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RELAY TRIP CIRCUIT DESIGN

A Special Publication

by the

IEEE Power System Relaying Committee

Relay Trip Circuit Design Working Group

TABLE OF CONTENTS

Relay Trip Circuit Design

Foreword

This IEEE Special Publication has been prepared by the Relay Trip Circuit Design Working Group of the Power System Relaying Committee. Its purpose is to document and share information about the practices of electric utilities in the design of protective relay tripping circuits and associated control and protective functions. This information has not been widely disseminated before and the Working Group hopes that its publication may help to encourage uniformity as well as help others avoid the snares and pitfalls which have been found through hard experience.

This document is not a recommended practice or a design guide. Trip circuit design has evolved over many years in many different utilities and their practices vary widely. The designs of individual utilities are very much influenced by their individual operating practices and past experiences. In those areas where the Working Group was not in consensus about a particular practice, we have attempted to present both viewpoints by listing the advantages and disadvantages of a particular scheme or approach. The reader must then decide which approach is best for his or her application.

The practices described herein have evolved largely in an environment of individual component relays in which the functions of measurement, timing, communication, and tripping have been performed by separate units connected together in a customized configuration by the utility or the protection system supplier. The increasing acceptance of digital, integrated relays will alleviate many of the system integration problems which are described by this document. However, since these new digital devices themselves require auxiliary power, contain surge protection devices, and must be integrated into existing systems, the information presented here should be of continuing interest.

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1. SUBSTATION DC SYSTEMS

The principal purpose of the station dc system is to provide a reliable source of auxiliary power for the station's control and protection functions. The dc system consists of one or two storage batteries and associated charger(s) and a dc distribution panel at which the dc feeders originate. The dc panel may use either fuses or circuit breakers.

The principal loads on the dc system are the station's power circuit breakers and, increasingly, the power supplies of electronic relays and communication apparatus. Dc feeders can be assigned to these loads in various logical arrangements, ranging from only a few feeders, each supplying a number of loads, to an individual feeder for each load. The design objectives are,

- Provide a level of redundancy which is consistent with the redundancy of the rest of the protective system, e.g. if the station has redundant relaying or the breakers have redundant trip coils, a single failure of a dc feeder should not disable the protection.
- Arrange the feeders in a logical and consistent pattern so that the effects of a dc feeder outage will be readily apparent to operating and maintenance personnel. Avoid connecting a load from the positive pole of one feeder to the negative pole of another.
- Provide a sufficient number of feeders that at least one can be switched out for maintenance purposes without critically affecting the integrity of the system protection.
- Keep currents and voltage drops in the dc system to within acceptable values.
- Accomplish the above objectives at minimum cost.

Fuses and molded case circuit breakers used for trip circuit protection should be rated for dc operation. The rated voltage should be greater than the equalizing voltage of the battery charger. The current rating should be adequate to carry the continuous load and any momentary surges during high voltage breaker operation. The interrupting rating must exceed the maximum short circuit duty.

DC DISTRIBUTION SYSTEMS

Feeder-per-breaker Scheme

One of the most widely used dc distribution schemes is the feeder-per-breaker scheme shown in Figure 1.1. In this scheme, an individual dc feeder originates at the dc panel for each switchyard breaker. This feeder supplies tripping, closing, and dc auxiliary power for its assigned breaker. In a simple configuration with only one circuit breaker, one relay system, and one trip coil per line, the breaker dc feeder also supplies power to any auxiliary tripping relays or relay power supply. This is shown as +AUX- on Figure 1.1. If the circuit breakers

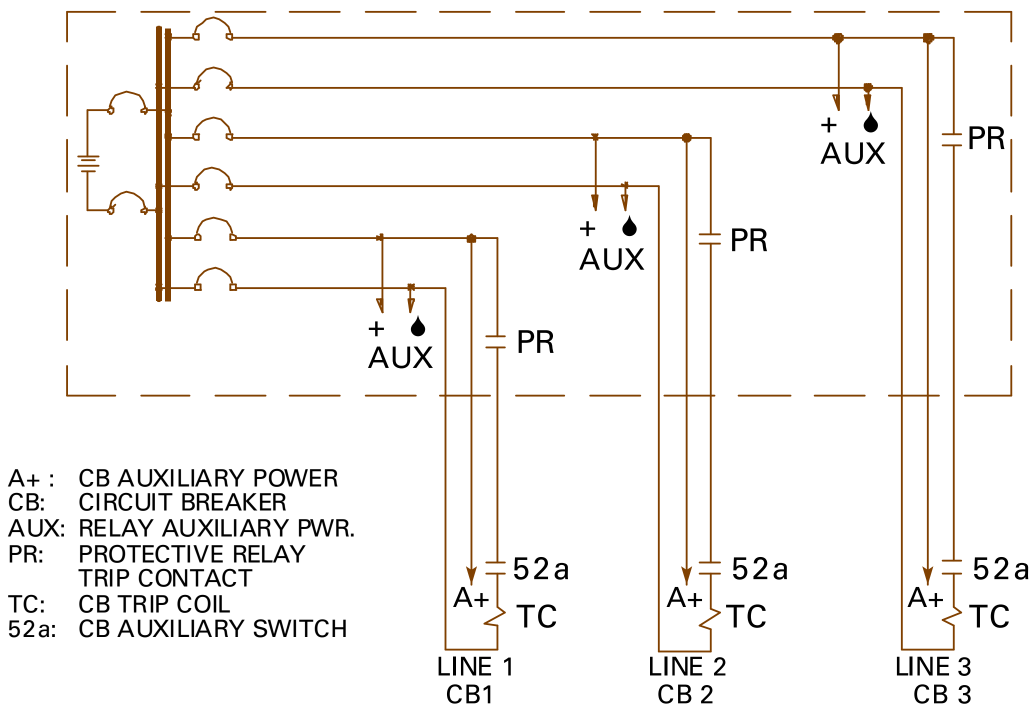

Figure 1.1 - Basic Feeder-per-Breaker Scheme

have redundant trip coils, then another feeder connects the second trip coil and the arrangement becomes two-feeders-per-breaker.

When the bus configuration has more than one breaker per element (line, transformer, etc.), the relay power is usually taken from a "relay" feeder or "switchboard" feeder rather than one of the breaker feeders. This allows the breaker feeder to be de-energized, provided the associated breaker is open, without impairing the protection. Figure 1.2 shows the feeder-per-breaker scheme with auxiliary power for the relays taken from a separate relay feeder. This arrangement is also used with any relays which trip several breakers, such as bus differential protection. Practices vary as to how many relay feeders are used in a station. At one extreme, one feeder per relay system (each line relay, each bus protection, each transformer protection, etc.) might be used. At the other extreme, numerous relay systems might be supplied from a single tapped feeder, often with fusing to isolate failed relay systems from the main feeder. A typical minimum might be four such "relay" feeders in a station, two each for the high and low voltage levels of the station, with redundant relays for each voltage level divided up between the two feeders.

Tapped-Feeder Scheme

Another method of dc distribution is the tapped feeder or tapped bus scheme. In simplified form, this arrangement is shown in Figure 1.3. For a single-breaker-per-element station,

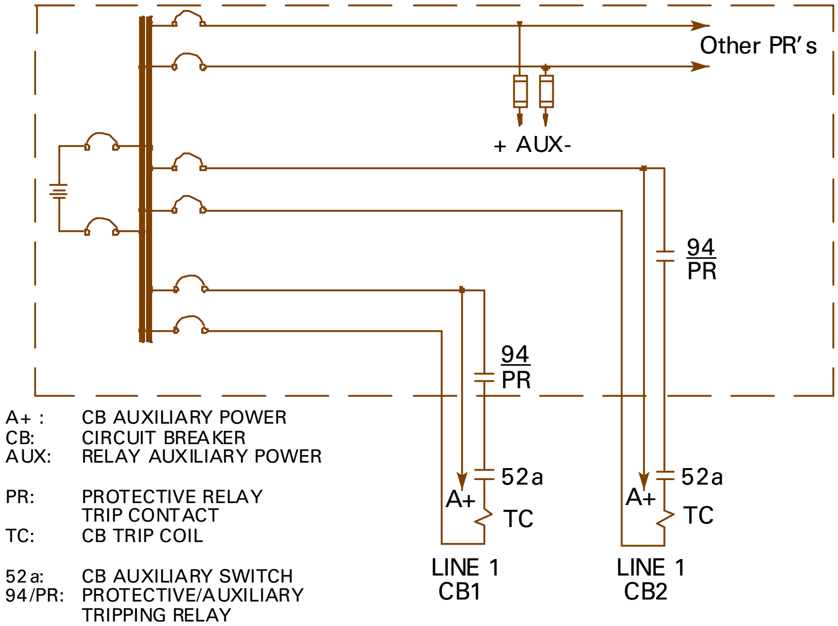

Figure 1.2
Feeder-per-Breaker Scheme, Two Breakers per line with Tapped Feeder

without duplicate trip coils, only one feeder is necessary, though more would usually be used to meet maintenance needs. This feeder runs from the dc panel to each of the switchboard

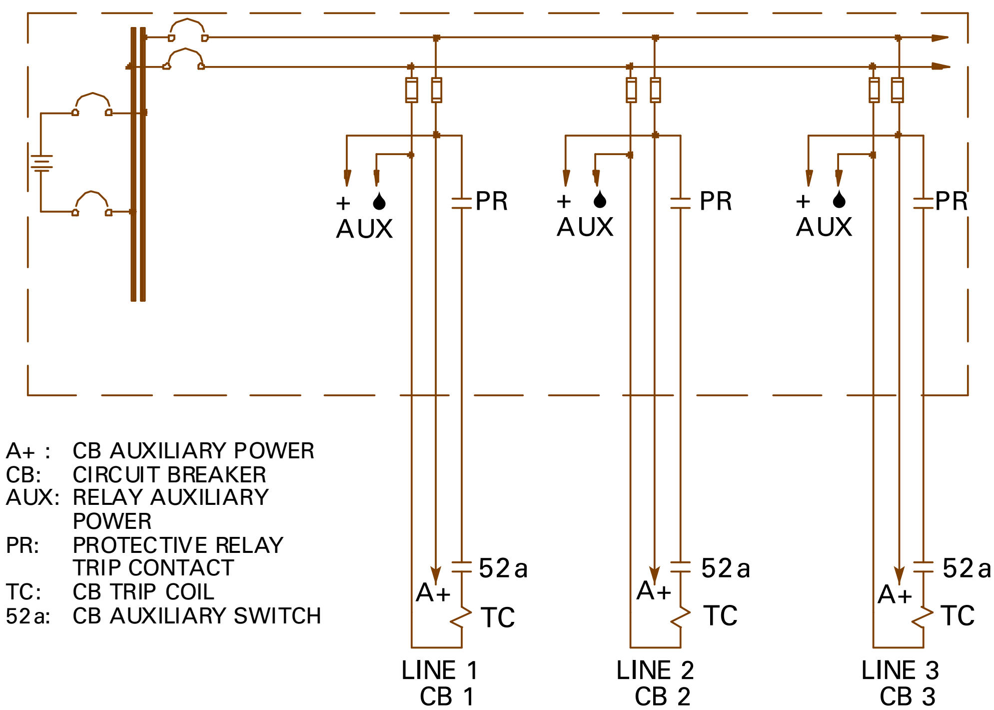

Figure 1.3 - Tapped Feeder (Bus) Scheme

panels, or switchgear cubicles, in turn and is tapped, often with fuse protection at each tap. The feeder can also be in the form of a dc bus running behind the switchboard panels.

The tapped-feeder scheme, with fused taps, is not fundamentally different from the feeder-per-breaker scheme. The difference is in whether the breaker feeders originate at the dc panel or at the taps on the switchboard bus. Figure 1.4 shows the tapped feeder arrangement with a relay feeder for relays which trip more than one breaker per relay.

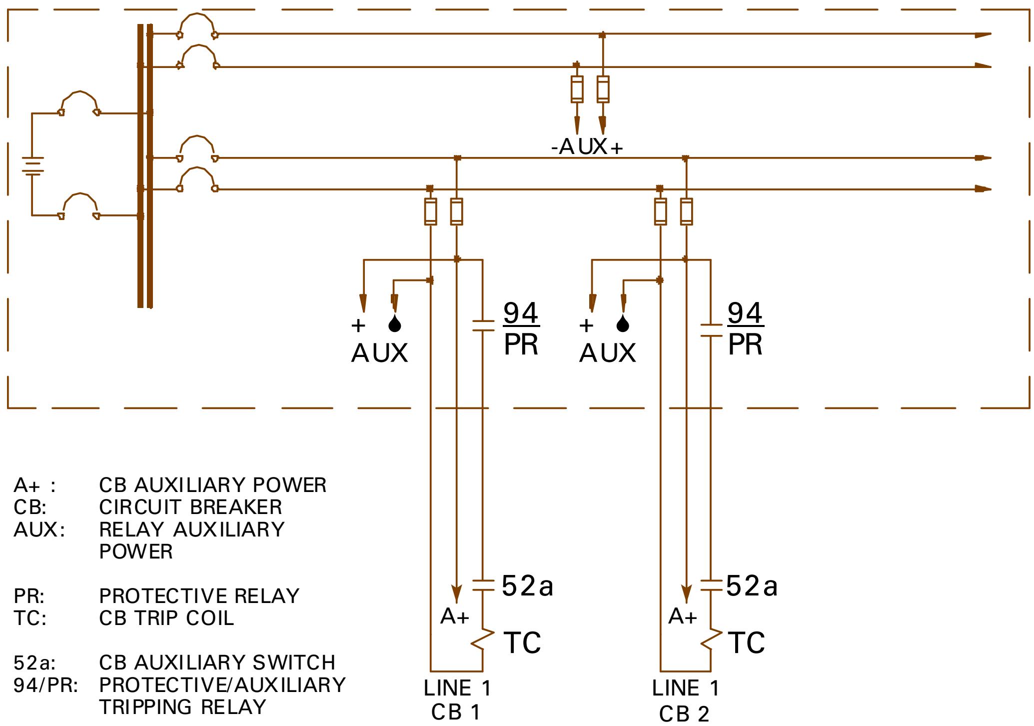

Figure 1.4
Tapped Feeder Scheme, Two Breakers per Line with Tapped Relay Feeder

A single tapped-feeder (bus) for all breakers would only be suitable for a very small station. In a larger station, several buses would be provided, divided between breakers in some logical pattern. When duplicate trip coils, duplicate batteries, or redundant relays are used, additional buses would be used to eliminate the possibility that an outage of one dc bus could prevent necessary tripping.

The detailed design of the relay and control circuit protection will usually depend upon the high voltage bus arrangement and the configuration of the trip circuits. For a single-bus-single-breaker arrangement, the primary and backup relaying will usually directly operate the trip coils, and a single branch fuse for each will protect both the relay system and breaker trip coil, as illustrated in Figure 1.5.

Where the protective relays are required to trip two breakers, such as in a ring bus, auxiliary tripping relays are usually employed. In this case, it is preferable to isolate the relaying from the trip coils as shown in Figure 1.6.

The circuit configurations shown in Figures 1.5 and 1.6 provide an economical means of isolating circuits so that a single failure will not result in the loss of both trip coils of a circuit breaker or both primary and backup relay systems.

The disadvantages of these circuits are the uncertainties in coordinating the molded case feeder breaker with the branch fuses (where used) and the loss of several relay and control circuits for a feeder fault. As a result, some utilities prefer to supply the relay system and breaker trip circuits directly from dc distribution cabinets with separate molded case breakers for each circuit, as described above for the feeder-per-breaker system. The two line relay systems and the two breaker trip coils should each be supplied from separate dc sources. The bus and breaker failure relay circuits, which are not redundant, may be served

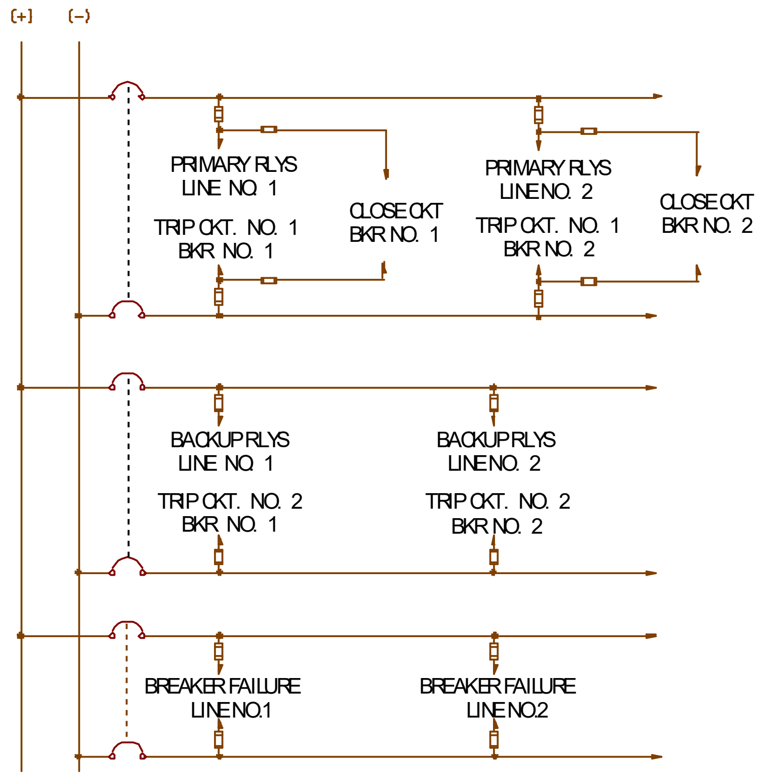

Figure 1.5

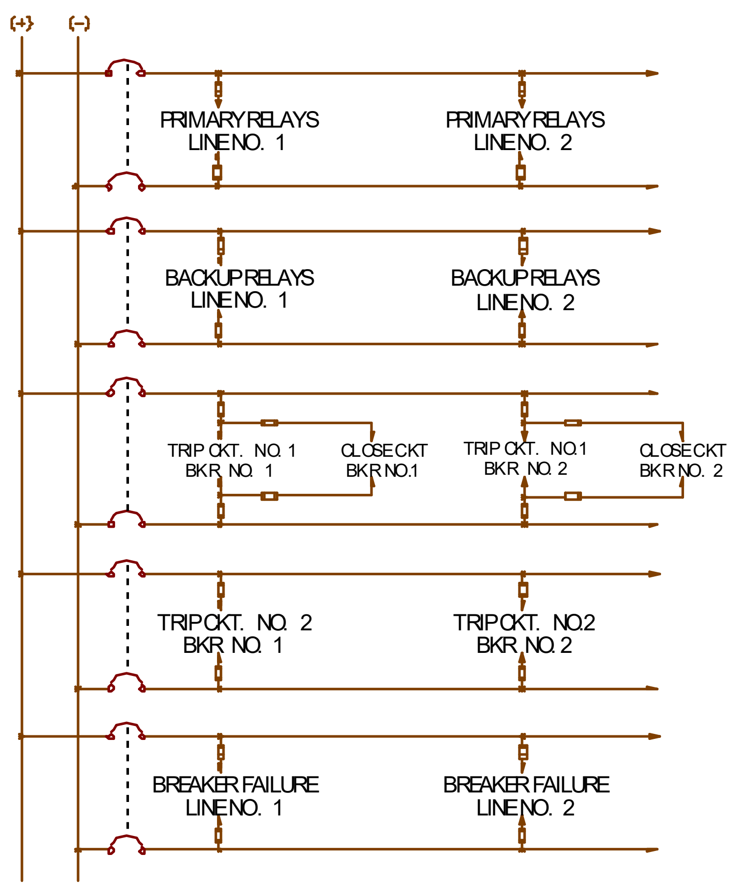

Figure 1.6

by a common dc circuit. Separate batteries should be considered for critical stations.

As a general rule, the closing circuits should be included with the trip coil protection and not fused independently. If separate fuses are employed for the close circuits, they should be located on the load side of the trip circuit protection. This ensures that at least one trip coil has control power when closing the breaker. The close circuit fuses should be coordinated with the trip circuit fuses.

Non-fused Feeder Taps

Not all utilities who use tapped feeders provide fuse protection at each of the feeder taps. Those who omit fuses on some or all of the taps reason that if the various circuit breaker and relay loads are distributed amongst several feeders, the loss of an entire feeder for a short circuit in one of the loads can be tolerated without unacceptable loss of the protection integrity.

The fused tapped-feeder scheme has the advantage of isolating each relay system fault or maintenance interruption to one system. Such disturbances thereby have no affect on the other systems. The main disadvantage of this arrangement is that it introduces a large number of fuses into the system with their associated problems of failure and monitoring. To alleviate the failure problem, high quality fuses are usually used. Some utilities use only large fuses (30 - 35 ampere), designed only to protect the cable and power source, not to protect trip coils against burn out. The monitoring problem can be handled by alarm relays or by the newer generation of protective relays that monitor themselves and would report a fuse failure.

The non-fused tapped-feeder scheme has the advantage of minimizing the number of fuses and feeders required. All primary relaying, for one primary bus, is fed from one common feeder or bus; the backup relaying is supplied from a second bus. Care should be taken to insure that no common fault will de-energize both buses. This system is only applicable when backup relaying is available. When one dc feeder is out of service, all protection supplied from that feeder is out of service. Therefore protection must be supplied by relaying connected to another dc feeder.

The feeder-per-breaker system provides the most isolation between relay systems; however complications arise when double trip coils, multiple breakers per element, or breaker failure relaying is encountered. These can be resolved by providing separate feeders for each trip circuit, each relay system, and the breaker-failure system. This method becomes cumbersome for large, complex stations. Many feeders are required and often the coordination of dc circuit breakers is required to assure that common circuits do not trip for individual component failures.

TRIP CIRCUIT ROUTING

In stations with outdoor switchyards and indoor relay panels, it is possible to route the dc circuitry in several ways. These methods may be equivalent in a schematic sense, but they can differ in important aspects such as conductor voltage drop, potential for electromagnetic interference, and cost.

Figure 1.7 shows a routing method herein called "radial", since the dc circuitry to the breakers radiates outward from the control building. Routing of the conductors is from the dc supply to the relay panels or switchboards and then on to the breakers. Positive and negative conductors are carefully routed together so that sudden changes in current, such as those from tripping a breaker, do not result in large magnetic coupling to other control and measuring conductors. (The effects of external magnetic fields tend to cancel when the "go" and "return" conductors are in close proximity.) All wires of a circuit should be contained in the same cable so that all are affected similarly by any inductive coupling.

Figure 1.8 is a variation of the radial dc system in which the dc supply is first routed to the

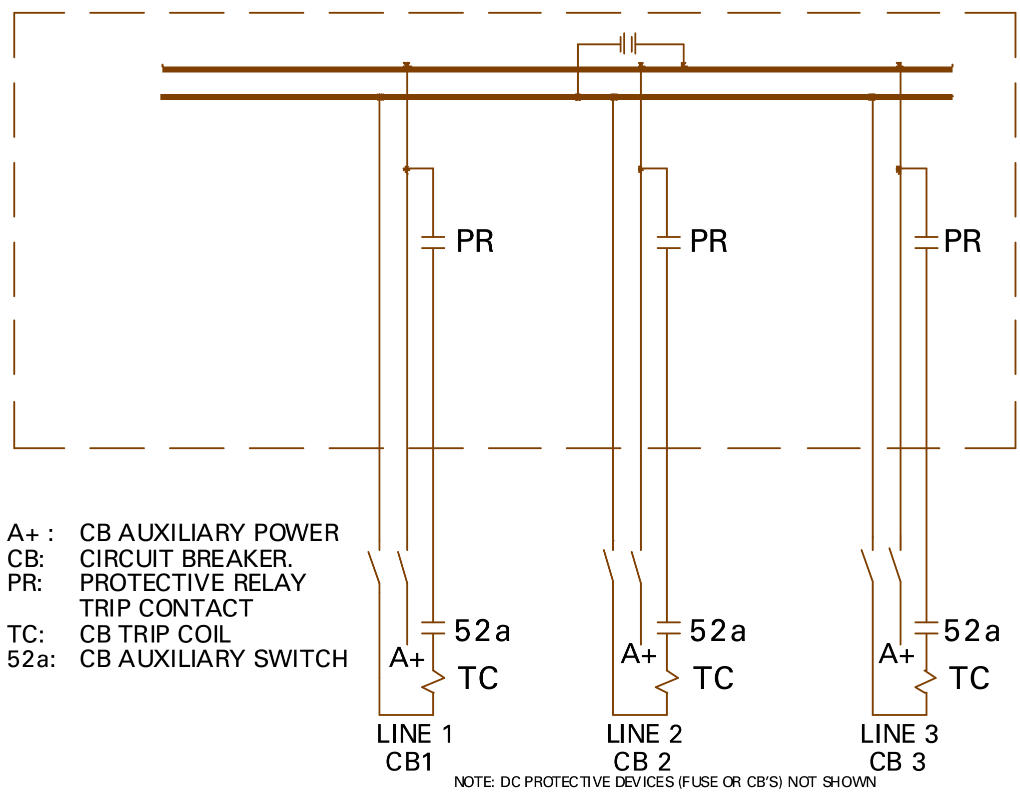

Figure 1.7 - Radial dc System

breaker and then returns to the control building for use by the relays. The advantage of this method is that the breaker dc power switch de-energizes the dc controls to the breaker. This may be important for some types of maintenance practices. However, it does not de-energize alarm and other circuits that may be present at the breaker unless additional switch poles are used for these circuits. The blocking of all breaker controls by the dc power switch, the primary maintenance safety requirement, is also accomplished by the arrangement of Figure 1.7. The major drawback to the scheme of Figure 1.8 is that the total length of the trip circuit is nearly doubled, because it must run from the control building out to the circuit breaker and then back. This may require larger wire size to reduce the resistance and keep voltage drop within acceptable limits.

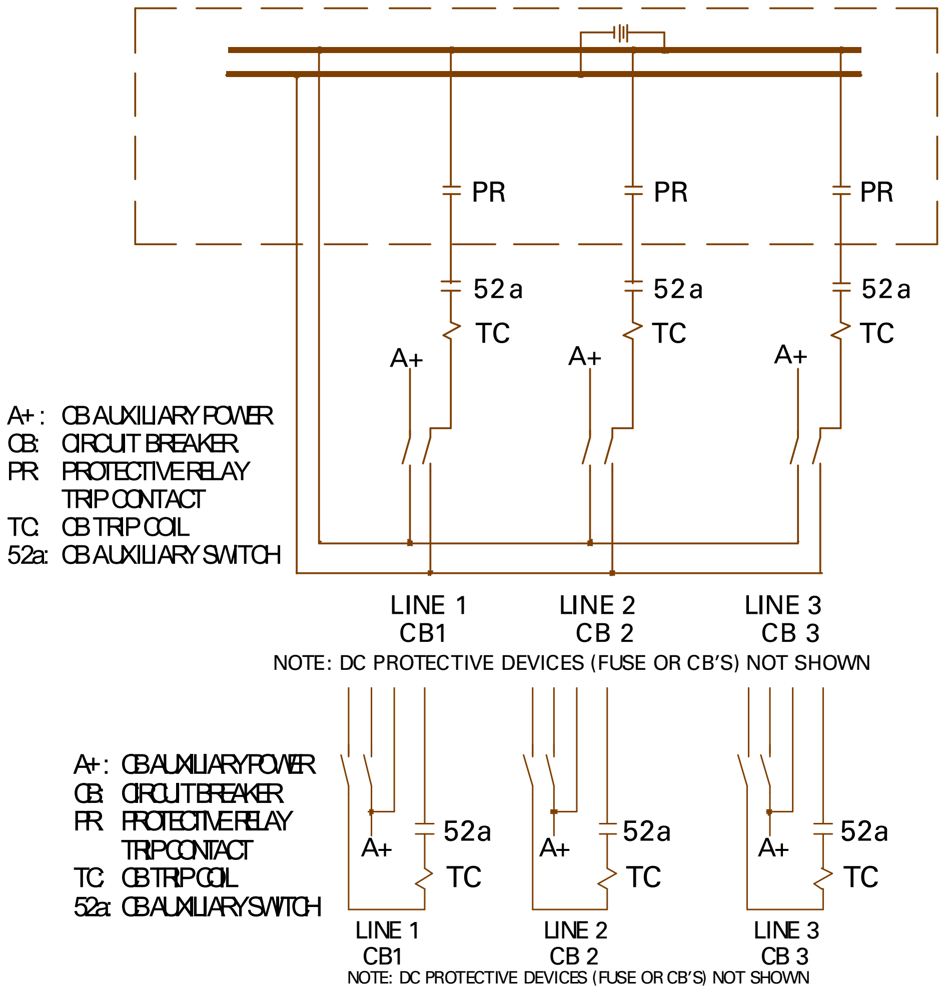

Figure 1.8 - Radial dc System with Switchyard Routing

The scheme of Figure 1.9 is herein called a "loop" dc system, because the positive and negative conductors of the breaker trip circuit do not follow the same path. The positive conductor runs from the dc supply to the relay switchboard and then to the breaker. The negative return runs from the dc supply to the breaker along with the positive conductor for breaker auxiliary power. The consequence of a loop arrangement is large magnetic surges into other control and measuring circuits in the switchyard when a breaker is tripped. These surges have the potential to cause misoperation of, or damage to, sensitive devices like static relays or data-acquisition equipment.

Radial systems are preferred to loop systems, particularly for the large switchyards typical of HV and EHV stations, in order to minimize the described inductive surges. However, many utilities successfully operate small, distribution-class stations with loop dc.[1][1]

[1] Numbers in square brackets [1] refer to references listed in Section 10.

DC SYSTEM FAULT CURRENTS AND PROTECTIVE DEVICE COORDINATION

Fuses or circuit breakers used in dc systems must be carefully selected to insure that their ratings apply to dc application. (U.L. did not require dc ratings on ac-rated devices as late as 1987.) The time-current characteristic curves of fuses and circuit breakers normally used in 250 volt and lower dc systems vary from one manufacturer to another. Studies, by one utility, of fuse curves from four leading manufacturers revealed that mixing of different manufacturer's fuses in a coordination string requires plotting of the time-current curves even if the ampere values (e.g. 15A, 30A, 60A) suggest that coordination will be achieved. However, the use of the same manufacturer's fuses in a coordination string should provide reasonable coordination. Relay engineers may be more aware of the difference in circuit breaker curves between manufacturers because of experience with ac low-voltage systems.

The dc interrupting current ratings of fuses and circuit breakers should be checked to verify that the ratings are greater than the available dc fault current. The approximate momentary value of dc fault current (I_{SC}) deliverable by a battery can be calculated as follows:

$$I_{SC} = \frac{I_d \cdot V_{CV} \cdot 9}{K \cdot 2.059}$$

where

- I_d = one-minute discharge current to 1.75 volts/cell
- V_{CV} = prefault voltage per cell
- K = temperature correction factor for the cell size

Refer to the battery manufacturer for the specific values of these parameters.

The device dc interrupting rating should exceed the I_{SC} by a margin of 20% or more since this is an approximate calculation. The battery charger can be neglected in these calculations since its built-in current-limiting features will prevent it from making any significant contribution to a fault. The literature reports development of a computer short-circuit program that considers the internal resistance of different types of lead storage and nickel-cadmium batteries as a function of the discharge.[2]

2. RELAYS TRIPPING A SINGLE CIRCUIT BREAKER

Typical applications of tripping a single circuit breaker are,

- Distribution feeder circuits
- Subtransmission line circuits
- Power plant or industrial auxiliary feeder circuits

The use of a single circuit breaker per protected element (circuit) at higher transmission line voltages is not as common as at lower voltages.

Relay Coil Connections

In order to minimize the effect of corrosion, relay coils should be permanently connected to the negative bus in dc control schemes. If moisture is present and the coil is directly connected to the positive bus, electrolytic corrosion may occur, causing the coil to become open-circuited and preventing the relay from operating.

Selection of Control Voltage

In general, most protective relay control scheme circuits operate infrequently, and contaminants can accrue on the contacts, thus reducing or preventing the full voltage from being delivered to the operating coil in a control scheme. Where the control circuit contacts are exposed to the environment, higher control voltages are required. Typically, 125 Vdc or 250 Vdc is selected. In the case where the control scheme contacts are protected from the environment, lower voltages may be utilized, provided excessive voltage drops are not encountered.

Circuit Breaker Features

Some of the control features of power circuit breakers are listed below:

- **Antipump** - In the event that a breaker is closed into a fault, while the operator is applying a close signal via a closed control switch, the circuit breaker should trip and prevent closing again until the closing circuit has been de-energized by the operator's releasing the control switch.

- **Trip Free** - In the event that the breaker is called on to trip at the same time a close signal is present, the breaker must always trip.

- **Mechanical Latch** - Positive latches which operate to ensure that the breaker remains closed when closed and open when tripped until the trip or close coils is/are respectively energized.

DIRECT TRIP

When a power circuit breaker is directly tripped by protective relays, care should be used to ensure that the trip circuit design is sufficient to provide maximum available current and voltage to the circuit breaker trip coil(s). Items of concern are the control circuit conductor size and length, number of terminal block connections in the circuit (these should be kept to a minimum), proper selection of the seal-in coil taps, the number of target and seal-in coils in series, and the rating of the relay contacts for tripping duty.

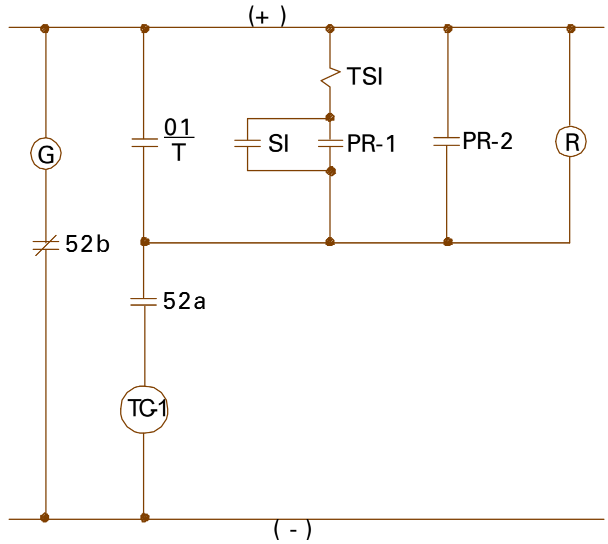

Figure 2.1 - Direct Trip of Single Breaker

Targeting and Seal-in for Direct Trip

The target seal-in relay rating of a protective relay should be selected based on the amount of current the trip circuit draws when operated. Older circuit breakers with solenoid trip coils may draw close to 30 amps, while more modern trip coils may draw as little as 2 amps. Typically, the target seal-in elements have taps of 0.2 and 2.0 amps. Static relays may provide a wider selection of operating values. See Section 9.2 for more detail.

Relay trip or control circuits may involve a variety of components, the ratings of which must be properly coordinated to accomplish the desired purpose. Protective relay trip circuits are usually intended to operate the output device (circuit breaker or switcher) at high speed and, at the same time, actuate operation-indicators or targets of all relays which may be expected to operate simultaneously.

When more than one relay operates for a given fault, the available trip coil current divides among the several relay circuits in inverse proportion to the resistance of the paths. The trip circuits of different relays may have different target and seal-in (TSI) coil ratings and resistances. Some trip paths may have two or more TSI's in series and the path may also contain a tripping diode. This path could be in parallel with another relay having a single TSI of only 0.1 ohm resistance which would severely limit the current in the higher-resistance path. For example, a simultaneous operation of a Zone 1 and a carrier pilot relay may drop only the Zone 1 target unless resistance is added to the Zone 1 trip circuit to equalize the division of trip current.

Diodes added to the trip circuits for isolation or event monitoring alter the division of trip current because of their fixed voltage drop of about 0.7 volt. An indicating instantaneous trip (IIT) contact circuit has only the resistance of the contact. When an IIT operates, it effectively short-circuits the TSI coils of any other relays which may operate simultaneously with the IIT.

Some utilities add series resistors to relay trip circuits to equalize the division of trip current among the several parallel paths. Others accept imperfect targeting in order to keep the trip circuits as simple and direct as possible. Any added resistors must permit targeting by all relays which may operate simultaneously, but must not cause excessive voltage drop if only one protective relay operates. It should be kept in mind that at least 1.5 times the minimum operating current of a TSI unit is required to reliably drop targets during the short time the breaker trip current actually flows.

In addition to energizing the breaker trip coil, the protective relays may also operate,

- Zone 2 and 3 timers
- Out-of-Step Blocking auxiliaries
- Breaker Failure Initiation relays
- Carrier receiver relay auxiliaries
- Transfer trip transmitter keying

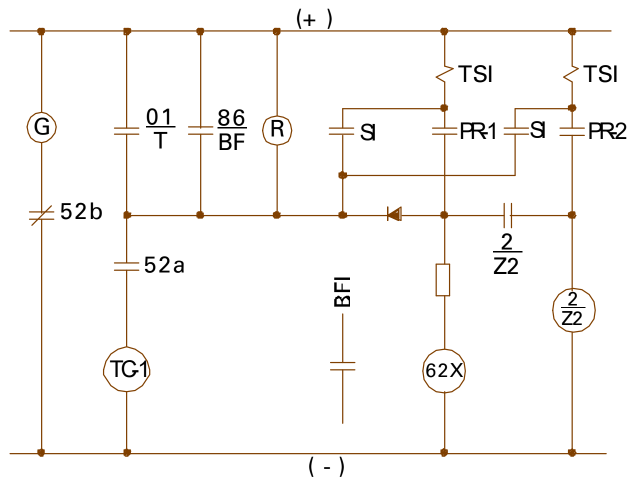

Figure 2.2 - Tripping Diode for Single Breaker

The seal-in unit must not operate on the current required by these auxiliaries alone; otherwise it would cause a false trip. Moreover, the seal-in must drop out after the breaker opens, while still carrying the current of these auxiliaries. The dropout current of TSI's is about 30-50% of the pickup value. Seal-in dropout is usually only a problem when low-current TSI taps (0.2 amp) are used, typically with auxiliary tripping relays rather than direct trip. However, dropout may need to be considered for direct tripping of breakers or circuit switchers with unusually low trip coil currents.

Sneak circuits can cause false keying of a transfer trip, shut-off of a carrier transmitter, or other problems. Care should be used to ensure that "sneak circuits" are not created. Generally, these can be avoided by careful designs and by adhering to the following when laying out the control circuit designs,

- Use a ladder diagram and keep it as symmetrical as possible
- Avoid line crossings
- Avoid continuation of the scheme on a second sheet
- Examine the consequences of diode failure (see Section 3)
- Check the dropout voltage of auxiliary relays to ensure that the resistance of any lamp circuit which monitors the control scheme status is high enough so that after the protective relay contact opens, the voltage to the coil is below the dropout level.

CAUTION: as more lamps are added in parallel, a potential "sneak circuit" may occur.

A tripping diode can be used to prevent seal-in of a BFI auxiliary, zone 2 timer, or other auxiliary through the trip circuit monitoring red lamp, and to provide separation of two relay systems tripping a single breaker. Connecting the seal-in contact to the breaker trip coil side of the tripping diode avoids possible seal-in of the auxiliaries after the protective relay contacts open. See Figure 2.2.

INDIRECT TRIP

Tripping may be done indirectly via auxiliary relays (see Section 3). When auxiliary relays are used for tripping, redundancy is necessary to provide the same dependability as with direct tripping.

DUAL TRIP COILS

If a power circuit breaker has more than one trip coil, redundant tripping incorporating independent dc trip circuits for each trip coil may be applied. These circuits could consist of a primary and secondary (or backup) protective relay, or simply a second dc trip circuit employing a single set of protective relays which have two sets of operating and seal-in contacts.

For the protection of important extra high voltage (EHV) lines, it has become standard practice to install two primary relaying systems and possibly a third level backup relaying system. Many utilities virtually double everything that can have an influence on the operation of a protective relay. Each relay system is connected to a different ct, cvt (or cvt secondary), battery, and circuit breaker trip coil.

The use of dual breaker trip coils is preferred for EHV circuit breakers, and the benefit is realized when a breaker with one trip coil is unable to trip due to a shorted or open trip coil, thus resulting in a breaker failure operation which causes additional circuit breakers to open and clear the fault.

When two primary systems are installed and they are completely independent of each other, as was mentioned above, then each primary system can be associated with its own circuit breaker trip coil.

When the relay systems are not both high speed, popular practice has been to energize one set of trip coils with the primary relaying system and the second set with the backup. This is done in an attempt to maintain separation of the primary and the backup trip paths. This practice can lead to an undesirable situation where, if the trip circuit associated with the primary relays is open and the backup relays are slower, an unnecessary breaker failure operation may result. Possible solutions to this problem are:

- ✐ Design the breaker failure scheme such that breaker failure initiation "retrips" the breaker before the breaker failure timer times out. Retrip must, of course, go to the backup trip coil.

✐ Energize both trip coils from each relay system (cross-tripping). See Fig. 2.3.

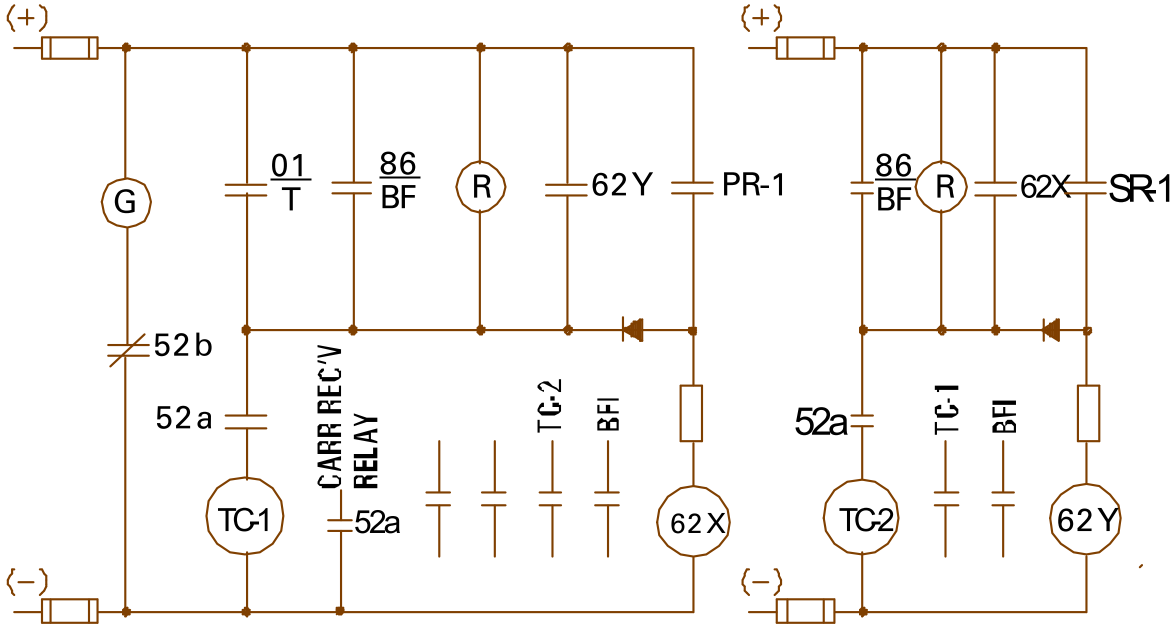

Figure 2.3 - Dual Trip Coils for Single Breaker

Another practice is to separate the primary relaying system and any high speed backup relays from the time delay backup with the use of isolating diodes, and arrange the time delay backup and breaker failure scheme to be supplied from a switchboard dc circuit and not the breaker dc supply. In this case, all relays initiate tripping of trip coil #1, and an auxiliary relay, which is part of the breaker failure relay, or is energized by breaker failure initiation (BFI), retrips the breaker using trip coil #2 before the breaker failure timer times out. The second trip coil should be supplied from a different dc source to back up either a shorted or an open trip coil #1.

An important consideration with dual trip coils is the possibility of a common magnetic flux path to both trip coils. Where such a situation exists and both trip coils are energized simultaneously but with opposite voltage polarity, the action of the trip mechanism is defeated and the breaker is unable to trip. This also applies to the dual trip-free coils of breakers so equipped. The inductive coupling of dual trip coils may also need to be considered to avoid sneak circuits energized by the coupling. Section 9.3 has further information on both of these topics.

Another consideration is trip coil monitoring. Both trip coils can be monitored by red lights.

3. RELAYS TRIPPING MORE THAN ONE BREAKER OR OTHER DEVICE

Power system reliability and system operation flexibility considerations have imposed bus designs in high voltage and extra high voltage systems where it is necessary to trip more than one breaker due to a single relay action. A number of bus arrangements are listed below:

- Breaker-and-a-half bus
- Ring bus
- Double-bus, double-breaker

Tripping of more than one breaker is necessary for bus faults, line faults, and transformer and generator faults. Although some relays, especially modern electronic types, provide two or more tripping outputs, many discrete relays provide only one tripping contact. This chapter discusses techniques used when a single-output relay must operate multiple devices.

In designing relay trip circuits, the following should always be taken into consideration:

- Make sure there is adequate margin for the minimum voltage to trip the breaker(s).

- Make sure that targets from several relays can be dropped to assure that adequate information is received for the stations to evaluate breaker operations.

- Make sure that dc cables which may carry the trip current of multiple breakers are sized to limit the voltage drop to an acceptable value even when all the breakers must be tripped simultaneously.

- Select the proper tap or rating of series indicating contactor switches or target and seal-in units to coordinate with the tripping current.

DIODES VERSUS AUXILIARY RELAYS

To accomplish tripping of more than one breaker by a single-output relay, two methods have been widely utilized:

- Diodes
- Auxiliary relays

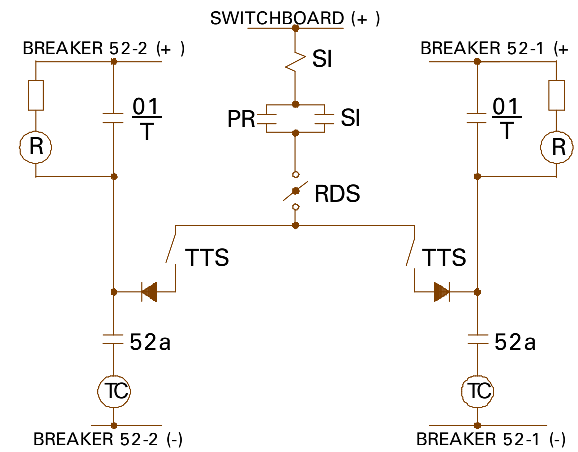

Figure 3.1
Direct Trip of Two CB's Through Diodes

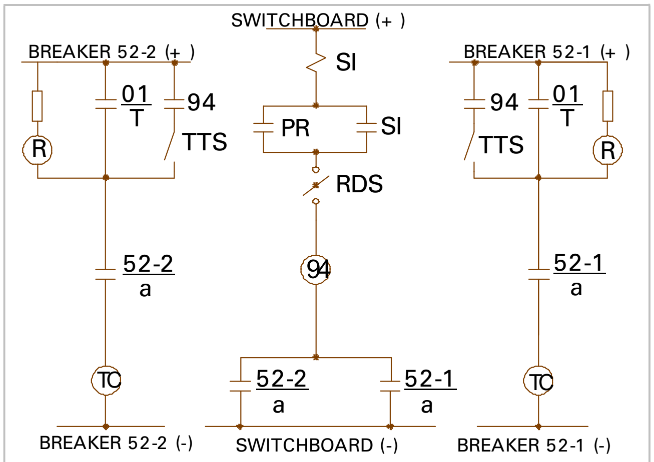

Figure 3.2
Indirect Trip of Two CB's by Aux Relay

LEGEND

PR: PROTECTIVE RELAY
RDS: RELAY DISABLING SWITCH
SI: SEAL-IN
TTS: TRIP TEST SWITCH

Figure 3.1 shows tripping of two breakers using diodes for breaker dc and tripping isolation. Figure 3.2 shows tripping of two breakers utilizing an auxiliary relay for breaker dc and tripping isolation.

There are advantages and disadvantages in using diodes or auxiliary relays in tripping more than one breaker. A number of advantages and disadvantages are listed below:

DIODES

Advantages

- There is no additional time delay in tripping.
- There is a direct path from the protective relay to the trip coil.
- Diodes do not require such extensive testing as auxiliary relays.
- Diodes usually fail in the shorted mode. Therefore, tripping can still be accomplished through them.
- Diodes are less costly than auxiliary relays.

Disadvantages

- The direct tripping of two or more breakers through diodes is limited to breakers having relatively low trip current. The 30A. momentary maximum trip rating of the protective relay contacts should not be exceeded. The voltage drop through the relay trip circuit should be calculated to be sure it is not excessive for the trip coil.

- The dc circuits are not isolated.

- When a diode fails in the shorted mode, operation of other devices tripping one breaker (control switch or protective relays for another system) can falsely trip additional breakers. This could interrupt both sources of supply to a load.

AUXILIARY RELAYS

Advantages

- Auxiliary relays are provided with a large number of contacts that can be used to trip a number of breakers as well as to perform other functions.

- Auxiliary relays provide better breaker dc and tripping isolation than diodes.

Disadvantages

- Auxiliary relays add additional time delay in tripping.

- The breaker(s) cannot be tripped if the auxiliary relay fails.

- Auxiliary relays are more expensive than diodes.

- Auxiliary relays need to be tested and maintained regularly.

APPLICATIONS OF DIODES IN CONTROL CIRCUITS

Although there are many types of diodes, the most prevalent in control circuits is the silicon junction diode. A second common type is the zener diode, whose volt-ampere characteristic is similar except in the region of reverse-voltage breakdown. The transition is very sharp and the voltage is practically constant with increasing current due to the zener avalanche process.

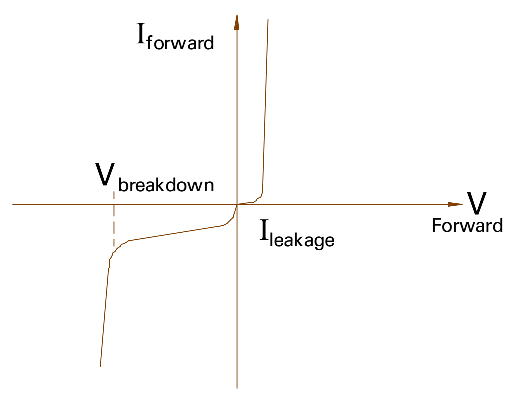

Figure 3.3 - Junction Diode V/I Characteristic

There are two main applications for diodes in dc control circuits: those for which the diode carries a relatively high current (such as may be drawn by a breaker trip coil) and those for which the current requirement is much less. Diodes for the high-current application are frequently called tripping diodes or tripping rectifiers, and those for lower current are called blocking diodes, blocking rectifiers, or steering diodes. Low-current devices may be used to trip breakers; however, close attention must be paid to the very limited current-versus-time capabilities.

A typical tripping diode application is shown in Figure 3.4. The diodes allow the protective relay contact (PR) to trip two circuit breakers, while preventing the control switch of one breaker from tripping the other. Note that in this application the combined tripping current should not exceed the capability of the relay contact, and the voltage drop through the relay circuit must not be excessive. The advantages of this arrangement over the use of auxiliary relays are simplicity and the elimination of the auxiliary relay pickup time.

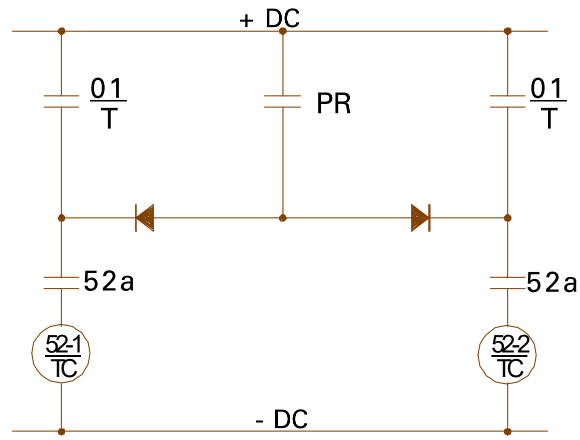

Figure 3.4 - Tripping Diode Application

A typical blocking diode application is shown in Figure 3.5. In this case it is desired that the protective relay pick up a trip auxiliary and key a tone transmitter while preventing other functions which key the transmitter from energizing the trip auxiliary.

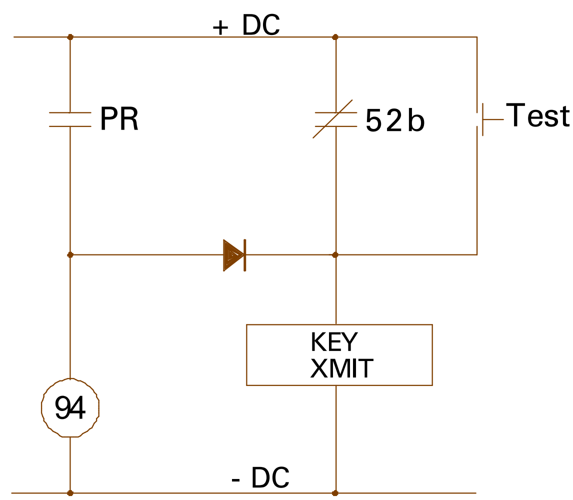

Figure 3.5 - Blocking Diode Application

A third application of diodes is to suppress transient voltages produced by the interruption of inductive current. In Figure 3.6, a protective relay contact is afforded protection from the inductive "kick" of the auxiliary relay because the diode allows a path for the coil current to continue to flow after the relay contact opens. The continuation of current will, however, delay the dropout of the auxiliary relay. Under quiescent conditions, the diode has no effect on the circuit because it is reversed biased.

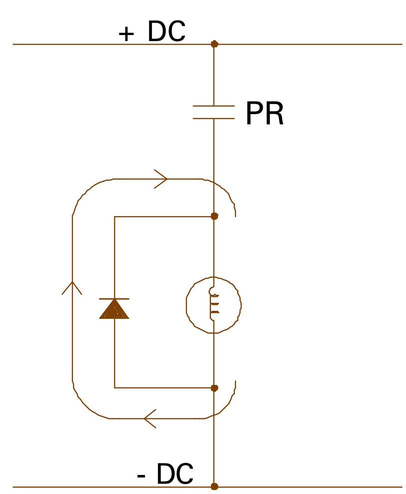

Figure 3.6 - Transient Suppression Diode

Diode Characteristics

The parameters of interest in applying a diode are its current-carrying capability, its breakdown voltage, its breakdown characteristic (rectifier vs. avalanche diode), and its reverse leakage current at the control circuit voltage.

The breakdown voltage (PIV) of commercially available tripping and blocking diodes ranges from 300 to 600 volts. Industrial diodes of appropriate current capability with breakdown voltages of up to 1200 volts can also be obtained. These ratings are more than adequate under quiescent conditions, but may be stressed in the presence of control circuit transients. For this reason, silicon junction diodes are generally protected with bypass capacitors which prevent the imposition of dangerously high voltages of short duration. The capacitor will, however, establish an unwanted path for current flow, (See Figure 3.7.) Usually the time constant of the circuit is substantially less than the auxiliary relay response time so that the current flow through the capacitor causes no unwanted operation. However, where the relay response is extremely fast, the circuit may have to be altered in some manner; for example by using a smaller capacitance or adding shunt resistance across the relay to shorten the time constant. The use of a suitable Zener diode eliminates the need for a capacitor and its attendant problems since the Zener can withstand repetitive reverse breakdown without damage.

The current-carrying capability of tripping diodes is typically 10 amperes continuous and 30 amperes for 1 second. Blocking diodes typically have a continuous rating of approximately 1 ampere. Their short-time ratings can be obtained from the manufacturer.

The reverse leakage current (current that flows in response to a reverse-bias voltage) is usually specified at one or more voltages and temperatures. In general, the higher the current-carrying capability of the diode, the higher the leakage current will be. Using an over-rated diode (with several milliamperes of leakage current) may cause problems with sensitive relays failing to drop out once picked up through another path.

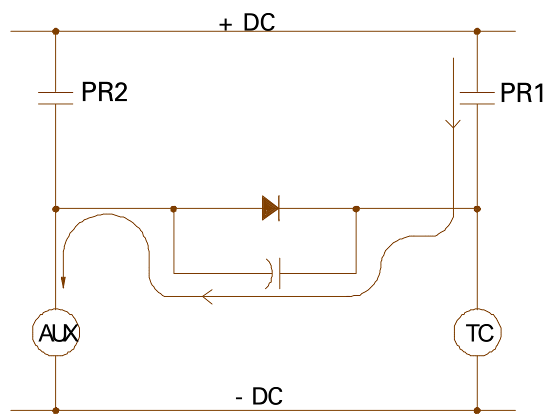

Figure 3.7 - Unwanted Path Through Capacitor

Reliability Considerations

The usual failure mode for a diode is to short circuit. Although failures are rare, it may be advisable, depending on the consequences of a failure, to connect two diodes in series. However, conventional diodes in series may not share the voltage equally, resulting in failure of the low-leakage unit first and then failure of the higher leakage unit. Zener diodes break over in a controlled avalanche mode so that two in series will share the voltage more equally.

APPLICATION OF AUXILIARY RELAYS

Many variations of auxiliary tripping relay schemes have been developed by relay manufacturers and utilities. All these schemes have three basic goals.

1. Operate the tripping relay at high speed to minimize the delay which the relay introduces into the tripping path.

2. Draw sufficient current through the target and seal-in coil of the initiating protective relay(s), for a sufficiently long duration, to insure reliable operation of the targets.

3. Reduce the interrupting duty on the initiating relay's contacts to within the relay's capability, or eliminate the interrupting duty entirely by opening the circuit with another contact.

The various auxiliary tripping relay schemes can be classified in a number of ways. One useful distinction is between low voltage/high current relays and high voltage/low current types.

Low Voltage relays have coils whose continuous voltage rating is typically in the range of 10 - 25% of the system's rated dc voltage. Since the coils cannot withstand system dc voltage continuously, some means has to be provided to reduce or disconnect the coil voltage shortly after the relay has operated. Low voltage relays operate quickly because of the overvoltage initially applied to their coils. Low voltage relays usually inherently provide adequate initial current to operate protective relay targets.

High Voltage tripping relays have coils which are rated for continuous energization at rated voltage. Low armature inertia is generally essential to provide high speed operation. The operating current of high voltage relays is generally insufficient to operate relay targets and some supplementary means is usually required to perform this function. Conversely, the operating current is low enough that protective relays may be able to successfully interrupt it.

Another useful distinction in auxiliary tripping relay schemes is in the means of resetting the auxiliary relay after its operation is completed.

Self-Reset schemes require the protective relay to deenergize the auxiliary when the protective relay resets following fault clearance.

Manual-Reset schemes use mechanical latch or electrical seal-in circuits to hold the auxiliary relay operated until an operator takes some action, e.g. pushing a button or turning a handle, to reset the auxiliary.

Time-delay Reset automatically resets the auxiliary relay after some preset time has elapsed. The time delay is made longer than the longest breaker tripping time (including the possibility of breaker failure tripping), but shorter than the reclosing time.

Auxiliary-switch Reset uses 52a switches from the controlled circuit breakers to reset the auxiliary tripping relay.

Figures 3.8 - 3.10 show a number of different auxiliary relay schemes, using self-reset or auxiliary-switch reset. Each of these is described in detail below.

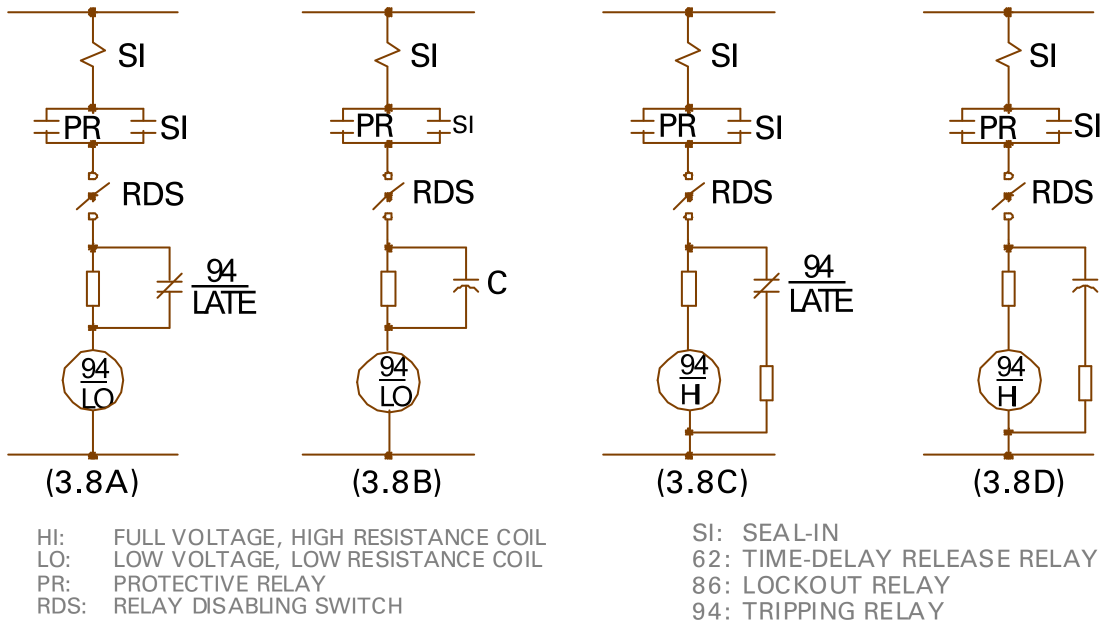

Figure 3.8 - Self-Reset Schemes

Figures 3.8A and 3.8B are self-reset schemes using a low-voltage relay. The current is initially high since it is limited only by the low resistance coil. This high current operates the protective relay target and seal-in (TSI) and picks up the 94 relay rapidly. In Figure 3.8A, the normally closed 94 contact then opens and inserts a resistance which reduces the current to a level which is high enough to hold the 94 armature picked up, but is lower than the seal-in dropout and can be interrupted by the protective relay contacts. If 94 operates in less than 1 cycle, then the 94 resistor contact may need to be a "late-opening" type to give a sufficient current impulse to operate the target. In Figure 3.8B a capacitor gives the same initial impulse current as the scheme of 3.8A, and then charges to reduce the current to the same steady-state level as 3.8A.

Figures 3.8C and 3.8D are duals of 3.8A and 3.8B, using full voltage, high-resistance auxiliary relays with parallel resistors for the target-dropping impulse. The capacitors in 3.8B and 3.8D assist the protective relay in interrupting the auxiliary relay current by reducing the rate-of-rise of voltage across the contacts after they open.

In Figure 3.8C, the late-opening contact of 94 removes the target dropping resistor after operation of the relay. The protective relay contacts must break the low magnitude inductive 94 relay current.

If a 94 relay with a low-voltage coil is used to obtain fast operation, the protective relay contact interrupting duty may be reduced by connecting the normally closed late-opening 94 contact in series with its coil, and paralleled loading resistor, and shunting the contact with a resistor which will reduce the coil voltage to below its continuous rating. This scheme is shown in Figure 3.9A. After operating, the coil voltage must be greater than its dropout value.

When an auxiliary self-reset relay is used for tripping, the seal-in contact should be disconnected if the holding current through the relay is greater than the seal-in dropout level; otherwise, the auxiliary relay could never drop out. The holding current could include other auxiliary devices (e.g. zone timers) besides the auxiliary relay, as described in Section 3.4. It should be determined that the protective relay contacts have the capability to interrupt the holding current; slow-opening contacts, such as those found in induction-disk relays, may not have this capability.

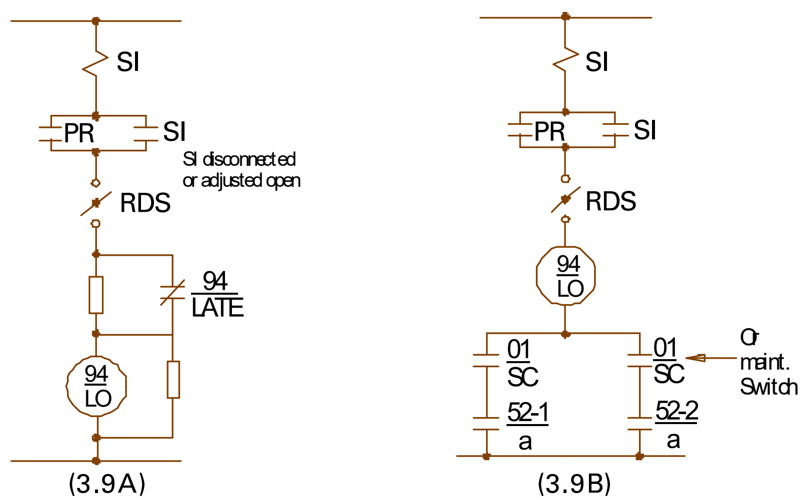

Figure 3.9 - Self and Auxiliary Switch Reset Schemes

The 94 tripping relay of Figure 3.9B, an auxiliary-switch reset scheme for tripping two breakers, has a low voltage coil, is energized at several times its continuous rating for faster operation, and is generally designed for sufficient current to operate the targets of all protective relays which may operate simultaneously. A parallel loading resistor may be added if necessary to drop targets. This arrangement, which essentially mimics direct tripping of a circuit breaker, was once quite popular, but is no longer preferred, for a variety of reasons.

- If one of the two breakers of Figure 3.9B is out of service and closed, a trip operation will not open the out-of-service breaker to de-energize 94, thereby burning up the relay. The addition of a control switch slip close (SC) contact, or a breaker maintenance switch contact, in series with each 52a contact will open that circuit when the breaker is out of service. Another solution is to insert a series resistor to make the circuit continuously rated and bypass the resistor with a capacitor to provide the high inrush current for fast operation and target dropping. This latter arrangement is essentially a combination of Figures 3.8B and 3.9B.

- The 94 relay of Figure 3.9B should not be used to initiate breaker failure relaying, since, as described in Section 4, BF relay initiation must not depend on a 52a switch. A revised arrangement, shown in Figure 3.10A, avoids this problem by using the 52a switches only to interrupt the target-dropping resistors and uses a high-resistance, continuously rated relay for 94. Since there are no 52a contacts in the 94 circuit, 94 may be used for BFI. The target-dropping resistor may either be continuously rated, or small enough to safely burn open if the breaker fails to open promptly. Unlike Scheme 3.9B, this scheme does require the protective relay to drop out the 94 relay.

The use of paralleled 52a contacts presents breaker outage control complications as described above and requires relay system wires to be extended to the breaker and control panel -- an undesired hazard. The protective relay circuits may be made completely independent of the circuit breakers and confined to the relay panel by use of high speed, low energy tripping relays. Contacts of the 94 relay trip one trip coil of each breaker and initiate BF relaying. A 0.25 second time delay mercury contact relay (62) opens a target dropping loading resistor to drop out all seal-in relays after the fault is cleared. This arrangement is shown in Figure 3.10B. A more complete development of this scheme, with dual trip coils, is shown in Figure 4.6 in Section 4.

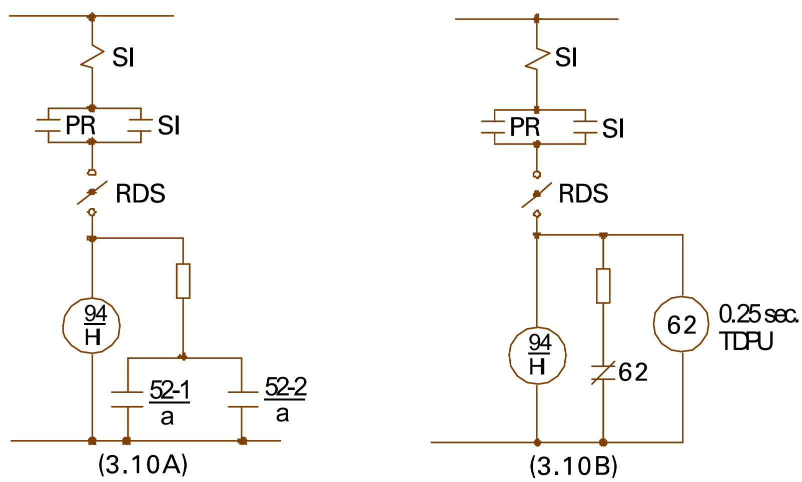

Figure 3.10 - Improvements on Figure 3.9B

Figures 3.11A, B, C, and D are lockout schemes in which the tripping relay remains operated until manually reset. Figure 3.11A uses a mechanically latched relay with a low resistance, high current coil that draws sufficient current to operate the protective relay targets. The lockout relay's normally-closed contact opens the initiation circuit immediately upon operation.

The arrangements of Figures 3.11B, C, and D (and 3.12A, B, and C) utilize a contact of the tripping relay to electrically seal in the tripping relay until it is reset either manually (3.11B - D) or automatically after a time delay (3.12A - C). The reset pushbutton shown on 3.11B - D could alternatively be an appropriate contact of the breaker control switch(es), to reset the relay when the trip has been acknowledged or the breaker removed from service.

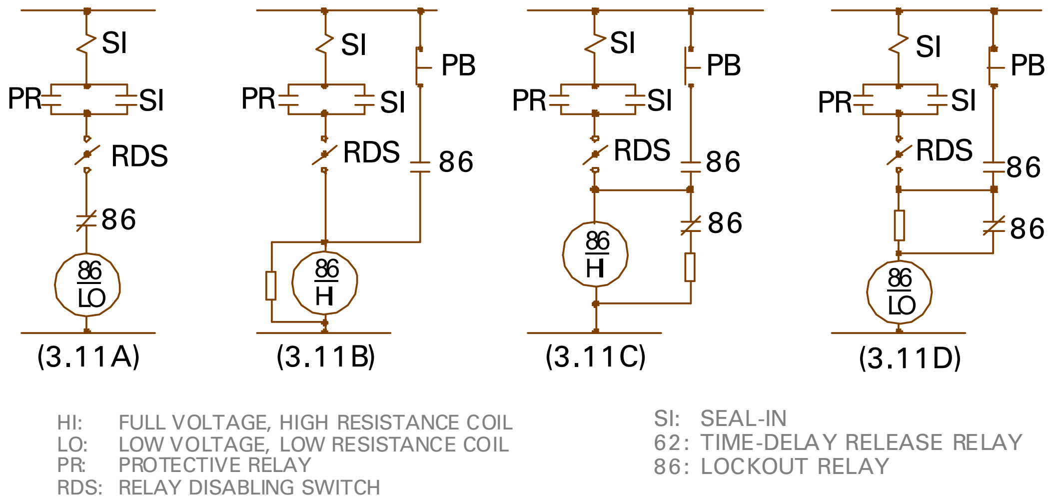

Figure 3.11 - Manual-Reset Schemes

The sealing-in contact of these schemes (86 for the lockout schemes, 94 for those with time-delay reset) shorts out the seal-in coil of the protective relay. Thus, to obtain proper targeting, these schemes are limited to applications where one cycle or greater operating time is acceptable.

The schemes of Figures 3.11B and C use relays with high resistance coils and have a parallel shunting resistor to draw sufficient current to operate the protective relay targets. Scheme 3.11C uses a normally-closed contact of the 86 relay to open the shunt resistor circuit to reduce the power dissipation after 86 has operated. Scheme 3.11D uses a relay with a low resistance coil (typically a high-inertia auxiliary rated at 20% of the dc system voltage) and a normally closed contact of 86 to insert a dropping resistor after 86 has operated.

Schemes 3.12A - C are automatic time-delay reset versions of 3.11B - D. The timer 62 is energized when 94 picks up. After the set time delay, the 62 contact opens to break the electrical seal-in. Typical time delays for 62 could range from 0.25 sec. to several seconds, depending upon whether reclosing is applied to the controlled breakers.

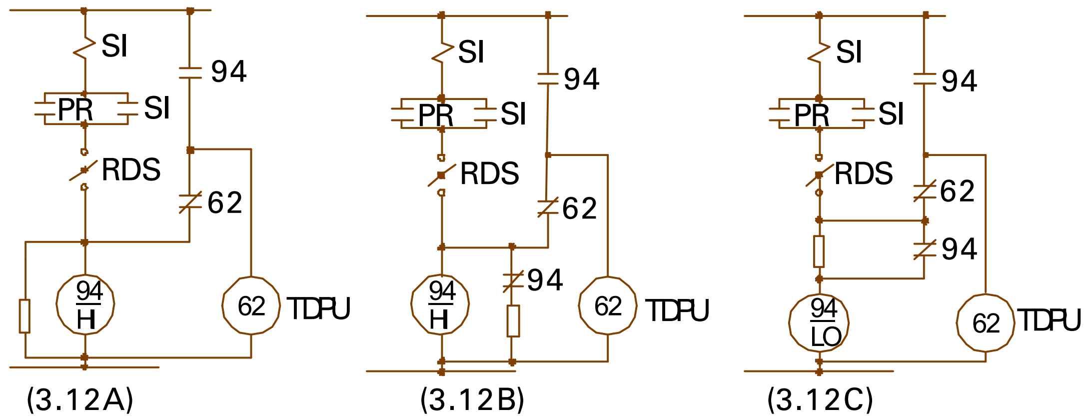

Figure 3.12 - Time-Delay Reset with Housekeeping Auxiliary

The one-cycle minimum operating time of schemes 3.11B - 3.12C can be circumvented by using an additional, slower auxiliary relay 94X to perform the "housekeeping" functions, as shown in Figure 3.13. This also makes available all of the contacts of 94 for use as high-speed tripping contacts. 94X should be a continuously rated auxiliary with a nominal operating time of 1 - 3 cycles. This delay is sufficient to permit targeting by the protective relays. In scheme 3.13A, 94 is a high-speed, continuously rated, low inertia relay which can provide tripping in less than one-half cycle. Scheme 3.13B typically applies a high-inertia relay with a coil rating of 10% of system dc voltage, yielding operating times of the order of one-half cycle.

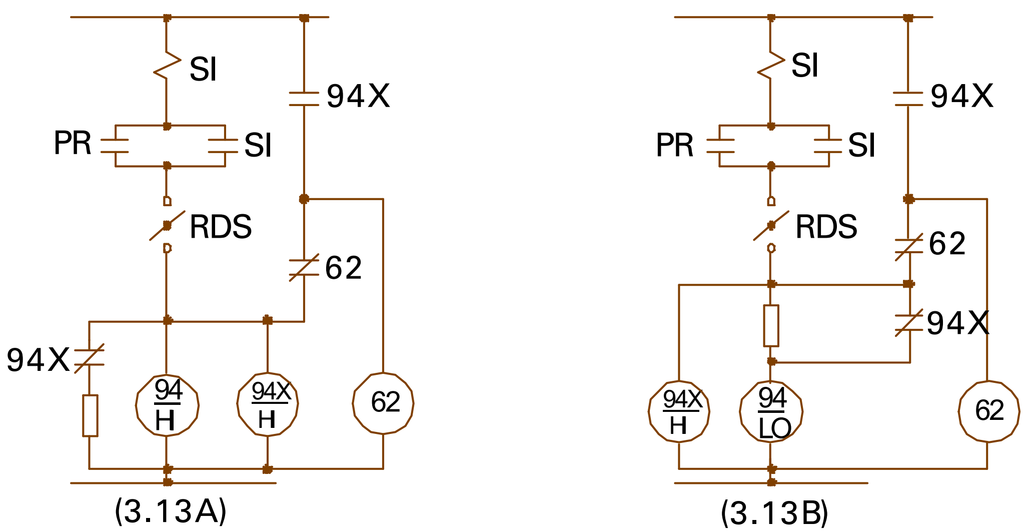

Figure 3.13 - Time Delay Reset Schemes

TARGETING AND SEAL-IN WITH AUXILIARY RELAYS

Lockout relays usually require substantially less current to operate than circuit breaker trip coils. However, breaker trip current flows for several cycles with fast rise due to low inductance, whereas lockout relay current flows for less than a cycle with a slower rate of rise due to the inductance of the coil. This is the reason why the 0.2 ampere tap is frequently selected when tripping through a lockout relay. Several times the minimum tap current is required to drop the targets in less than a cycle.

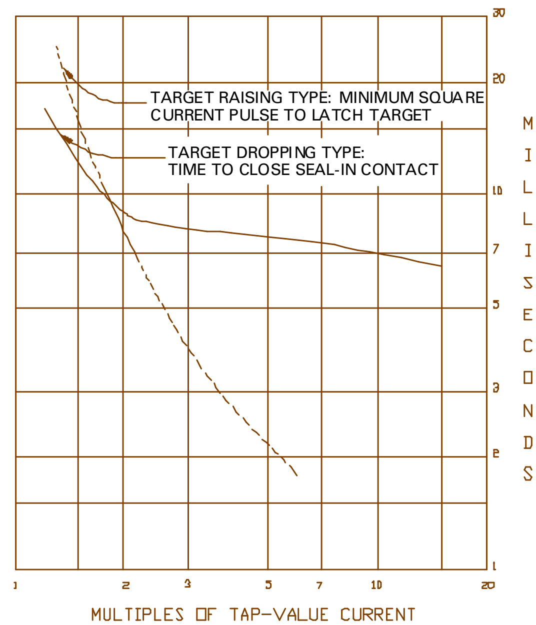

Figure 3.14 - Illustrative TSI Time/Current Characteristic Curves

Figure 3.14 illustrates the time current characteristics typical of target and seal-in units. Note that the curves shown are for two different types of assemblies and two different tests. The Appendix contains additional information on the time/current values necessary to provide reliable series target operation.

When two or more lockout relays are operated in parallel or when multi-shaft lockout relays are used, then the 1.0 or 2.0 ampere tap should be used to avoid excessive voltage drop that could result in slower lockout relay operation or no operation at all. In some applications such as bus relaying, when two buses are tied together, a number of tripping or lockout auxiliary relays are paralleled. The relay targets must operate reliably for both normal and paralleled conditions without causing excessive voltage drop.

A loading resistor may be required in parallel with the auxiliary relay coil to draw sufficient current to operate all the targets in the event two or more relays operate simultaneously. The resistor size depends on the current magnitude to operate all the targets reliably. The resistor watt rating depends on the length of time the resistor is expected to remain energized.

For example, one common lockout relay draws about 0.8 ampere at 125 V. and will operate one 0.2 A. target/seal-in. If two protective relays may operate simultaneously, a loading resistor will be needed to insure operating both targets.

When a 0.2 A. target rating is used, care should be exercised to avoid timers or auxiliary units which draw nearly 0.2 amp. This combination could result in a false target or false trip.

Use of two 0.2 ampere targets in series may result in excessive voltage drop. For example, two such units (13-15 ohms total) in series with a 28 ohm lockout relay coil will result in less than 70% of rated voltage being applied to the relay. The relay will likely still operate, but will be slow and less reliable. The sluggish operation may not be noticed by test personnel, but will show up when an actual operation is required.

TRIP TESTING AND TRIP TEST SWITCHES

In installations where a relay or relay system trips more than one circuit breaker or other device, it is often desirable to be able to individually disconnect these multiple trip outputs for test purposes. Figures 3.15 & 3.16 show the basic concept wherein the TTS switches enable the trips to be disconnected individually from breakers 52-1 and 52-2.

The primary purpose of such switches is to allow trip testing (see Section 9.6) of one circuit breaker at a time, allowing power equipment connected through multiple breakers to remain in service while the trip testing is performed. Protection for the equipment is provided by other means, e.g. backup relays, during this period. The TTS's also provide a means to disconnect the relay under test from the circuit breakers if no RDS is provided. The TTS's may be a part of the protective or auxiliary tripping relay, or they may be separately mounted switches (see Section 9.5).

While trip-testing individual circuit breakers may be convenient, it should be realized that it is a less thorough test than tripping all the circuit breakers simultaneously, since the voltage drop caused by one breaker will be less than the drop caused by tripping all breakers. Therefore, on initial testing, it is important to test for simultaneous tripping of all circuit breakers from each auxiliary tripping relay. If the portion of the tripping circuit which is common to two or more breakers (for example, the switchboard feeder and relay in Figure 3.15) has significant resistance, the initial simultaneous trip test should be done at 80% voltage (or add appropriate resistance to the trip circuit) to insure that tripping will operate properly even at low battery voltage.

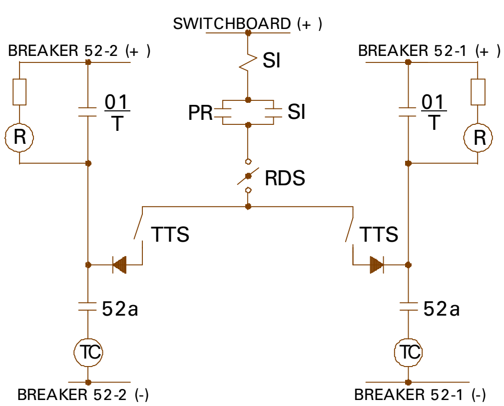

Figure 3.15 - Trip Test Switches with Diodes

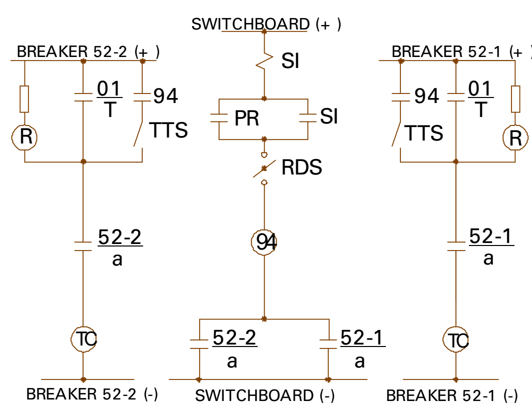

Figure 3.16 - Trip Test Switches with Aux Relay

Problems in tripping two breakers simultaneously have been experienced even though the same breakers trip-tested correctly one-at-a-time from the same relay system [3]. In the referenced paper, the trouble was caused by a series capacitor in the breaker trip coil circuit. The inrush current to the capacitor and trip coil was high, causing excessive voltage drop in the relay trip circuits and less than minimum voltage to operate the breakers. The effect was marginal, so that the relay was capable of tripping one circuit breaker at a time, but not both simultaneously.

4. LOCAL BREAKER FAILURE RELAY INITIATION

Breaker failure relaying is usually initiated by all protective relays which trip the breaker.[2] This includes any direct or permissive transfer tripping from a remote source. Breaker failure relay initiation (BFI) may be a contact of the breaker tripping auxiliary relays or of separate BFI auxiliary relays if necessary to obtain adequate redundancy. The BFI auxiliary relays are typically fast-pickup, fast-dropout, low-current relays. The following considerations should be applicable to various manufacturer's relays. Relay application engineers should consult the manufacturer for the characteristics of specific relays.

Separation of Relay Circuits and Breaker Trip Circuits

A short circuit or blown fuse in the circuit breaker trip circuit should not prevent the protective relays from initiating breaker failure relaying.

For dc separation, the following should be considered:

- For each breaker, consider two trip coils and two relay systems with each relay system and trip coil separate so they provide backup for each other.

- For two or more breakers, the relay system should be independent of the breaker trip circuits. Each relay system may operate either one or both trip coils of each breaker.

- Use separate cables and separate dc supply buses which include separate batteries if possible.

- When a breaker with a single trip coil must be used on the common dc tripping supply, the trip coil may be fused so that relays will still initiate breaker failure relaying if a problem occurs in the breaker trip circuit.

For security and redundancy, the following design features are recommended,

- Security is enhanced by letting the BFI or BF relay immediately re-trip the protected breaker. This can avoid an accidental trip of more than one breaker if the BFI is inadvertently operated while the current detector is picked up, as can happen accidentally during testing.

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[2] Utility practice varies as to whether tripping by Local Breaker Failure Relaying should initiate the Breaker Failure relaying for the backup breakers. Those who do so reason that a second breaker failure is a possibility. Those who do not initiate see a very low probability of simultaneous breaker failures.

- For redundancy, the BFI relay should trip via the alternate trip coil if the protective relay is connected directly to the main breaker trip coil.

See Figure 4.1 for a typical arrangement for a tripping scheme with redundant relaying (PR-1 & SR-1), redundant BFI (62X & 62Y) and duplicate breaker trip coils.

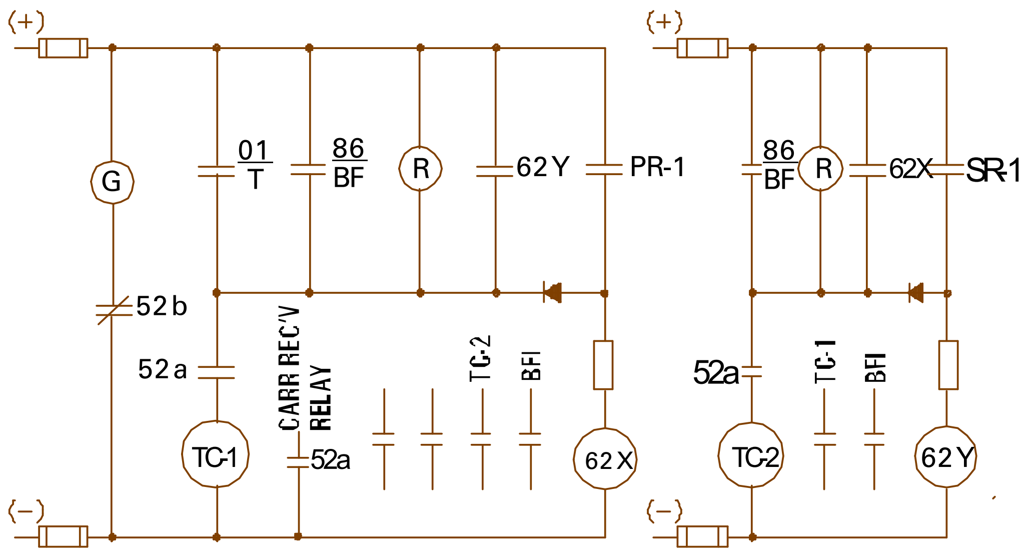


Figure 4.1 - Redundant Tripping Scheme showing Breaker-Failure Initiation

Maintaining Breaker Failure Initiation

Certain types of relays and system conditions must be checked to insure that BFI is properly maintained. Never seal in the BF timer to overcome a non-maintained BFI problem unless this feature is part of the design of a breaker-failure relay which supervises its timer with an overcurrent unit. Particular situations requiring consideration are as follows:

- For a zero-voltage 3-phase fault and loss of memory action on distance relays, the BFI will drop out. A high set instantaneous overcurrent (IOC) unit can be used to maintain BFI in this case.

- A trip initiated by a non-maintained direct or permissive transfer trip will suffer loss of initiation when the transfer-trip signal drops out. For direct transfer-trip, a dropout time delay at the transmitter or receiver long enough for the breaker failure timer to operate may be used. For permissive transfer-trip, a contact of the BFI relay may be used to bypass the transfer-trip receiver output contact.

- A relay scheme using 52a switches may drop out BFI relays or seal-in's. BFI must not depend on a seal-in through a breaker 52a switch. Never use a 52a contact in the BFI relay circuit except to supplement a fault detector. Where

52a is used in a protective relay circuit, seal in the BFI auxiliary relay through a permissive relay. Refer to Section 4.4, Breaker Auxiliary Switches.

- Use of a relay that does not have maintained contacts (such as a timer with a passing contact) will cause loss of BFI. Provide seal-in through the protective relay which initiates the timer or use a timer with maintained output.

- Relays that require shorting to protect their internal components (typically high-impedance differential relays) can be inadvertently caused to drop out. Provide BFI from the lockout relay in addition to that from the BFI auxiliary relay or arrange the circuit so as not to short out the overcurrent element of the relay. See Figure 4.2.

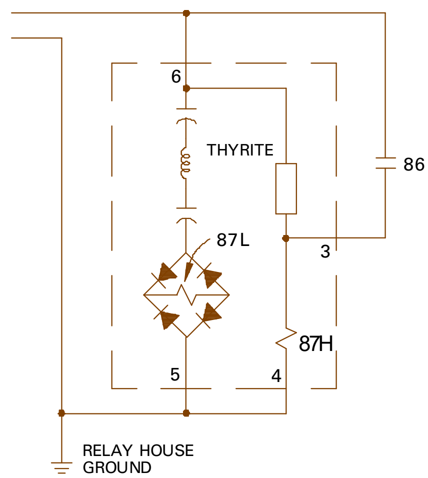


Figure 4.2 - Shorting Device 87

BFI Auxiliary Relays

BFI Auxiliary relays are usually designated as device function 62X or 62Y. Static relay outputs may be simply designated "BFI." The following are some considerations for the use of these relays:

1. Use a BFI relay that draws low current so that protective relay contacts can interrupt the circuit without damage. The BFI relays should not be interrupted by anything except the protective relays. Check the seal-in unit tap to be sure that the target and seal-in function is not kept sealed in by the BFI relay, zone 2 timer, or TT transmitter keying current.

   Protective relays with SCR trip outputs can be sealed-in by the current of the BFI auxiliary relays even though the current is quite low, causing unnecessary retripping. Separate, contact-type BFI outputs are usually necessary on relays with SCR trip outputs to avoid this problem.

2. Inadvertent grounds on the dc system should not cause a trip. Therefore, avoid overly sensitive auxiliary relays that could operate from capacitor discharge:

   - from the capacitance of long dc control cables or,

   - from surge capacitors on SCR or contact outputs, battery ground clamps, or surge protection.

3. Examine the relay scheme for sneak circuits which could cause misoperation of the BFI relay when dc is turned off, when one pole is opened (such as in

isolating a dc system ground), or from a reverse polarity pulse from the breaker trip coil when the breaker is closed.

✐ Determine if reverse polarity can cause operation. If so, add a diode across the BFI relay coil.

✐ Increase security by using auxiliary relays that will not operate below half of maximum battery voltage, so that battery grounds will not cause inadvertent operation of the auxiliary. See Section 9.4.

✐ If protective relays are on a single breaker trip coil dc, do not fuse the relay negative separately from the trip coil negative. To do so may cause an inadvertent operation of the BFI relay and trip the breaker when the relay negative fuse is removed. See Figure 4.3.

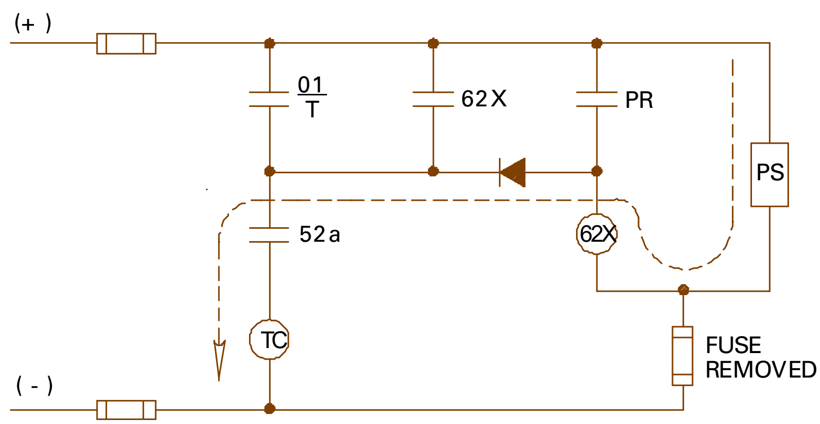


Figure 4.3 - Inadvertent BFI (62X) Operation

4. Installation of suitable diodes and loading resistors may eliminate problems in 2. and 3. above.

5. Fault detectors or 62X or 62Y relays which supervise the dc power to static breaker failure relays add to the security of the breaker failure protection.

6. If a common lockout relay is used for tripping and BFI, consider using an additional auxiliary relay to provide redundant BFI. This may not be necessary if redundant protection is provided.

Breaker Auxiliary Switches

In general, breaker auxiliary switches should only be used in conjunction with current detectors in an "OR" scheme for breaker failure relaying, i.e. the breaker failure relaying should not be totally dependent on a 52a switch for its proper operation. This is because an auxiliary switch could be open because of a broken linkage, or improper adjustment, or because the breaker mechanism could operate but the main contacts not interrupt. Several considerations for using these breaker auxiliary switches are:

- 52a switches may have to be used because a current detector may not detect low magnitudes of current. See Figure 4.4.

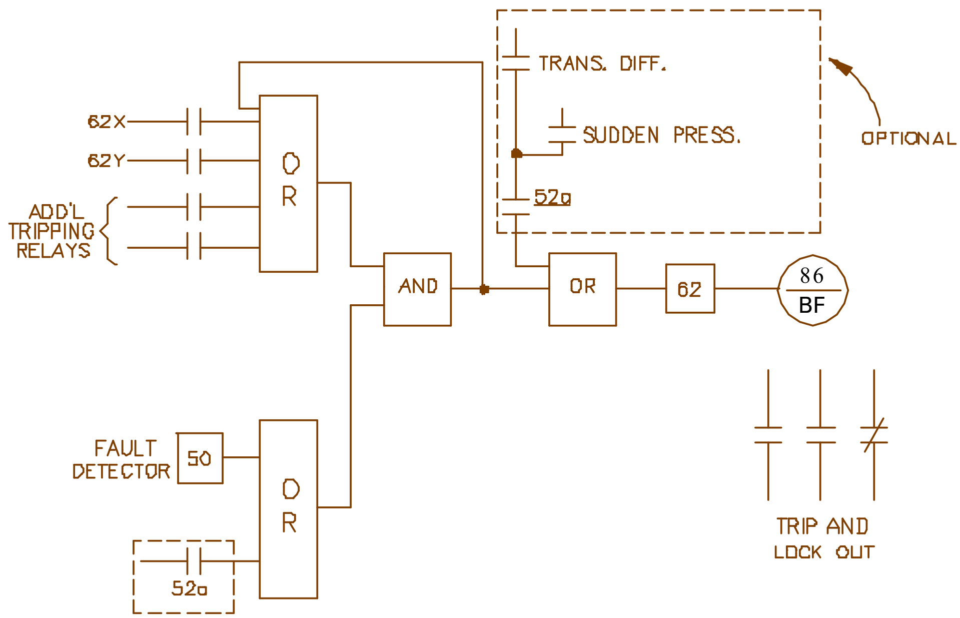


Figure 4.4 - 52a Switch in Breaker-Failure Relaying

- When a breaker is out-of-service and left closed, its 52a switch cannot open if a relay system attempts to trip the breaker. If a 52a switch is used to supplement the overcurrent fault detector in the breaker-failure protection, the switch circuit needs to be disabled for the out-of-service breaker to prevent an unwanted breaker failure relay operation. This can be done by adding a control switch slip close (SC) contact in series with the 52a contact or by the use of a breaker maintenance switch.

- For a single breaker using a 52a switch in the carrier receiver relay circuit, the carrier receiver relay contacts can be bypassed by contacts of the BFI auxiliary relay in order to maintain BF timing if the 52a switch should open. If the BFI relay is fast, a resistor is required in the BFI contact bypass of the phase carrier receiver relay contact to permit the carrier relay target to operate. (The BFI otherwise shunts the target coil before it can operate.) See Figure 4.5. If other relays operate into this same trip bus, BFI relay contact resistors in series may be required to avoid false carrier relay targets.

As an alternative to 52a switches

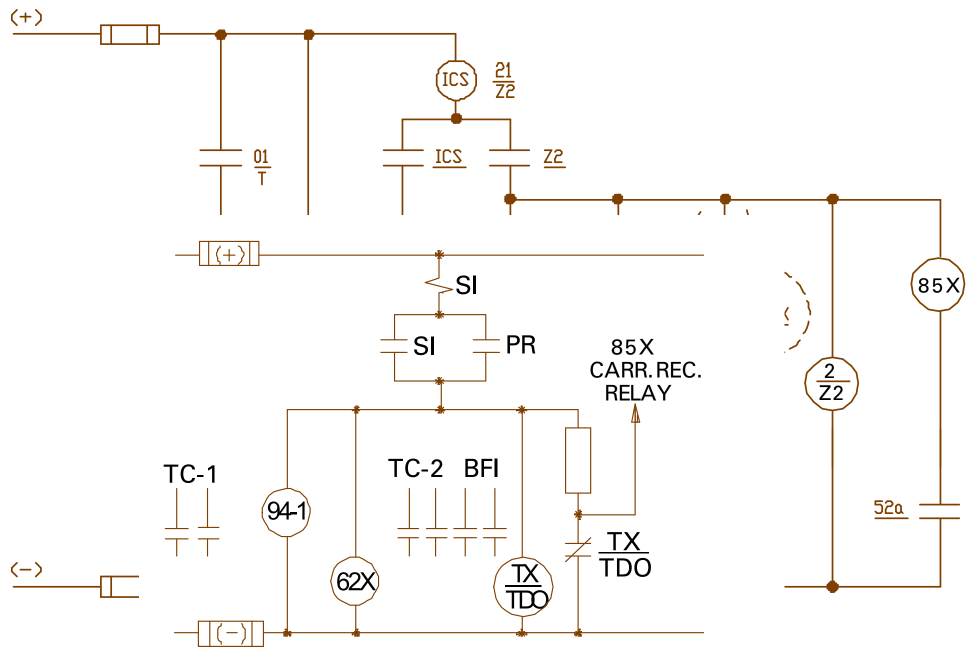


Figure 4.6 - 52a Replaced by TDO Relay

for dropping out relay targets, seal-in elements, etc., a time delay relay may be used to maintain BFI long enough to operate the BF timer. Check that a non-seal-in such as an IOC unit does not open the circuit before the Time Delay Opening (TDO) relay operates. Provide a seal-in for an IOC relay. Figure 4.6 shows an arrangement using the TDO concept.

5. TRANSFER TRIPPING

"Transfer Trip" is a term applied to a relaying method using a communication channel to transmit a tripping signal from the relay location to a remote location. The application may be direct tripping such as the tripping of remote breakers for transformer/reactor protection or breaker failure, or the remote tripping may be made dependent upon the simultaneous operation of a local "permissive" directional fault detector relay for relaying of line faults. The transfer trip equipment may use frequency shift keying (FSK) of audio tones on microwave, fiber optic cable, leased circuit, or power-line carrier, direct FSK on power-line carrier, or a digital encoding scheme on digital microwave or optical fiber.

Transmitter Keying

Security against false keying is a primary concern for relay applications. Keying may be at low signal levels by static relay or at battery voltage. The following points should be observed in the keying circuit design:

- ✐ Require a high level threshold, about 70% of normal voltage, to initiate keying.
- ✐ Avoid excessive length. Use shielded cable for long runs.
- ✐ The input impedance should be sufficiently low to avoid keying from surges. The input may be loaded with resistance, if necessary. Values of a few hundred to a few thousand ohms are commonly used.
- ✐ There must be no capacitors on the keying circuit which could delay transmitter shut-off.

The transfer trip facilities usually include a 3-position control switch -- TEST-OFF-ON. In the TEST and OFF positions, the trip and relay keying circuits are opened. The TEST position keys the transmitter. Some users provide a pushbutton in the test keying circuit of Direct Transfer Trip channels for additional security against accidentally sending a direct trip signal. An indicating lamp may be used to indicate an abnormal position of the TEST-OFF-ON switch.

Receiver Output Circuits

Audio Tone

The typical frequency shift transfer trip receiver output has two relays -- a guard relay which is operated by the normal frequency signal, and the trip relay which operates when the remote transmitter is keyed. The trip circuit logic requires dropout of the guard relay and pickup of the trip relay within a few cycles. Failure to obtain a trip output within that time interval after losing the guard signal is usually arranged to lock out tripping for any subsequent trip relay operation and to operate the loss of signal alarm. This logic prevents false tripping from interference in the signal channel. This logic may be incorporated in the electronics of the receiver output or included in a separate 85X relay as shown in Figure 5.1. This relay also includes the target and seal-in unit to bypass the receiver and logic unit contacts once the trip circuit has been completed.

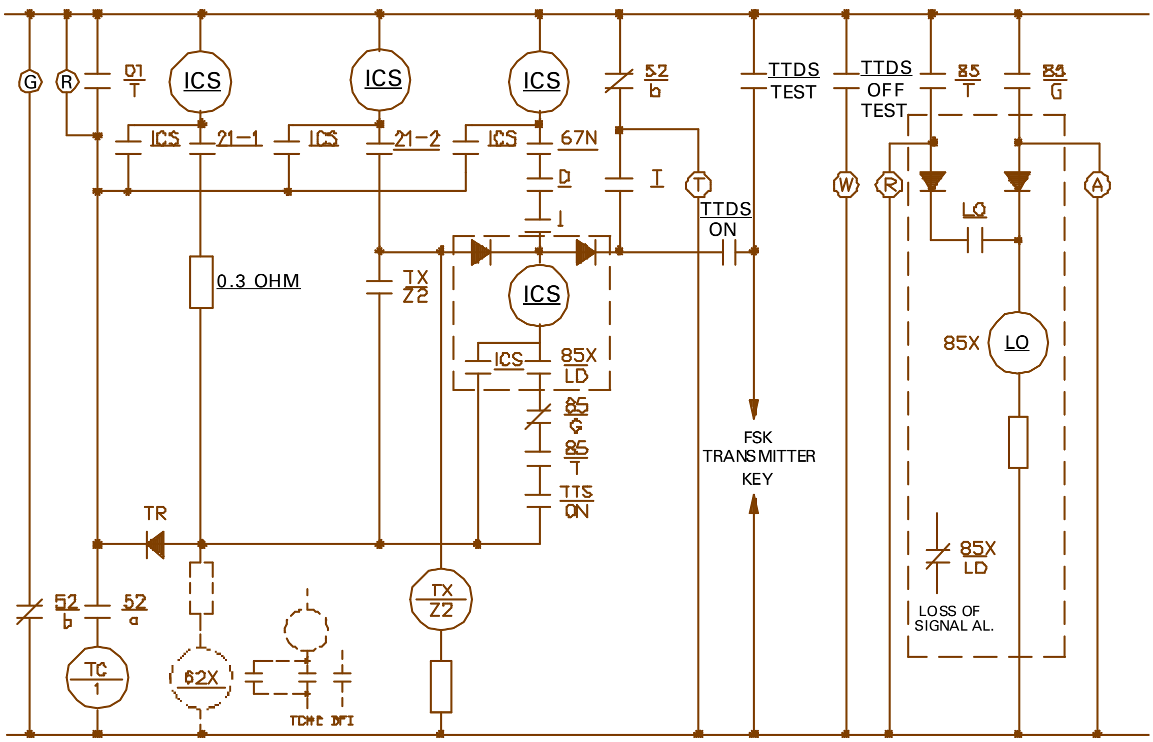


Figure 5.1 - Permissive Overreaching Transfer Trip Dc Control

Tone receivers which incorporate the guard-before-trip logic in the electronics of the receiver may use tripping outputs from devices such as SCR's, transistors, or light-duty contacts. Some of these may not be suitable for directly energizing breaker trip circuits and will require an appropriate auxiliary relay.

Digital Receiver Output Circuits

A typical digital transfer-trip receiver has a static output device. The current capacity of the output device may not be adequate for circuit breaker tripping duty and an appropriate auxiliary lockout or interposing relay may be required. Guard relays are normally not incorporated in digital transfer trip schemes since the inherent reliability and built-in monitoring of the digital channel makes them unnecessary. The guard relay function can be provided by a second digital channel when the external logic of the transfer trip scheme requires it. Digital receivers typically provide a loss-of-channel alarm built into the logic of the equipment.

Transfer Trip Switch

The trip circuit should include a Transfer Trip Disabling Switch to permit turning off the transfer trip. The switch may also operate a lamp or alarm in the OFF position. A single switch is commonly used to disable both the transmitter keying and receiver output of a line relay system.

Direct Transfer Tripping

A direct transfer trip is one involving no other protective relay operation at the receiver and breaker tripping location. For a breaker failure, the transmitter is keyed by a contact of the breaker failure lockout relay. For tripping of remote breakers for protection of a transformer tapped to a transmission line, the transmitter is keyed by a contact of the transformer protection.

A direct transfer trip may also be used for line protection whereby the transmitter is keyed by the zone 1 or underreaching instantaneous line protective relays. Tripping diodes are used to block transmitter keying by other elements of the trip circuit.[3] See Figure 5.2. Since the keying signal lasts only as long as the relays are picked up, some form of dwell extender or seal-in may be necessary to insure that the transfer trip output lasts long enough that the breakers at the remote end have time to trip and perform breaker-failure backup relaying, if necessary.

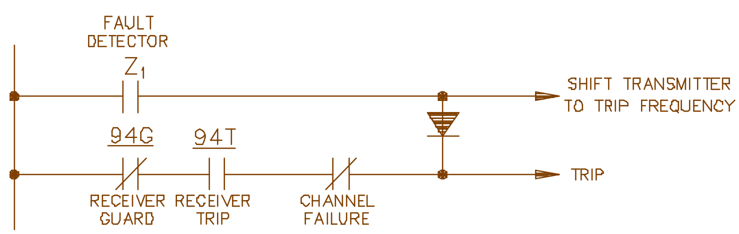


Figure 5.2 - Direct Transfer Trip

Greater security of a direct transfer trip system using FSK tones is obtained by using two tone channels, both keyed simultaneously. The frequencies of the two channels are shifted in opposite directions and the two receiver outputs are connected in series. The output circuitry can be designed so that failure or outage of one channel causes the transfer trip to revert to single channel operation, provided the second channel is intact and functioning. The design must be such that loss of both channels will not cause tripping.

Dual-channel systems can also provide greater security against accidentally sending direct transfer trip signals during work on the protection circuitry. This is accomplished by using

[3]Some utilities key direct transfer trip from any line protection relay which trips. This offers an improvement in tripping dependability and sometimes an increase in speed at the remote terminal.

separate keying contacts for each channel on each auxiliary relay which keys the direct transfer trip. With such an arrangement, accidentally energizing one of keying leads will not result in opening the remote breakers.

When used for remote breaker failure tripping, the receiver should disable automatic reclosing as well as trip the breakers. When used for remote transformer tripping, the receiver would typically block reclosing. Alternatively, if it is desired to disconnect the transformer and then automatically re-energize the line, the transfer trip could be arranged to postpone reclosing until the transformer disconnect switch has opened and removed the transfer trip signal. Additional logic could be included to cancel reclosing if the transfer trip signal persists for more than 10-15 seconds, indicating failure of the switch to open.

Permissive Overreach Transfer Tripping

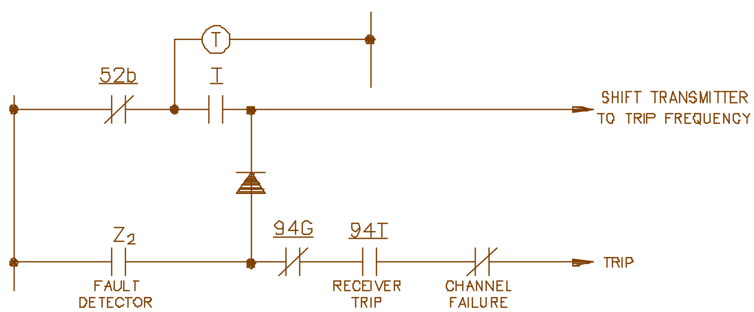


Figure 5.3 - Permissive Overreach Transfer Trip

Permissive overreach transfer trip (POTT) requires operation of the local directional fault detector relay in addition to receipt of a tripping signal from the remote terminal to complete the trip circuit. At each line terminal, overreaching phase and ground relays, as shown in Figure 5.3, or an overreaching directional instantaneous overcurrent ground relay, are connected to key the transmitter. The receiver trip relay contacts are connected to trip the breaker through the same permissive protective relays which key the local transmitter, requiring both to operate in order to trip. Tripping diodes are included, as needed, to prevent the directional ground relay from operating the zone 2 timer. See Figure 5.1.

When the relays of two different lines directly trip a common breaker, special care is needed to prevent unwanted keying of the transmitter for the unfaulted line for a fault on the opposite line. Such action can cause a false trip of the unfaulted line, since the remote terminal permissive relays may operate. The transmitter may be keyed by sneak circuits through zone 2 or 3 timer relays or the red lamp after the 52a switch opens. Note that the unfaulted line POTT receiver contacts will be closed. The trip circuit must include properly placed diodes to isolate the two line relay systems. Even when separate trip coils on a common trip solenoid are used, energizing one trip coil produces a positive pulse from the other trip coil which can falsely key the transmitter through the closed POTT receiver contacts unless a tripping diode is applied.

Underreaching

Figure 5.4 shows a permissive underreaching scheme. It will be noted that this scheme is quite similar to an overreaching one except that the transmitter is keyed by underreaching (Zone 1) relays.

If it is desired to apply an underreaching transfer trip activated by zone 1 relays in addition to the POTT, the scheme may be made permissive by the same zone 2 relays at the receiver terminal. If direct tripping at the receiver terminals is desired, it may be combined (in series) with the POTT receiver contacts for more security. Diodes provide isolation from other trip circuit functions. For tone systems, the frequencies of the two channels are shifted in opposite directions for added security.

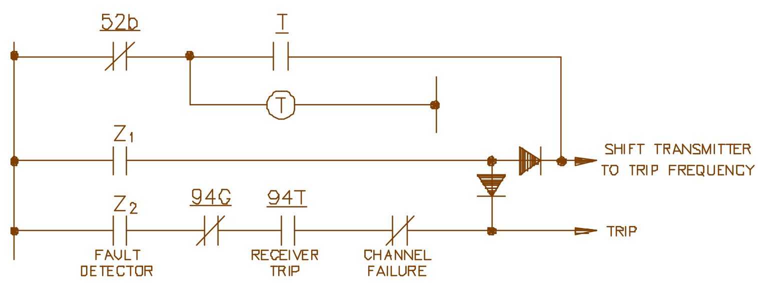


Figure 5.4 - Permissive Underreach Transfer Trip

52b Switch Keying for a Permissive Transfer Trip System

When the breaker at one end of a line is open, its relays cannot operate to send a trip signal to the closed terminal when a line fault occurs. The relays of the closed terminal cannot overreach the line with the remote end open. Therefore, it is common practice to key the transmitter of the open breaker by a 52b contact to permit instantaneous relaying for any line fault. An auxiliary relay delays keying about 2 cycles to insure that the remote end permissive relays reset before receiving the trip signal after the local breaker is opened for an external fault. For a terminal having two breakers, the 52b contacts are in series, requiring both breakers to be open to key the transmitter. To complete the circuit when the breaker is out of service and closed, each 52b contact may be bypassed with a control switch slip (ST) contact, auxiliary contacts of a breaker disconnect switch, or a contact of a breaker maintenance switch.

52b switch keying should be used with a POTT system for a 3-terminal line in order to permit instantaneous relaying of the closed terminals when one terminal is open. It should be noted that 52b switch keying cannot be used with a three-terminal permissive underreaching scheme, since the two receiver contacts are connected in parallel, and the permissive relay overreaches both remote terminals.

6. POLE DISAGREEMENT TRIPPING/INDEPENDENT POLE TRIPPING

As power circuit breakers evolved toward higher opening speeds, their design moved away from oil as the insulating and arc-interrupting medium to vacuum, air-blast, and sulfur-hexafluoride as the insulating and arc-interrupting media. The extra-high voltage (EHV) power circuit breaker philosophies branched into high pressure air-blast and SF6 technologies, and it became impractical to mechanically link all of the interrupting contacts to a single operating mechanism. Pneumatic operating mechanisms were already well-developed, so they were adapted to electrically control the poles of the EHV circuit breakers in what has become known as independent-pole operation.

But just how independent can pole operations become? Some utilities use single-pole tripping and reclosing schemes for clearing phase-to-ground line faults where it is mandatory to clear such faults with a minimum disruption to the system, such as the case where generation is located on the end of a long line supplying system load. These applications are beyond the scope of this discussion; our concern here is to detect when the 3 poles of a circuit breaker do not operate in unison, either opening or closing, and take corrective action.

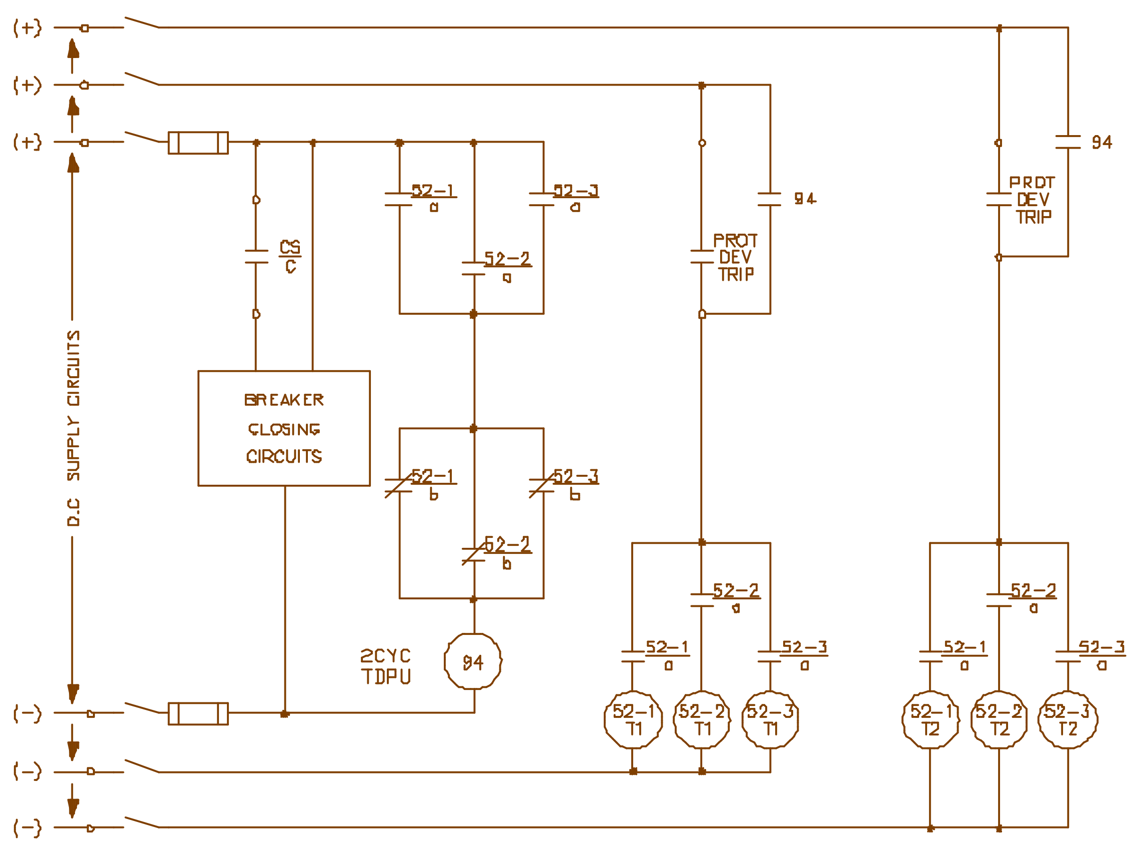


Figure 6.1 - Pole Disagreement Tripping, Single 94 Device

Independent-pole operation does have one major advantage over 3-pole mechanically-linked operation: if one pole fails to open for a severe fault, such as a 3-phase fault or a double-phase-to-ground fault, the opening of the other two poles degrades the fault to a single-phase-to-ground fault, thereby lessening the impact of system stability [4,5]. This is fine, but we must still get the stuck pole open, either by acting on the stuck pole or by initiating breaker failure backup.

Schemes to act further on the breaker and attempt to open it are called pole-disagreement tripping schemes. An early scheme [6] used pneumatic feedback circuits to open the breaker, but schemes used today employ series-parallel connected circuit breaker auxiliary switch contacts to operate auxiliary tripping relays (device 94). These schemes vary in details from that using a single 94 relay as shown in Figure 6.1, which must be connected to a power supply not directly involved with tripping, to dual 94 relays, one on each tripping supply circuit (Figure 6.2). The scheme shown in Fig. 6.2 also includes optional cross-tripping wherein each 94 relay attempts to trip the breaker via each trip coil.

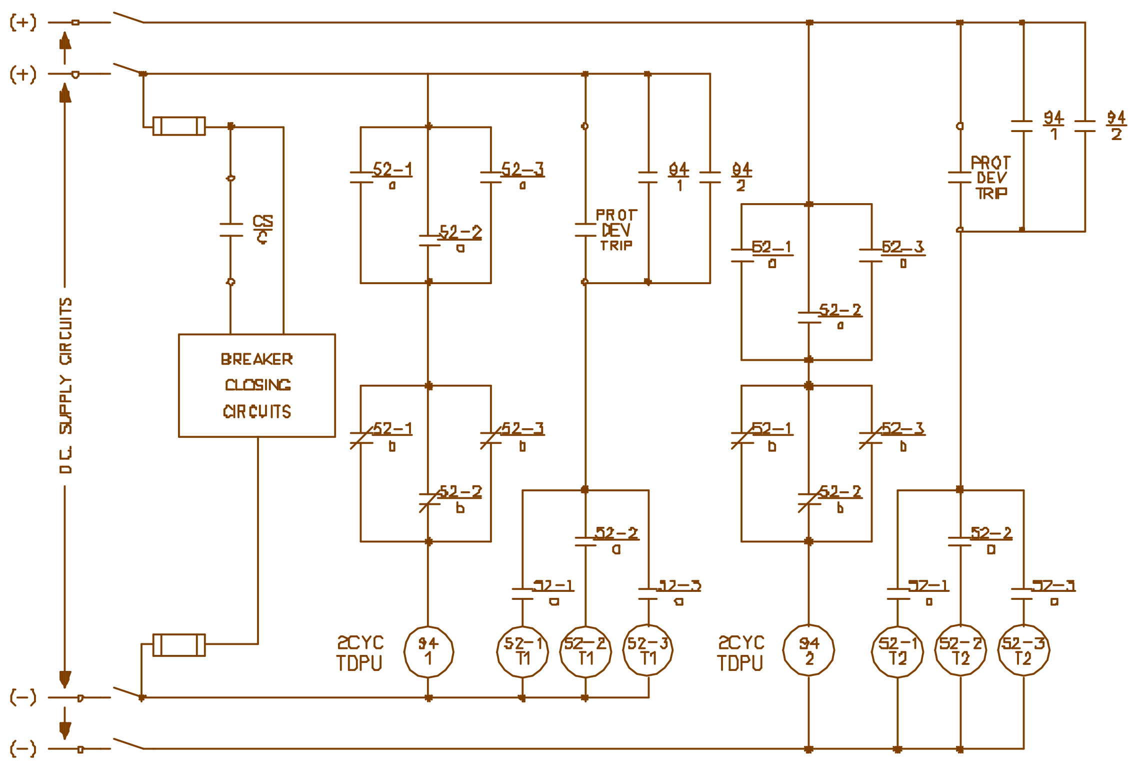


Figure 6.2 - Pole Disagreement Tripping, Dual 94 Devices

Another variation, used on air-blast circuit breakers, supplements the 94 tripping with series-parallel connected auxiliary switch contacts to bypass the cutoff contacts for the series-connected tripping air valve solenoids, as shown in Figure 6.3.

Regardless of these variations, these circuits have one thing in common: they attempt to energize the circuit breaker trip circuits to open the breaker. If the breaker still doesn't open, the trip coils will likely burn up. Other contacts of the 94 relay can be used to start breaker failure operation and give an alarm. If the pole-disagreement tripping works, then the 94 device(s) reset, breaker-failure timing can be aborted, and the breaker reclosed. However, the alarm that a pole disagreement has occurred should be a signal that the breaker should be checked to find the problem before it evolves into a breaker failure.

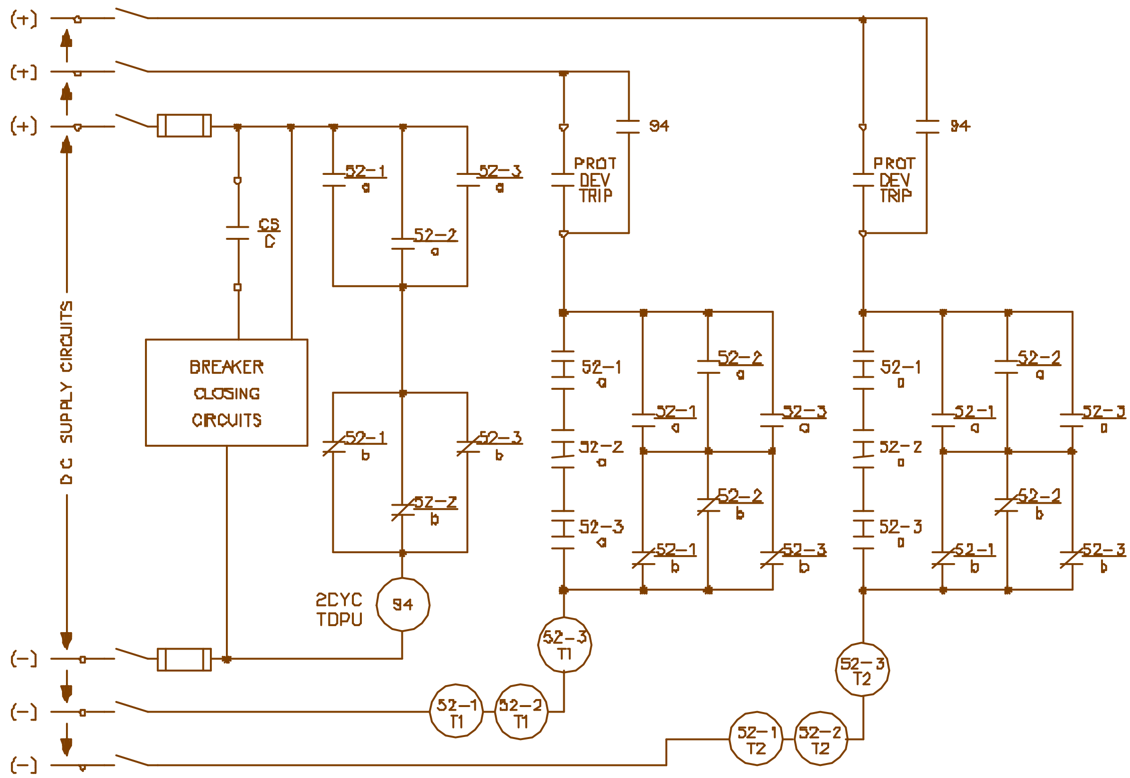


Figure 6.3 - Pole Disagreement for Series Trip Coils

Some models of breakers with series trip coils, and without the series-parallel connected auxiliary switches in the trip coil circuit, have the 94 contact connected to energize the trip coils directly. The 94 contact must be able to break the trip coil current. With any model where the 94 trip contact can break the trip coil current, burning up the trip coils for a stuck pole can be avoided by the addition of a time delay relay (94Y) to dropout 94 as shown in Fig. 6.4. Reclosing should also be blocked.

Many of these independent pole operating circuit breakers are installed in ring-bus or breaker-and-a-half schemes, and the pole disagreement circuits described herein are positional, depending only on breaker auxiliary switch contacts. These schemes should be supplemented by some sort of open-pole detection relaying to eliminate open-pole operation.

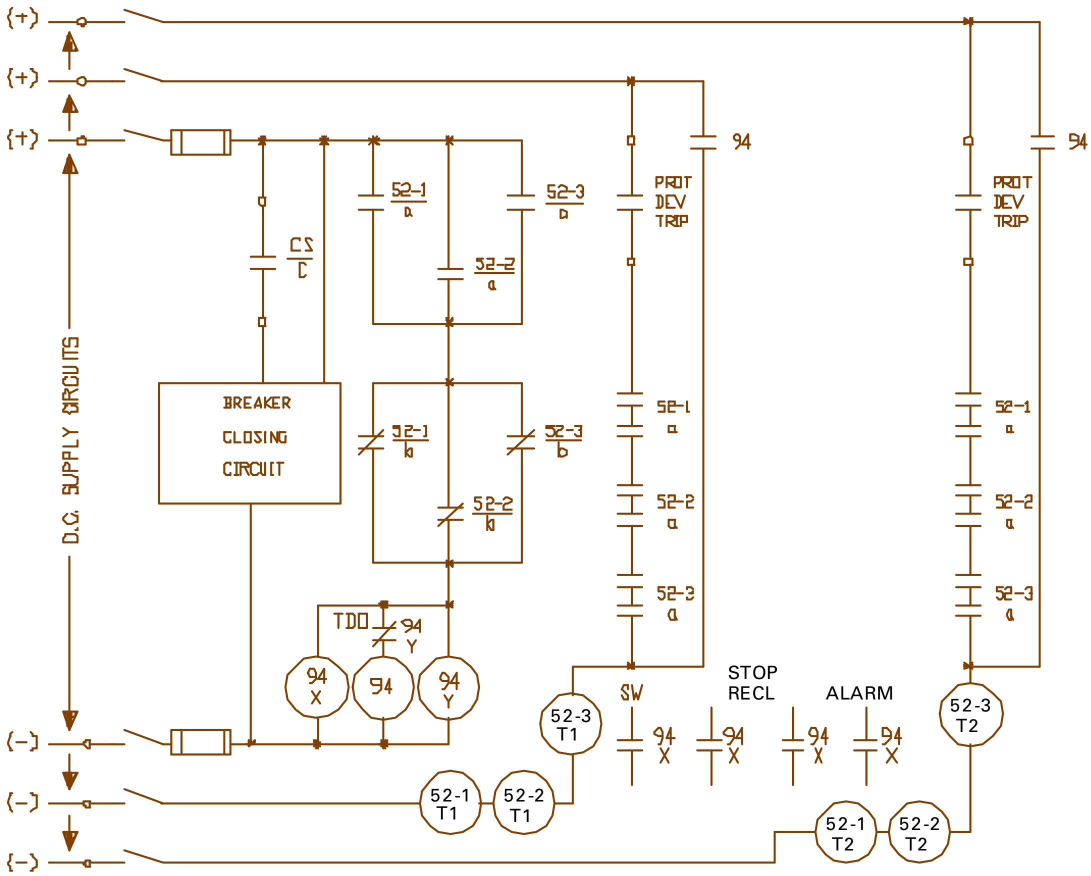


Figure 6.4 - Pole Disagreement with Time Delay Cutoff, for Series Trip Coils

7. TRIP CIRCUIT MONITORING AND SUPERVISION

There are six areas of vulnerability regarding the dependable tripping of a circuit breaker. These are failure of:

- the dc supply
- the tripping contact
- wiring runs
- the circuit breaker auxiliary contact
- the trip coil
- the circuit breaker mechanism

Failure of the circuit breaker mechanism can only be detected by attempting to trip the circuit breaker, and the integrity of operation of the tripping contact can only be assured by exercising it. Without a very sensitive ohm meter, shorted turns in the trip coil cannot be detected. However, the other items can be monitored with relative ease.

This monitoring and supervision is treated as having greater or lesser importance by different utilities. Those who do not employ it reason that if the trip battery or trip circuit fails, then either a duplicate trip circuit and trip coil or back-up or breaker failure protection will clear the fault.

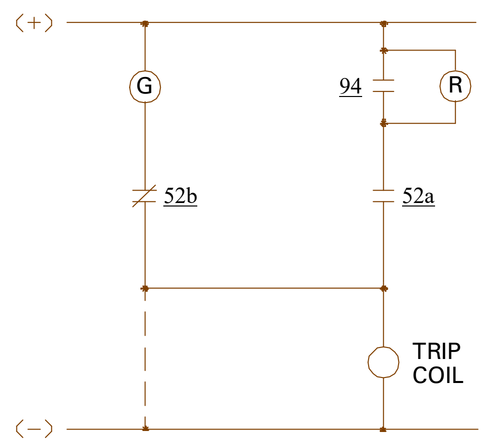


Figure 7.1

Monitoring and supervision can take several different forms. The simplest and most common is a red lamp connected across the circuit breaker tripping contact for each trip circuit and a green lamp energized through a 52b contact on one trip circuit as shown in Figure 7.1. When the breaker is closed, the red lamp monitors the presence of tripping voltage and the continuity of the trip wire, 52a contact, and trip coil. The green lamp indicates the presence of tripping voltage when the breaker is open and the red lamp cannot do so. These lamps also indicate the open/closed status of the breaker. If the close circuit and the trip circuit have the same dc supply, then the green lamp may also monitor the voltage supply for the close circuit as well as monitoring the trip circuit when the breaker is open.

The lamps are usually 24V lamps with a series resistor so that a short-circuited lamp or socket will not trip the breaker. Lamps monitor the dc supply in only a crude way. They will indicate that voltage is present but not necessarily that the supply is capable of operating the circuit breaker. Corrosion at the battery terminals can produce a series resistance of several ohms. This will not affect the brightness of the lamps but can prevent circuit breaker operation.

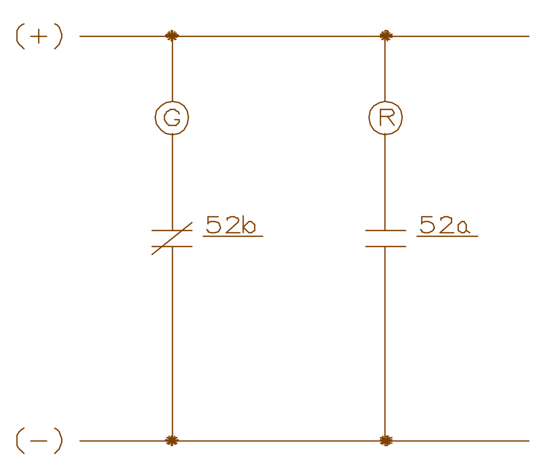


Figure 7.2

LED's have been used for some monitoring functions to avoid the problem of burned-out incandescent lamps. However, they should be used for trip circuit monitoring only if designed to draw sufficient current so as not to appear lighted through a high resistance such as a burned-open trip coil. Use of a zener diode in place of much of the series resistance will prevent LED indication through a high resistance.

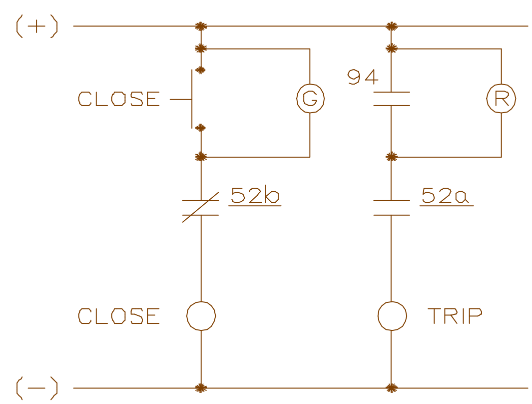


Figure 7.3

Sometimes, the red and green lamps are connected only to the 52a and 52b contacts, respectively, as shown in Figure 7.2. This arrangement only monitors the dc supply and indicates the circuit breaker status.

The connection for the green lamp shown in Figure 7.3 should only be used where the switching device has no anti-pump relay, as the lamp current could cause such a relay to misoperate.

The red lamp in the trip circuit can be replaced by the coil of an auxiliary dc relay. This is shown in Figure 7.4. The current drawn by the lamp or relay must, of course, be small compared to the minimum current needed to operate the trip or close coil. If the relay is used for circuit breaker position indication for SCADA, it also provides the trip circuit monitoring function when the circuit breaker is closed. However, it should be noted that this use of the relay for SCADA breaker position may not register a breaker closure when closed into a fault because the 94 contact may close to trip the breaker before the monitoring relay has time to pick up.

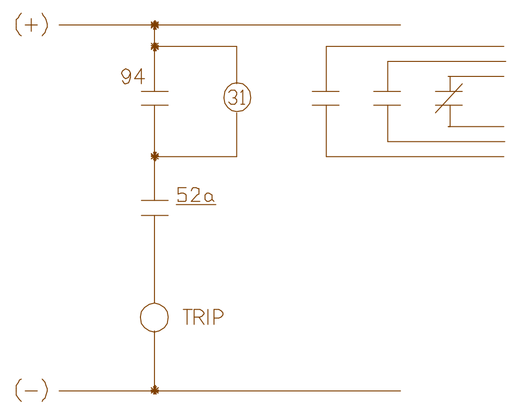


Figure 7.4

The main vulnerability of the trip circuit is the wiring between the trip contact and the circuit breaker trip coil. Underground runs can be cut by excavation work, for example. The red lamp connected as shown in Figures 7.1 and 7.3 will indicate that the wiring has been broken when the circuit breaker is closed; however, when the circuit breaker is open, there will be no indication of a broken wire.

A more comprehensive supervision circuit is shown in Figure 7.5. Although supervision is only carried out when the circuit breaker is closed, the contacts of the A relay can be connected to a SCADA system for position indication, and there will be no unwanted alarm output from the B relay when the circuit breaker is open.

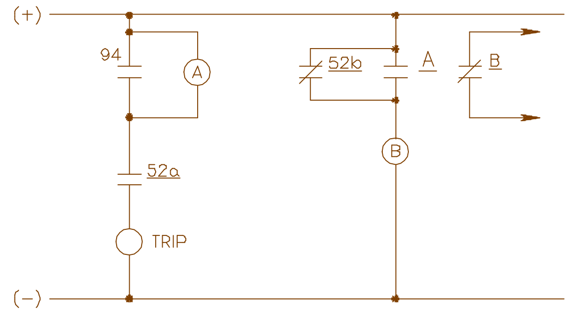


Figure 7.5

The most comprehensive monitoring and supervision system encountered is shown in Figure 7.6. This monitors the tripping circuit whether the circuit breaker is closed or open and will only give an output if the tripping circuit or the trip coil becomes open circuited or the dc supply fails. Relay A must operate at full voltage; relay B must pick up in series with relay A.

In Figures 7.5 and 7.6, the auxiliary relays will have short time-delayed drop-out. The relays

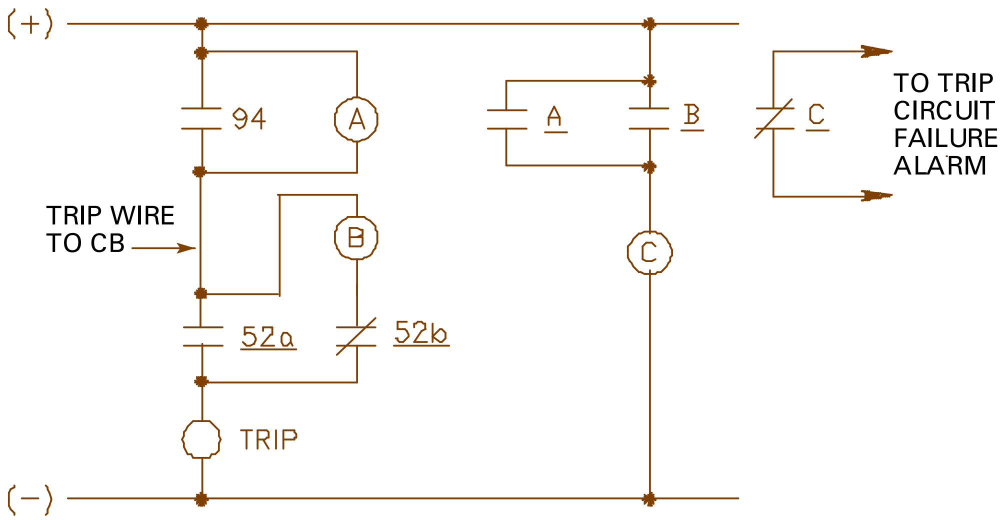


Figure 7.6

are usually supplied with externally mounted series resistors chosen such that if any one component is short circuited, circuit breaker tripping will not result.

The following table lists the features of all of the schemes that have been described:

Figure Reference	**Features**
Figures 7.1 & 7.3	If the lamp is out, then the lamp or the tripping circuit might be faulty.
Figure 7.2	Monitors the dc supply only.
Figure 7.4	Monitors the trip circuit only when the circuit breaker is closed, but the provision of alarm contacts allows remote indication of dc supply and of trip circuit failure.
Figure 7.5	Monitors the trip circuit only when the circuit breaker is closed; the provision of alarm contacts allows remote indication of dc supply or of trip circuit failure; and there will be no unwanted alarm when the circuit breaker is open.
Figure 7.6	Gives complete monitoring of the trip circuit and dc supply when the circuit breaker is open or closed and provides contacts for remote alarm.

Monitoring Circuits for Auxiliary Tripping Relays and Lockout Relays

The dc protective relay tripping circuits to auxiliary relays are usually monitored by a lamp or alarm relay connected across the dc supply. The circuit to a lockout relay may be monitored by a lamp or alarm relay connected across the protective relay contact similar to the red lamp of a breaker trip circuit. Figure 7.7 shows a typical application monitoring the lockout relay of a breaker failure relaying scheme. If the circuit includes a timer, such as the breaker failure relay timer of Figure 7.7, then seal-in of the timer through the monitor lamp is prevented by either a tripping diode or lockout relay contact in the timer coil circuit.

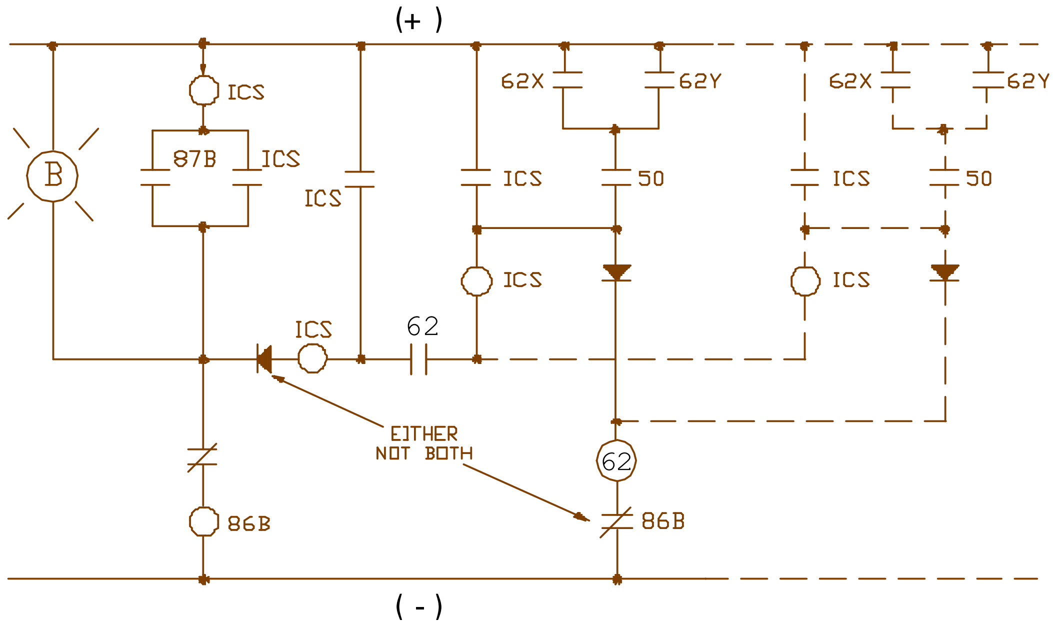


Figure 7.7 - Monitoring 86B Trip Circuit with a Lamp

8. RECLOSING INITIATION AND CANCELLATION

Reclosing

In a simple, non-selective reclosing scheme, the reclosing relay is initiated simply by the opening of the controlled circuit breaker, as sensed by a 52a or 52b auxiliary switch; no connections from the breaker trip circuit to the reclosing scheme are necessary. Such schemes are commonly used for lines operating at distribution voltages.

Higher voltage transmission and subtransmission lines frequently use more sophisticated reclosing schemes in which the decision to reclose and/or the time delay before reclosing is influenced by which protective relays caused the breaker to be tripped. For example, if a breaker can be tripped by either line or bus protective relays, it may be desired to have the breaker reclose following a line relay trip, but remain open if tripped by the bus protection relays. To provide the reclosing scheme with the intelligence to know which of several protective relays have operated, it is often necessary to connect auxiliary devices in the trip circuits. Static relay systems may contain special outputs for reclosing control purposes, but auxiliary relays, diodes, and latching devices are usually necessary when electromechanical relays with only a single output are used.

Two different control signals have come into common use to provide selective reclosing. These are called Reclosing Initiation and Reclose Cancellation (or Reclose Blocking). Either one or both of these signals may be used to provide the desired operation of the reclosing scheme.

Reclosing Initiation

Reclosing initiation (RI) is the name given to a control signal which becomes energized only when the breaker has been tripped by a fault for which reclosing is desired. In the example given above, an operation of the line protective relays would energize the signal while an operation of the bus protection relays would not. The reclosing logic is designed to require the signal to be present before a reclosing cycle can be initiated.

Since all the trip signals to a breaker are combined at the conductor which connects to the trip coil, selective reclosing initiation requires some means of segregating the trip signals. There are two basic ways to accomplish this separation,

- By using tripping diodes and a shunt auxiliary relay, as shown in Figure 8.1.

- By using a series-connected, current-operated auxiliary relay, as shown in Figure 8.2.

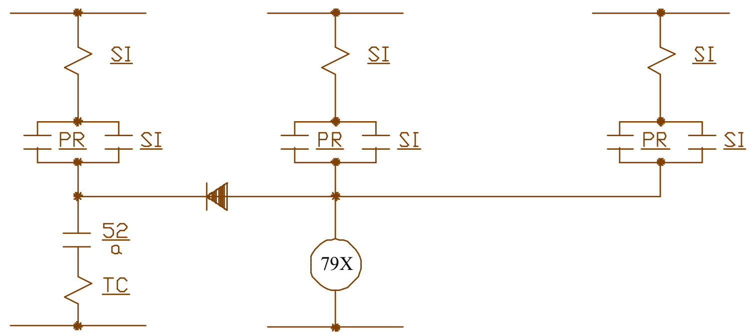


Figure 8.1 - Shunt 79X Device

Either of these approaches can be made to provide the required signals, but each has its own advantages and disadvantages. The shunt scheme per Figure 8.1 requires diodes in addition to the auxiliary relay. A failure of the diode might lead to an automatic reclose for a bus fault for which no reclosing was desired. The shunt relay must either be de-energized by a 52a switch of the circuit breaker, requiring an additional control lead from the breaker or it must be dropped by the protective relay trip contacts if the 52a switch is omitted. In the latter case, the interrupting ability of the contacts should be determined and not exceeded. Suppression of the relay coil's inductive surge may be necessary.

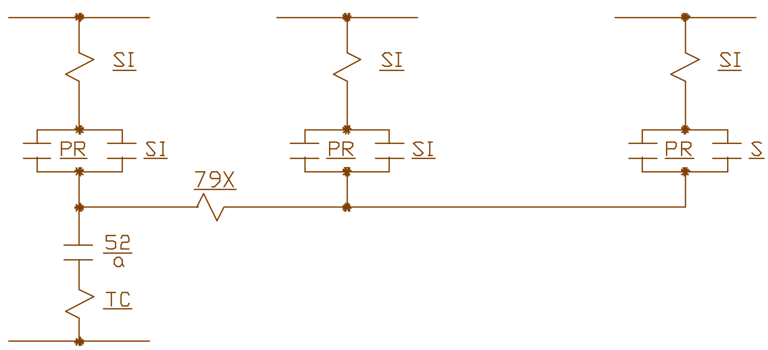


Figure 8.2 - Series 79X Device

The series auxiliary relay adds resistance to the trip circuit. Also, it is only energized for the brief period of time between energizing the trip coil and the opening of the breaker's 52a switch in the trip circuit. Thus the relay must be a quick-operating type since the trip current may only flow for a fraction of a cycle on modern high-speed breakers.

Another problem arises if several series auxiliary relays are used instead of a single one (Figure 8.3). This configuration is sometimes proposed since it appears to eliminate the need to bring all the reclose-initiating trip circuits to a single point. The problem with using several series auxiliary relays is that it may not be possible to select a coil rating which will reliably operate when several of the reclose-initiating relays operate at once, and still have an adequately low resistance and adequately high current capability to be satisfactory when a single relay operates and all the breaker trip current flows through a single series auxiliary. This problem is similar to that of series target coils, discussed in Sections 2.1 and 9.2.

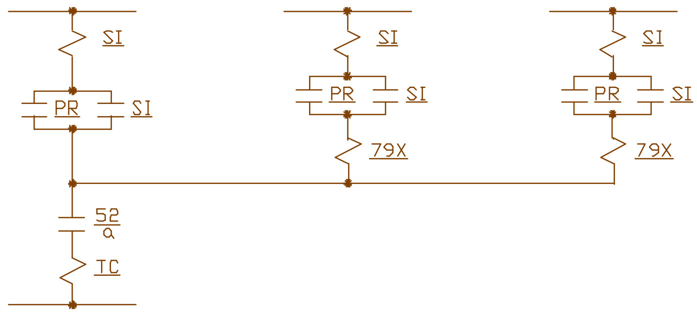


Figure 8.3 - Multiple Series 79X Devices

Reclose Cancellation

The use of Reclose Initiation alone is sometimes not sufficient to guarantee that reclosing will only occur when desired. In the above example, a fault on the circuit breaker might operate both the line protection and the bus protection. Since the line protection initiates reclosing, the breaker will be reclosed even though that would probably be considered undesirable for a fault on the breaker itself. Reclose Cancellation is a means to cancel or block the reclosing operation in order to resolve the above conflict.

Reclose Cancellation can be derived from the trip signals of the relays for which it is desired to block reclosing, using either of the schemes mentioned above. However, since the types of protection for which reclose canceling is desired (bus protection, breaker failure protection, etc.) often trip through lockout relays, the reclose cancel signals could also be taken from isolated contacts of these relays. This technique avoids the problems mentioned under Reclosing Initiation.

Another approach which is possible when lockout relays are used is to connect normally closed contacts of the lockout relays into the close or reclose circuits to prevent an unwanted reclosing signal from reaching the breaker. When this approach is used, one needs to be sure that the reclosing relay will not "store" the reclose and then cause a surprise closing of the breaker when the lockout relay is reset.

Duration and Sequence of Reclosing Control Signals

Signals derived as described above may be of very short duration, particularly those from series auxiliary relays. If the reclosing relay or scheme cannot recognize and latch such brief inputs, it may be necessary to use some form of "dwell extender" to prolong the signals. These dwell extenders could be slow-dropout relays or auxiliary time-delay-on-dropout timers. Avoiding the need for such extenders may be an important aspect in the selection of the reclosing scheme to be used.

The derivation of the Reclosing initiation and cancellation signals and/or the design of the reclosing scheme should be such that the scheme operates as desired even if the 52a, RI, and Reclose Cancellation signals arrive out of the expected sequence.

9. TRIP CIRCUIT APPARATUS

AUXILIARY RELAYS

Electromechanical

Electromechanical auxiliary relays are usually of the hinged armature (clapper) construction. Relays with high inertia moving parts are essentially slow speed devices which have an operating time in the range of 2-5 cycles. On some relays, the operating time can be reduced by operating the relay above rated voltage. For ac relays, applying twice rated voltage produces operating times of 1 cycle. The same operating times can be obtained on dc relays if the voltage applied is five times rated. However, the relays are not capable of withstanding this voltage continuously, and provisions must be made to reduce the voltage applied to the coil to rated values. Pickup is usually 80% or higher of coil rating. The dropout-to-pickup ratio is normally low; about 75% for ac relays and 38% or less for dc relays.

The contacts of most high inertia relays are rated to carry 12 amperes continuously and have a one-minute rating of 30 amperes. The contact interrupting ratings vary depending on the voltage and the L/R ratio of the circuit being switched. At 125 Vdc, the contacts of a typical high-inertia relay can interrupt a resistive current of about 3 amperes.

The energy requirements are dependent on the style of relay selected and vary from 3 to 8 watts for dc relays and 12 VA (closed gap condition) for ac relays. The energizing characteristics of the relay are typical of energizing a series R-L circuit.

A dc auxiliary relay with low inertia components, a sensitive electromagnet, and a proper L/R ratio can produce operating time of approximately 4 milliseconds, including 1 millisecond contact bounce. The pickup and dropout values and energy requirements are similar to the high inertia relays. However, the contacts can only carry 3 amperes continuously and 30 amperes for about 10 cycles. Typical contact interrupting rating for a 125 Vdc circuit is 0.5 A. Therefore, breaker auxiliary contacts or equivalent must be used to interrupt the tripping current.

The interruption of current through a relay coil or a breaker trip coil will produce a transient overvoltage condition in the dc circuits due to coil inductance. Ideally, this could be expressed by the familiar expression of 📪 = -L di/dt, where L is the inductance and di/dt is the time rate of change of current.

In actuality, the contacts interrupting the current do not act as a perfect switch and therefore act as a mechanism for transferring the high potential stored in the stray capacitance of the dc system. As the contacts start to part, a small arc is generated which effectively completes the circuit. As the contacts move farther apart, due to spring action, the arc plasma lengthens, cools, and extinguishes. The dc current is suddenly chopped, and a low frequency oscillatory voltage begins to build across the coil due to the collapse of the magnetic field. This voltage rises rapidly, exceeds the breakdown voltage of the contacts, re-establishes the arc, and discharges the stray capacitive charge into the system. Since the contacts are still moving, the arc is lengthened, cooled, and extinguished only to be re-established again. This restriking is repeated many times. At some point, the voltage built up across the coil is insufficient to cause further breakdown. This overall effect is illustrated in Figure 9.1.

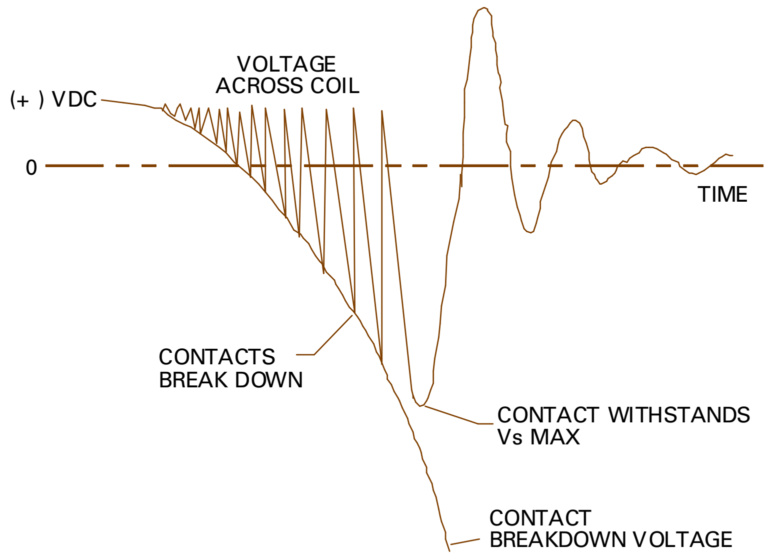


Figure 9.1 - Coil Current Interruption

Static Relays

Static auxiliary tripping relays may include: SCR tripping circuits with series hand-reset mechanical targets, telephone type auxiliary relay units for reclose initiation, breaker failure initiation, and reclose cancel, target lamps, and contact converters for electromechanical relay contact inputs into the static logic.

Printed circuit cards with "AND", "OR", and "NOT" basic logic are used in the relay. The presence or absence of a signal, rather than the magnitude of a signal, controls the operation. Signals are measured with reference to a negative reference bus. In general, a signal below 1 volt represents an "OFF" condition, while for an "ON" condition the voltage is normally in the range of 10 to 15 volts.

The gate source pulses at a high rate to fire the SCR when tripping is required. The SCR requires some minimum current to sustain conduction; therefore, trip circuits with very high L/R ratios, coupled with high resistance, can sometimes inhibit tripping. The high L/R ratio and the high resistance slow the current buildup and shorten the gate pulsing duration. The trip current will have insufficient time to build up to the level required to seal-in the SCR. It is important to ensure that for a trip-free operation, as well as a normal trip of the circuit breaker, the SCR circuit functions as desired. If the breaker trip circuits do inhibit tripping, resistance should be added to ensure seal-in. Minimum design requirements are a current of

100 ma in the SCR trip circuit for 0.6 ms. Careful design of the gate circuit is required to avoid false tripping from transients occurring in the dc trip circuit.

Static tripping relays are frequently equipped with E/M auxiliaries. Typical characteristics are:

- ✐ The breaker failure initiate contacts will pick up in 3-5 ms and drop out in 14-17 ms.
- ✐ The reclose initiate contacts have a pickup time of 14-17 ms and a dropout time of 130-160 ms.
- ✐ Both contacts are rated for 3 amperes continuously and can only interrupt 0.5 amperes (inductive) at 125 Vdc.
- ✐ The standby burden of the relay is 2-3 ma at 17 Vdc and will draw 100 ma in the trip mode.
- ✐ The breaker failure relay coil circuit burden is 48 ma at 125 Vdc.

Lockout Relays

A lockout relay is a two-position electrically operated switch which is usually reset manually or electrically. The contacts are typically rated for 600 volts and 20 amperes continuous. The interrupting rating of a typical 125 Vdc lockout relay is 7.5 amperes (resistive) and 2.85 amperes (inductive 0.031 H).

The relays are available in models having up to 40 contacts available. Some models have two to four shafts ganged to a single operator requiring a high energy operating spring and tripping solenoid. The relay operating time is about one cycle. The operating coils have resistances of from 12 ohms to over 100 ohms for 125 Vdc operation. Some models require a specified dc polarity to the operating coil. The trip coil of the switch has a low continuous current rating.

When tripped, interruption of the coil may produce a transient voltage in the control circuit many times the control circuit voltage. If the control circuit has components that may be damaged by overvoltages, then some form of protection should be provided.

Older models with a large trip solenoid were at one time supplied with a capacitor across the coil interrupting contact to aid in interrupting the circuit. However, this capacitor coupled the transient voltage from the coil into the control circuit with disastrous effect to static relays. Therefore, manufacturers recommended using two interrupting contacts in series without a capacitor. If additional transient suppression is desired, a small diode, or Transorb, and series resistor (100 ohms) may be connected across the coil [7].

Many utilities believe that it is important to periodically trip test lockout relays. See Sections 3.5, 9.5, and 9.6 for information on facilities to permit such testing.

TARGETING AND SEAL-IN DEVICES

Generally, a protective relay is provided with an indicator which provides local indication that the relay has operated to trip a circuit breaker. Such "operation indicator" or "target" or "flag" may be one of the following types:

Mechanical

A simple shutter which is released by mechanical action when the protective relay operates. It is typically manually reset.

Electromechanical

A mechanical shutter is positioned so that the colored portion or flag is not visible when reset. It is moved to a visible position when the solenoid coil is energized by the trip circuit current. It must be manually reset.

Electromagnetic

A small cylindrical permanent magnet which is magnetized across its diameter and lies between the poles of an electromagnet. The magnet, which is free to rotate, lines up its magnetic axis with the electromagnet's poles. The magnet can be made to reverse its orientation by the application of an electrical field, thus exposing the edge of the magnet which is colored to give indication.

Light Emitting Diode (LED)

Normally used on solid state or microprocessor-based relays, the LED is the electronic version of the mechanical flag. An electronic latch circuit causes the LED to remain on until reset.

Normally, only those relays intended to trip circuit breakers are equipped with targets. A push button or some other mechanism is provided to reset the targets after the operating personnel have recorded their indications.

Relay target information is very important for the analysis of system operations. After the occurrence of a fault, the first question asked is, "What were the targets?" so that it can be determined if the operation was correct or incorrect and the appropriate action taken. It is very important that control circuits are designed appropriately to provide target indications from all relays which have given a command to trip a circuit breaker or otherwise control power system equipment.

There are two principal types of targets:

- Shunt targets
- Series targets

Shunt Targets

Shunt targets are operated directly by the protective relay and do not depend on the flow of circuit breaker trip current for their functioning. Their operation indicates the closing of the protective relay's trip contact and not necessarily the completion of a trip circuit to the breaker. Even though the protective relay's trip contact closed, the trip circuit may not have been completed because of other supervising contacts in the trip circuit or because the breaker was already open when the protective relay operated.

Series Targets

A Series Target in the trip circuit operates when a trip circuit has been completed by protective relay contacts, and the flow of current through the trip coil has been established. The series target is generally preferred in the trip circuit, because it gives definite assurance that there was current flow in the trip circuit. However, they can be more complicated to apply because of the need to insure adequate current magnitude and duration to operate the targets of all the protective relays which may operate simultaneously.

Series Seal-In's

When protective relay contacts close to trip a circuit breaker, they momentarily carry the circuit breaker trip coil current. The protective relay contacts are not designed to interrupt the circuit breaker trip coil current. A common practice is to use an auxiliary dc-operated relay to "seal-in" or bypass the protective relay contacts. When the circuit breaker opens, the breaker auxiliary switch (52a) will open to interrupt the trip coil current.

A typical seal-in connection is shown in Figure 9.2. The seal-in relay may display the target, in which case it is referred to as a series target and seal-in unit. The seal-in coil carries the trip coil current once the protective relay contact has closed and, in turn, closes its own contact to bypass the protective relay contact. The seal-in performs the following functions,

- Prevents the protective relay contact from interrupting the trip circuit current.

- Keeps the trip circuit securely closed even if the protective relay contacts chatter.

- Removes the thermal stress on the fine wires connected to the moving contacts of electromechanical protective relays.

Series target and seal-in devices must have their coil ratings matched with the trip circuit on which they are used.

The target and seal-in element of electromechanical relays typically has a dual rating of 0.2/2 amperes or 0.6/2 amperes. In some cases, a 1 ampere rating is also available.

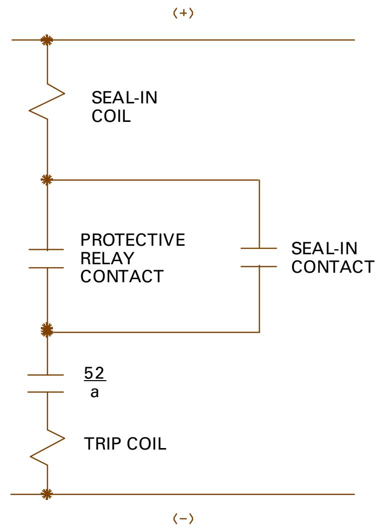


Figure 9.2 - Relay Seal-In Circuit

Typical Ratings of Target & Seal-in Coils

Tap, min pu (amps)	0.2	0.6	1.0	2.0
Dc resistance (ohms)	7-8	0.7-0.8	0.1-0.3	0.15-0.2
Carry continuously (amps)	0.35	1.0	1.8-2.8	2.3
Carry 30 amps for (sec)	0.05	0.5	0.85-3	2.2

The tap to be used on the target and seal-in elements is determined by the current drawn by the trip coil.

- The 0.2 ampere tap is used with trip circuits that operate on currents ranging from 0.2 to about 3 amperes at the minimum control voltage or when a low current auxiliary relay is used for indirect tripping. If the 0.2 ampere tap is used with trip coils that require more than 3.0 amperes, there is a possibility that the higher resistance of this tap could reduce the trip current and prevent the circuit breaker from operating.

- The 2.0 ampere tap should be used with trip circuits that take 3.0 amperes or more at the minimum control voltage, provided that the tripping current does not exceed 30 amperes at the maximum control voltage.

- The target/seal-in coil rating or tap used is critical to obtaining proper targeting, operation of the trip circuit, and proper tripping of the breaker. Therefore, documentation and field verification of the target/seal-in rating or tap setting should be treated the same as other relay settings.

Additional information on coordination of series target coils with breaker trip currents is provided in Sections 2 and 3. Use of series target coils with auxiliary relays is discussed in Section 3.4. The Appendix provides test data on the time/current values required for the reliable operation of targets in target/seal-in units.

BREAKER TRIP COIL CHARACTERISTICS

Voltage Ratings

Circuit breakers must operate correctly over a range of voltages around their nominal voltage rating. This range is specified in ANSI/IEEE Standard C37.06-1987, Table 9 [8].

Low and Medium Interrupting Capacity Breakers Rated 5 Cycles Interrupting Time

Breakers of this type are generally tripped by a trip solenoid to release the trip latch. The trip solenoid armature may be directly linked to the trip latch, or it may operate a rod or pin to strike the trip latch lever. Those breakers which are not mechanically trip free also include a trip-free valve coil in series with the trip coil to exhaust air from the closing cylinder.

The trip coils are usually full voltage coils requiring from 5 to 11 amperes at 125 V.

It is usually essential that full tripping voltage be applied to the trip coil during the first cycle to obtain reliable tripping. The inertia of the moving trip armature may be needed to strike the trip lever with sufficient force to reliably release the trip latch and rollers which may tend to freeze after long periods of inactivity. If the trip coil is energized gradually, it may never trip the breaker. Inadequate initial trip coil voltage is the primary cause of breakers failing to trip and burned up trip coils.

High Capacity Breakers Rated 3 Cycles or Less Interrupting Time

Full voltage trip coils have considerable inductance which do not permit high speed tripping. Higher speed requires reduced inductance of the trip coil by fewer turns, more current, and series resistance to limit the current and reduce the L/R ratio. One design used a 12 ohm, 10 A coil for 5 cycle breakers and the same trip solenoid with a 6 ohm, 20 A coil (1/2 the turns, same wire size) with no series resistor for 3 cycle breakers. The same ampere turns are required. Larger wire could be used but would require a series resistor to limit the current to 20 A.

Another design uses a magnetic latch where the spring loaded trip latch armature is held in place by a permanent magnet. The trip coil demagnetizes the structure to permit high speed tripping. When the breaker is closed, an exciting coil is momentarily energized to magnetize the magnet and hold the latch armature. One design has a trip coil current of 6.7 A at 125 V and includes a series connected trip-free coil. Other designs have a trip coil operating at 5 to 6 A with a 15 ohm series resistor (for 125 Vdc) and a parallel trip-free coil, requiring 5 to 10 A, which is energized only with air pressure in the closing cylinder. Therefore, the tripping current requirements are 5 to 6 A for the initial trip and 10 to 16 A for trip-free operations when closed into a fault.

A modern SF6 three pole breaker uses gas valves requiring low energy to operate for tripping. This breaker has a 25 ohm trip coil and 25 ohm series resistor drawing only 2.5 A at 125 Vdc. The two trip circuits are made completely independent by the use of two separate tripping valves.

Gas Operated Independent Pole Breakers

High speed gas operated breakers use high pressure gas to open and/or close the breaker contacts. Tripping involves operating gas valves at high speed. Some designs use low energy devices with the three trip coils of the three independent phases connected in series for three phase operation. The trip current may be from 8 to 15 A for 125 V with the current limited primarily by series resistance. The circuit has negligible reactance. The trip circuit with three coils in series also includes a 52a switch arrangement to insure that all three poles are tripped and pole disagreement circuitry to trip all poles if one should fail to operate. See Figure 6.3 for a typical arrangement. It may also include provisions to prevent burning up the trip coils and initiate backup tripping if one pole fails to open.

The three trip coils may also be connected in parallel for three pole operation as in Figure 6.1, or operated independently for single pole breaker operation.

Other designs of gas operated breakers require high energy input to operate the tripping gas valves against high pressure gas. This may apply for three pole dead tank breakers having only two independent trip coils and also live tank breakers having up to four trip coils per pole for each of two independent systems. The high impulse trip current required to operate the valves is obtained by use of low resistance trip coils energized through capacitors shunted by a resistor to limit the continuous current. The values for one 3-pole 345 kV breaker are 1.5 ohm trip coil, 500 µF capacitor, and a 10 ohm resistor. The impulse current is 30 A or more, and the steady state current is 11 A. The impulse current of other breakers may be 40 A or more at 125 V. when tripping all three poles.

The nameplate for this type of breaker may list only the steady state current requirement, not the impulse current. However, the trip circuit must be designed to deliver the impulse current value for successful high speed breaker tripping. By the time a seal-in relay picks up, the capacitor has charged and the trip current is limited by the resistor. The breaker will not trip at the steady state current value. This means that the total trip circuit wiring and relay contacts, target, and seal-in coil resistance must be such that the voltage drop is not excessive when carrying the impulse current. When tripping two breakers, or one or more breakers with redundant trip coils, it may be necessary to have no common wiring except from the battery to the power distribution panel.

Trip Circuit Characteristics - Interactions of Multiple Trip Coils

Some breaker designs use two independent trip solenoid units so that there is no mechanical or electrical interaction between the two coils. Other designs use a single trip solenoid with either two independent coils or a single spool with two coils, one wound over the other. A manufacturing requirement of the latter design is to insure adequate insulation separating the two windings. With the usual connection, the induced voltage produced when the trip circuit is opened appears across the insulation separating the two windings. The enamel insulation of the wire is not adequate.

With two trip coils on the same magnetic structure, energizing one coil will induce a pulse into the other trip coil and trip wire. This usually causes no problem, but may need to be considered in connection with transfer trip as discussed in Section 5.4. When the trip coil is de-energized, a negative pulse is induced into both coils by the collapse of magnetic flux, but the voltage is blocked from the trip wire by the 52a contact.

One breaker design uses a pneumatic control valve with 4 coils wound on one spool✍close, cutoff, and two trip-free coils. The breaker has a magnetic trip latch with an exciting coil and two trip coils. When returning the breaker to service after a lengthy station outage, one utility experienced immediate tripping without relay targets. Investigation revealed that closing the breaker produced two positive pulses of about 140 V on the trip circuit and then one negative pulse. The positive pulses came from the trip coil when the exciting coil was energized and from the trip-free coil when the air valve cutoff coil was energized. The negative pulse was caused by the reversed flux through the trip coil when the magnetic trip latch armature closed. The positive pulses were blocked from the relay circuit by the trip circuit diode. The negative pulse, however, was passed by the diode and operated the high speed breaker failure initiation auxiliary relay which tripped the breaker via the opposite trip coil. The solution was simply a diode across the auxiliary relay coil. The problem had not been recognized earlier, because no false tripping occurred at normal battery voltage. At the time of the problem, the station battery had been discharged and was being held at 140 V temporarily.

Where the individual trip coils operate independent trip solenoids, the dc circuit polarity to each coil is not important. Where both trip coils operate a common solenoid or trip latch mechanism, the same dc polarity must be applied to both. If the trip latch contains a permanent magnet, then the dc circuit polarity to the exciting coil and both trip coils must be as specified by the manufacturer.

Since both trip coils of a breaker may be energized simultaneously by the two relay systems, initial tests of the breaker and tests after any trip circuit wiring changes should verify proper tripping by each trip coil alone. Then both trip coils should be energized simultaneously to verify proper tripping and proper dc circuit polarity to both coils if on a common solenoid. One utility experienced failure of new breakers to trip when both trip coils were energized simultaneously -- not because of reversed polarity to one coil, but due to too high an energy level with both coils energized. The manufacturer furnished series resistors to limit the current in each coil for satisfactory operation with each coil or both.

Pneumatically trip-free breakers must observe proper relative polarity to the close, cut-off, and trip-free coils which operate the common solenoid valve. Initial tests and tests after any wiring changes should verify proper trip-free operation with either trip circuit energized and with both trip circuits energized simultaneously.

SURGE PROTECTION DEVICES

Surge Capacitors

Surge capacitors, connected from positive-to-ground and negative-to-ground, are found in many protective relays and supervisory equipment to reduce the magnitude of high frequency surges found on the substation battery. Dc system surges have been measured in the control houses to be as high as 4 kV with the operation of a breaker trip or close coil. Electromechanical relays can withstand trip and close coil surges without the addition of surge protection capacitors, while much of the electronic equipment requires surge protection capacitors. It has been found that in large stations, dc surge capacitors added to normal wiring capacitance-to-ground produce an overall capacitance-to-ground as high as 100 to 300☞f. This high capacitance, produced by both lumped and distributed capacitance on both the positive and negative station battery leads, can result in inadvertent auxiliary relay operation (resulting in undesired breaker tripping). Low-energy auxiliary relays operate readily when capacitances of these magnitudes are charged or discharged through the auxiliary relay's coil. Please see Figure 9.3.

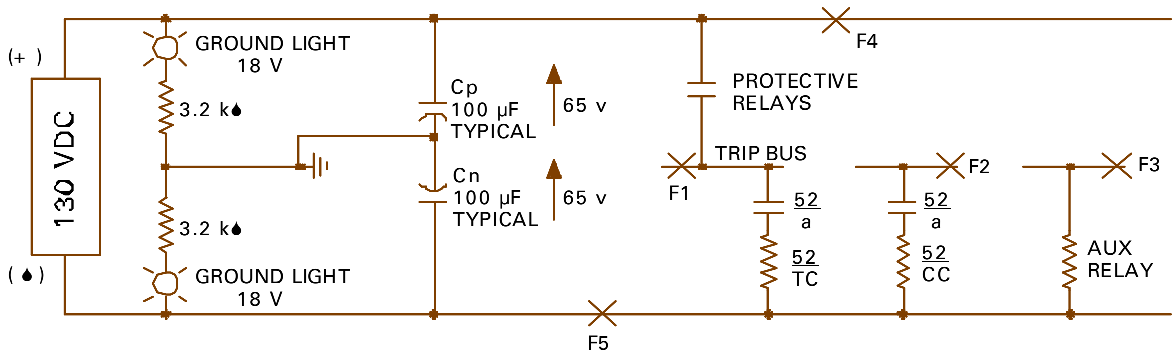


Figure 9.3

In Figure 9.3, 52/TC and 52/CC represent a circuit breaker trip and closing coil. Aux is an auxiliary relay. Cp represents the combined effects of lumped and distributed capacitance on the positive battery leads, and Cn represents the same for the negative battery lead. The values of the capacitance Cn and Cp are normally equal capacitance.

Therefore, with equal leakage current through each capacitor and normal resistance-light grounding, the voltage across Cn and Cp will be equal to 1/2 of the battery voltage. Therefore, for a 130 V battery, one can measure 65 volts across Cp and Cn under normal conditions.

If the trip bus is accidentally grounded at F1, the capacitance of Cn with its 65 V will discharge through the trip coil. In addition, Cp will charge through the coil to 130 volts with the combined effect possibly picking up the trip coil and calling for a trip if sufficient energy is present in the circuit. Also, a ground applied at F2 could result in closing the breaker if it were open at that time. A ground at F3 can result in the operation of the auxiliary relay if it has a pickup threshold of less than one-half battery voltage. A ground to either the positive or negative bus (F4 or F5) will not cause a relay pickup.

Some electric utilities have installed resistance grounding at the station battery to reduce the charge on Cn and have thereby reduced the chance of inadvertently picking up relays (see Figure 9.4).

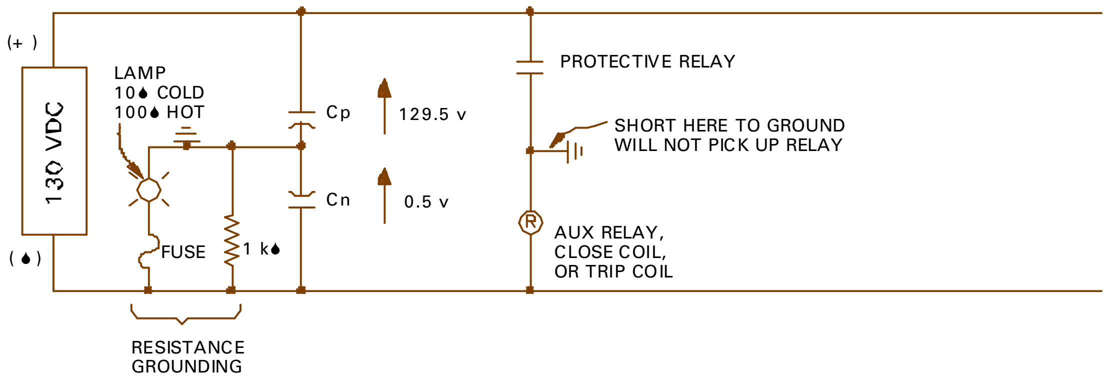


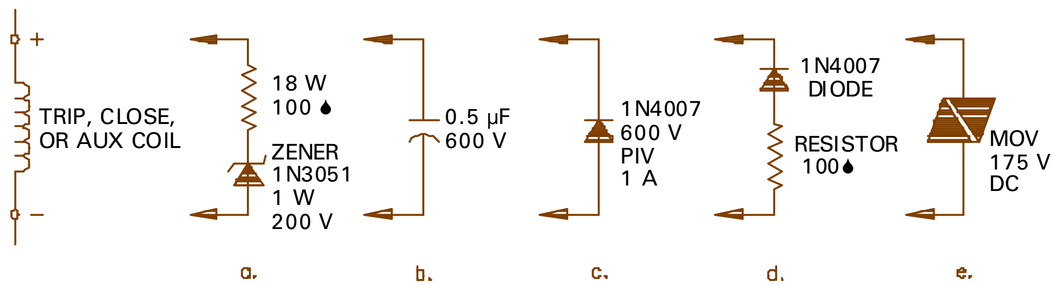
Figure 9.4

Varistors

Varistors are used to provide overvoltage protection to relays and other equipment tied to the dc station battery supply. MOV (metal-oxide varistors) are used to clamp voltage surges and prevent damage to equipment due to overvoltage surges. These devices are voltage dependent, symmetrical, metal-oxide semiconductor devices. Their characteristics (similar to back-to-back zeners) enable them to protect against high transient voltage spikes. When protected equipment encounters a voltage surge, the varistor impedance changes from a very high standby value to a very low conducting value, clamping the transient voltage to the protective level. MOVs can be used on both ac and dc circuits. MOVs have relatively high capacitance and therefore cannot be used in high frequency circuits where the high capacitance would short the signal (a typical 130 Vac - 175 Vdc 70 Joule unit has a capacitance of 1900 pF). Energy rating is important in choosing MOVs to prevent thermal failure due to excessive heating.

Coil Surge Suppressors

Trip and close coils can produce very high voltages (more than 4 kV) when the operating current is interrupted. Therefore, surge protection is often used to prevent damage to delicate electronic equipment found in modern substation control houses. One utility company found that their new supervisory equipment would fail to operate reliably until coil surge protection was added to breaker trip and close coils. Figure 9.5 shows several types of surge protection circuits. Values are typical for 130 Vdc systems.



a. Resistor and Zener combination are used for surge reduction. Resistor is used to allow coil operation should zener short. Zener slows dropout of coil, but does not affect pickup.

b. Capacitor is used to reduce surge peak value. This capacitor will slow pickup and dropout of coil.

c. Diode will prevent voltage kick, but can short and prevent coil operation. Slows drop-out of coil.

d. Resistor combination similar to "a," but uses plain diode. Diode more likely to fail compared to zener with controlled reverse breakdown voltage. Diode slows drop-out of coil; no effect on pick-up time of coil.

e. MOV similar to back-to-back zener; must be sized to absorb surge energy from coil and withstand steady-state station voltage without conduction.

Figure 9.5

SWITCHES IN RELAY TRIP CIRCUITS

Utility practices vary widely concerning the use of switches in the dc power and trip circuitry for protective relays. Some utilities do not permit switches at all, whereas others use them extensively. There is also not a standard nomenclature as to what name to use for the various switching functions. The terms "cutout" and "cutoff" switches are frequently used, but are not preferred because of imprecision and possible confusion with other devices.

Types of Switching Functions

1. **Trip Test Switches** are used to disconnect the contacts of a tripping device or auxiliary tripping relay from the trip coils of one or more circuit breakers or circuit switchers. The Trip Test Switches are operated by relay test engineers or technicians and not usually by station operating personnel, except upon direction by the technicians. Some users prefer the Trip Test Switches to be mounted on the rear of the switchboard panel on which the tripping relays are located. Other users prefer the Trip Test Switches to be mounted at the front of the panel where access to the relay contacts and controls is also available.

It should be noted that these Trip Test Switches are incorporated within the case of some styles of auxiliary tripping relays. The test switches are covered except when the covers are opened for testing. The Trip Test Switches for a specific scheme, such as a transformer differential lockout relay, are normally grouped together in one location with nameplates or tags for easy identification.

Trip Test Switches are often in the form of small knife switches. The contacts are often identified as the "blade" (the moving contact) and the "clip" (the stationary contact). Some users prefer to connect the trip coil lead to the clip side of the switch so that accidental contact with the exposed blade contact in the open position cannot cause an accidental trip. However, this choice of connection is reversed from the connections to the corresponding test switches incorporated in the cases of some styles of protective and auxiliary tripping relays. In those relays, the external connections are made to the blade terminal. Therefore, other users, seeking uniformity, connect the trip coil lead to the blade terminal of separately mounted Trip Test Switches to match the practice of the relay case test switches.

2. **Control Power Switches** (ANSI Device 8), often called "DC Cutouts" or "DC Power Switches" are used to remove control or auxiliary power from a relay or relay system to facilitate maintenance. They are generally accessible only to authorized relay maintenance personnel, through either procedures or mechanical covers and locking means.

3. **Relay Disabling Switches** (ANSI Device 5), are often called "Relay Cutout Switches", "Relay Test Switches" or, sometimes, "Trip Cutout Switches." They are used to disable a particular relay or relay system by disconnecting the relay trip contacts from the trip coil of its associated circuit breaker or auxiliary relay. These switches are mounted on the front of the switchboard panel with associated nameplates indicating their function. The Relay Disabling Switches are operated by station operating personnel manually or remotely and are used to take certain relays out of service when a relay misoperates, during certain operating conditions, or during relay testing.

4. **Feature Disabling Switches** (ANSI Device 43), often called "Feature Cutout Switches", "Relay Control Switches", or "Operation Selector Switches" are used to select a given automatic feature or relay system manually or remotely. The Feature Disabling Switches are mounted on the front of the switchboard or relay equipment rack with identifying nameplates and are operated by station operating personnel. A common example is the "Channel Cutoff Switch" or "Carrier Relay Switch," used in directional-comparison blocking line protection schemes, which disables tripping by the carrier blocking scheme, but leaves the Zone 1 and time-delayed zones in service.

The practices of various utilities in the use or avoidance of such switches have developed over time, heavily influenced by experience, the type of switchyard arrangements used, and the training given to personnel. It is not appropriate for this document to recommend one practice over another. However, the following list of advantages and disadvantages may give some guidance.

Advantages

The basic advantage of using switches is the flexibility which they provide.

- They may permit maintenance of relay equipment without the need to remove power equipment from service, provided adequate alternative or backup protection is provided.
- They can improve the security of relay testing by giving confidence that all trip paths from the equipment under test have been opened.
- The switches can also permit abnormal operating arrangements without requiring intervention by technicians to maintain adequate protection. For example, a certain bus arrangement may require the disabling of a differential relay.
- Finally, they may permit rapid restoration to service of power equipment which has been unnecessarily tripped by defective relays, again provided that adequate backup protection is available.

Disadvantages

Besides the cost of the switches and their installation, there are some other disadvantages to their use.

- The switches may fail, whereas a direct connection would be less likely to fail.
- The switches may be operated incorrectly, disabling needed protection.
- The switches may be inadvertently left open, disabling protection for an extended period of time.

These hazards to protection must be addressed during the overall protection system design. If switches are to be used, careful consideration must be given to who has access to them and to specific procedures for their use.

TRIP TESTING

Trip testing is utilized by many utilities to verify that individual relays or relay systems actually trip the breaker(s) or energize the appropriate auxiliary relays they were intended to by design. This verifies the continuity of each trip circuit as well as the target operation of different relays. Trip testing is performed during the initial installation and at any time changes are made to the dc trip circuits or when a new breaker trip coil is installed. Trip testing is also performed as the final act of a complete routine maintenance testing operation.

Trip testing is done by manually closing the tripping contact of each electromechanical relay and making sure that the breaker operates. Static relays are operated either by test current or built-in trip test switches; manually closing the output relay contacts of a static relay is not as good a test since it could fail to detect some incorrect wiring conditions, e.g. lack of dc power supply to the relay. Initial trip tests, and after wiring changes, should also include all seal-in contacts to insure that their wiring is intact.

In order to avoid numerous circuit breaker operations during trip testing, many relay testing engineers or technicians disable circuit breaker tripping and simulate the breaker trip coil with a temporary lockout auxiliary relay. After all tripping relays have picked up the auxiliary relay, the breaker is tripped only once by one relay or relay system. This procedure could be used during minor trip circuit design modifications but is not appropriate for initial installations.

If a temporary breaker substitution test box is used for most trip testing as described above, it is important to make sure that the actual breaker is tripped by the relay system having the greatest impedance through target and seal-in coils. If there is any doubt of tripping voltage adequacy because of relay contact circuit impedance, a transient recording of the tripping voltage at the breaker terminals should be made. An alternate method would be to use a reduced voltage tap of the station battery, or insert a resistor to give a 15 or 29 volt drop, to insure that there is adequate margin for reliable tripping.

Each relay or relay system is different from other relays or relay systems; and the voltage drop in these relays is different during tripping, thus applying different voltages to the breaker trip coil. Problems in tripping a breaker with a different relaying system have been experienced due to large voltage drops in the relaying system and the dc wires from the battery to the relay panel.

Another form of trip testing, usually done at initial installation, involves closing the contacts of all relays which can be expected to operate simultaneously in order to verify that all will drop targets under this condition. If auxiliary relays are used in the tripping scheme, their operation should be included in the test. Trip circuits should be designed to permit this type of testing.

Trip testing is a very important part of the installation of new relays and circuit breakers, and it can guarantee proper functioning of the dc trip circuits only if it is done properly.

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11. APPENDIX

This appendix reports on the results of tests made by one of the Working Group members to determine the magnitude and duration of trip current pulses necessary to assure reliable operation of electromechanical relay targets. Tests were made on three relays of U. S. manufacture. All tests were made with a source voltage of 24 Vdc and a programmable electronic load which provided essentially square current pulses of programmable magnitude and duration.

Data is reported here for six test sequences, as indicated below,

Test #	Target Type	Pickup Tap	Seal-In Type
1	Dropping	2 amp	single, enabled
2	Dropping	2	single, disabled
3	Dropping	2	double, enabled
4	Dropping	0.2	single, enabled
5	Raising	2	single, enabled
6	Raising	0.2	single, enabled

Notes:

1. A "dropping" target type is one in which the shutter is normally latched and, when released by the armature, falls under the influence of gravity to expose the colored target.

2. A "raising" target type is one in which the shutter is raised and latched by the armature to expose the colored target.

3. A double seal-in provides seal-in for two trip circuits, a single seal-in for only one.

4. When the seal-in was disabled, the stationary contacts of the seal-in were adjusted so that the moving contacts could not reach them.

5. These data were taken on only a single relay of each type. The results should not be construed as guaranteed or even average values. However, they may be useful in indicating the approximate values of current and duration needed for reliable target operation.

Target Test Results

Notes: 1. All tests made at 24 Vdc with HP 6063B programmable electronic load with rise time of 0.833 a/μs, an essentially instantaneous rise compared with the pulse duration.
2. PU = Pickup; DO = Dropout

Test 1. Type: **Target Dropping** Rating: 0.2/2 on **2 amp tap** Seal-in: **single, enabled**

Test PU = 1.80 amps Test DO = 0.7 amps

Targets per 10 Operations

Duration (ms)	2 amps	3 amps	5 amps	7.5 amps	10 amps
5	0	0	0	0	0
7.5	0	0	0	0	0
10	0	0	0	0	0
12.5	0	0	0	6	6
15	0	10	8	6	6
20	0	10	10	10	10
25	9	10	10	10	10
30	10	-	-	-	-

Test 2. Type: **Target Dropping** Rating: 0.2/2 on **2 amp tap** Seal-in: **single, disabled**

Test PU = 1.85 amps Test DO = 0.50 amps

Targets per 10 Operations

Duration (ms)	2 amps	3 amps	5 amps	7.5 amps	10 amps
10	0	0	0	0	0
12.5	0	0	10	10	10
15	0	10	10	10	10
20	0	9	10	10	10
25	4	10	-	-	-
30	10	10	-	-	-

Test 3. Type: **Target Dropping** Rating: 0.2/2 on **2 amp tap** Seal-in: **double, enabled**

Test PU = 1.85 amps Test DO = 1.20 amps

Targets per 10 Operations

Duration (ms)	2 amps	3 amps	5 amps	7.5 amps	10 amps
10	0	0	0	0	0
12.5	0	0	3	4	5
15	0	5	3	3	4
20	0	8	8	9	8
25	5	10	10	10	10
30	5	10	10	10	10
35	10	10	10	10	10

Test 4. Type: **Target Dropping** Rating: 0.2/2 on **0.2 amp tap** Seal-in: **single, enabled**

Test PU = 0.18 amps Test DO = 0.07 amps

Targets per 10 Operations

Duration (ms)	0.2 amps	0.3 amps	0.5 amps	0.75 amps	1.0 amp	2.0 amps
5	0	0	0	0	0	0
7.5	0	0	0	0	0	2
10	0	4	0	9	0	4
12.5	0	1	10	10	7	10
15	0	10	9	10	10	10
20	9	9	9	10	10	10
25	10	10	10	10	10	10

Test 5. Type: **Target Raising** Rating: 0.2/2 on **2.0 amp tap** Seal-in: **single, enabled**

Test PU = 1.8 amps Test DO = 0.8 amps

Targets per 10 Operations

Duration (ms)	2 amps	3 amps	5 amps	7.5 amps	10 amps
7.5	0	0	0	0	0
10	0	0	8	9	10
12.5	0	10	10	10	10
15	0	10	10	10	-
17.5	0	10	-	-	-
20	0	10	-	-	-
25	10	10	-	-	-
30	10	-	-	-	-

Test 6. Type: **Target Raising** Rating: 0.2/2 on **0.2 amp tap** Seal-in: **single, enabled**

Test PU = 0.18 amps Test DO = 0.08 amps

Targets per 10 Operations

Duration (ms)	0.2 amps	0.3 amps	0.5 amps	0.75 amps	1.0 amp	1.5 amp
7.5	0	6	10	10	10	10
10	0	10	10	10	10	10
12.5	0	10	10	-	-	-
15	0	10	-	-	-	-
17.5	10	-	-	-	-	-
20	10	-	-	-	-	-