy and may not be detected by overcurrent protective devices.

- **Multiple High Impedance Fault(s)** – A condition where multiple circuits fed from a single power distribution source each have a high impedance fault.

- **Line-to-Line Fault** – A fault generally involving a three-phase power system in which conductors from two or more phases make contact and result in abnormal current flow. Unlike hot shorts, line-to-line faults cause high fault currents, which are generally detectable by circuit overcurrent devices.

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

- **Conductor-to-Conductor Short** – An abnormal connection (including an arc) of relatively low impedance between two conductors. A conductor-to-conductor short between an energized conductor of a grounded circuit and a grounded conductor results in a ground fault. A conductor-to-conductor short between an energized conductor and a non-grounded or neutral conductor results in a hot short. Conductor-to-conductor shorts between an energized conductor of an ungrounded circuit and the reference ground or neutral conductor(s) has the same functional impact as a ground fault.

- **Three-Phase Bolted Fault** – A fault in which all three phases short with zero impedance. A three-phase bolted fault produces the highest short circuit currents in virtually all electrical power distribution systems. Most short circuit studies conducted to determine maximum available short circuit currents are based on three-phase bolted faults.

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

Circuit Failure Mode – The manner in which a conductor fault is manifested in the circuit. Circuit failure modes include loss of motive power, loss of control, loss of or false indication, open circuit conditions (e.g., a blown fuse or open circuit protective device), and spurious operation.

Coordination – The application of overcurrent protective devices in series such that (of the devices carrying fault current) only the device nearest the fault will open and the devices closer to the source will remain closed and carry the remaining load.

Overcurrent – A current that exceeds a continuous current rating, including overloads, short circuits, and ground faults.

Overcurrent Protection – A form of protection that operates when current exceeds a predetermined value.

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

Off-Scheme Circuits/Cable – Circuitry and cables located off of the primary component scheme (e.g., interlock and permissive circuitry that could actuate contacts on the component of concern or otherwise prevent proper operation of the component).

Active Component Function – A component whose credited function requires the component to actively change state(s) or operate to accomplish the credited PRA function. This type of component includes power-operated valves that must change positions, motors that must run, electrical power supplies and their switching devices, and process monitoring instruments. Note that some components may perform both active and passive functions, depending upon the Basic Events associated with the component.

Passive Component Function – A component whose credited function does not require motive or control power for the component to accomplish the function.

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

Inter-Cable Fault – A fault between conductors of two or more separate cables.

Intra-Cable Fault – A fault between two or more conductors within a single multi-conductor cable.

Required Cables – The set of cables that must remain free of fire damage to ensure that the subject component can perform all of its required functions from the control room or emergency control station. Cables that are associated circuits by spurious actuation and/or associated circuits by common power supply are also considered required cables since these cables can also affect proper performance of credited systems or equipment.

Source Cable or Source Conductor – A cable or conductor that is energized (e.g., before the fire) and is therefore capable of producing a hot short should it come in contact with a target conductor(s).

CABLE AND CIRCUIT FAILURE MODES

Definitions (continued)

Target Cable or Target Conductor – A cable or conductor (initially energized or not) that, if energized by contact with an appropriate source cable or conductor, would lead to a hot short and possibly a spurious operation if the target cable or conductor was associated with equipment or device(s) that would spurious operate.

Hot Short-Induced Spurious Operations – A circuit fault mode wherein an operational mode of the circuit is initiated (in full or in part) due to failure(s) in one or more components (including cables) of the circuit. For example, a pump (starting or stopping) or a valve spuriously repositioning.

NOTE: The PIRT panel defined this based on the definition of spurious actuation in RG 1.189 (Ref. 16), "The undesired operation of equipment, considering all possible functional states, resulting from a fire that could affect the capability to achieve and maintain safe-shutdown."

CABLE AND CIRCUIT FAILURE MODES
Definitions (continued)

Incredible – The term “incredible” when used in conjunction with a fire-induced circuit failure phenomenon, is used to support the PIRT panel’s conclusion that the phenomenon cannot occur. In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring, and there was no credible technical argument to support its occurrence during a fire. Any probabilistic numbers assigned to these types of phenomena would have little meaning.

Implausible – The term “implausible” when used in conjunction with a fire-induced circuit failure phenomenon, is used to support the PIRT panel’s conclusion that the phenomenon, while possible in theory, would require the convergence of a combination of factors that are so unlikely to occur that the likelihood of the phenomenon can be considered statistically insignificant. In these cases, the PIRT panel could find no evidence of the phenomenon ever occurring in operating experience or during a fire test. Any likelihood value assigned to these types of phenomena would not be meaningful.

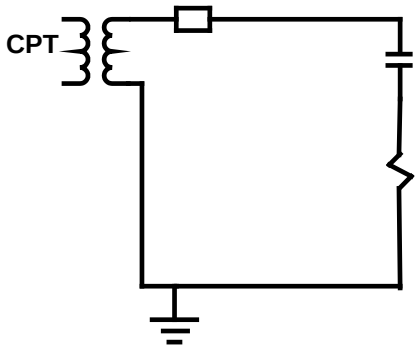
CABLE AND CIRCUIT FAILURE MODES

General Conventions

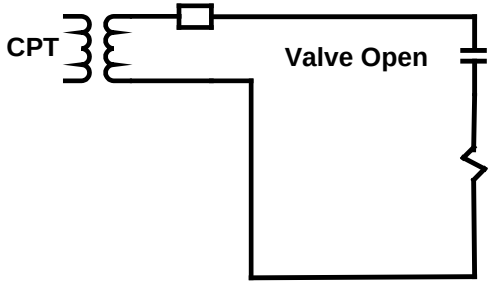
- Polarity – AC & DC Circuits
- 3-Phase vs. Single-Phase Power
- Delta vs. Wye Connected Circuits
- Normally Open vs. Normally Closed Contacts
- Conductor, Cable, & Raceway IDs
- Electrical vs. Physical Connectivity

CABLE AND CIRCUIT FAILURE MODES

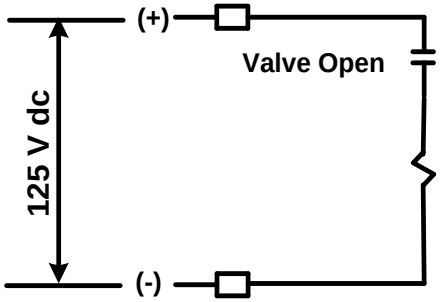
Circuit Design Basic Configurations



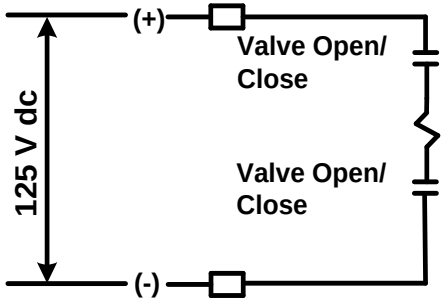
Grounded AC



Ungrounded AC



Ungrounded DC
[or 120 V ac Distributed]



Ungrounded DC
[or 120 V ac Distributed System]

CABLE AND CIRCUIT FAILURE MODES

Grounded vs. Ungrounded Circuits

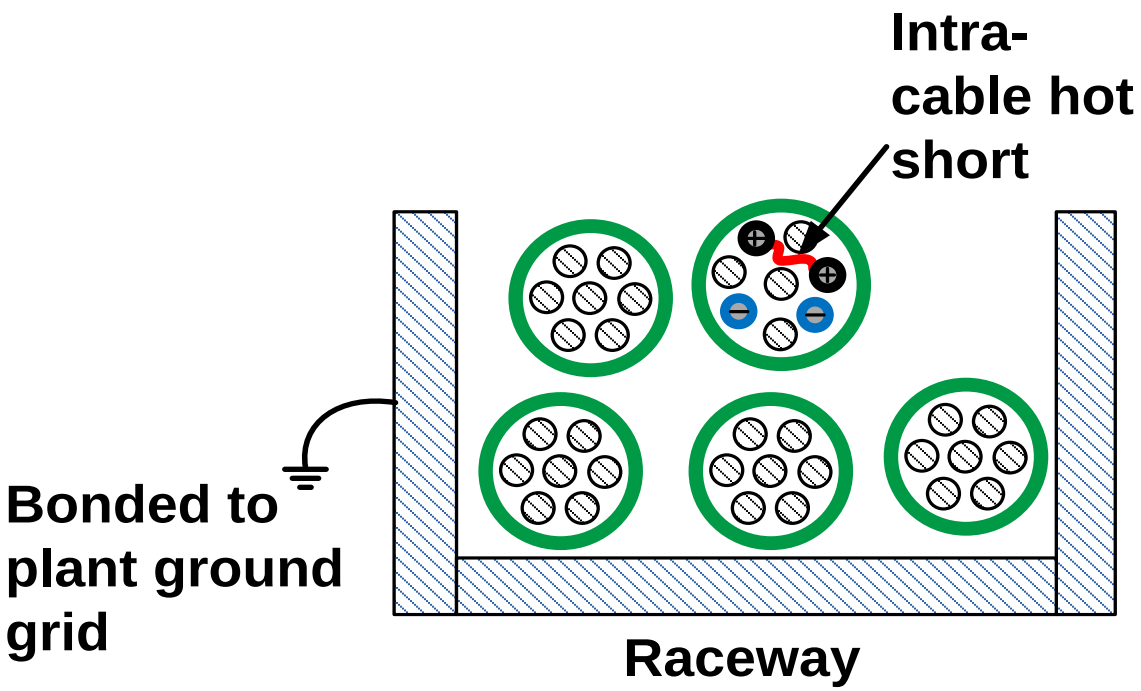
- How can you tell?
- Why one or the other?
- Advantages & disadvantages
- Affect during normal circuit operation?
- Affect during abnormal circuit operation?
- Where will you likely see in practice?
- Types of grounding
  - Solid
  - High Impedance or Resistance
  - Low Impedance or Resistance
- Where is ground point established?
- Why do we care so much about grounding?

CABLE AND CIRCUIT FAILURE MODES

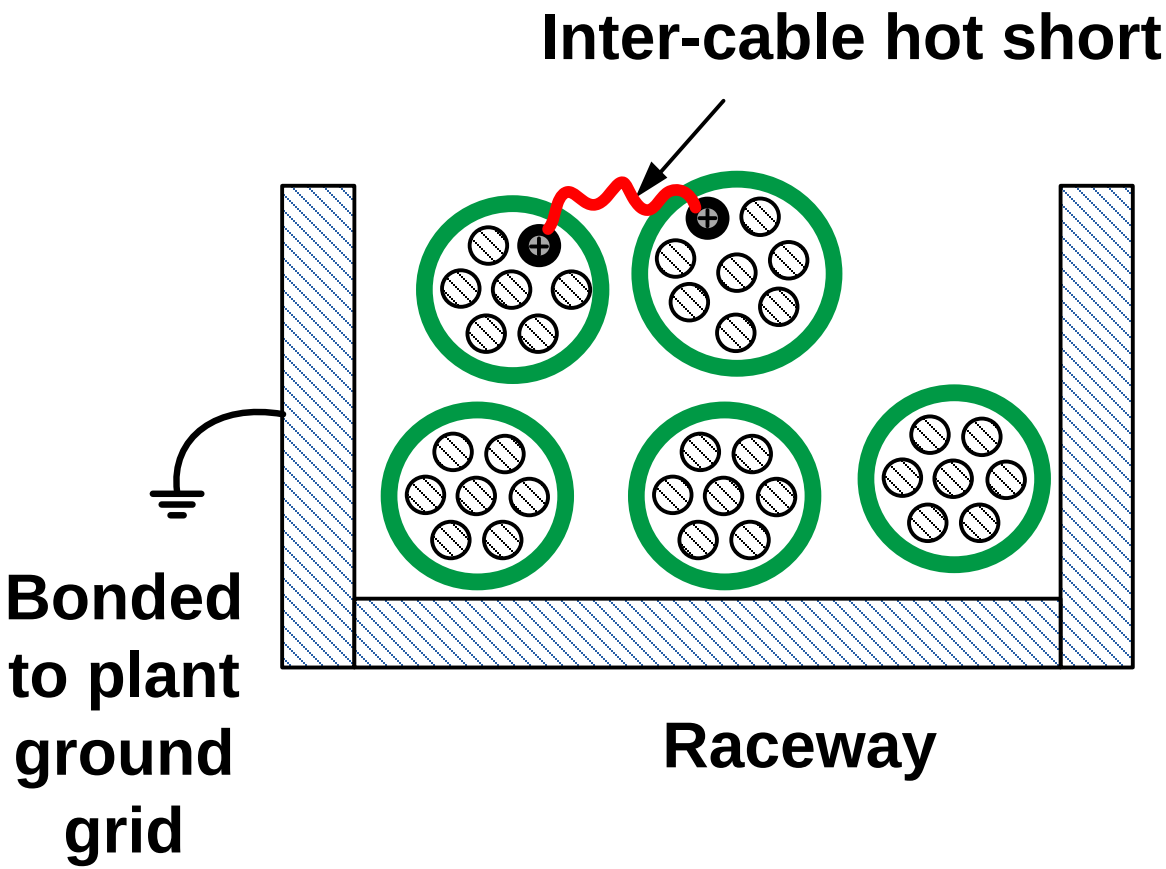
Fault Modes

- Open Circuit
- Short-to-Ground
- Hot Short
  - Proper Polarity Hot Short
  - Multiple Hot Shorts
    - Independent Circuits
    - Dependent Circuits
  - Ground Equivalent Hot Shorts
  - Three Phase Hot Shorts
- Inter-Cable & Intra-Cable

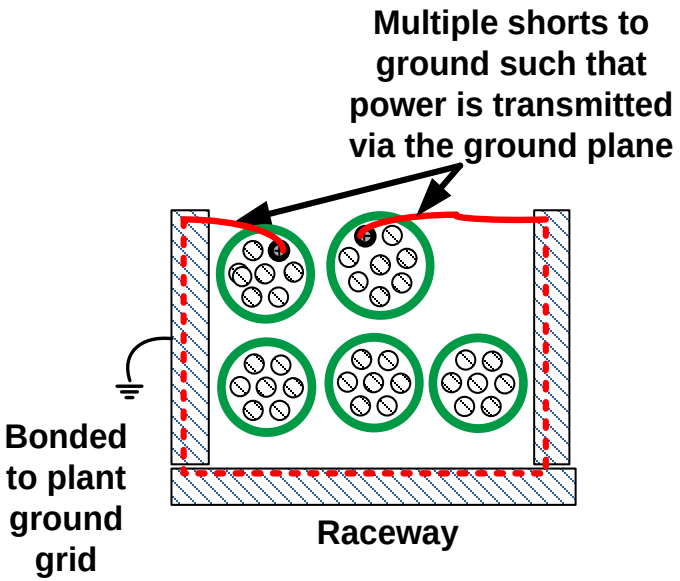
Intra-Cable Hot Short

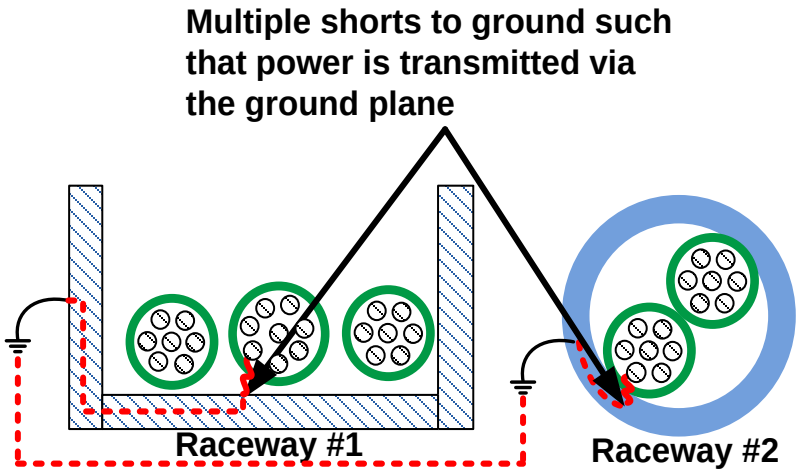


Inter-Cable Hot Short

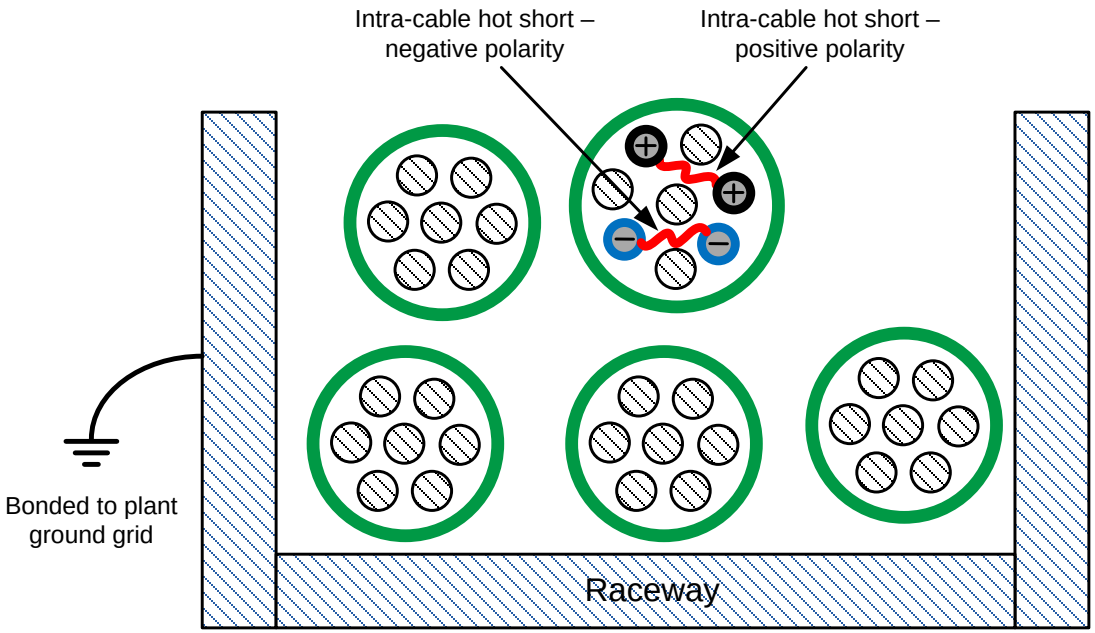


Ground Fault Equivalent Hot Short



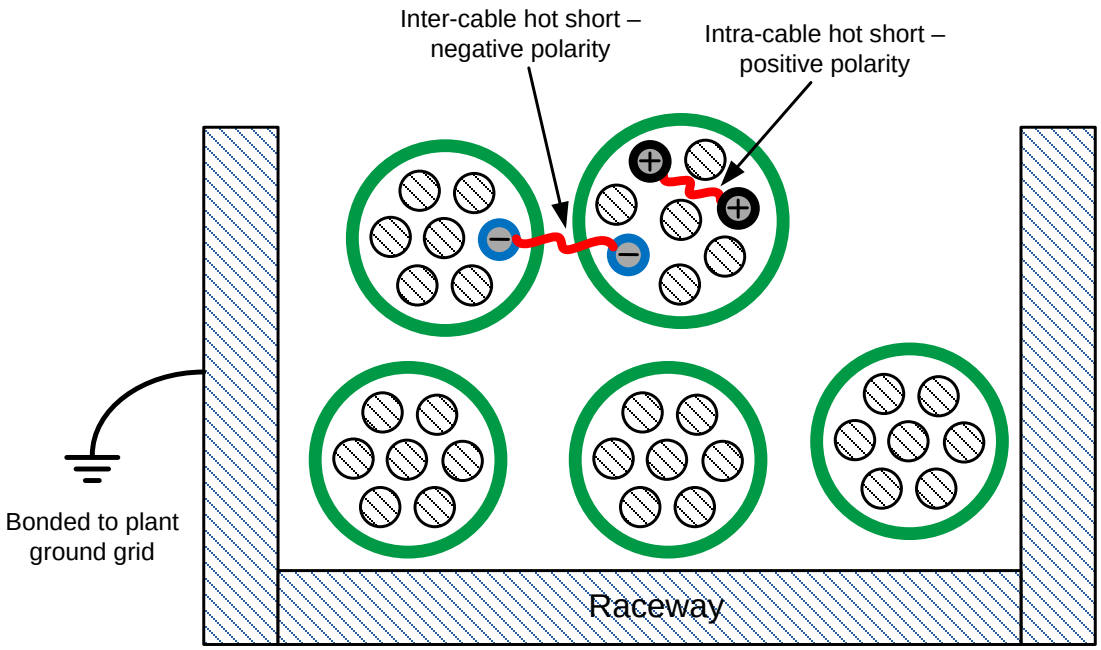


Proper Polarity Hot Short – Intra / Intra



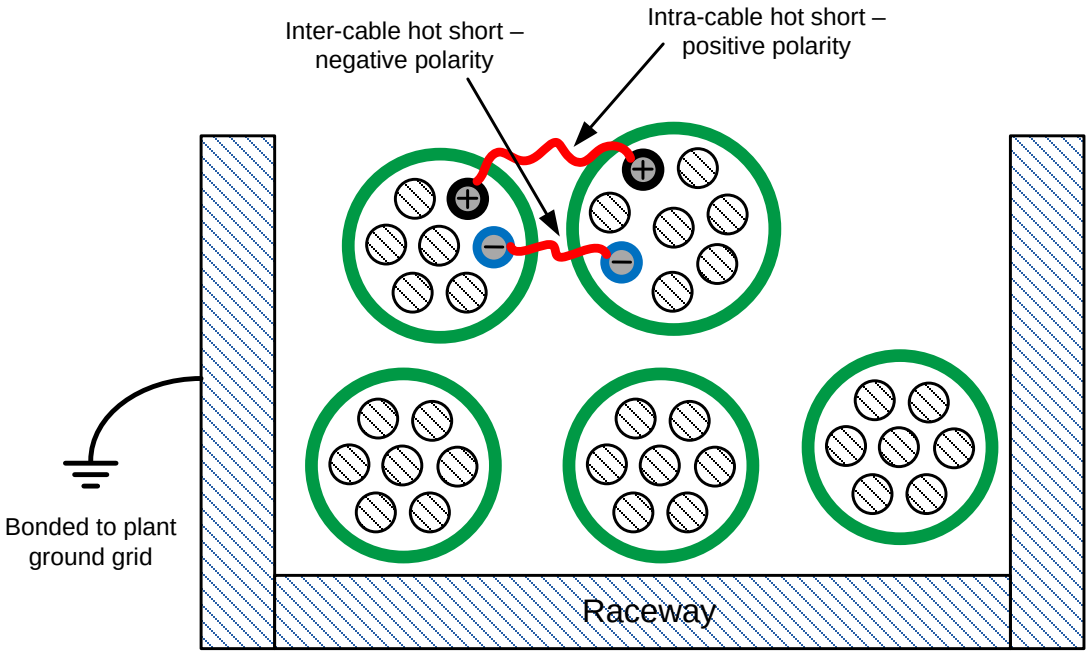
CASE 1:
Proper polarity hot shorts are the result of selective shorts betweens same polarity conductors within a single cable.

Proper Polarity Hot Short – Intra / Inter



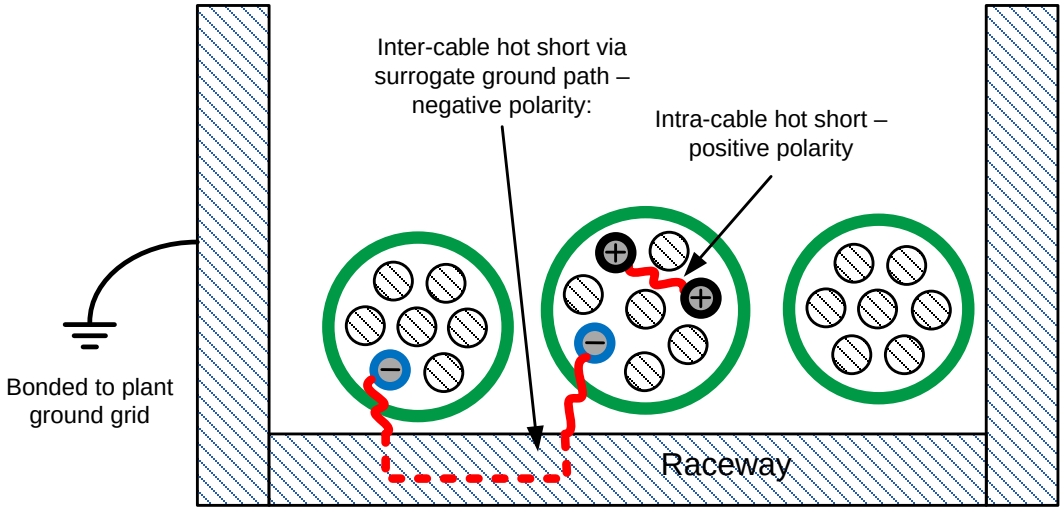
CASE 2A:
Proper polarity hot shorts are the result of one intra-cable short and one inter-cable short.

Proper Polarity Hot Short – Inter / Inter



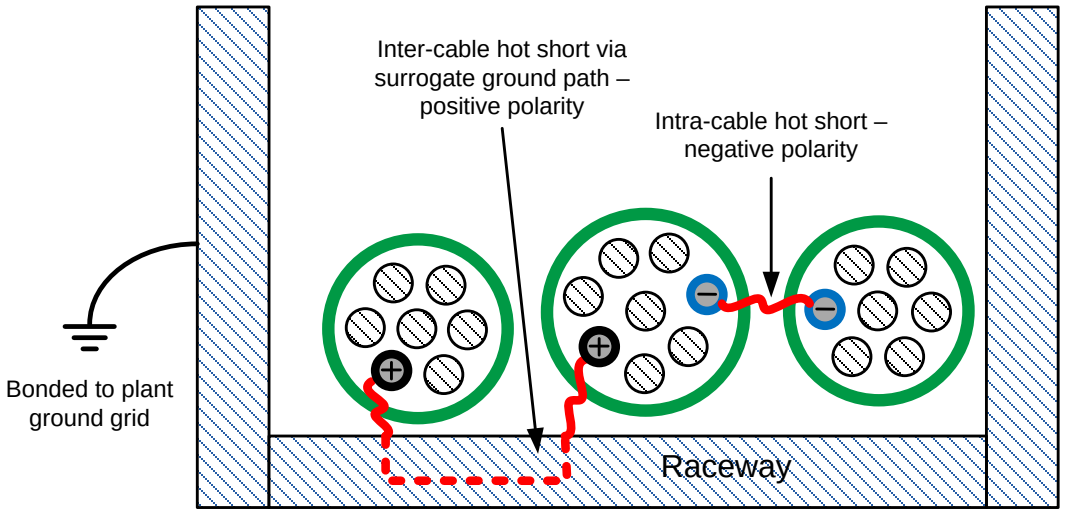
CASE 3A:
Proper polarity hot shorts are the result of two independent inter-cable shorts involving the proper polarity. The inter-cable shorts do not need to be between the same cables.

Proper Polarity Hot Short – Intra / GFE



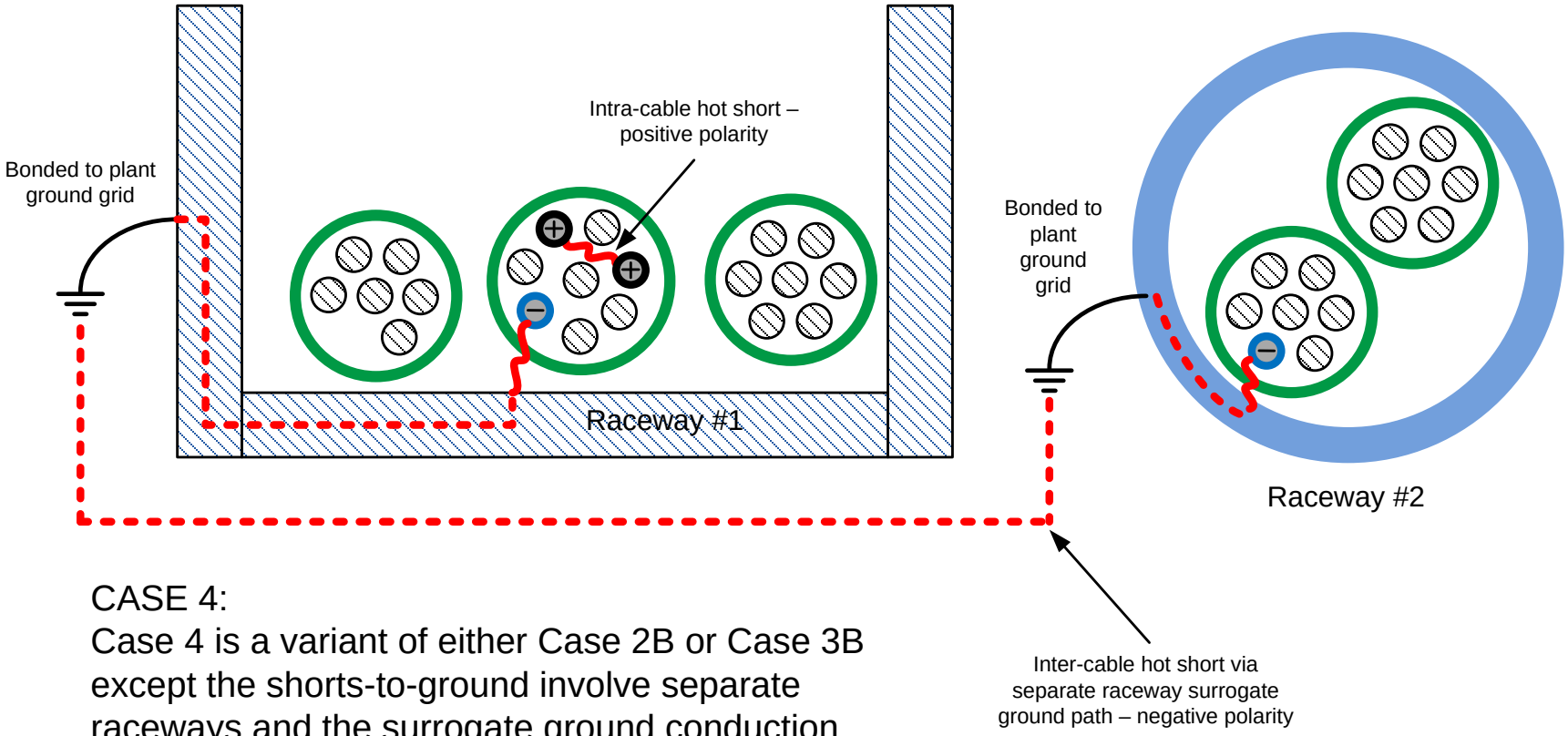
CASE 2B:
Proper polarity hot shorts are the result of one intra-cable short and one inter-cable short. The inter-cable short is caused by two conductors of the same polarity shorting to the raceway with the raceway then serving as a surrogate conduction path.

Proper Polarity Hot Short – Inter / GFE



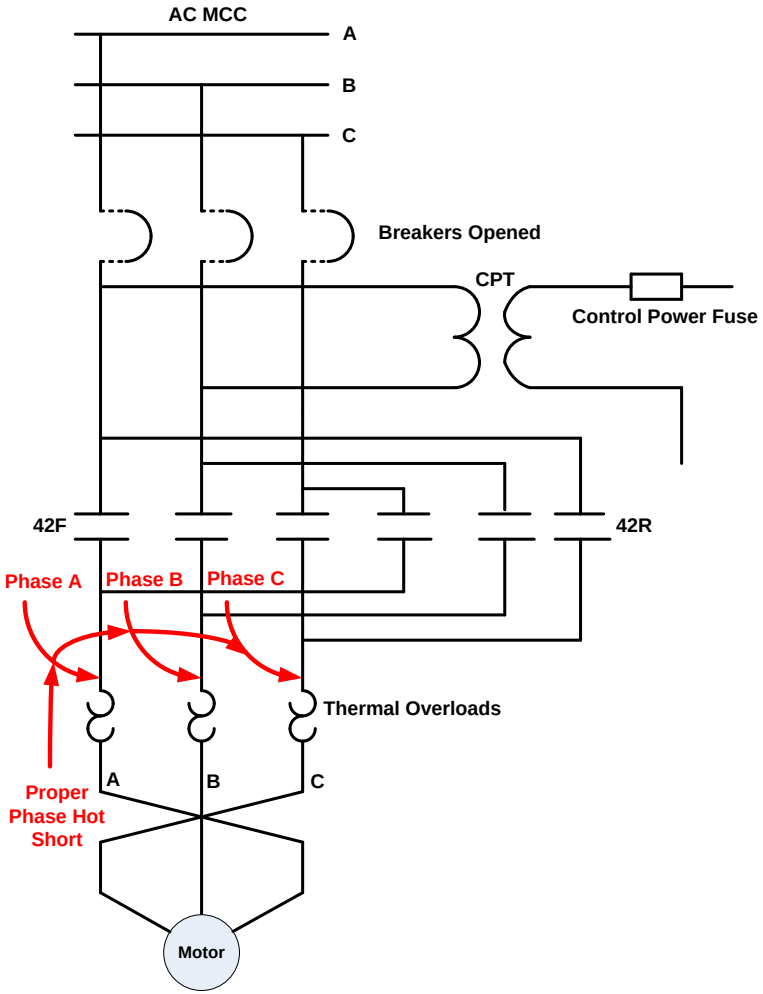
CASE 3B:
Proper polarity hot shorts are the result of two independent inter-cable shorts involving the proper polarity. For this case one of the two inter-cable shorts is caused by two conductors of the same polarity shorting to the raceway with the raceway then serving as a surrogate conduction path.

Proper Polarity Hot Short – Intra / GFE (Variation)

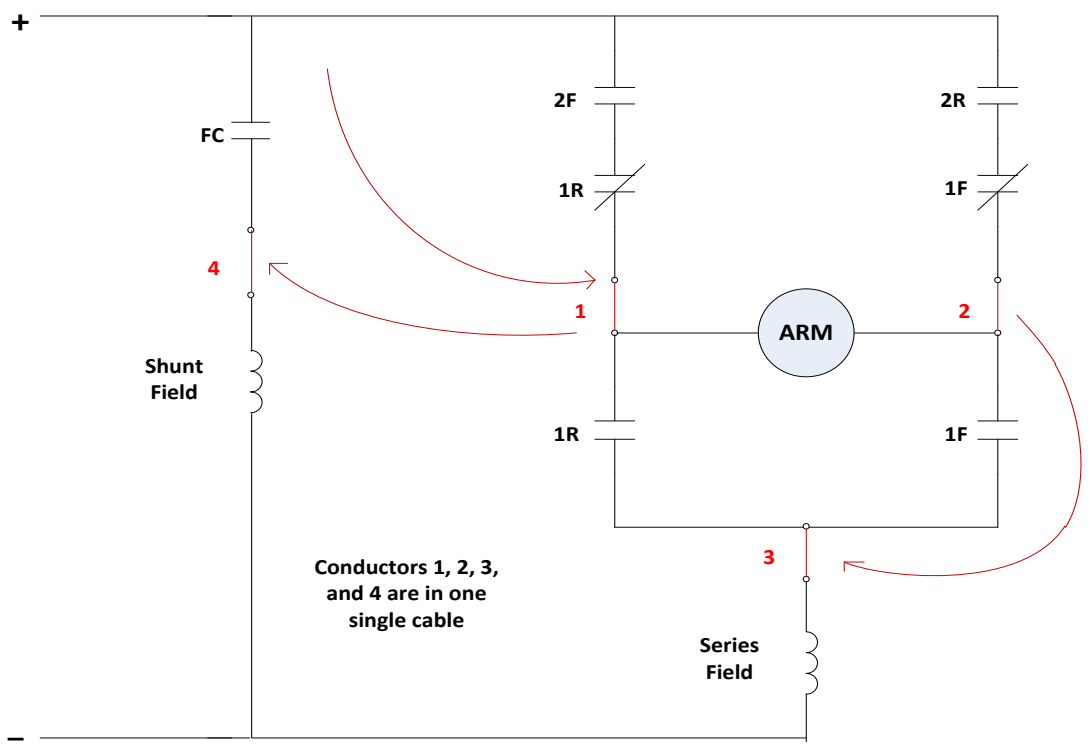


CASE 4:
Case 4 is a variant of either Case 2B or Case 3B except the shorts-to-ground involve separate raceways and the surrogate ground conduction path is via an unspecified route in the plant ground grid.

Three-Phase Proper Polarity Hot Short

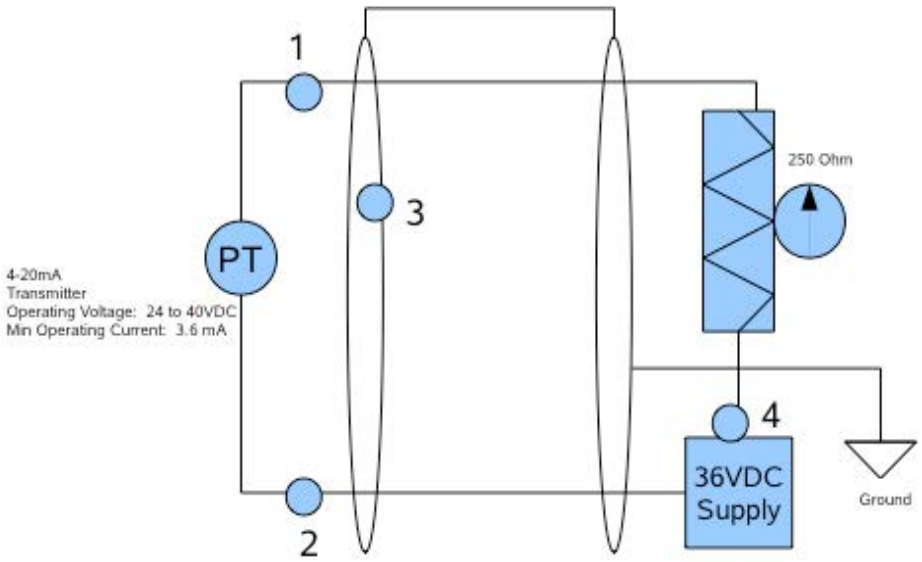


DC Compound Motor Proper Phase Hot Short



Instrument Loop Short Circuit

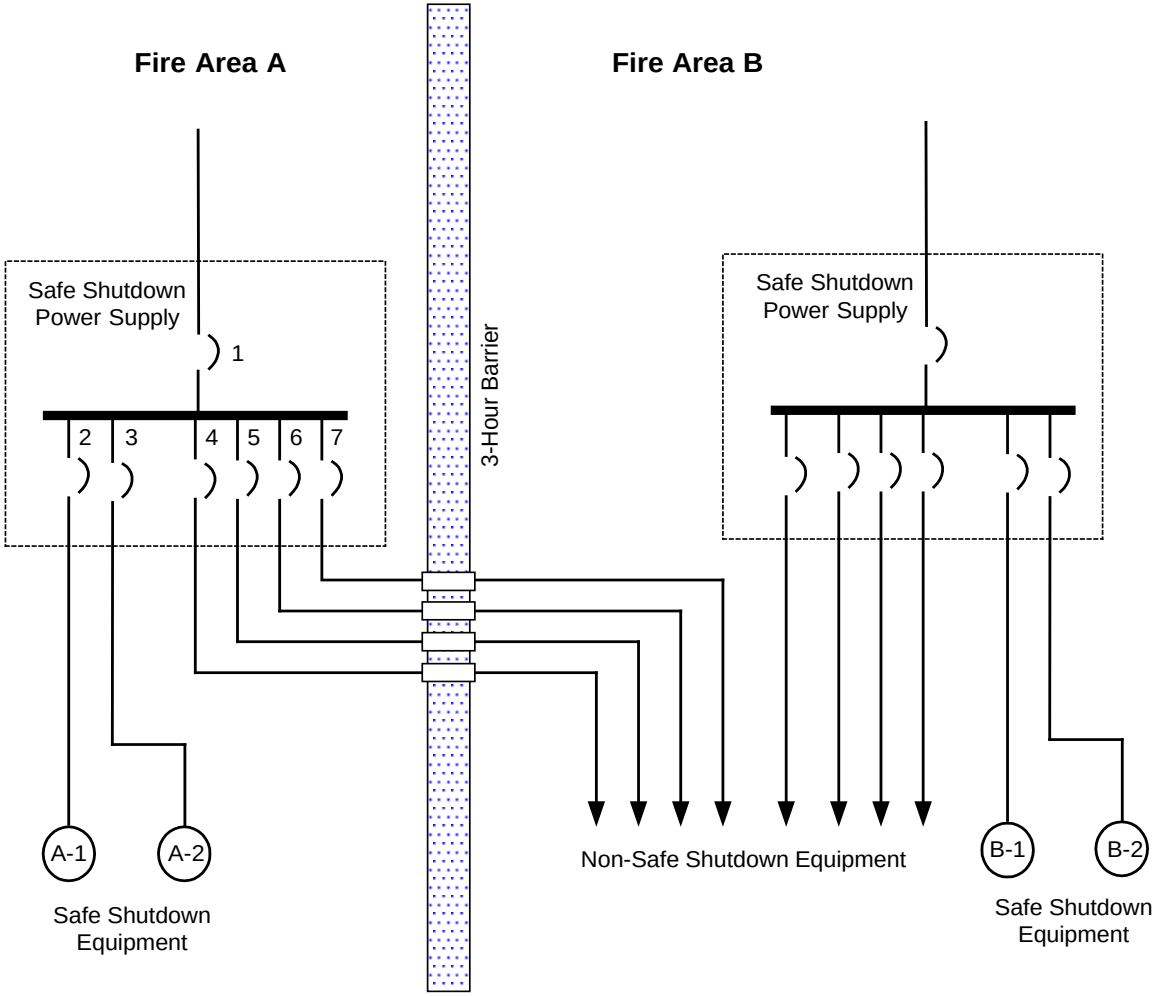
Typical 2-Wire Input Control Loop
- PT modulates loop current
- Input device has a 250 Ohm resistor to convert 4-20mA signal to 1 to 5 VDC.



Short between 1 and 2 would remove could cause current passing through input device to vary between 4mA and ~ 144mA depending upon the output of the transmitter and the quality of the short.

Short between any other points could cause current passing through input device to vary between 0mA and <20mA. depending upon the output of the transmitter and the quality of the short. Exception: Points 3 and 4 are at the same potential with respect to ground.

Multiple High Impedance Faults (MHIFs)



Open Circuit Current Transformer

- BNL conducted CT Open Circuit Testing
- Test results are documented in NUREG/CR-7228 (no failures)
- NUREG/CR-7150, Vol. 3 provides new technical position on open circuit CTs

These conclusions lead to the following recommendation by the working group.

Given the absence of secondary fires or any other fire precursor and the unique combination of low probability events needed for its occurrence; the working group concluded that secondary fires resulting from open circuited CT installations up to and including 15kV primary circuit voltage are incredible. On this basis, the working group recommends no further consideration of secondary fires as a result of CT failures for low and medium voltage switchgear (up to and including 15kV).

This recommendation represents a consensus opinion among the working group members. The recommendation is consistent with the technical discussions and operating experience documented in the PIRT Report, but eliminates the original 1200:5 turns ratio limitation contained in the PIRT Report. This recommendation applies to *CTs used in low voltage and medium voltage switchgear*. This recommendation does not apply to high ratio pedestal-style CTs used in high voltage switchyards or transmission systems.

CABLE AND CIRCUIT FAILURE MODES

High Ranked Parameters for Spurious Operation

- Cable Routing/Raceway – panel wiring
- Cable Raceway Fill – bundles (Note: PIRT panel considered important even though it is ranked medium)
- Conductor Insulation Material [for inter-cable hot shorts (thermoset (TS) versus thermoplastic (TP))]
- Cable Grounding Configuration – ac only (e.g., ground or drain wire, shield wrap)
- Armor Grounded versus Ungrounded Circuit (for ac) and Armored versus Unarmored (for dc)
- Cable Wiring Configuration (number of sources, target, ground/neutral and their locations)
- Grounded versus Ungrounded Circuits for ac only (for inter-cable hot shorts)

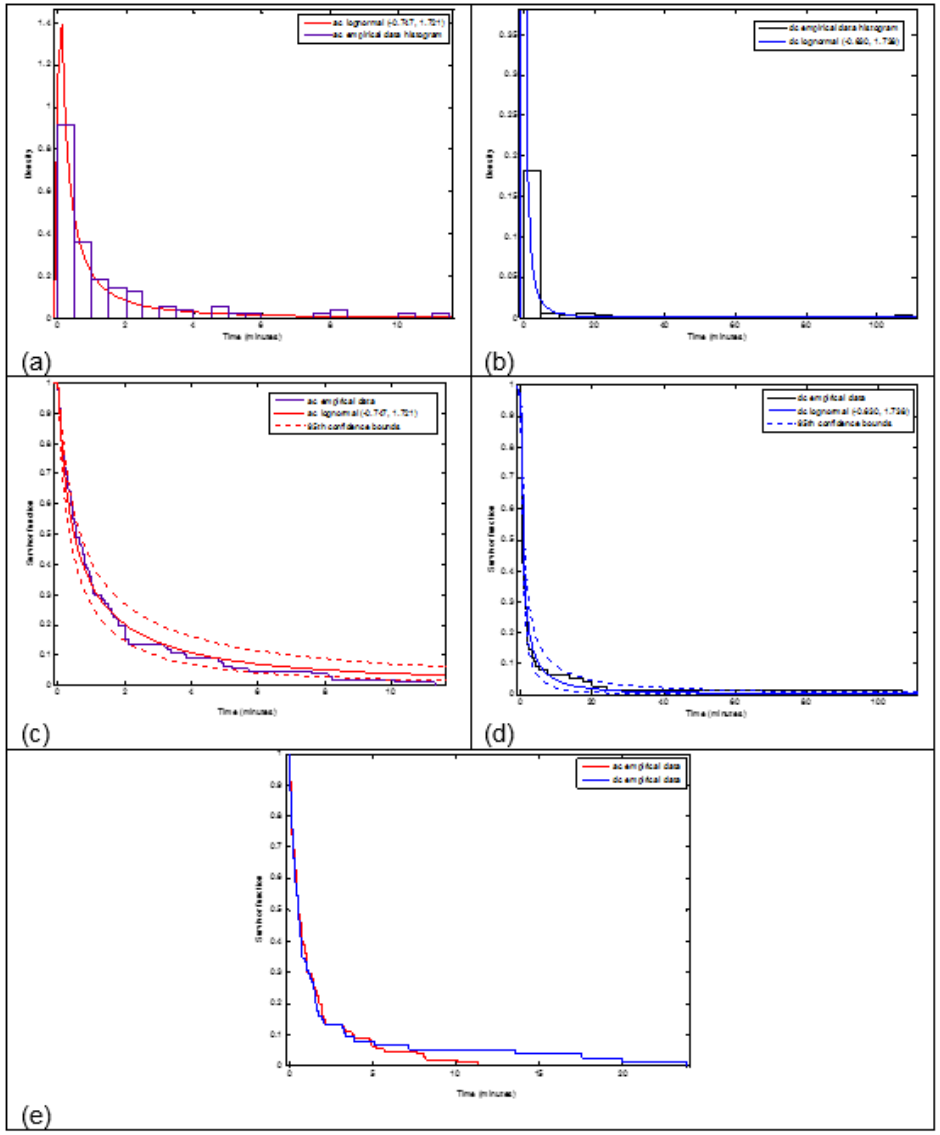
CABLE AND CIRCUIT FAILURE MODES

High Ranked Parameters for Spurious Duration

- Fire Exposure Condition
- Cable Routing/Raceway – panel wiring
- Cable Raceway Fill – bundles (Note: PIRT panel considered important even though it is ranked medium)
- Time-Current Characteristics – fuses/breaker size
- Cable Wiring Configuration (number of sources, targets, ground/neutrals and their locations)
- Latching versus Non-latching devices (e.g., motor operated valves)

CABLE AND CIRCUIT FAILURE MODES

Duration



Duration of hot-shorts and spurious operations will be discussed under Task 10 Presentation

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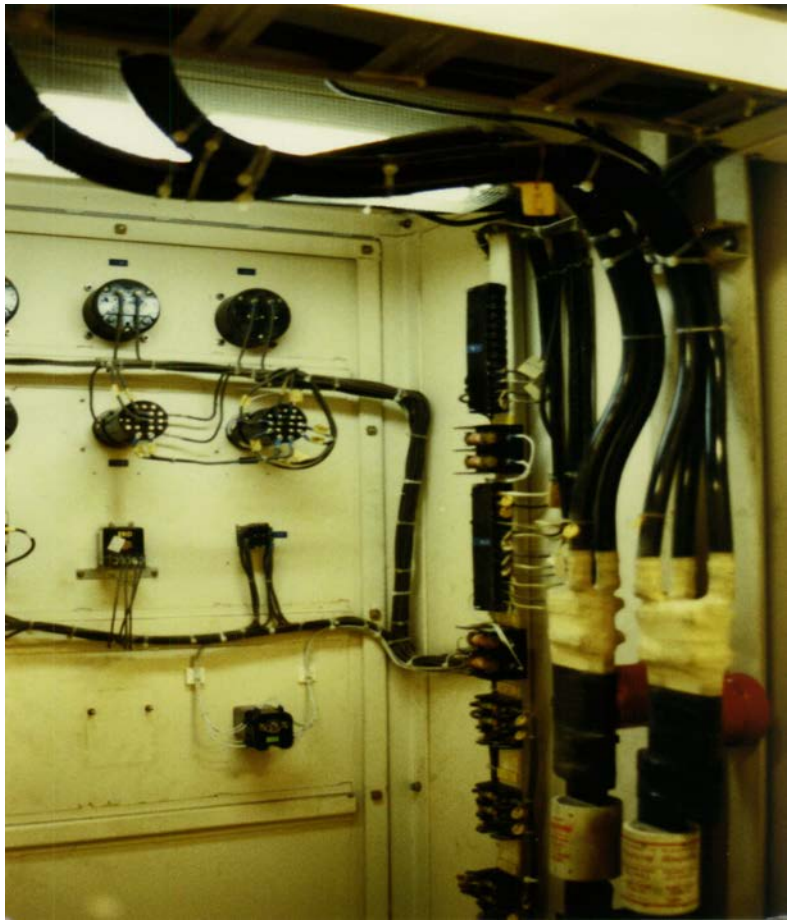
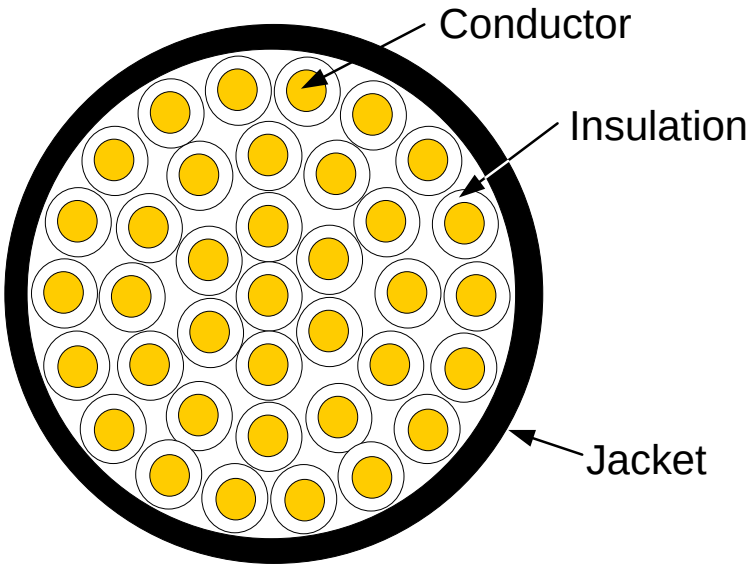
Panel Wiring

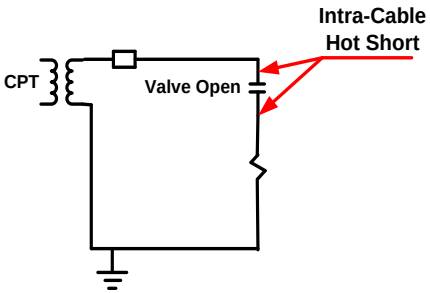


Trunk Cables

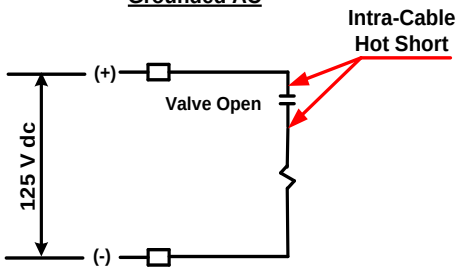


Single Break Control Circuit

Intra-Cable Hot Short

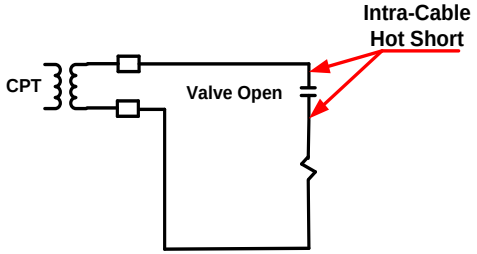


Grounded AC

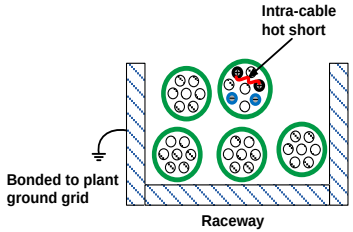


Ungrounded DC

[or 120 V ac Distribution System]



Ungrounded AC



Physical Configuration

Notes:

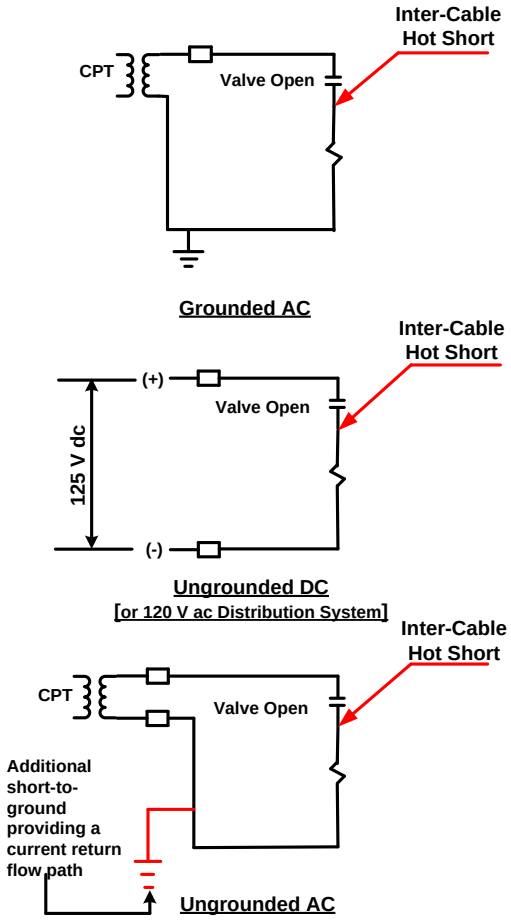
1. Component is energize to open.
2. A fire-induced intra-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the intra-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will close when the intra-cable hot short is eliminated, e.g., goes to ground.
   c. If power is lost to the target control circuit prior to device actuation by blowing the control power fuses or by a failure of the power supply to the fuses, the component will not open regardless of whether or not it is a latching or non-latching circuit.
3. The behavior described on this drawing is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 2.

Case 1 – Single Contact Intra-Cable Hot Short-Induced Spurious Operation

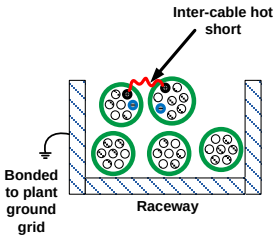
Simplified Schematic Configuration – Single Break Control Circuit

Single Break Control Circuit

Inter-Cable Hot Short



Simplified Schematic Configuration – Single Break Control Circuit



Physical Configuration

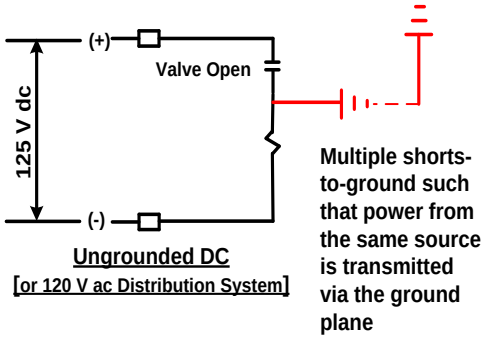
Notes:

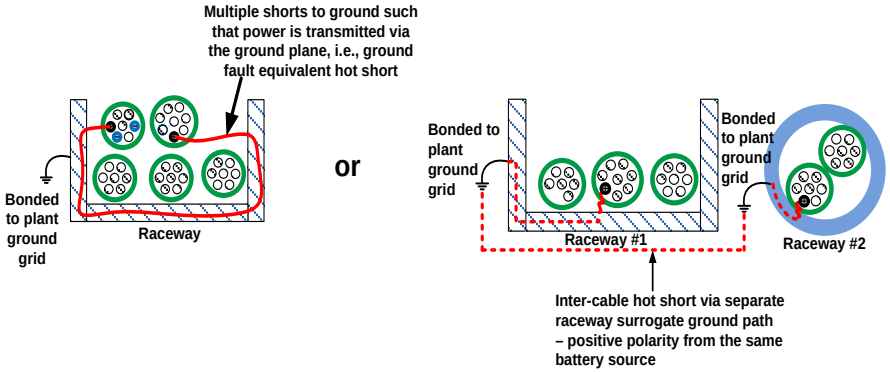
1. Component is energize to open.
2. A fire-induced inter-cable hot short will open the component.
   a. If the component is a latching circuit, the component will remain open even if the inter-cable hot short is eliminated, e.g., goes to ground.
   b. If the component is a non-latching circuit, the component will close when the inter-cable hot short is eliminated, e.g., goes to ground.
   c. If power is lost to the control circuit by blowing the control power fuses on the aggressor circuit or by a failure of the power supply to the fuses in either the primary or aggressor circuit, the component will close regardless of whether or not it is a latching or non-latching circuit.
3. For the case of the ungrounded DC or ungrounded distributed AC circuit, the inter-cable hot short must come from the same battery or power source. This is required since an inter-cable hot short from a different battery or power source will not have a current return flow path.
4. For the case of the ungrounded AC circuit power from a CPT, the inter-cable hot short must be accompanied by a short to ground on the return leg of the circuit providing a current return flow path to the power source of the aggressor circuit that is grounded. If the aggressor circuit is an ungrounded AC source off of a CPT, the aggressor circuit will also require a ground on the return leg to complete the circuit and cause the spurious operation.
5. For the case of the grounded AC circuit powered from a CPT, if the aggressor circuit is an ungrounded AC source off of a CPT, the aggressor circuit will also require a ground on the return leg to complete the circuit and cause the spurious operation.

Case 2 – Single Contact Inter-Cable Hot Short-Induced Spurious Operation

Single Break Control Circuit

Ground Equivalent Hot Short





Simplified Schematic Configuration – Single Break Control Circuit

Physical Configuration

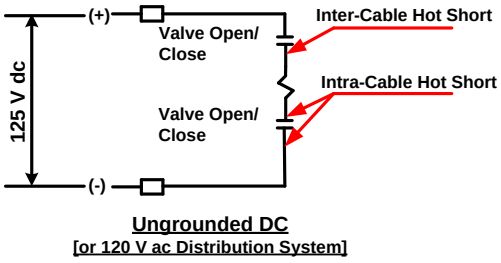
Notes:

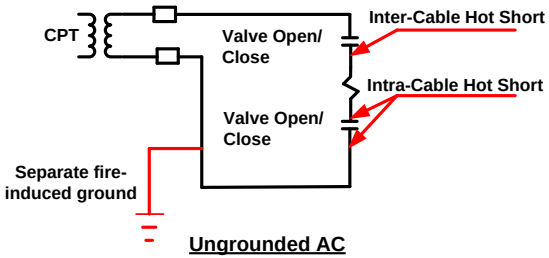
1. Component is energize to open.
2. A fire-induced hot short can open the component.
   a. If the component is a latching circuit, the component can remain open even if the hot short is eliminated.
   b. If the component is a non-latching circuit, the component will close when the hot short is eliminated.
   c. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will close regardless of whether or not it is a latching or non-latching circuit.
3. For the case of the ungrounded DC or an ungrounded AC distribution system circuit, the ground equivalent hot short hot short must come from the same battery source. This is required since a ground fault equivalent hot short from a different battery source will not have a current return flow path.

Case 3 – Single Contact Inter-Cable Hot Short-Induced Spurious Operation Via A Ground Plane Interaction From Cables In The Same Or Different Raceway

Double Break Control Circuit

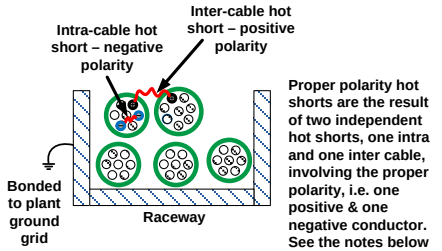
Intra-Cable and Inter-Cable Hot Short





Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.



Physical Configuration

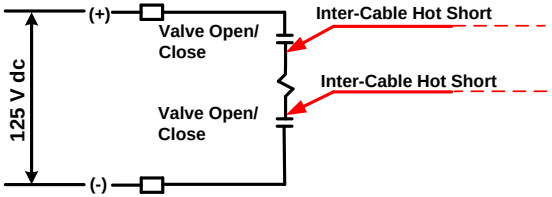
Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced inter-cable plus an intra-cable hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or the ungrounded AC distribution system circuit, the inter-cable hot short must come from the same battery or power source. This is required since an inter-cable hot short from a different battery or power source will not have a current return flow path.
4. For the case of the ungrounded AC circuit powered from a CPT, the inter-cable hot short must come from a separate and compatible ac source. If the aggressor circuit is an ungrounded AC circuit powered from a CPT, the aggressor circuit must also experience a fire-induced ground on its return leg to provide a ground path for the return current. Additionally the target circuit must also be accompanied by a fire-induced short to ground on its return leg providing a current return flow path. In summary, for the case of an ungrounded AC circuit powered from a CPT attacked by another ungrounded AC circuit powered from a CPT, for the spurious operation to occur, a third fire-induced circuit failure, i.e., a ground equivalent hot short, must occur.
5. The behavior described on this drawing for the intra-cable hot short is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 5.

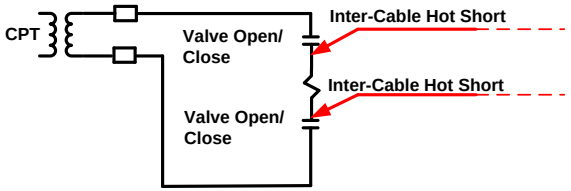
Case 4 – Double Break - One Intra and One Inter-Cable Hot Short-Induced Spurious Operation

Double Break Control Circuit

Two Inter-Cable Hot Shorts



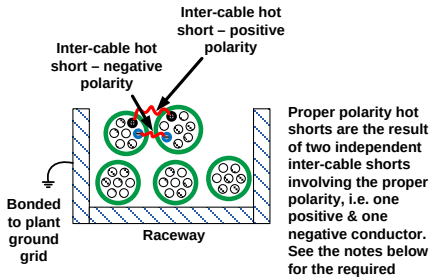
Ungrounded DC
[or 120 V ac Distribution System]



Ungrounded AC

Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.



Proper polarity hot shorts are the result of two independent inter-cable shorts involving the proper polarity, i.e. one positive & one negative conductor. See the notes below for the required characteristics of the hot shorts.

Physical Configuration

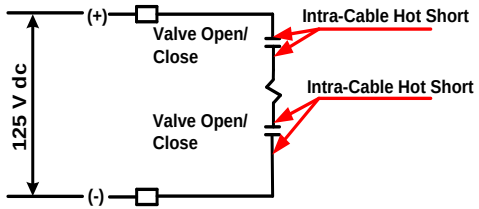
Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced inter-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the solenoid will de-energize and the affected component will return to its original position.
   b. If power is lost to the target control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will remain energized since the hot shorts are powered from a separate aggressor circuit.
   c. If power is lost to the circuit for the aggressor cables, the component will de-energize and the affected component will return to its original position.
4. For all cases aggressor cables must be from a compatible source, i.e., a common source providing both the positive (or hot) and negative (or neutral, i.e., return) legs so that the current will have a flow path to the same power source.
5. For the ungrounded AC case, if the aggressor circuit is a grounded AC circuit with a CPT, then a single ground on the underside of the coil is sufficient to cause a spurious operation. Both the inter-cable hot short and GFEHS are from the grounded AC circuit CPT power source.

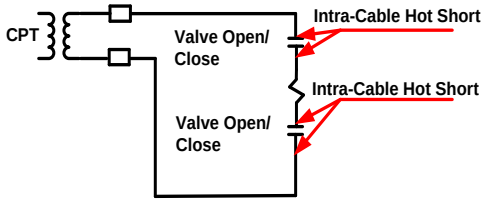
Case 5 – Double Break – Two Inter-Cable Hot Shorts-Induced Spurious Operation

Double Break Control Circuit

Two Intra-Cable Hot Shorts



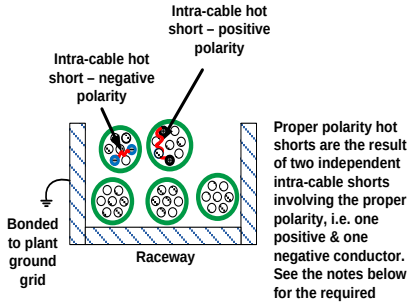
Ungrounded DC
[or 120 V ac Distribution System]



Ungrounded AC

Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.



Physical Configuration

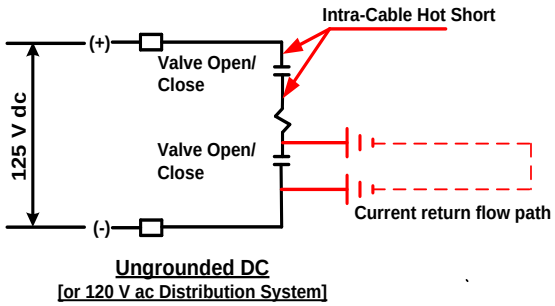
Notes:

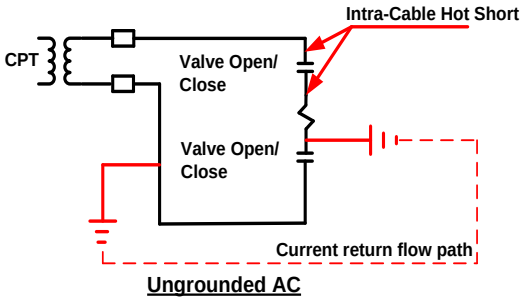
1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. Two fire-induced intra-cable hot shorts will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
4. The behavior described on this drawing is typical of intra-cable hot shorts from conductors within the same circuit. If the intra-cable hot shorts are from conductors in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 5.

Case 6 – Double Break – Two Intra-Cable Hot Shorts-Induced Spurious Operation

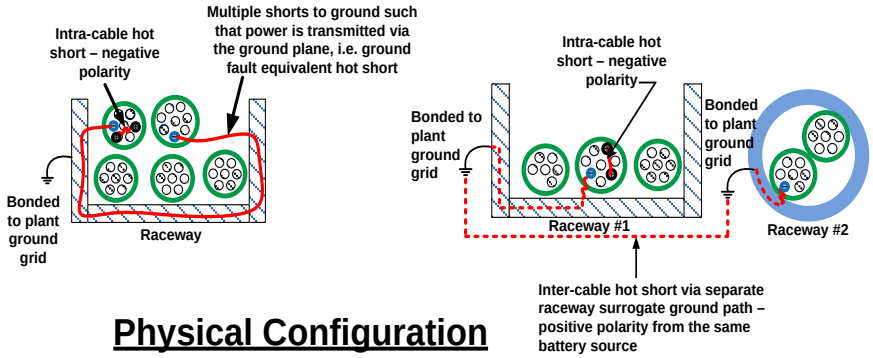
Double Break Control Circuit

Intra-Cable and GFE Hot Shorts





Schematic Configuration – Double Break Control Circuit



Physical Configuration

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

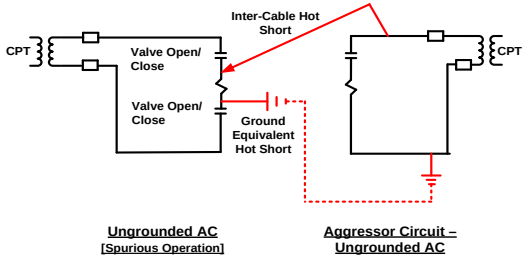
Notes:

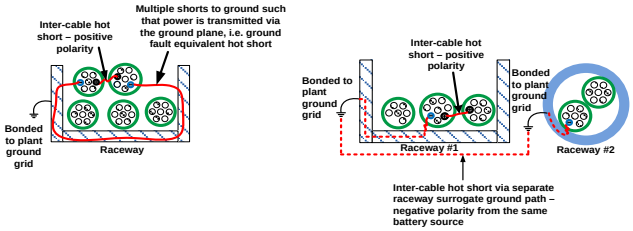
1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. The double break design requires two hot shorts to energize the component.
3. A fire-induced intra-cable plus a ground equivalent hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses or by a failure of the power supply to the fuses, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or an AC ungrounded distribution system circuit, the ground equivalent hot short must include a ground on the negative (or return) leg of a circuit from the same battery source. This is required since a ground equivalent hot short from a different battery (or power) source will not have a current return flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
4. For the case of the ungrounded AC circuit powered from a CPT, the ground equivalent hot short must include a short to ground on the negative leg of the ungrounded AC circuit providing a current return flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
5. The behavior described on this drawing is typical of an intra-cable hot short from a conductor within the same circuit. If the intra-cable hot short is from a conductor in the same cable, but from a different circuit, the behavior will be governed more by the characteristics described for the inter-cable hot short in Case 8.

Case 7 – Double Break – Intra and Ground Fault Equivalent Hot Short-Induced Spurious Operation

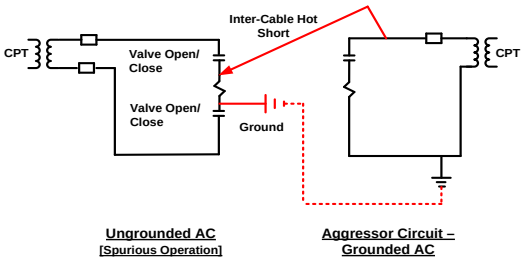
Double Break Control Circuit

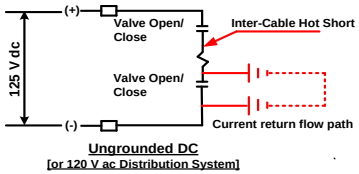
Inter-Cable and GFE Hot Shorts





Physical Configuration





Notes:

1. The component is energized to either open or close a respective valve. In this example, when the component is de-energized, the valve will return to its original position.
2. Except as noted below, the double break design requires two hot shorts to energize the component.
3. Except as noted below, a fire-induced inter-cable plus a ground equivalent hot short will energize the component.
   a. If either hot short is eliminated, the component will de-energize and the affected component will return to its original position.
   b. If power is lost to the control circuit by blowing the control power fuses on the aggressor circuit or by a failure of the power supply to the fuses on the aggressor circuit, the component will de-energize and the affected component will return to its original position.
3. For the case of the ungrounded DC or an ungrounded AC distribution system circuit, the inter-cable hot short and the negative (or return) leg of the ground equivalent hot short must come from the same battery (or power) source. This is required since hot shorts from a different battery (or power) source will not have a current flow path. The orientation of the two types of hot shorts, i.e., either above or below the coil, has no impact on the spurious operation of this circuit.
4. For the case of the ungrounded AC circuit powered from a CPT, the aggressor circuit can be either a grounded or an ungrounded AC circuit. In either case, the inter-cable and return leg of the ground equivalent hot short must be from the same AC circuit powered from the same CPT. This assures the availability of a current flow path through the aggressor circuit. If the aggressor circuit is a grounded AC circuit, then all that is required is a ground below the solenoid, since the ground in the aggressor circuit will provide the current flow path.

Schematic Configuration – Double Break Control Circuit

Note: The examples in this figure show one proper polarity alignment that could result in a spurious operation. Refer to the section of this NUREG/CR Report that describes Proper Polarity to understand those additional proper polarity alignments that may also apply.

Case 8 – Double Break – Inter and Ground Fault Equivalent Hot Short-Induced Spurious Operation

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CABLE AND CIRCUIT FAILURE MODES

QUESTIONS ??