IEEE Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines

IEEE Power & Energy Society

Sponsored by the
Power System Relaying Committee

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IEEE Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines

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Power System Relaying Committee
of the
IEEE Power & Energy Society

Approved 8 June 2012

IEEE-SA Standards Board

Abstract: Current reclosing practices for transmission and distribution lines are described. Application considerations and coordination practices of reclosing are also discussed.

Keywords: automatic operation, circuit breaker, distribution, IEEE C37.104, reclosing, transmission

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Introduction

This introduction is not part of IEEE Std C37.104-2012, IEEE Guide for Automatic Reclosing of Circuit Breakers for AC Distribution and Transmission Lines.

The art and science of protective relaying for the automatic reclosing of circuit breakers associated with distribution and transmission lines following the clearing of a fault have evolved over many years. This guide is an effort to compile information on the application considerations associated with this practice. The guide presents generally accepted practices for autoreclosing. Its purpose is to describe the methods and considerations associated with situations in which it is desirable to reclose automatically. It is intended for engineers who have a basic knowledge of power system protection. This is an application guide and does not cover all of the requirements for autoreclosing for every situation or protection scheme. Additional reading material is suggested so that the reader can evaluate the application of autoreclosing for the individual situation.

Contents

IEEE Guide for Automatic Reclosing of ~~Line~~ Circuit Breakers for AC Distribution and Transmission Lines

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1. Overview

1.1 Scope

~~The purpose of~~ This guide documents present practices regarding ~~is to establish guidelines for~~ the application of automatic reclosing control ~~facilities~~ to line circuit breakers. Both transmission and distribution line practices are addressed. The guide is not intended to provide guidance for the operation of the bulk power system in matters of reclosing, such as enabling or disabling automatic reclosing or providing for manual closures following automatic tripping of an element.

~~This guide describes current automatic reclosing practices for ac distribution and transmission lines. Included within this description are application considerations and coordination practices for reclosing.~~

1.2 Purpose

The guide provides benefits of automatic reclosing and provides application considerations for proper coordination with other system controls (e.g., autosectionalizing, fast-valving, etc). The guide includes a section on emerging technologies (e.g., IEC 61850) and their application to automatic reclosing. Supplementary information is comprised of annexes containing a bibliography of technical literature concerning reclosing as well as a brief history of the use of automatic reclosing.

~~Automatic reclosing can restore or facilitate restoration of the system to normal, following automatic tripping of distribution and transmission facilities. Throughout this guide, the shorter term "autoreclosing" will be used in place of~~ ~~*automatic reclosing*~~~~. Italicized terms are defined in Clause 3 of this guide.~~

~~Autoreclosing may be applied for the purpose of restoring distribution and transmission lines to service subsequent to automatic tripping of their associated circuit breakers due to electrical faults. Experience indicates that many faults on the overhead power system are temporary. In the absence of autoreclosing, longer duration outages could be experienced unnecessarily. Successful autoreclosing can enhance stability margins and overall system reliability. However, autoreclosing into a permanent fault can adversely affect system stability, damage equipment, or have adverse effects on customers; hence, due consideration shall be given to this aspect of any application. See Annex B for a brief history of automatic reclosing.~~

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~This guide shall be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply.~~

IEEE Std ~~ANSI~~ C37.06™ IEEE ~~-2000~~, ~~American National~~ Standard for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis—Preferred Ratings and Related Required Capabilities~~[1]~~ for Voltages Above 1000 V.[1,2]

IEEE Std C37.04™ ~~-1999~~, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.

IEEE Std C37.60™ ~~-1981 (Reaff 1992)~~, IEEE Standard Requirements for Overhead, Pad Mounted, Dry Vault, and Submersible Automatic Circuit Reclosers and Fault Interrupters for AC Systems.

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IEEE Std C37.63™, IEEE Standard Requirements for Overhead, Pad Mounted, Dry Vault, and Submersible Automatic Circuit Sectionalizers for AC Systems.

IEEE Std C37.116™, IEEE Guide for Protective Relay Application to Transmission-Line Series Capacitor Banks.

~~IEEE Std C37.61™-1973 (Reaff 1992), IEEE Standard Guide for Application, Operation, and Maintenance of Automatic Circuit Reclosers.~~

3. Definitions

For the purposes of this document ~~guide~~, the following terms and definitions apply. The *IEEE* ~~100™ [B6]~~ *Standards Dictionary Online* should be consulted ~~referenced~~ for terms not defined in this clause.[3]

~~NOTE—Those terms marked with an asterisk (*) are also listed in IEEE 100 [B6].~~

automatic: Refers to either local or remote switching operations that are initiated by relay or control action without the direct intervention of an operator.~~*~~

automatic circuit recloser: A self-controlled device for automatically interrupting and reclosing an alternating-current circuit, with a predetermined sequence of opening and reclosing followed by resetting, hold-closed, or lock-out operation.

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[3] *IEEE Standards Dictionary Online* subscription is available at http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

automatic line sectionalizer: A self-contained circuit-opening device that automatically opens the main electrical circuit through it after sensing and responding to a predetermined number of successive main current impulses equal to or greater than a predetermined magnitude. It opens while the main electrical circuit is de-energized. It may also have provision to be manually operated to interrupt loads.

autoreclosing: The automatic closing of a circuit breaker in order to restore an element to service following automatic tripping of the circuit breaker. Autoreclosing does not include automatic closing of the circuit breakers associated with shunt or series capacitor banks or shunt reactors.

blocking: Refers to the automatic prevention of an action following specific relay tripping operations.

breaker autoreclosing time: The elapsed time between the energizing of the breaker trip coil and the closing of the breaker contacts to re-establish the circuit on the autoreclose operation.

dead time: That period of time the circuit breaker is open and the controlled circuit is de-energized following the tripping operation for a fault and before the autoreclosing attempt.*

delayed autoreclosing: Refers to the autoreclosing of a circuit breaker after a time delay that is intentionally longer than that for high-speed autoreclosing.

drive-to-lockout: The process of forcing the autoreclosing function to its lockout state.

high-speed autoreclosing: Refers to the autoreclosing of a circuit breaker after a necessary time delay to permit fault arc deionization with due regard to coordination with all relay protective systems. This type of autoreclosing is generally not supervised by voltage magnitude or phase angle.

lockout: The state of the reclosing relay wherein the controlled line breaker is open and the relay disabled from making any further reclose attempts.*

manual: Refers to either local or remote switching operations that are initiated by an operator.

multiple-shot autoreclosing: Refers to the autoreclosing of the circuit breaker(s) more than once within a predetermined autoreclosing sequence.

permissives: Those measured functions or system conditions that must be satisfied prior to allowing the reclosing action to proceed.

reclosing relay: Programmable relay whose function is to initiate the automatic reclosing of a circuit breaker.

shot: Autoreclose attempt that is initiated by command of the reclosing logic.

single-phase autoreclosing: *See also:* **single-pole autoreclosing.**

single-pole autoreclosing: Refers to the autoreclosing of one phase of a circuit breaker following a designed single-phase trip for single-phase-to-ground faults.* Also referred to as single-phase autoreclosing.

sync check: *See also:* **synchronism check**

synchronism check: A verification that voltages on both sides of the breaker are within predetermined limits of magnitude, phase angle, and frequency.

transfer trip: A form of remote trip in which a communication channel is used to transmit a trip signal from the relay location to a remote location.*

4. Fundamentals and applications

~~4.1 Basics~~

This clause describes fundamental concepts common to automatic reclosing for both transmission and distribution line breakers. In the most common applications, automatic reclosing is performed following a protective relay trip for a fault on the protected line, in particular, where there is a good probability that the fault was temporary, and automatic reclosing can be used to quickly re-energize the line to restore system integrity, service to customers, or both. However, as discussed, circuit breakers may also be automatically reclosed following a relay initiated bus trip, again where there is a good possibility that the fault was temporary and automatic reclosing will speed restoration of the bus and system integrity.

As most faults on overhead electrical systems are temporary in nature, the use of automatic reclosing (autoreclosing) aids in the restoration of the system in a timely manner, much more quickly than is possible by local-manual or remote-manual control. To apply autoreclosing properly, several factors should be considered ~~addressed~~. Some of the most common considerations ~~frequently asked fundamental questions~~ are as follows:

a) What is the probability of successfully reclosing the ~~faulted~~ circuit following a trip?

b) What is the potential for damage to the system components by autoreclosing into a fault?

c) Are special interlocks required to inhibit autoreclosing under certain conditions?

d) Should the autoreclosing be time-delayed or is high-speed autoreclosing allowed?

e) How many autoreclosing attempts should be used for the application?

f) Should voltage supervision be applied?

g) Should there be a synchronism check?

h) What are the consequences of not autoreclosing?

i) On networked lines, what terminal of the line should be selected as the lead reclosing terminal?

j) How should autoreclosing be initiated?

These ~~above~~ fundamental questions are discussed in the remainder of this guide.

4.1 The autoreclosing function performed by a reclosing relay

The autoreclosing function has traditionally been performed by a reclosing relay that is dedicated to a specific circuit breaker. However, the autoreclosing function can be performed by any number of devices or processes that get an input to identify when the circuit breaker is opened or closed, and, in some cases, how the breaker is tripped, i.e., manually, or by protective relay action. Programmable Logic Controllers, substation computers, and even supervisory control and data acquisition (SCADA) systems have been used to perform the autoreclosing function. Most microprocessor-based transmission line and distribution feeder protective relays have a built-in autoreclosing function. For the sake of consistency, this document refers to a reclosing relay as a device that performs the autoreclosing function, regardless of whether it is a separate relay, or it is a function within a protective relay, or it is simply logic programmed into another device.

The autoreclosing function can be considered to be in one of four distinct states:

— Reset state: The circuit breaker is closed and the autoreclose function is waiting to receive an initiate to start timing to reclose after the breaker opens.

— Cycle state: The circuit breaker is open and the autoreclose function is timing toward its set time to close the circuit breaker, OR, the circuit breaker is closed following a successful autoreclose, timing toward its set time to return to the reset state.

— Lockout state: The autoreclosing function has advanced through its programmed or set sequence of circuit breaker close operations, and in each case the protective relay has detected a fault and tripped the circuit breaker open again. The circuit breaker is now open and locked out, meaning that the circuit breaker must now be closed by some other means (local-manual or remote-manual).

— Power-up state: May be used in some autoreclosing relays when the relay is powered up. In this state, the autoreclose relay assesses its inputs to determine the state of the breaker and the autoreclose initiate and supervision inputs. After assessing these inputs, the autoreclose relay typically changes to the reset state if the breaker is closed and no other inputs are active, or to the lockout state if the breaker is open or if drive-to-lockout inputs are active.

When the autoreclosing function is in the reset state, the autoreclosing function can be initiated in one of two ways to start timing toward its initial autoreclose attempt, depending on the device design or scheme logic:

— Detecting that the breaker opened, which starts the timing of the first open/reclose interval, or

— Detecting that the protective relay tripped the circuit breaker, followed by confirmation that the breaker opened, which starts the timing of the first open/reclose interval

When the controlled breaker opens, the reclosing relay starts timing toward its initial autoreclose attempt. This transition to timing toward the first autoreclose attempt changes the reclose function from the reset state to the cycle state. At the completion of this delay, the reclosing relay closes its output contact to initiate breaker closing and confirms that the breaker has closed through a state change of the breaker status input. If the breaker fails to close within a predetermined time, the reclosing relay may go to lockout, releasing the close output, or continue to assert the close output, depending on the reclosing relay design and programming. When the breaker closes, ~~At this point,~~ the reclosing relay starts its reset timer (also known as reclaim timer). If the breaker stays closed, indicating that the fault was temporary, then the relay continues timing toward reset. At the completion of the reset time delay, the autoreclosing function returns to the reset state and remains there as long as the breaker is still closed.

If ~~the illustrated sequence,~~ the fault is not cleared and the protection scheme initiates a second trip, the reset timer is stopped and reset, and the reclosing relay begins timing toward a second autoreclosing attempt if it is programmed or set for more than one autoreclose attempt. If after any of the autoreclose attempts the breaker remains closed for the duration of the reset delay timer, the reclosing relay returns to the reset state. ~~and initiates closing of the breaker.~~

If the fault is permanent ~~persists~~ and the number of programmed/set autoreclosing attempts expires, the reclosing relay advances to the lockout state, leaving the breaker open. The autoreclosing function ~~relay~~ is now "locked out" ~~disabled~~ until the breaker is closed by other means. Depending on the design of the reclosing relay, the relay may then reset immediately or after a reset time delay. This may be the same reset delay used for successful reclose, or a different delay used exclusively from the lockout condition. In the event that the breaker is manually closed and fails to remain closed, ~~care should be taken in the~~ reclosing relay circuitry/logic should be designed to prevent the reclosing relay from operating. Likewise, it may also be desirable to prevent the reclosing relay from resetting if closing the breaker causes protective relay elements to pick up and start timing to trip. If the reset time delay is less than the tripping time delay, a breaker pumping condition can occur which may ultimately lead to breaker damage, system equipment damage, and possible public hazard.

4.2 Autoreclosing ~~Timing~~ nomenclature

There are many autoreclosing relay designs in service today. Electromechanical, solid state, and microprocessor-based autoreclosing relays or functions are similar in many respects, but may have subtle design differences. These differences may be important when comparing and documenting autoreclosing schemes and settings. Nomenclature is important to make sure that the documentation conveys a clear understanding of the autoreclosing scheme operation.

Autoreclose timing nomenclature is an important aspect of autoreclosing scheme documentation. Timing nomenclature varies with the type or manufacturer of reclosing relays. Also, the same autoreclosing sequence may be documented in different ways, leading to confusion about the desired and actual scheme performance.

For example, an autoreclosing relay may have an inherent time delay of 0.2 s, whereas another relay may have virtually no inherent time delay. In the first case, an instantaneous reclose (having no intentional time delay) may be described as having a reclose time of 0.0 s, when it will actually have a reclose time of 0.2 s because of the relay's inherent time delay. Conversely, if the scheme is described as having a first reclose time of 0.2 s to account for the inherent time delay, and this is construed by others to mean that the relay should be set with an intentional reclose time of 0.2 s, the actual reclosing delay will be 0.4 s. Also, if both types of relays are set with a reclosing delay setting of 0.2 s for consistency, the relay with virtually no inherent time delay will issue its breaker close command 0.2 s faster than the relay with the inherent delay, possibly leading to damaged motors or generators that are re-energized before their isolating devices had a chance to operate.

~~One other fundamental concern deals with timing nomenclature. A problem occurs with how the autoreclosing times are indicated. Various utilities may indicate the same autoreclosing sequence but in different ways that can lead to misunderstandings between them. For example (using the basic symbol R to indicate one autoreclosing shot):~~

~~One utility may not indicate a time if the inherent time of the reclosing relay is used. For example, if the inherent time delay were 0.2 s, then this utility would indicate the autoreclosing mode as R.~~

~~However, settings from another utility may use $R_{0.2}$. Confusion could arise as to whether this means an autoreclosing time of 0.2 s or 0.4 s. For the purpose of this guide, the notation $R_{0.2}$ indicates a setting of 0.2 s in addition to any internal delay of the relay.~~

Additional confusion can arise in how multiple autoreclosing shots are indicated. For example, a two-shot autoreclosing may be described as ~~$R_{15}R_{30}$~~ having a sequence of 15 s and 30 s reclosing times. The 30 s may indicate the time after the first autoreclose attempt failed and the breaker tripped a second time. Or it may indicate the total elapsed time from the initial trip. In the first instance, this means the second attempt occurs at the 45 s point after reclose initiation. In the second interpretation, this means the second attempt occurs 30 s after reclose initiation.

Some relays control autoreclosing using an open interval time that typically starts after the breaker opens. Microprocessor-based relays may also have additional settings to stall the open interval timing if the tripping logic is still asserted, skip reclosing shots if specific conditions are not met, and stall reset. Sequence coordination is also commonly used with multi-shot reclosing on distribution circuits to coordinate fast and delayed curve tripping between series connected protective devices.

Even more basic is that some devices define reclosing or open interval time delay settings in seconds or fractions of a second, while others may be set in cycles or fractions of a cycle. So it is extremely important that the nomenclature used to document the autoreclosing scheme operation and settings be clear and concise to avoid confusion and possible damaging effects of improper autoreclosing.

See Annex C for a sample method of indicating the autoreclosing mode and timing. The annex also presents a timeline for a sample autoreclosing scheme.

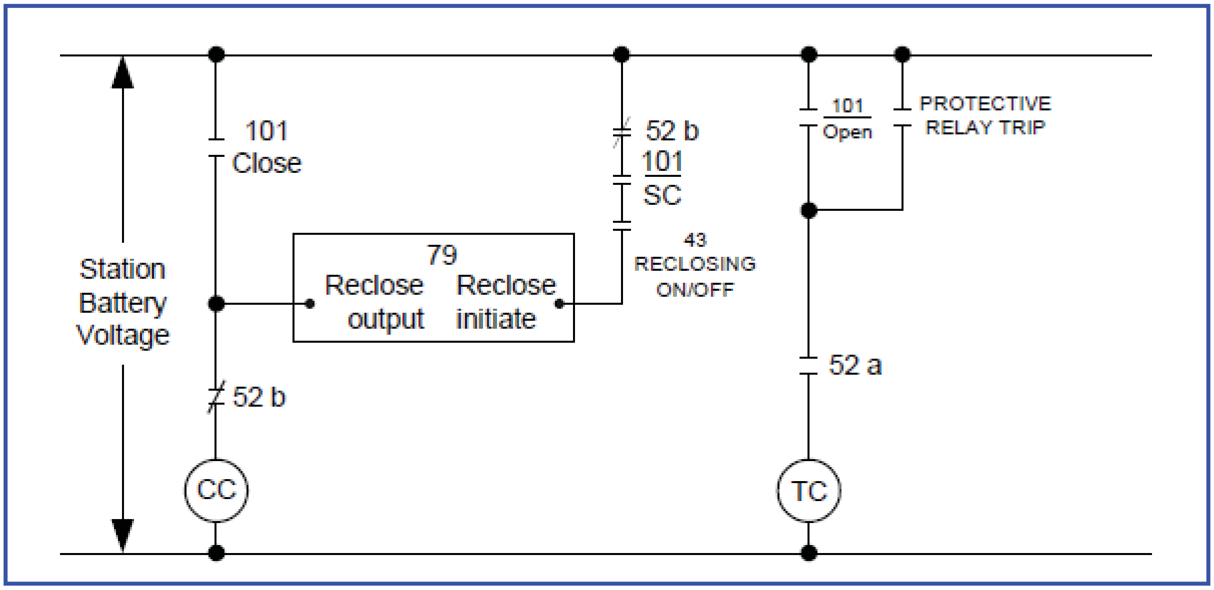
4.3 Autoreclosing circuitry and logic ~~permissives~~

~~4.3.1 General~~

Autoreclosing is initiated either by the transition of a circuit breaker auxiliary contact on breaker opening or by protective relay trip, and possibly ~~but not~~ both. ~~When a recloser is substituted in a substation for a feeder circuit breaker, the IEEE recloser standards and codes should be used for application (IEEE Std C37.60-1981; IEEE Std C37.61-1973).~~ Control circuitry or logic is required so ~~to ensure~~ that circuit breakers autoreclose only when intended. The control circuitry/logic is different depending on the type of autoreclose initiation required by the relay design and its available features. If the reclosing relay is to be initiated by a breaker status contact (52a opening or 52b closing), then additional control circuitry or logic is needed to distinguish between a local-manual control switch or remote control trip, and a protective relay trip, since autoreclosing is not desired for a local-manual or remote trip.

One technique used to prevent autoreclosing of local-manual trips is to install ~~then~~ a slip contact of the circuit breaker control switch ~~is installed~~ in series with the reclosing relay close initiation input. This contact of the circuit breaker control switch disengages when the circuit breaker is manually opened. It engages when the circuit breaker is manually closed. ~~A control switch OFF contact should be added to this circuit such that an instantaneous autoreclosure is not enabled until after a successful manual reclosure and the control switch is released.~~ This series combination prevents the reclosing relay from recognizing the open position of the circuit breaker when it is manually tripped, and permits the reclosing relay to reclose the circuit breaker automatically when it trips for a fault following a manual closure. Alternatively, and especially with microprocessor-based relays, the control circuit can be designed to lockout reclosing for manual circuit breaker trips. ~~Protective relay circuits, when properly designed, operate only during a fault. Autoreclosing should not be initiated by protective relays when the breaker is opened manually. Autoreclosing is initiated by the closure, then opening of protective relays' contacts, signifying that a fault has occurred. This operation cycle signifies that a fault was interrupted and autoreclosing can now proceed~~

NOTE—Slip contact generally refers to contacts that remain closed in the normal-after-close or normal-after-trip position. The slip contact used in the autoreclosing logic remains closed in the normal-after-close position.[4]



(New)

Figure 1—Control circuit design with slip contacts and reclosing ON/OFF switch

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[4] Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

Figure 1 illustrates a simplified control circuit with autoreclosing. Contacts shown in the figure include:

— 101: Manual breaker control switch

— 101/Close: Contact closed when control handle turned to CLOSE position, contact open when control handle turned to TRIP position and in the normal-after-close and normal-after-trip position

— 101/Open: Contact closed when control handle turned to TRIP position, contact open when control handle turned to CLOSE position and in the normal-after-close and normal-after-trip position

— 101/SC: Contact closed when control handle turned to CLOSE position and in the normal-after-close position, contact open when control handle turned to TRIP position and in the normal-after-trip position

— 43/Reclosing On/Off control switch: Contact closed when reclosing is to be enabled (43/ON), otherwise open (43/OFF)

— 52a: Breaker position auxiliary switch, closed when main breaker contacts are closed, and open when main breaker contacts are open

— 52b: Breaker position auxiliary switch, closed when main breaker contacts are open, and open when main breaker contacts are closed

~~It may be desirable that a time delay be used when restoring the autoreclosing function when the circuit breaker is manually closed. Some reclosing relay and control circuit designs disable the reclosing relay for a manual operation of the circuit breaker by setting the reclosing relay to the ''locked out'' condition. When enabling the autoreclosing function, these relays can be caused to wait for the period of the reset time delay within the relay. This feature, sometimes referred to as switch onto fault, is used to ensure that if the breaker were closed into a permanent fault, then the reclosing relay would not be initiated and attempt its programmed number of operations prior to locking out.~~

~~Another timing circuit can disable autoreclosing if autoreclosing permissives are not satisfied within the prescribed time interval. For example, for dead-line autoreclosing, if the line voltage does not drop to zero (less than the setting of the undervoltage element) on all monitored phases within a time interval after the reclosing relay is initiated, usually 30 s, then autoreclosing is disabled. This prevents unexpected autoreclose operations later when the permissive condition is satisfied. For autoreclose initiation by protective relay, if the protective relay does not reset within the prescribed time interval, then autoreclosing is also disabled.~~

4.3.1 Understanding selective autoreclosing logic

Autoreclose logic has been applied in many ways, primarily because there are many application scenarios and different opinions on the best way to address them. Autoreclosing logic can be set up to recognize and respond to specific system conditions, providing selectivity to the reclose function. Selective autoreclosing is most often used where the possible negative effects of autoreclosing into a specific type of fault or system condition are deemed unacceptable.

There are several reasons to provide selective breaker automatic reclosing, including:

— Reclosing for protective relay tripping, and not for manual and remote/SCADA tripping

— Reclosing for selected fault types, such as phase-to-phase and phase-to-ground faults that are typically temporary faults, and not for three-phase faults that are more likely to be permanent

— High-speed reclosing for pilot scheme/communications-assisted tripping, and delayed reclosing for non-pilot trips that may involve delayed tripping

— Reclosing only when the line side of the breaker is dead to verify that downstream or remote generation is off-line

— Reclosing only when the line side of the breaker is energized to verify that the remote line breaker is closed and the line is no longer faulted

— Reclosing only when sync-check function allows

Selective autoreclosing schemes control reclose operations in one of two ways: limiting the initiation of reclosing logic, or blocking reclosing logic after it has been initated. It is possible for selective autoreclosing logic to use both these methods in a single scheme.

Most, if not all, selective autoreclosing schemes use the operation of specific relays or relay elements to initiate the scheme. With electromechanical relays, the reclosing is initiated either by the breaker status contact and/or protective relay operation. The advent of microprocessor relays with the ability to assign specific relay elements to output contacts has allowed for very flexible selective autoreclosing schemes. ~~There are a large variety of schemes used today.~~ Some schemes only initiate autoreclosing for ~~on~~ pilot (communication assisted) trips where it is likely that a similar pilot trip will occur if the fault re-establishes on autoreclose. Others avoid ~~only block (or fail to initiate)~~ autoreclosing for conditions such as multiphase faults where system stability is of concern, time-delayed trips where pilot is used, when out-of-step tripping is used, or where sensitive or critical loads can be affected. ~~Almost any element of the microprocessor relay can now be used in site specific schemes~~.

Autoreclose blocking can be similarly applied by initiating reclosing relay operation for any breaker trip and using blocking logic to stop and reset reclose relay operation, or block the reclose relay close output if the breaker is tripped manually, either locally or remotely. The blocking logic may be more complicated because it must operate before the first reclose time occurs and because the reclosing relay must be allowed to run to lockout before the block is removed. Failure to verify that the reclose relay is in the lockout or reset state before removing the block can result in unexpected and undesired breaker closing operations, so simply halting reclose relay operation is not an option.

In some cases, such as reclosing for only selected line voltage conditions, reclose blocking is the more acceptable choice because there will be a time delay between breaker tripping and when the line voltage condition is checked. The reclosing cycle is allowed to run to the first reclose time, at which point the line voltage is checked to determine if the conditions are suitable for closing. If not, the reclosing relay close output is blocked from closing the breaker, and the reclose relay is either driven to lockout, cycled to the next reclose time interval (if applicable), or allowed to wait for a period of time until the acceptable line voltage condition occurs. In this latter case, the waiting time period may be restricted to prevent unexpected and undesirable breaker closing at a much later time.

When applying selective autoreclosing, one should bear in mind that faults are often dynamic in nature. The probability of autoreclosing into unacceptable conditions needs to be weighed against the likelihood of the fault not reigniting and therefore re-establishing the circuit in a timely manner. ~~In addition,~~ Some microprocessor algorithms may not always properly identify the fault type, which could unnecessarily prevent proper autoreclosing, or allow autoreclosing when not intended ~~vice versa.~~

4.3.2 Understanding of device internal logic and processing

To design reclosing controls using microprocessor relays, the designer should first understand how, and in what order, the relay processes the programmable logic. Since every element and word bit in the relay cannot be scanned and processed simultaneously, the relay will have some type of specific scanning and processing order. This information is usually found in the relay instruction manual, but the designer may have to refer to the factory for this information. As an example, one manufacturer's programmable logic controller processes its logic top-to-bottom and left-to-right one rung at a time based on the logic ladder diagram. Other manufacturer's relays process all logic within a specific time interval, usually several times in a power system cycle. During this interval, all inputs are scanned, internal and intermediate logic is processed, and the resulting logic is applied to virtual or hardware outputs, providing a deterministic operating time.

4.4 Autoreclosing settings

4.4.1 Number of reclosing attempts ~~operations~~

Single-shot autoreclosing is the autoreclosing of a circuit breaker one time, often within a prescribed period. This can be either high-speed or time-delayed. Multiple-shot autoreclosing is the autoreclosing of a circuit breaker more than one time in a predetermined autoreclosing sequence. Multiple-shot autoreclosing systems should be designed considering available air or gas pressure for breaker operation, system stability, potential equipment damage due to excessive current or heating, and potential adverse effects to customers and their equipment.

4.4.2 Dead time

~~6.2.1.1 Deionizing time~~

Several factors are important to consider before attempting to autoreclose any circuit breaker that has just tripped for a fault. Although the goal is to restore the line to service as quickly as possible, ~~a certain interval of time is required to ensure that the path of the arc is sufficiently deionized so that the fault does not re-establish itself on closing.~~ an autoreclose attempt without sufficient time delay to allow the dielectric to re-establish its strength results in an unsuccessful reclose attempt ~~event~~.

The ionized-gas path created by the fault arc will start conducting again after the autoreclose if sufficient time is not allowed for the gas to disperse. The deionization time depends on the voltage, the conductor spacing, the magnitude of fault current, and the weather conditions (Westinghouse Electric Corporation [B103]).[5] An example of ~~Under normal conditions,~~ a good minimum delay is given by ~~established using~~ Equation (1) for deionization of air at the fault location:

$$t = 10.5 + V_{L-L} / 34.5 \qquad (1)$$

Where t is time expressed in cycles, and V_{L-L} is rated line-to-line voltage (kV).

For some ~~other~~ types of circuit breakers, a delay needs to be added to either the breaker time or the autoreclose time in order to exceed the arc deionization time. For example, breakers are available that can reclose in as little as two or three cycles; the application of such breakers will require a delay to avoid reclosing before the arc extinguishes.

The arc deionization time can increase if a nearby adjacent parallel line helps to sustain the arc or if single-phase ~~pole~~ tripping is used and the energized phases sustain the arc. ~~Frequently, with oil circuit breakers, the minimum closing time of the circuit breaker exceeds this deionization time.~~

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[5] The numbers in brackets correspond to those of the bibliography in Annex A.

4.4.3 Autoreclosing reset time and autoreclosing lockout

A reset timer is typically provided in a reclosing relay to reset the relay after successful autoreclosure of the circuit interrupting device. If the autoreclosing is successful, the reclosing relay returns to its reset state after the reset time delay expires. Selection of the reset delay may depend on the nature of the fault and expected clearing time. For example, a longer reset delay will reduce ~~Even if the autoreclosing is successful, the reclosing relay is not rearmed until the reset time delay expires~~. ~~This lessens~~ the possibility of excessive tripping and autoreclosing for intermittent faults. A delay shorter than the duration between intermittent faults will allow the reclosing to reset, thereby preventing lockout. Lengthening of the reset time on the reclosing relay prevents the excessive operations but could cause undesirable lockout operations.

If the autoreclosure is not successful, the relay moves to a lockout position so that the interrupting device cannot be automatically closed. Autoreclosing is ~~also~~ locked out, or terminated, after the programmed number of attempts to reenergize the line are tried and unsuccessfully completed. The lockout condition is useful in preventing excessive wear on the interrupting device from multiple operations due to frequent transitory faults on the line, such as tree limbs affected by wind and galloping conductors ~~distribution feeder, which can be caused by wind, tree contact, or lightning during storm conditions.~~

Some ~~Modern~~ autoreclosing systems can be programmed to provide a lockout condition to prevent subsequent autoreclosing if the number of faults exceeds a certain number within a window of time. For example, a three-shot autoreclosing system could be programmed to lock out if seven faults are detected within a 30 min window.

Lockout is also useful in preventing a circuit interrupting device from inadvertently autoreclosing when it is closed manually into a faulted line. The lockout condition is automatically reset after the breaker is closed manually, either locally or remotely, and remains closed for a preset period of time so that a fault does not exist at the time of breaker closure.

4.5 Autoreclosing supervision

~~6.2.2.2 Phase angle, frequency, and voltage considerations~~

Various forms of autoreclose supervision have been applied to autoreclosing. These include elements such as bus and line voltage monitoring, synchronism check, transfer trip signals, and parallel line supervision.

Autoreclose supervision serves such purposes as preventing autoreclosing when systems are out of synchronism, preventing autoreclosing that might cause damage to generators or motors, minimizing the number of unsuccessful autoreclosings, preventing autoreclosing into faulted equipment such as transformers and reactors, and helping maintain system stability.

Synchronism-check relays can be used where analysis shows that for credible system conditions there could be harmful effects on the system, generators, or customers due to excessive differences in frequencies, phase angles, or voltage magnitudes across the closing breaker. When applying synchronism-check relays, appropriate consideration should be given to avoiding unnecessary restriction of breaker autoreclosing or manual closing following major system disturbances. It may, however, be necessary to use means to prevent ~~ensure~~ undesired autoreclosing modes from occurring ~~do not take place~~.

Voltage supervision of autoreclosing allows for the system conditions to be checked before autoreclosing and can improve system restoration times. Types of voltage supervision that could be applied are:

a) Dead-line

b) Live-bus/dead-line (also known as "hot-bus/dead-line")

c) Live-line (also known as "hot-line")

d) Live-line/dead-bus (also known as "hot-line/dead-bus")

The voltage supervision would monitor either a single-phase voltage or three-phase voltages, depending on system configuration and/or line connections.

The following are typical elements, application examples, and considerations for autoreclose supervision. Applications will vary depending on particular system configurations and ~~requirements and~~ utility practices.

— Synchronism check is applied to supervise autoreclosing when there is a realistic possibility of an excessive phase angle, frequency difference (slip), or voltage magnitude across the breaker contacts to be closed. The setting of the synchronism check function is based on the differences between the two voltages and is designed to minimize the impact to the system when the breaker is closed. When studies or actual system events identify lines that are subject to tripping during system separation, consideration should be given to adding synchronism check even if it is deemed unnecessary for normal operating conditions, since preventing undesired live-bus/live-line autoreclosing during out-of-step conditions may avert damage to generating and substation equipment.

— Receipt of transfer trip signal. Lines that have transformers or reactors connected without a breaker should not be autoreclosed for faults in those devices ~~the equipment~~ until it can be assured that the faulted transformer or reactor has been isolated. This autoreclosing can be supervised by receipt of a transfer trip signal from the remote terminal. This transfer trip signal can also be applied to block autoreclosing if there has been a breaker failure operation at the remote terminal. Where the transfer trip function is also part of the line protection, such as in a permissive overreaching transfer trip scheme, it is necessary to distinguish between a transfer trip received for a communication-assisted line relay operation, which would permit autoreclosing, and a transformer, reactor, or breaker failure operation, which would not initiate autoreclosing. This can be accomplished by time discrimination. If the transfer trip signal is received for longer than the normal clearing time, ~~then~~ autoreclosing is blocked. Alternatively, separate transfer trip signals could be used; one for the communications-assisted line protection, and a separate transfer trip signal for the transformer, reactor, or breaker failure transfer trip function.

— Voltage monitoring serves to supervise autoreclosing for live-bus/dead-line or live-line conditions. It enables lead/follow end autoreclosing where the lead end autorecloses first on dead-line (zero or very low voltage) conditions and the follow end autorecloses after the line is successfully re-energized (when the line voltage is normal). ~~It can also serve to protect against undue energizing and damage to generators and motors.~~ While one relay connected to one phase of a line terminal may be sufficient for voltage monitoring, ~~many utilities elect to~~ three relays (one per phase) may be applied to provide for added reliability. It should also be noted that particularly for high-voltage transmission lines with line reactors, ~~after a line tripout on a~~ the trapped charge is expected to maintain near rated voltage for a considerable time following a single line-to-ground fault operation. This voltage decays with the natural frequency of the line and reactors. This should be considered in the application of voltage monitoring relays.

— Parallel line current supervision can serve to block autoreclosing where a parallel line is out of service and there is concern with autoreclosing out of synchronism. ~~Note that~~ These current elements should be set above the line charging current.

— Typical autoreclose monitoring applications. For high-speed autoreclosing (typically less than 1 s), utilities often elect not to monitor the autoreclosing since autoreclosing is generally fast enough that the synchronizing angle changes very little during the open period, or parallel ties will verify synchronism. However, some utilities apply a degree of high-speed monitoring with high-speed autoreclosing. For example, the designated lead terminal could autoreclose with no supervision with the follow terminal set to autoreclose only after voltage has been restored on all three phases. There is very little time difference in closing time between the two terminals since reclosing relay timing is initiated by tripping. In some cases, parallel line current supervision could also be applicable for high-speed autoreclosing.

~~With delayed autoreclosing (autoreclose time typically more than 1 s) only one terminal of a transmission line is usually autoreclosed at a time and it is typical practice to make extensive use of voltage monitoring. For example, after a fault tripout the lead terminal autoreclose timing can start on loss of line potential. This ensures that the other terminal has tripped. The following terminal's autoreclose timing starts if there has been a loss of potential followed by a restoration of potential. If there are insufficient or weak parallel ties to assure that synchronism is maintained during the dead period, the following end's autoreclosing can be monitored by a synchronism check relay.~~

4.5.1 Voltage supervision of autoreclosing

Autoreclosing is often supervised by voltage permissives. These voltage permissives ~~are~~ often use only a single potential ~~phase~~, connected, phase-to-neutral (or occasionally phase-to-phase). If a line has tapped terminals and these terminals can back-feed the line, ~~then~~ the main terminal ~~which~~ re-energizing the protected line should be supervised by dead-line voltage sensing. Voltage supervision allows for the time delays of the reclosing relay to be decreased ~~thus improving system restoration performance~~. Without voltage supervision, ~~the~~ autoreclosing should ~~need to~~ be delayed long enough to permit all terminals to clear the fault.

A method to confirm ~~ensure~~ that all three phase voltages for autoreclosing supervision are proper is to use three single phase-to-ground voltage transformers connected grounded wye–grounded wye (care should be taken to avoid ferroresonance or overvoltage to these voltage transformers when back fed from a delta winding) or two phase-to-phase voltage transformers connected open delta–open delta. If only one voltage transformer connected single phase-to-ground is employed, then proper voltage sensing may not occur, especially if a source of back-feed exists and is connected via a delta-connected transformer. If a single phase-to-ground fault exists ~~occurred~~ with back-feed from such a source and single phase sensing was utilized, ~~then~~ two phases may have high voltage and one phase low or ~~almost at~~ zero. Thus, if dead-line voltage supervision was used, ~~then~~ the autoreclosing could occur in error. A single phase-to-phase connected voltage transformer could possibly be used if the source of back-feed did not use independent pole operated circuit breakers. If the unmonitored phase did not open properly, the autoreclosing could occur in error. Also, failure of the voltage supply by a blown fuse or other defect could cause autoreclosing in error. Therefore, sensing could be by two relays connected to different phases, or dropout of a single relay could be monitored or alarmed.

Under stressed operating conditions, the voltage on some energized portions of the system may vary significantly from nominal. Depending on the voltage thresholds used to detect live or dead conditions, undesired reclosing may occur. For example, if a line is energized at 0.75 per unit voltage, live-bus/dead-line reclosing may occur (even though the line is energized) if the threshold for sensing the line dead is greater than 0.75 per unit. When reclosing relays are applied with adjustable voltage threshold settings for determining whether system elements are live or dead, consideration to the thresholds selected is necessary to minimize the risk of unintended and potentially undesirable reclosing attempts.

Live-bus and live-line voltage detectors should be set at or below the lowest system voltage for which automatic reclosing is deemed desirable on a stressed system. A setting in the vicinity of 0.8 per unit is appropriate and not unusual.

Dead-bus and dead-line detectors should be set as low as possible, but also should be set high enough to verify that a disconnected element is determined to be dead even in the presence of trapped charge on a cable or capacitor bank or induced voltage from a parallel transmission line in the same right-of-way. Dead-line reclosing voltage supervision is typically set as low as 0.2 or 0.3 per unit for a single-circuit line, but in some cases (such as parallel circuits) the setting may need to be significantly higher.

It is important to recognize that considerations for setting live and dead voltage detectors, including personnel safety, equipment protection, reclosing under desirable conditions, and preventing reclosing under undesirable conditions, may lead to conflicting criteria. When this occurs, it should be clear that protecting personnel and equipment have the highest priority.

4.6 Autoreclose blocking

Autoreclosing is typically blocked under the following scenarios:

a) Manual trips. Autoreclosing is blocked if the breaker is opened manually at the station or by remote control. When a breaker is opened in this manner, it is desirable that it be under operator control for closure.

b) Line-side voltage supervision. Autoreclosing can be blocked if voltage exists on the line. Such supervision is usually provided if large motors, generators, or other sustained sources are connected to the line. Autoreclosing is blocked if these downstream sources are maintaining voltage on the line in order to prevent possible damage to the associated rotating equipment due to being energized out of phase or to the establishment of an undesirable system operating condition. (See 4.5.1 and 4.7.8.)

~~b) Bus faults. Autoreclosing of lines can be blocked for bus faults. (See 5.2.4 and 5.3.5 for possible exceptions.)~~

c) Faults on buses, transformers, or underground cables. These faults are most likely permanent in nature, and autoreclosing a breaker could aggravate electrical equipment damage. Consider the risks and benefits of autoreclosing versus blocking all autoreclosing.

d) Voltage unbalance. Autoreclosing can be blocked if a voltage unbalance condition is detected at the station. A source-side open phase can cause such unbalances. Restoring service under unbalanced conditions could cause damage to customer equipment.

e) Breaker failure protection. Breaker failure protection typically trips all breakers connected to the bus directly or through the bus differential protection. Restoration of the bus is usually under an established procedure that includes isolation of the failed breaker. Autoreclosing of the healthy breakers is blocked until the failed breaker is isolated and the bus is restored.

f) Breaker failure to close. If an attempt is made to autoreclose, and the breaker does not close (based on 52 auxiliary contact) or fails to close within the expected close time, or if a discontinuity (open circuit) is detected, then further attempts to autoreclose are blocked.

~~i) Hot line maintenance. Improve safety by disabling autoreclosing while line crews perform hot line maintenance.~~

g) High-current faults. A high-set instantaneous element can be used to block autoreclosing for close-in, high-magnitude faults. This type of blocking is typically applied where these faults are likely to be permanent or in the substation equipment or exit cables, or exceed the damage rating of the source transformer or other equipment.

h) Cumulative operations lockout. Used in locations with fault duty approaching adjusted circuit breaker rating to block autoreclosing after a predetermined number of operations until inspection and necessary maintenance can be performed.

i) Receipt of transfer trip. During the receipt of a transfer trip signal. In some schemes, a timer is initiated by the receipt of the transfer trip signal. If this timer times out, operation of the reclosing sequence is prevented.

j) Zone 3 or backup tripping. An overreaching distance zone used for backup tripping can be configured to disable reclosing, since a trip by this zone indicates a protection failure in a different zone.

k) Automatic load shedding (underfrequency or undervoltage). Feeders tripped by automatic load shedding typically have autoreclosing blocked.

~~k) Breaker failure to trip or trip circuit monitor alarm. If a relay trip has occurred, but the breaker stays closed longer than the expected breaker trip time (e.g., 6 10 cycles), block autoreclosing and initiate tripping of the backup breaker. Also, if trip circuit logic is available, then use this logic to block autoreclose if an open trip circuit is detected.~~

4.7 Application considerations

4.7.1 Lines with underground cables

Faults involving underground cables are often permanent, and ~~the use of~~ autoreclosing should be applied ~~used~~ within the guidelines of the following paragraphs. ~~Distribution~~ Lines that utilize underground cables for a portion of their total length present a special concern for utilities as to whether or not to incorporate autoreclosing.

If the line is completely cable, ~~it makes no sense to~~ autoreclosing should not be attempted. ~~into a permanent fault.~~ There is no need to subject the cable to ~~more importantly the customer to~~ additional damage and subject the circuit breaker, bus, and substation transformer and adjacent portions of the power system to additional stress and potential damage. Therefore, the use of autoreclosing on lines ~~feeders~~ entirely made of cable is not recommended as per IEEE Power System Relaying Committee Report [B50].

Depending on the location and length of the cable section relative to the total line length, some utilities consider this type of feeder as totally overhead and apply their standard autoreclosing practice. Others consider a single shot of autoreclosing to test the line for a temporary fault or other condition that could have caused the relay to misoperate. Another solution could be the use of sectionalizing to isolate the cable section together with a modified autoreclosing scheme.

If the line is partially cable and partially overhead, autoreclosing could be used if a determination can be made that the fault is not in the cable portion (Sufana et al. [B95]). ~~utility is willing to risk additional damage to the cable.~~ ~~Lines that experience a temporary fault on the overhead section that could be successfully cleared would benefit from the use of autoreclosing. If the fault were to occur in the cable portion, then the substation equipment and line would sustain further damage from the autoreclose attempt. If the cable portion of the line is where the feeder leaves the substation and goes a short distance to the overhead portion, then it could be possible to incorporate a relay scheme (perhaps by the use of a high-set instantaneous overcurrent element) that will determine if the fault is inside the cable and abort the autoreclose attempt.~~

~~If the cable portion of the distribution feeder is located ''out in the middle,'' then the use of autoreclosing may not be prudent. If expense were not a problem, it would be possible to install relaying (i.e., current differential, pilot wire, or phase comparison) on the cable portion to determine if the fault was in the cable and inhibit autoreclosing. This approach would be expensive, as there would be a need for a communication channel and additional current transformers.~~

It is also important to keep in mind as to which end of a hybrid line is to close in first for an autoreclosing attempt. Transient overvoltage studies using a transient network analyzer may need to be performed to identify any problems that could occur if the line is autoreclosed. These studies are especially important if a shunt inductor is added to the line as a means to control the voltage boost effect due to the cable capacitance (Sufana et al. [B95] and Truax et al. [B99]).

4.7.2 Autoreclosing following ~~Distribution~~ bus faults

Automatic reclosing after a bus fault is sometimes used to restore the system to normal operation. The decision to employ automatic reclosing after a bus fault is based on the trade-off between the impact of an extended bus outage versus the consequences of reclosing into a bus fault. Since power system buses generally terminate multiple elements, the impact of a bus fault and consequent bus outage can have a significant impact on the security and operability of the system. The benefits of automatically restoring a bus following a temporary fault are typically weighed carefully against the risks should the fault in fact be permanent, such as system stability factors and possible damage to primary equipment, transformers and turbine generators in particular.

For open-air type substations, autoreclosing on the bus breaker is sometimes performed when protective relays operate for faults on the bus. The autoreclose is generally time-delayed (e.g., 5 s) and not supervised except for buses that can be fed from another source. These other sources could be dispersed generation on the lines, tie breakers that normally run closed, or feeds from other transformers. In these cases, the autoreclose may be supervised by an undervoltage relay. Other system conditions could also require blocking the autoreclose, such as breaker failure, transformer differential, or underfrequency trip.

A bus that primarily uses open-air as the insulation medium is subject to faults from foreign objects, lightning, small animals, flashover of dirty insulators, and so on in much the same manner as any overhead transmission or distribution line. An example of this type of bus is an outdoor open rigid bus or open strain bus. If these types of faults are promptly cleared, there is some probability that reclosing without inspection will be successful. Bus conductor spacing, a function of bus voltage, can greatly impact this probability. Animal contact for instance, typically temporary in nature, is more likely at distribution voltages than transmission.

Because open-air buses are routinely protected from public exposure by substation fencing or other barriers, one might argue that the public safety risk associated with automatically reclosing for a bus fault is significantly lower than that of an overhead line. However, there are additional risks to maintenance or construction personnel who are within the fenced area due to the application of automatic reclosing for bus faults. This additional risk can be reduced by use of a reclose cutoff function to block autoreclosing when work is in progress, in much the same manner as the "live-line maintenance" feature typically used on distribution and transmission circuits.

A bus may be insulated so as to provide physical protection to the bus from outside interference. Examples of this type of bus are insulated cable, isolated phase bus, buses in metal-clad switchgear, SF_6 switchgear, and so on. A fault on a bus with this type of insulation is usually not self-clearing. For this reason, automatic reclosing of breakers is not likely to be successful for this type of bus.

If automatic reclosing is employed for bus faults, one of the breakers connected to the bus can be equipped with a single-shot reclosing relay to reclose the breaker for a dead-bus-live-line condition. It is a common practice to select a breaker for the task of testing the bus that will have the least impact to the system if the fault is permanent. Usually it is the live circuit with the least short-circuit capacity. However, the bus differential relay is required to be sensitive to the reduced fault level to permit tripping in case of a permanent fault. This can be achieved by lowering the pickup threshold on bus de-energization and for a short period of time following, or using a simple instantaneous overcurrent function associated with the reclosing relay. Typically, when deciding on the sensitivity of bus protection when reclosing, one takes into account the inrush current created by VTs and similar equipment permanently connected to the bus.

If reclosing of the first breaker is successful, the remaining breakers on the bus can be reclosed with automatic reclosing relays programmed to close the breakers for a live-bus condition provided other system conditions permit.

4.7.3 Circuit breakers

~~6.2.1.2 Minimum reclosing time~~

All circuit breaker mechanisms and interrupters require a minimum time between the initiation of the tripping action and the initiation of the ~~autore~~closing operation. This time allows for the dielectric within the breaker to stabilize to a point where the breaker will be able to interrupt a fault again on reclose. These times should be defined by the manufacturer. If this minimum time requirement is not incorporated into the breaker design, ~~a time delay could be required within~~ the reclosing relay dead time should be greater than this limiting time of the breaker ~~When there is a question regarding this feature, the breaker manufacturer should be consulted.~~

Another consideration is the time it takes for the breaker's stored energy mechanism to recharge following each trip. If the reclosing intervals are too short, the stored energy system, e.g., spring or compressed air, may not recharge sufficiently to allow a subsequent trip. If this happens, the breaker mechanism may employ an interlock scheme to prevent breaker closing until sufficient stored energy is available to permit a breaker trip.

These capability factors are defined in the standards for oil and air magnetic circuit breaker technologies where the time between short-circuit current interruptions is critical to allow the dielectric to recover strength within the interrupter of the circuit breaker. These derating factors may not be required for technologies such as SF_6 puffer or vacuum circuit breakers, as the dielectric recovery time is less than the open-interval ~~operating~~ time ~~of the circuit breaker between operations~~. However, the manufacturer should be consulted whenever the autoreclosing duty cycle of the breaker differs from the standards. Oil circuit breaker interrupting capabilities depend on the reclosing sequence and the fault magnitude.

Circuit breakers are required to have an interrupting capability rating based on the Rated Standard Operating Duty (standard duty cycle). The standard duty cycle, as defined by IEEE Std C37.04-~~1999~~, is two operations with a time interval of 15 s between operations [CO (close – open) + 15 s + CO]. Whenever the autoreclosing duty cycle characteristic is set for more than two operations, or the time interval between operations is less than 15 s, the interrupting capability rating on the circuit breaker is modified. An autoreclosing duty cycle could incorporate one or both of these characteristics, effectively reducing or derating the interrupting rating. This derating for autoreclosing is necessary to allow for the dielectric recovery of the insulating medium in the circuit breaker following arc extinction.

4.7.4 Effects of autoreclosing on disk type overcurrent relays (ratcheting or notching)

~~As mentioned in 5.2.2,~~ Electromechanical disk type time overcurrent relays respond to current above their pickup level in a time inversely proportional to the current level. When the current level is above the pickup, the disk begins to turn and continues to turn until the rotating contact meets the stationary contact to cause a breaker trip or until the current drops below the pickup level, as would occur if the fault were cleared by downstream protection. Disk reset will occur when the current has dropped below the pickup level for a period of time. The disk resets to its original position at a relatively slow rate by the action of a coil spring. This relatively slow reset action of the disk should be taken into consideration when autoreclosing is applied to any breaker or circuit recloser downstream of this breaker.

The most common application that requires special care is the circuit recloser operating to clear sections of a feeder downstream of a circuit breaker having disk type overcurrent relays applied. The circuit recloser can autoreclose the faulted section multiple times, resulting in several periods of fault current flow through both the circuit recloser and the upstream circuit breaker. In a coordinated system, the circuit recloser trips and removes the fault current flow before the disk type overcurrent relays reach their trip point. A minimum safety margin is normally provided for ~~to assure~~ good coordination. At the point the overcurrent condition is removed, the disk has rotated some percentage of the amount required to provide a trip.

If the disk is not fully reset by the time the circuit recloser operates to re-energize the faulted section, the disk will not have as far to travel as during the original fault. This ratcheting effect could lead to a loss of coordination resulting in the unnecessary tripping of the circuit breaker.

Another example of ratcheting is an application in which two or more breakers having disk type overcurrent relays are in series. When both encounter an overcurrent condition, different time-dial settings or unequal currents due to load could cause the percentage of disk travel of the upstream relay to vary considerably. Once again, if autoreclosing of the downstream breaker occurs before the upstream device is reset, a loss of coordination could occur.

Solutions for these loss of coordination events include use of larger safety margins to allow for partial reset of electromechanical relays, application of inverse time relays with fast resets on the upstream breakers, or longer dead times for autoreclosing. Microprocessor or static relay designs may have options to improve coordination such as instantaneous reset of the timing function or ~~as well as~~ other selective reset characteristics, including emulating electromechanical reset ~~which is normally considered in the coordination process.~~

4.7.5 Radical circuits

Since a radial line has just one source of supply, multiple-shot autoreclosing can be considered. If the line has no customers with either large motor loads or generation, which can be a source for backfeed, then the first autoreclosing shot can be made with no time delay other than that required for arc-path deionization. If the first attempt fails, subsequent shots are usually delayed for several seconds ~~and should be made with the instantaneous phase protection inhibited to permit transformer high side protection to operate. If this second attempt fails, autoreclosing should be locked out. Subsequent attempts to restore the circuit should be under manual control.~~

If the radial line has customers with either generation, or large motors, or both, the initial autoreclosure should be supervised by a dead-line voltage relay to permit autoreclosing only when the line voltage has decayed to the point at which autoreclosing will not damage the customers' equipment. A second autoreclose shot before lockout can be made as described above.

4.7.6 Lines with automatic sectionalizing

Radial distribution feeders and networked lines (connected to source buses at both ends) may employ automatic sectionalizing to reduce the amount of load affected by a fault on the circuit. Radial distribution circuits may use automatic line sectionalizers or other schemes to isolate the faulted line section and then allow autoreclosing to restore service to the loads on the unfaulted line section(s). These schemes are discussed in 5.3.2.

Networked transmission lines with tapped loads may also employ automatic sectionalizing to improve service to the tapped loads. An ideal practice would require a potential device on each end of the line to permit voltage supervision of autoreclosing as described in 4.5.1. However, the autoreclosing of the line-source breaker can be coordinated with the sectionalizing scheme to permit sectionalizing after the first autoreclosing shot and prior to the second shot. The first shot should be made before sectionalizing so that the entire line can be immediately restored should the fault have been temporary in nature. If the second shot fails, a fault between the source and sectionalizing point is indicated and the line is locked out. Transmission ~~A~~ line ~~with~~ automatic sectionalizing is discussed in 6.3.11 ~~can be either radial or connected to source buses at either or both ends.~~

Radial or networked lines that have loads with autotransfer (also referred to as throwover) schemes applied on them have similar reclosing considerations. This type of scheme is used to transfer to a second (or reserve) supply connected to a different line or feeder. Loss of the primary supply will start the transfer timer. If the line fault was temporary and automatic reclosing successfully re-energizes the primary supply ~~comes back ''live''~~ prior to the transfer timer timing out, the transfer timer stops and resets and the transfer is aborted. Therefore, the first autoreclosing attempt should be made with limited time delay to coordinate with the transfer time delay ~~accommodate the autotransfer abort;~~ If the first autoreclosing attempt is unsuccessful, then the second attempt should not be made until the autotransfer scheme has had time to complete its transfer function.

4.7.7 Adaptive autoreclosing

Many autoreclosing schemes can now be implemented which adapt to changing conditions, such as heavy load, time of day, or even due to a weather forecast. The schemes vary greatly depending on the system, and more importantly, the end customers served by a particular line ~~feeder~~. Here are examples of some proposed or installed adaptive autoreclosing schemes:

a) One scheme enables or disables fuse saving with multiple autoreclose shots during evenings and weekend hours. An industrial customer may consider any interruption in service during the operation of his facility to be the worst case. Thus, fuse saving is blocked during operating hours.

~~b) Another customer may consider a long voltage dip (time delayed fault clearing) to be worse than a trip. Thus, fuse saving with multiple autoreclose shots can be applied.~~

b) Another scheme allows operators to enable or disable autoreclosing based on weather conditions. Some utilities have historical data which show that a higher percentage of successful autoreclosures occur during thunderstorms.

c) The use of overcurrent elements to control the autoreclosing sequences on a line that includes downstream reclosers. In this scheme, a contact of the overcurrent relay closes when the current exceeds a level consistent with a fault downstream from the recloser and then is reduced below that setting. Closure of this contact indicates that the downstream recloser has operated for the fault and causes the reclosing relay to skip its initial autoreclosing attempt in the event the breaker ultimately is called on to interrupt the fault. ~~(See 5.3.4.)~~

d) Use of an overcurrent element as a load level detector to indicate that a customer is starting a large rotating machine and autoreclosing should not take place during this condition.

e) Use of a high-set overcurrent element or impedance element to determine that a fault has occurred in the cable section between the breaker and the transition to overhead construction; therefore, autoreclosing would be disabled.

f) Breaker failure to trip or trip circuit monitor alarm. If a relay trip has occurred, but the breaker stays closed longer than the expected breaker trip time (e.g., 6–10 cycles), block autoreclosing. Also, if logic is used to detect trip circuit continuity, consider using a trip circuit monitor alarm to block autoreclose.

g) Breaker failure to close. If an attempt to autoreclose a breaker is made, and the breaker does not close (based on 52 auxiliary contact) within the expected close time, block further attempts to autoreclose.

h) Inhibit autoreclosing until the fault arc is extinguished. This would require the use of line-side voltage transformers. (Horowitz et al. [B42] and IEEE Power System Relaying Committee [B49])

i) Block autoreclosing for multiphase faults. ~~This necessitates the use of single pole switching.~~ (IEEE Power System Relaying Committee [B49])

j) Initiate immediate autoreclosing for undesirable trips. A substation SCADA computer could initiate immediate reclose when fault data indicate an incorrect relay operation.

k) Change the synchronism check angle if sync-check autoreclosing is used. The angle could be adjusted in the event of a severe system disturbance. However, there may not be adequate computer algorithm capability or speed to facilitate a rapid calculation of the angle during rapidly changing system conditions. (IEEE Power System Relaying Committee [B49])

With the use of a *smart circuit breaker* it should also be possible to adjust the autoreclose delay time or the number of allowed autoreclose attempts based on the history of the breaker's operation. For example, if the breaker has had many operations in a short time, perhaps the delay time would be extended, or autoreclosing may even be inhibited. Lower current faults could allow for a shorter delay time. High-resistance faults may have the autoreclosing inhibited (Rockefeller et al. [B83]). Knowledge of the breaker operating history may allow a computer to rotate the autoreclosing duty for ring bus or breaker-and-a-half schemes (Horowitz et al. [B42]).

It should also be possible to adjust the autoreclosing mode for each line based on a system-wide approach. Through the use of a wide area network (WAN), the load dispatcher could communicate with each substation and adjust the autoreclosing based on studies performed for the current system conditions. In the extreme application of this technique, artificial intelligence methods could be used.

~~It is expected that adaptive autoreclosing schemes will become more common due to two factors: a) utilities are more willing to ''customize'' schemes in a competitive market, and b) developments in PLCs (programmable logic controllers), SCADA, and microprocessor based relays allow easier implementation of these schemes.~~

4.7.8 Reclosing and motor loads

When supply voltage is removed from an induction machine, flux is trapped in its rotor. This flux decays with time and produces a residual voltage in the machine windings until its rotation ceases. In isolated motors, the residual voltage can decay in a few cycles in small machines but may require up to five seconds in larger machines. In industrial facilities with many motors, the higher inertia machines will tend to act as generators feeding the lower inertia machines on the bus such that the entire group decays together. Synchronous machines have the added complication of having their own field excitation to maintain good healthy internal voltage during the dead-time before high-speed reclosing occurs.

One problem that is encountered by these motors maintaining a residual voltage is that they can back feed the distribution or transmission line. When reclosing occurs, the system voltage and machine residual voltage are typically out-of-phase. Utility autoreclosing can result in voltages above the motor insulation and mechanical design limits and result in high transient currents and torques. The motor(s) may not immediately fail, but the resulting high shaft torque and torque on the coils can eventually result in "unexplained" failures of the machines.

Additionally, the back feeding motor loads can keep ionized fault paths intact during the reclosing dead time so a high-speed reclose has a low probability of success. The result is unnecessary wear and stress on all the interposing equipment (utility breakers, transformers, motors).

To avoid these problems, transfer tripping can be applied to disconnect the motor loads prior to reclosing. Also, voltage sensing along with an appropriate time delay can be used to verify the line is dead before reclosing is allowed. In some cases, automatic reclosing may not be used at all.

~~6.3.10 Motors~~

~~For autoreclosing of transmission systems,~~ The most important consideration for motors is avoiding damage from the out-of-phase (or step) condition. The delay of autoreclosing needs to be such that the time between the loss of power and the restoration of power to the motor bus should be greater than the time required to remove the motor from the power system.

The autoreclosing time is determined by how long it takes the motor bus voltage to decay. The motor bus is usually supervised by an undervoltage relay (device 27) and/or underfrequency relay (device 81). The motor bus voltage decays with a time constant (t_d) and motor inertia (WK^2). Consequently, the pickup time depends on how fast the motor bus voltage decays. Since a large motor would have a larger inertia (WK^2), it takes a longer time for it to reach the pickup point. On the other hand, the smaller motors are almost instantaneously tripped off by an undervoltage relay since the decay time is less. Therefore, the autoreclosing time should be carefully selected to avoid damage.

See reference [B103] for additional information.

4.7.9 Wind turbines

Consideration should be given to potential effects of autoreclosing a line with connected wind generation. When wind speed is slow or zero, wind turbines may remain connected to the line through the fault and autoreclose sequence. In such cases, reenergizing the wind turbines may result in a system voltage depression as the machines reaccelerate (see 4.7.8).

Possible solutions are:

- — Configure the line protection to send transfer-trip to the wind turbine facility to disconnect the turbines prior to an autoreclosing attempt
- — On a dead-line condition, provide a device at the wind turbine facility to disconnect the turbines when the line voltage decreases below a threshold
- — Not allow autoreclosing at all on the line

In the case where the wind turbine speed remains adequate to keep the line energized, dead-line supervision may prevent autoreclosing as the voltage may be above the dead-line detection threshold.

4.8 Substation controller

A substation controller consists of an intelligent device to control operations of the circuit breakers within the substation and incorporates all the techniques described in this guide so far, just as a group of electromechanical or electronic devices would. By monitoring the conditions of all the controlled breakers, the controller adds another versatile dimension to autoreclosing, which can be used to improve outage times, or the time required to restore service after an event. It can also be used for load planning purposes to block or allow autoreclosing when certain lines are out of service. The controller can react to an event, or series of events, remote to an individual circuit or bus.

The substation controller can adjust autoreclosing times or sequences for different load or voltage conditions, different outage conditions, or even for different weather conditions. This provides a finer tuning of the autoreclosing system, which can minimize outage times.

4.9 SCADA

Supervisory control and data acquisition (SCADA) adds yet another dimension to ~~distribution circuit~~ autoreclosing. Depending on the complement of installed substation devices, the control center can either receive the circuit status and remotely adjust autoreclosing depending on system conditions, or it can remotely broadcast signals that will perform autoreclosing function changes at several substations. There are many different opportunities for adapting autoreclosing once SCADA is installed in a substation.

5. Autoreclosing for distribution systems

5.1 Distribution system overview

The distribution system is that portion of the electrical system used to transfer electric energy from the low-voltage side of the substation transformers to the customer's metering points. The distribution system can be a grounded or ungrounded system.

The distribution circuit is the composite of all system elements from the point of contact at the substation, usually the bus connected to the low-voltage side of the substation transformer, to the point of contact at the customer. It is normally a radial line comprising overhead conductors, underground cables, or a combination of both. The primary voltage of a distribution circuit is typically, but not limited to, 35 kV or below. Distribution circuits often contain sectionalizing equipment such as fuses, reclosers, and sectionalizers to isolate faulted sections of the circuit.

5.2 Distribution autoreclosing practices

5.2.1 Number of autoreclose attempts

~~There is never a reason to autoreclose an electrical circuit breaker following a trip unless there is reason to believe that the fault is no longer present on the circuit.~~ Historically, when distribution circuit breakers would trip and result in a circuit outage, the circuit was patrolled before the circuit breaker was closed. This practice delayed restoration. Records were kept of these events. It was discovered that for 85%–90% of the occurrences, no permanent faults were found. It generally became accepted to autoreclose these distribution circuit breakers. With the advent of additional ~~protective~~ devices available to the distribution engineer such as fuses, sectionalizers, and reclosers with which coordination was necessary, multiple autoreclose attempts were chosen.

In many areas, three autoreclose attempts were chosen. This results in four trips to lockout. This practice continued for several years.

As time went on, load increased and it became necessary for ~~that~~ distribution source transformer size and ~~increased as well as~~ the number of supplied feeders to increase. It is known that when transformers are subjected to any fault on the secondary that the transformer windings are stressed [B101]. If the transformer was not designed for the exposure that is encountered in distribution operation, it is possible that autoreclosing into a fault that would allow the transformer to contribute its maximum available short circuit current could result in deformation of the windings and subsequent arc damage to the transformer core and mounting structure. Often, repeated occurrences of these stress levels resulted in transformer failure. The practice of some utilities is to block autoreclosing for close-in faults or for faults with a fault current magnitude in excess of the transformer design capability in an effort to mitigate the cumulative effect of these severe faults.

Observation of fault events resulted in the conclusion by a number of utilities that the third autoreclose attempt was seldom successful. As source transformer size and distribution voltage increased, many engineers decided to remove the last autoreclose attempt as a means of reducing the exposure to through fault events.

5.2.2 Coordination concerns

Protective devices are coordinated such that the device closest to the fault will operate prior to any other upstream device locking out. This practice serves to limit fault-induced service interruptions to the fewest possible customers. Autoreclosing practices impact ~~on~~ the coordination of series connected protective devices. During the dead time of an autoreclosing cycle, the backup device begins to reset if it is a relay or cool if it is a fuse. Depending on the length of dead time provided, however, complete resetting of the backup relay or cooling of the backup fuse may not occur. The shorter the dead time, the less resetting or cooling is allowed. This effect needs to be taken into consideration when setting the associated protective devices and autoreclosing schedules so ~~in order to assure~~ that proper coordination will exist. When applied with induction disk overcurrent relays, the dead time is usually set greater than the reset time of the overcurrent relay to avoid miscoordination with downstream overcurrent relays ~~This is discussed in more depth in~~ (see 4.7.4).

~~The~~ Dead times ~~typically applied by engineers~~ vary based on voltage levels, stability, system configuration, and many other factors that affect each utility's philosophy (see 4.4.2). Table 1 illustrates an example of a range of reclosing dead times used at distribution voltages. ~~(less than 35 kV).~~

Table 1 —Dead time intervals

Dead time interval	Typical setting range (seconds)
Initial trip to 1st reclose (RT1)	0–5
2nd trip to 2nd reclose (RT2)	10–20
3rd trip to 3rd reclose (RT3)	10–30

5.2.3 Autoreclosing for distribution bus faults

Air insulated distribution buses are more likely to experience faults due to a foreign object or animal contact because the height of insulators and bushings is smaller than it is for higher voltage buses. For this reason, autoreclosing of the distribution bus following a bus fault is often used.

Further discussion of these schemes can be found in 4.7.2.

~~5.2.4 Distribution bus breaker autoreclosing~~

~~For buses constructed for operation at distribution voltages, the height of bus insulators and transformer bushings and the spacing between adjacent phases of buswork are smaller than those for higher voltage buses. In open air substations, animals that make their way into a substation are more likely to cause a short circuit on distribution buses than on higher voltage buses. These faults are temporary if the animal falls away from the bus following the incident and no permanent damage has occurred to the bus equipment.~~

~~In an attempt to restore service quickly to all customers connected to the distribution feeders supplied by the bus, it may be desirable to test the bus by autoreclosing a source to the bus after a dead time interval sufficient for a temporary fault to clear itself. For a bus supplying a distribution network, a breaker from the weakest source of fault current can be autoreclosed first. If the breaker is not tripped back out, then the rest of the breakers connected to the bus can be autoreclosed after a period longer than required for the bus protection to detect and retrip the closed breaker.~~

~~For enclosed distribution buses built inside a switchgear row and underground distribution circuit buses, bus faults cannot be considered temporary, so no autoreclosing is recommended.~~

~~5.2.5 Delayed autoreclosing~~

~~Delayed autoreclosing may need to be considered when the upstream protection is provided by electromechanical relays or fuses and the circuit protection is provided by microprocessor-based relays, unless the microprocessor-based relays can be set to mimick the reset characteristic of the electromechanical relays. Without this time-delay reset feature on the microprocessor-based relay, it is possible to have the upstream device operate incorrectly, resulting in an overtrip. As an example of this, the low-set instantaneous trip on a distribution feeder is eliminated to improve power quality by eliminating momentary service interruptions. If an instantaneous autoreclose is used after a time-delayed trip, an additional time margin needs to be used between the operating times of protective devices in order to maintain coordination of the feeder overcurrent relays and an upstream electromechanical relay or fuse. By delaying an upstream protective device to coordinate with the back-to-back operation of the feeder relay, coordination is maintained with the instantaneous reclose. Delaying the autoreclosing eliminates this problem by allowing all devices time to rest before the next fault.~~

~~Delayed autoreclosing is used on circuits that have automatic sectionalizers to allow proper coordination with the distribution circuit breaker. The time-delay autoreclosing of the distribution circuit breaker needs to be set to match the programmed time intervals of the sectionalizer switches to allow successful isolation of the faulted line section.~~

5.3 Autoreclosing coordination practices

5.3.1 Circuit reclosers

A circuit recloser is a self-contained device that can sense and interrupt fault currents as well as reclose automatically in an attempt to re-energize the line. When a recloser is substituted in a substation for a feeder circuit breaker, the IEEE recloser standards and guides should be used for application (IEEE Std C37.60~~-1981, IEEE Std C37.61-1973~~).[6]

5.3.2 Sectionalizers

A sectionalizer is a ~~protective~~ device used in conjunction with an automatic circuit recloser, or a circuit breaker and reclosing relay, which isolates faulted line sections (IEEE Std C37.63). The sectionalizer does not interrupt fault current. Instead, it counts the number of operations of the interrupting device upstream and opens while the upstream fault interrupting device is open.

Reclosing relays and automatic sectionalizers ~~equipment~~ are used together to isolate a faulted portion of a distribution circuit. After the downstream line sectionalizer has operated, the reclosing relay at the substation should have one autoreclosing cycle left to re-energize the unfaulted section of the circuit. It should be noted that line sectionalizers are not intended to operate at any time when the circuit is actually energized. The line sectionalizer operates its contacts only during the time that the circuit is de-energized. The actual making and breaking of the current is accomplished by the circuit breaker.

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[6] Information on references can be found in Clause 2.

If the sectionalizing sequence is to be successful, the autoreclosing times associated with the feeder breakers need to coordinate with the line sectionalizer(s) on the distribution circuit. Various types of sectionalizing equipment and numerous sectionalizing schemes exist on distribution systems. The intent here is to discuss two of these sectionalizing schemes and the coordination required between the reclosing relay and the sectionalizing equipment.

The pulse-counting sectionalizing scheme utilizes a downstream line sectionalizer that counts the number of high current pulses that pass through it. After a predetermined number of high current pulses (typically two, with the fault current being the first, and the reclose onto the fault being the second), it will open on the next loss of voltage or current when the feeder breaker opens.

The sectionalizer resets after a high current pulse if it detects no further high current pulses within its reset time. Therefore, if proper sectionalizing is to occur for a permanent fault beyond the sectionalizer, the autoreclosing time of the reclosing relay associated with the feeder breaker needs to be less than the reset time of the sectionalizer. The reclosing relay should have one autoreclose attempt left after the sectionalizer opens to re-energize the unfaulted portion of the circuit. In the scheme shown in Figure 2, the autoreclosing ~~sequence of the reclosing~~ relay associated with the feeder breaker has two relatively long open intervals, for example 20 s and 20 s, and then goes to lockout ~~(R20 R20)~~ if the second reclose attempt is unsuccessful. The downstream sectionalizer is set to count two current pulses before opening and has a reset time of 25 s to coordinate with the reclosing relay's 20 s open intervals.

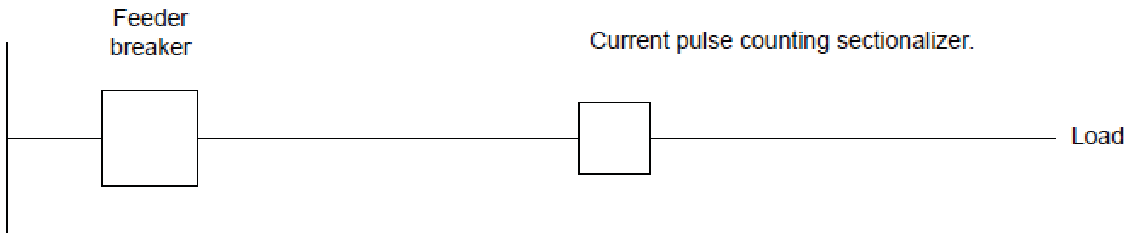
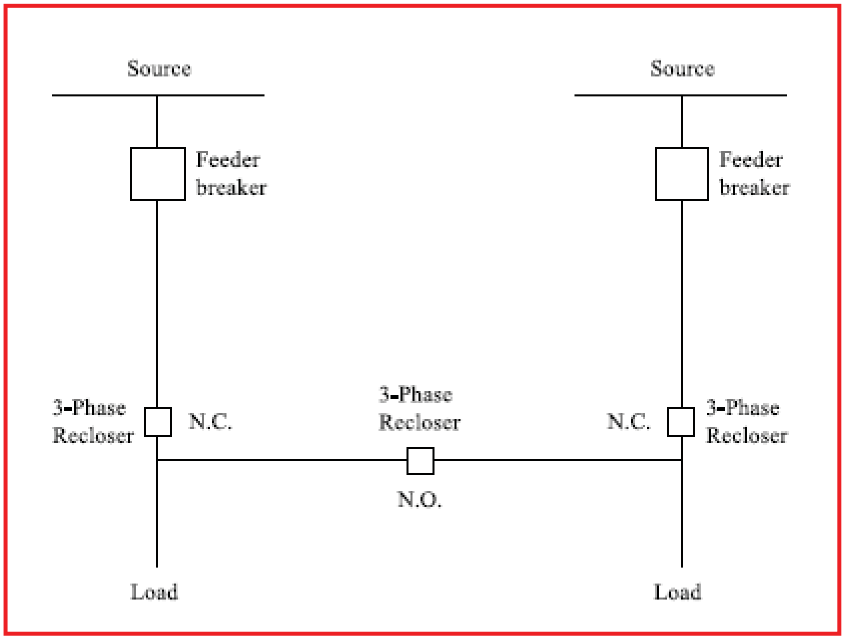


Figure 2 —Pulse-counting sectionalizing scheme

~~A three phase loop sectionalizing scheme (shown in Figure 3) consists of two distribution circuits each containing a normally closed three phase automatic line recloser (used as a sectionalizing switch) and a normally open three phase recloser as a tie switch installed between the two circuits. The three phase line recloser opens after a 50 s delay for loss of any phase potential on its source side and the tie switch closes after a 55 s delay for loss of all three phase potentials on either side of it. The feeder breaker autoreclosing sequence has to be less than the delayed opening of its associated line recloser for loss of potential. This allows the feeder breaker to restore the circuit to normal in the event of a momentary fault between it and the line recloser. For faults beyond the line recloser, unlike as described in the previous example of the current pulse counting scheme, the overcurrent function of the tie recloser is coordinated with the three phase reclosers and will open the tie recloser, and the feeder breaker will remain closed. The tie recloser has autoreclosing functions to lockout for overcurrent operations; however, it will not autoreclose for a loss of potential operation and has to be closed manually or via SCADA.~~



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~~Figure 3—Loop sectionalizing scheme~~

5.3.3 Fuse saving and fuse blowing schemes

5.3.3.1 Fuse saving schemes

Fuse saving schemes are used as a strategy to attempt to prevent permanent outages when temporary faults occur beyond tap fuses on a distribution system. Such schemes typically utilize instantaneous overcurrent relays on the feeder breaker, which are set to be capable of sensing faults beyond tap fuses on the associated line. As such, faults beyond these fuses can be cleared by the feeder breaker prior to the fuse being damaged. The low-set instantaneous relay typically is removed from service prior to the first or second autoreclose of the breaker. If the fault is permanent in nature, the fuse operates after the breaker autorecloses since the low-set instantaneous relays are no longer in service and the time overcurrent relays are set to coordinate with the tap fuses. The coordination allows the fuse to blow without interrupting the whole feeder the second time. If the fault is temporary, all customers are restored, including those beyond the fuse, when the breaker initially autorecloses.

When fuse saving schemes are used, it is beneficial to autoreclose the feeder breaker as rapidly as practical. Since, by action of these relays, the feeder breaker is allowed to operate for faults beyond downstream protective devices, and on a significant portion of the feeder, fast autoreclosing will mitigate the impact of more frequent breaker trips. It is common practice at many of the utilities utilizing fuse saving schemes to employ immediate autoreclosing (20 cycles of dead time to allow for deionization) on the first shot.

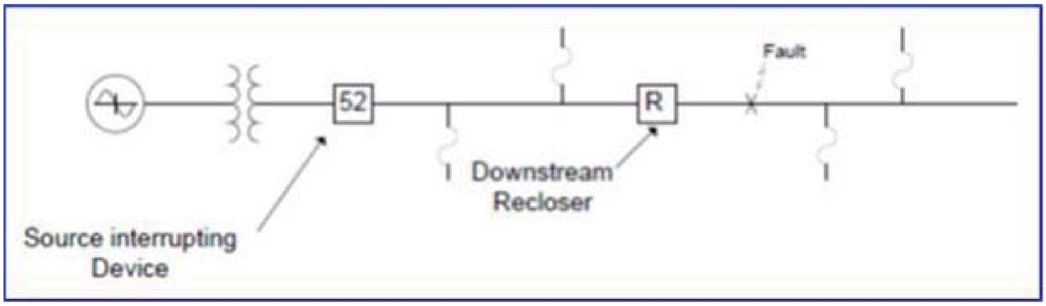
Often the low-set instantaneous overcurrent relays, or elements, are enabled just before resetting the reclosing relay. By doing this, a low-magnitude fault, for which the time delay relays have not completed their timing before the reset period of the reclosing relay expires, will be cleared. If this is not done, the reclosing relay will reset, and the reclosing sequence will be repeated a number of times. Alternatively, many microprocessor relays take care of this problem by blocking the reset timer whenever an overcurrent element is timing.

5.3.3.2 Fuse blowing schemes

Fuse blowing schemes are used to minimize the impact of a fault on the total feeder by allowing a fuse time to interrupt a faulted lateral if the fault is on the customer side of the fuse. In these schemes, a time delay sufficient for the fuse to operate before the upstream breaker is tripped is added to the instantaneous overcurrent elements, ~~or~~, This time delay allows the instantaneous overcurrent elements ~~are~~ not to trip ~~in service~~ during the initial trip of the feeder and ~~the time overcurrent elements are set to~~ allows coordination with the fuse ~~The instantaneous overcurrent elements are enabled into the tripping circuit following the initial autoreclose attempt~~.

5.3.4 Sequence coordination

Sequence coordination is a control function that can be included in an electronic recloser or microprocessor-based feeder relay package. This feature is applied to improve the service continuity on lines when two fault interrupting/autoreclosing devices are used in series as shown in the one-line diagram of Figure 3. An example of the coordination for this circuit is shown in Figure 4. This feature, when included in the source interrupting device, breaker, or recloser, prevents unnecessary interruptions to customers tapped between the two interrupting devices for faults downstream of the recloser. The optimal interrupting sequence can be accomplished for a permanent fault ~~anywhere~~ beyond the downstream recloser by time coordinating the fast trip of the overcurrent elements in the source device with those in the downstream device and coordinating the slow trip overcurrent elements in the two interrupting devices.



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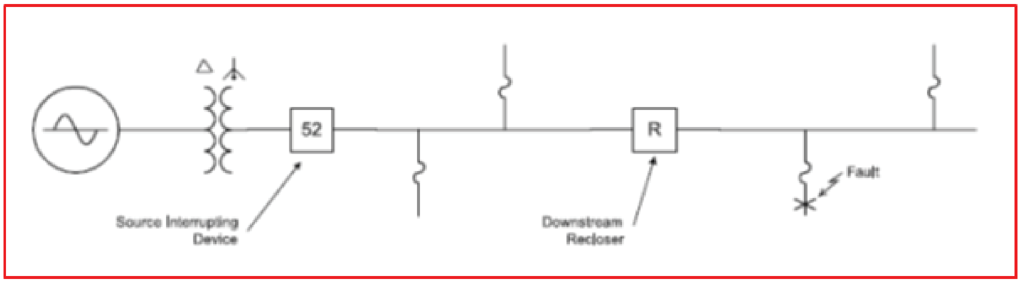

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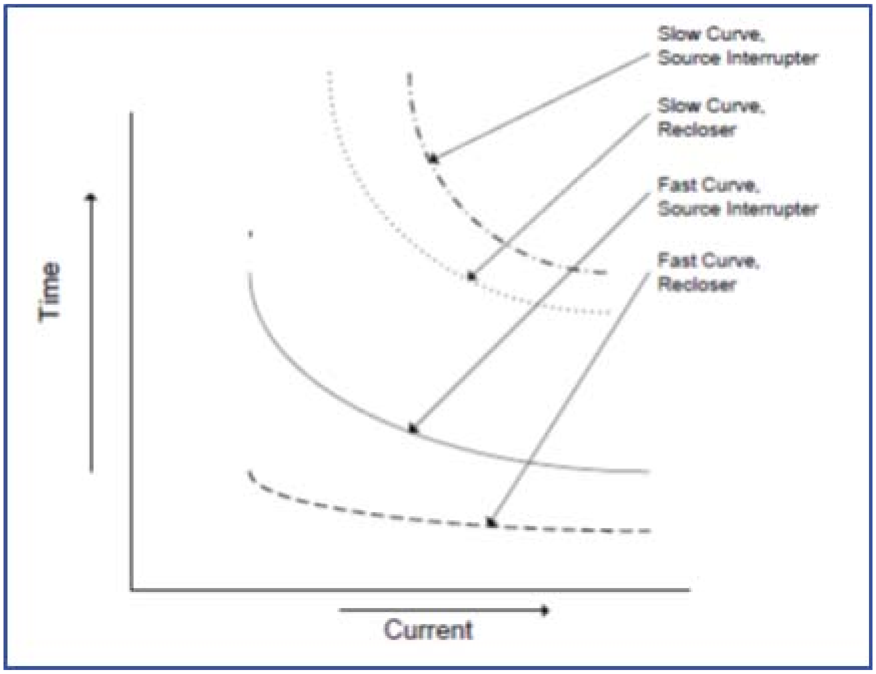
Figure 3 —One-line diagram



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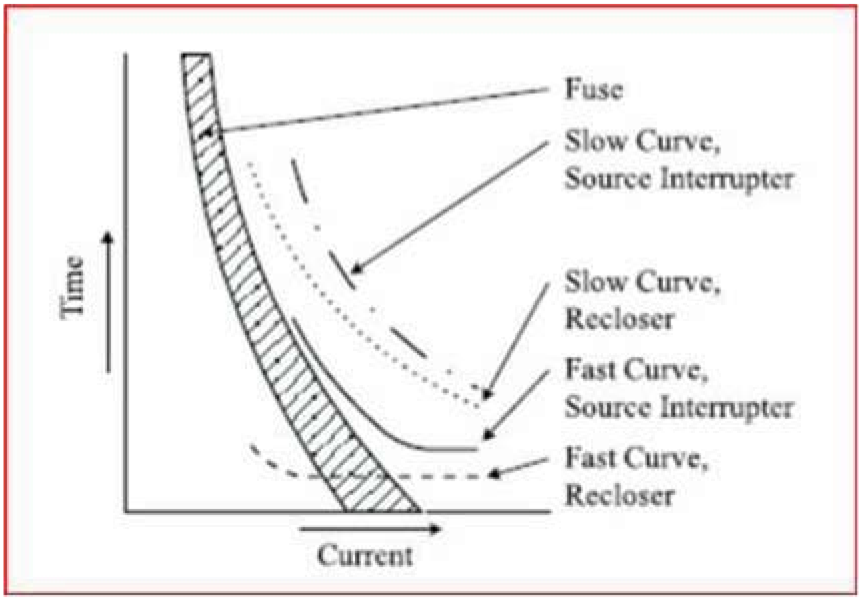

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Figure 4 —Typical circuit coordination with sequence coordination

NOTE—The overcurrent curves shown in Figure 4, Figure 5, and Figure 6 for both the source interrupter and the downstream recloser are shown in the quiescent condition waiting to respond when a fault should occur.

Without sequence coordination, the following occurs:

a) A fault occurs downstream of the reclosing device out on the line (assume the fault is permanent).

b) Downstream recloser opens by fast trip element.

c) Downstream recloser autorecloses, re-establishing the fault.

d) This sequence repeats for the number of fast trips programmed for the downstream recloser. The circuit coordination at this point is shown in Figure 5.

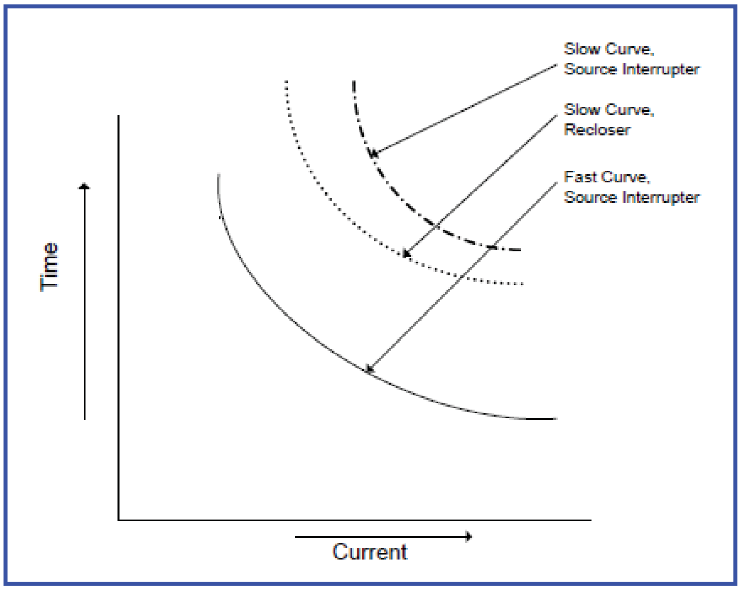
e) Source side fault interrupter opens by fast trip element because the downstream recloser now trips only by slow elements for the remainder of the sequence (until reset timer expires or lockout occurs).

f) Source side interrupter autorecloses.

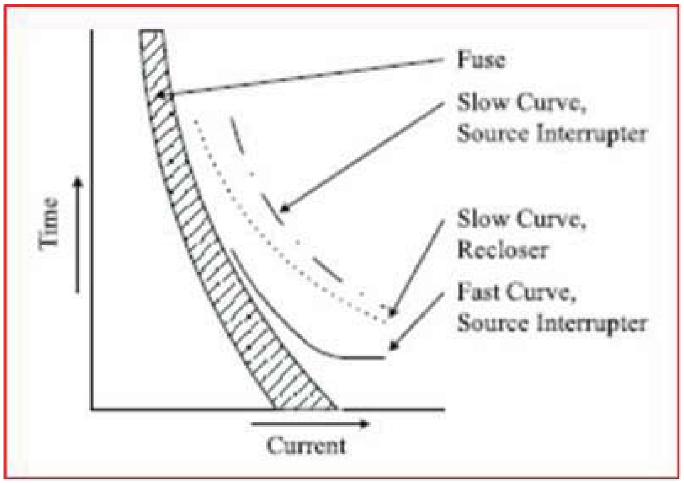
g) This sequence repeats for the number of fast trips programmed for the source-interrupting device.

h) Downstream recloser now trips by slow elements until reset time expires or lockout occurs. Source side interrupter now trips only by slow elements that should have been time coordinated with the slow elements of the downstream recloser.

With sequence coordination, the fast trip operation(s) of the source-side fault interrupter is/are eliminated from the sequence for the same fault condition as shown in Figure 6. The sequence coordination control function in the source-side fault interrupter senses the fast trip operation of the downstream recloser and, without tripping, advances the trip and autoreclosing sequence of the control package. The next time both fault interrupters sense the fault (if it occurs within the reset time delay), after the downstream recloser autorecloses, both control units are timing on the slow trip overcurrent elements as shown in Figure 6. With this sequence, the customers tapped between the two interrupters have no interruptions for the permanent fault event. The fast curve of the source interrupter must be slower than the fast curve of the recloser for sequence coordination to work properly.

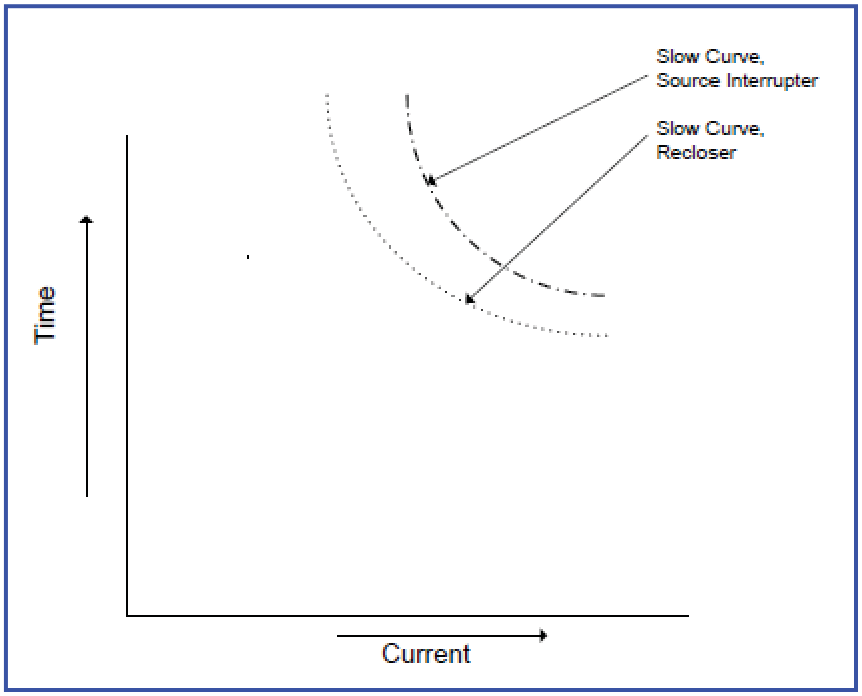


(New)



~~(Deleted)~~

Figure 5 —Coordination diagram without sequence coordination following fast trip(s) of downstream recloser



(New)

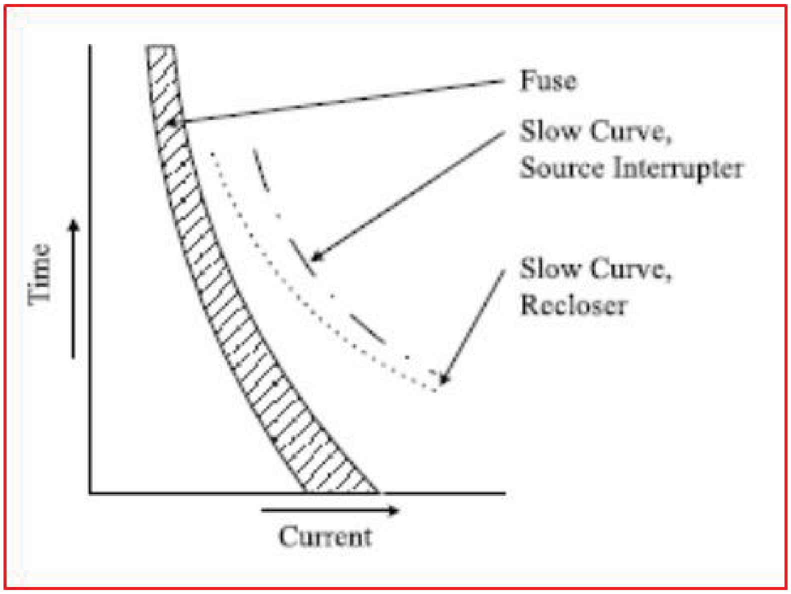


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Figure 6 —Coordination diagram with sequence coordination following fast trip of downstream recloser

5.3.5 Autoreclose blocking

Blocking requirements for autoreclosing will vary and depend on specific design features incorporated into the distribution system. In addition to those found in 4.6, below is a list of conditions that may require blocking or disabling of autoreclosing on distribution circuits ~~for various circumstances.~~ ~~The following are several conditions for which autoreclosing is blocked~~:

a) Underfrequency/undervoltage load-shedding schemes. When distribution circuits are tripped by action of load-shedding schemes, autoreclosing is blocked to avoid undesired load restoration during system overload conditions. Autoreclosing may be re-established when the frequency/ voltage condition has returned to normal and maintained that condition for some time.

b) Downed conductor protection. Autoreclosing can be blocked when protective systems designed to detect ~~protect for~~ a downed phase conductor operate. A downed conductor represents a permanent failure and a safety concern—autoreclosing is undesired for such a condition (Rockefeller et al. [B83]).

NOTE—In this context, a downed conductor may also be referred to as a high impedance fault.

5.4 ~~Special~~ Application considerations

5.4.1 Dispersed generation and other sources

Distribution circuits that have customer-owned ~~systems to which dispersed~~ generators connected require ~~provide utilities with~~ special consideration. The presence of generation can require special studies on the part of the utility.

In cases where the connected generator capacity is small, ~~Distribution circuits that have customer-owned generators connected to them present a special problem. In most cases,~~ it will be necessary to delay autoreclosing to allow the customer generator to be disconnected before the circuit is re-energized from the utility source. Removal of the customer generation is normally accomplished by the operation of an underfrequency, undervoltage, or reverse power relay, which tends to have longer tripping times. As the operating time for these devices may be slower to remove the connected generator than the relays that detected and cleared the fault, autoreclosing times could need to be extended to allow these devices to operate or the function be disabled. ~~Generators that are small as compared to the connected load need to have protection that should remove them from the circuit prior to re-energization and, therefore, do not cause a concern to the majority of utilities.~~ Owners of such units need to be made aware of the operating conditions of the circuit, including the autoreclosing parameters, to consider in setting up the generator protection schemes.

In cases where the connected generator is comparable to the load, it may be necessary to provide additional security against energizing the generator out of synchronism. In such cases it may not be necessary to disconnect the generator prior to restoring the system if the island can be resynchronized properly and safely. ~~In the case of generation that has the capacity to maintain the minimal connected load, it is necessary for the autoreclosing to be supervised by some type of line-side voltage supervision. This ensures that the generation has been disconnected prior to the re-energization of the circuit.~~ To maintain service to other customers, a communication-aided protection package could be needed. This additional security can be provided by dead-line autoreclosing logic, synchronizing check, or transfer trip protection.

Generation that is connected to the system by means of a static power converter can be self-protecting. Such units can disconnect the sources from the system prior to the re-energization of the circuit.

Large motor loads could require special studies by the utility; however, most such loads are not a factor in setting distribution circuit autoreclosing practices.

Three-phase monitoring may be desirable ~~used~~ for dead-line checking on distribution lines with distributed generation when fuses are applied between the substation and generation. Three-phase monitoring will prevent incorrect detection of a dead line that may occur if single-phase monitoring is used and a fuse is blown on that phase.

~~5.4.3 High-impedance faults~~

~~The technology for detecting high impedance faults is now becoming commercially available in some protective relays. At the time of this writing, the algorithms used in these devices can take several minutes to declare that a high impedance fault exists. Assuming that the circuit is automatically tripped as a result of the detection algorithms, the decision has to be made whether or not to risk autoreclosing. This decision needs to be an evaluation of the risk of re-establishing a high impedance fault that again could take several minutes to detect and clear versus the possibility of a false operation or the need for re-establishing service to perhaps critical loads. The electrical utility industry is now just beginning to assess the ramifications of following either policy with no clear choice yet determined.~~

~~5.4.4 Effects of autoreclosing on interrupt ratings of breakers~~

~~As an example, using the equations and the information contained in IEEE Std C37.04-1999 and IEEE Std C37.010-1999, a breaker with a 39 kA interrupting capability rating is derated as shown in Table 2 for various autoreclosing duty cycles with one or both of the above characteristics applied. The details in Table 2 do not account for other factors such as applying the breaker at less than rated voltage, asymmetrical current, or rotating machinery considerations, which could also modify the interrupting capability of the breaker.~~

~~Table 2—Effect of autoreclosing on interrupting rating~~

~~Autoreclosing duty cycle~~	~~Duty cycle characteristic applied~~	~~Reclosing relay delay settings~~	~~Modified interrupting rating (kA)~~
~~CO + 5 s + CO~~	~~b~~	~~R_{T1} = 5~~	~~37.31~~
~~CO + 20 s + CO~~	~~None~~	~~R_{T1} = 20~~	~~39~~
~~CO + 5 s + CO + 15 s + CO~~	~~a and b~~	~~R_{T1} = 5~~	~~34.78~~
		~~R_{T2} = 15~~	
~~CO + 5 s + CO + 15 s + CO + 30 s + CO~~	~~a and b~~	~~R_{T1} = 5~~	~~32.24~~
		~~R_{T2} = 15~~	
		~~R_{T3} = 30~~	
~~CO + 0 s + CO + 10 s + CO + 30 s + CO~~	~~a and b~~	~~R_{T1} = 0~~	~~30.55~~
		~~R_{T2} = 10~~	
		~~R_{T3} = 30~~	
~~CO + 15 s + CO + 15 s + CO + 30 s + CO~~	~~a~~	~~R_{T1} = 15~~	~~33.93~~
		~~R_{T2} = 15~~	
		~~R_{T3} = 30~~	

~~5.4.6 Recurring faults and excessive fault frequency~~

~~As mentioned in 5.2.3, there are a number of fault conditions that could occur, which could result in intermittent recurrence of the fault. Among these are tree limbs affected by wind, conductors blowing together, and countless other similar conditions. Autoreclosing is generally applied to restore service for temporary faults, but the number of fault operations should be limited whenever the fault is permanent. Since the difference between a temporary fault and a permanent fault is determined by the absence of a fault for the reset time setting of the reclosing relay, these recurring fault events may appear to be temporary faults yet could result in an excessive number of fault current exposures within a relatively short period of time.~~

5.4.2 Capacitors

Shunt capacitors are applied to distribution buses and lines to provide reactive power ~~Var~~ support and control the voltage along the lines. Because of the diverse application of capacitors on the distribution system and the expectation that the time delays within the associated automatic voltage controls are longer than the reclosing delay times, the controls of shunt capacitors are not expected to present a problem to the application of reclosing relays. However, depending on the location of the shunt capacitor and the tripping action of the protection, and the point-on-wave of the interruption of the source to the capacitor, consideration should be given to the potential for trapped charge. If the capacitor is connected to the line, it is expected that the connected load would drain the charge during the interruption time. If the capacitor is connected to the distribution bus, a reclosable bus trip could present a problem due to the possibility of residual charge remaining on the capacitor following the reclosing delay interval. If a significant amount of industrial load is lost, a reclosure into an unloaded line might result in an unusually high rise in voltage if capacitors are fixed and cannot automatically switch off.

~~5.4.9 Other special application considerations~~

~~5.4.9.1 Sync-check relaying~~

~~Sync-check relaying is applied to verify that the systems to be connected are in phase prior to breaker closing. The locations of single-phase and three-phase potential devices need to be considered to prevent cogeneration or a switching procedure from backfeeding of the circuits. Also, consideration should be given to whether or not the sensing for these relays is to be phase-to-phase or phase-to- ground. (See 4.3.2.)~~

~~5.4.9.2 “Distance to fault” calculations~~

~~“Distance to fault” calculations or impedance measurements based on an area map can be used to control distribution autoreclosing. (This could be more applicable to adaptive transmission line relaying.)~~

5.4.3 Transformer load tap changers ~~(LTC) blocking during autoreclose~~

Having an autoreclose on the feeder breaker fed from a transformer during a tap change operation increases the chances of exposing the LTC components to a through-fault event that could result in damage. Therefore, ~~It is a common practice to~~ blocking the LTC controls while an autoreclosing sequence is in progress may be considered.

6. Autoreclosing for transmission systems

6.1 Transmission systems overview

The loss of a single line in the transmission system can have a significant ~~great~~ impact on the economics and reliability of the system. Autoreclosing a line is applied to minimize this impact. The methods of high-speed and time-delayed autoreclosing are ~~still~~ widely and effectively used. The availability of greater amounts of information through SCADA and intelligent relaying systems can allow for more selective autoreclosing, which can improve the success rate of reclosing, while helping to minimize further damage to the system from closing into permanent faults. Increasing use of single-phase tripping, controlled breaker closing, and adaptive autoreclosing techniques has resulted in better reliability and has reduced the negative impact that failed autoreclose attempts have on the system.

In addition to autoreclose methods, many elements ~~common~~ in transmission systems require consideration of their effects on the application of autoreclosing. For example, consider a network transmission line that requires autoreclosing to be supervised by a synchronizing device. To reduce system impact, only one end of the networked line could be autoreclosed to "test" the line. More elements that affect autoreclosing include: multiple-terminal lines, generators, large motors, transformers, capacitors, reactors, and others.

The methods of autoreclosing and the consideration of system elements that affect the application of autoreclosing to transmission lines are presented in detail in the following subclauses of this guide.

~~6.1.1 Common considerations for autoreclosing~~

~~6.1.1.1 Circuit breaker capability~~

~~When autoreclosing times and sequences should be selected with due regard to circuit breaker interrupting capability, derating, voltage withstand capability, closing or opening resistor thermal capability, and overall breaker design.~~

~~6.1.1.4 Breaker failure operations~~

~~Autoreclosing following breaker failure relay operation should not be attempted until the failed breaker is isolated.~~

6.2 Autoreclosing methods

6.2.1 High-speed autoreclosing

High-speed autoreclosing is the automatic closing of a circuit breaker with no intentional delay beyond an allowance for arc deionization (see 4.4.2 and IEEE PSRC Report [B53]). Given the high success rate of autoreclose attempts for temporary faults, it is appropriate to consider ~~makes sense to attempt a~~ high-speed autoreclosing.

Some ~~additional~~ benefits of high-speed autoreclosing that may be realized:

a) Provides fast restoration of power to customers

b) Can help to maintain system stability

c) Restores system capacity and integrity

In order to use high-speed autoreclosing on networked lines or other lines with multiple sources, high-speed tripping needs to be used to clear all of the sources. Typically, this is accomplished by using some form of pilot or line differential protection scheme. Generally, the autoreclose is fast enough that the synchronizing angle changes very little and can be ignored. If conditions exist where this angle becomes too great, then high-speed autoreclosing should not be used.

When system separation occurs, the angular separation between isolated portions of the system may increase rapidly. In such cases, unsupervised high-speed autoreclosing may result in closing at angles at or near 180°, presenting a high risk of equipment damage and adverse system impact. When studies or actual system events identify lines that are subject to tripping during system separation, consideration should be given to disabling high-speed autoreclosing or adding supervision to the high-speed autoreclosing scheme (e.g., a high-speed voltage element could be connected to measure the difference in voltage across the circuit breaker). Preventing undesired high-speed autoreclosing during out-of-step conditions may prevent damage to generating and substation equipment necessary for prompt system restoration. Consideration should include weighing the benefits of high-speed reclosing for the typical trip and reclose sequences that occur for normal system events against the risks associated with high-speed reclosing during unusual system events, which typically are infrequent in comparison.

To minimize potential adverse consequences of high-speed reclosing, consideration needs to be given to:

~~In order to ensure successful high speed autoreclosing, some considerations need to be given to:~~

a) Large motors connected to the line can sustain the arc beyond a time where a high-speed autoreclose is possible. Consideration should be given to monitoring the voltage on the load side of the breaker when the inertia of the motor and its load may maintain this voltage following a trip. If the motor is critical to the plant operation, it could be necessary to monitor the voltages on both sides of the breaker as well as the phase angle across the breaker. (See 4.7.8.)

b) An unsuccessful autoreclose attempt (particularly three-phase faults) close~~-~~-in to a generating plant can contribute to accelerated torsional fatigue on the turbine-generator shafts (Jackson et al. [B63]). This can be dealt with by not autoreclosing near generating plants or by blocking the autoreclose for close-in ~~faults~~ or three-phase faults. (See 6.3.2)

c) Ideally, reclosing dead-time should be nearly equal (within a couple of cycles) at each terminal. For example, this may be an issue if one terminal has an oil circuit breaker with a dead-time of 12 cycles and the remote terminal has an SF_6 gas breaker with a dead-time of 20 cycles. In this case, staggered high-speed reclosing (one shot from each terminal) would result, potentially prolonging the fault duration, unless these time differences are properly accounted for in the autoreclosing design.

d) Ensuring appropriate delays are inserted in the breaker mechanism or reclosing relay to allow dissipation of the ionized path before allowing reclosing (important for ultra fast breakers, which can have rated closing times as fast as two cycles).

6.2.1.1 Stability considerations

When high-speed autoreclosing is under consideration as a means for increasing the transient stability margin of a system, restoring service to critical loads, or restoring needed system interconnections, it should be recognized that there is a risk as well as a possible benefit associated with ~~attending~~ its use. The risk is that stability could be endangered rather than benefitted if a line is autoreclosed into a permanent fault at the wrong time. Stability studies can be used to indicate whether or not the use of high-speed autoreclosing would ~~to ensure that high speed autoreclosing does not~~ endanger stability.

6.2.1.2 Switching surges

High-speed autoreclosing should not be used where transient voltage analysis studies indicate that high-speed autoreclosing could produce switching surge magnitudes exceeding the equipment design levels.

6.2.2 Time-delayed autoreclosing

Delayed autoreclosing may be used, following design analysis, when restrictions such as in 6.2.1 exist. Delayed autoreclosing can also be used following an unsuccessful initial high-speed autoreclose attempt, and where multiple-shot autoreclosing is used.

6.2.2.1 Time considerations

Typically, for three-phase autoreclosing schemes (whether or not series capacitors are applied), the initial autoreclose dead time for a particular circuit can be anywhere from ~~fall in the range~~ 0.5 - ~~1.5~~ seconds to tens of seconds, depending on requirements (e.g., stability studies, autosectionalizing, etc). On transmission systems, the autoreclose delay times are frequently determined by transmission planning engineers and should be based on stability studies to allow damping of system oscillations following a disturbance. The autoreclose timing settings for a particular circuit should satisfy transient stability concerns. ~~If stability studies on a particular circuit are not available, a 1.5 s delay appears to be conservative for most systems.~~

6.2.4 Single-shot and multiple-shot autoreclosing

In some cases, an autoreclosing sequence on an EHV terminal might consist of a high-speed autoreclose on a carrier or pilot trip, unsupervised by either dead-line or synchronism-check relaying, followed by a time-delayed autoreclose supervised by dead-line relaying. A successful autoreclose would then permit the other terminal(s) to close after a time delay by synchronism-check relaying.

~~In general, most modern transmission circuit breakers are capable of any practical multiple shot autoreclosing duty cycle. Certain constraints, with respect to breaker components, such as closing or opening resistors, available fluid and gas pressures or stored spring energy and recharging time, or a derating factor based on the maximum expected fault current and total possible number of interruptions in a specific time period, can be limiting factors on the repetitive number of operations or duty cycles. Reference should be made to pertinent sections of current revisions of IEEE Std C37.04-1999 and IEEE Std C37.010-1999 in any circuit breaker application.~~

Multiple-shot autoreclosing is generally not used where system stability can be jeopardized by the shock of multiple autorecloses into a permanent fault or where other restrictions such as sensitive loads exist. Where it can be used, the second attempt needs to be delayed long enough to permit ~~postfault~~ transients from the first autoreclose attempt to diminish. Likewise, single-or multiple-shot autoreclosing should not be used where mechanical damage to generators or large motors could result.

Autoreclosing on EHV systems is predominantly single~~-~~-shot. It is considered prudent to obtain line protection relay targets, either by an operator or via downloaded fault information from SCADA, to assess the type of fault and the risk to the system prior to attempting an additional manual reclose. Where criticality of the line, remoteness, or load demographics allow, multiple-shot autoreclosing has gained acceptance even though the success rate for additional dead-line autoreclose attempts is poor.

Experience has shown that, in general, there is a greater success in the use of dead-line autoreclosing on a transmission line when the first attempt is delayed ~~for typically 5 s~~ to allow the cause of the fault to fall clear or for ionized gases to dissipate. This is especially true where the line protection is non-pilot and additional time is required to allow for time-delayed tripping of one or more terminals.

6.2.4 Single-phase tripping and autoreclosing

Single-phase tripping ~~(often referred to as single pole tripping)~~ requires more complex protection and control systems that can distinguish between single phase-to-ground and multi-phase faults and operate single-phase or three-phase accordingly. The circuit breakers need to have segregated poles with a separate trip and close mechanism for each phase. During the period of the open phase, unbalanced currents are detected by the ground relaying. These relays need to be coordinated to prevent overtripping of adjacent lines due to increased unbalanced currents or the misoperation of any negative sequence polarizing elements. The zero sequence currents flowing during the open-phase period can adversely affect system ground relaying in external circuits as well. Some typical requirements for the protection system are listed as follows:

a) If single-phase trip and autoreclosing is to be applied, the autoreclose times for single-phase and three-phase tripping should be independently adjustable.

b) A selector switch may be provided to select different trip and autoreclose modes.

c) The protection needs to be capable of detecting a fault involving other phases during the open pole period.

With single-phase tripping, only the faulted phase is tripped and autoreclosed for single line-to-ground faults. This process is usually implemented after transient stability/EMTP studies have demonstrated that expected transient overvoltages with one-phase open operation are well within the equipment design range and such an operation promotes system stability. When one phase opens during a single-~~-~~phase trip operation, load is carried through the unfaulted phases, causing unbalanced currents to flow in the system. The impact of the unbalanced currents on rotating machines needs to be carefully addressed. ~~System current balance would be restored utilizing high-speed autoreclosing of the opened phase (0.5–1.0 s).~~ Successful autoreclosing for a temporary fault is conditioned on the extinguishing of the secondary arc and attaining a favorable recovery voltage.

During the open-phase period, approximately half of the power just prior to the fault is transmitted over the two remaining phases. This flow of power reduces the rotor drift between synchronous machines and helps to maintain stability. On autoreclosing, it also has the effect of lessening the transient torques that can be produced in generator shafts and ~~of~~ lessening the shock to the system compared to that for three-phase tripping and autoreclosing.

Considering ~~that~~ the majority of faults on transmission systems are single line-to-ground, not permanent, and are typically lightning induced, ~~then~~ it follows that single-phase tripping can prove effective. This is particularly true where there is a single transmission line to a major power source with no other significant parallel ties.

With one phase open to clear a single line-to-ground fault, a voltage is induced in the isolated phase due to capacitive coupling and to a lesser extent by inductive coupling. This coupling has the effect of prolonging the arc deionization time, referred to as maintaining the secondary arc current. This secondary arc current is proportional to the circuit voltage and the transmission circuit length. The minimum dead time before allowing autoreclosing is a function of the duration of secondary arc current. If this time is longer than that allowed to maintain system stability, the line capacitance needs to be compensated. One common method of compensation is by the application of shunt reactors including neutral reactors. Since many EHV transmission lines require shunt reactors for compensation of the positive sequence charging current, by proper connection these shunt reactors can also serve the purpose of suppressing the ground fault secondary arc current. Typical single-phase autoreclose times applied by utilities are in the order of 0.5 to 2 ~~1~~.0 s.

The single-phase reclosing time should be set faster than the breaker pole discordance (or pole discrepancy) time to avoid tripping all three phases prior to a successful reclose operation. In addition, this time should be less than the fastest operating time of unbalance protection on nearby transmission elements (i.e., transmission lines, transformers, etc).

Single-phase tripping is more common in Europe than in North America. However, with the advent of breakers with separate phase mechanisms now more common and with increasing favorable experience, single-phase tripping is now being more frequently applied in North America.

~~6.2.6 Substation controller autoreclosing~~

~~The use of substation computer, PLCs, and intelligent electronic devices (IEDs) in the power system have increased greatly. These devices can be used to provide autoreclosing functions that to date were performed using individual dedicated relays.~~

~~Several utilities are incorporating computers and PLCs to perform not only control functions but also to effect relay tripping functions. Complete tripping and autoreclosing schemes can thus be programmed and the amount of hardware reduced (Berger et al. [B2], Power System Relaying Committee [B9], and Jackson et al. [B12]). At present, fault detection with PLCs is limited.~~

~~The use of these computer type devices means that elaborate autoreclosing schemes may be programmed in software rather than using dedicated relays. It is easy to program a scheme that, e.g., would allow multiple shots of autoreclosing, each shot with different voltage supervision. Autoreclosing can be easily inhibited or changed by the use of the communication link between the substation and the load dispatchers.~~

~~If adaptive relaying is incorporated, then it would be possible for the substation computer to adjust autoreclosing settings ''on the fly.'' The use of a substation local area network (LAN) would allow the PLCs and IEDs to communicate with the host computer and adjust settings according to system conditions. Design considerations may be that it is best to leave the actual autoreclosing software and closing features (i.e., contacts) in the PLC or IEDs. Thus, the substation computer would only monitor and provide setting changes.~~

~~The use of PLCs would also allow IEDs that may not have their own autoreclosing scheme built in but do have multiple output contacts to initiate autoreclosing on a selective basis. This would require the ability to have the output contacts respond to different internal relay logic trips. Thus, a relay that has high impedance fault detection logic could inhibit autoreclosing but allow autoreclosing if only the overcurrent element logic operated.~~

~~6.2.7 Remote operations controller (SCADA)~~

~~Today, most transmission substations are provided with SCADA capabilities. The information and control available to a manned central control center makes it possible to modify the practices associated with autoreclosing. Consider the fact that for a given fault, each successive autoreclose attempt has a much lower chance of success than the previous attempt. Consider also that each unsuccessful attempt is damaging to the equipment and the system. With access to control and information, it is possible to reduce the number of autoreclose attempts and allow the control center operator to conduct further remote/manual reclose attempts based on information available for the fault and system operation conditions. The information can include the type of fault, the fault magnitude, possible fault location, and the equipment affected. This information shall determine whether another reclose attempt is to be made, whether to cancel further reclosing until inspection is performed, or where to sectionalize the system if possible.~~

~~Operation of the circuit breakers through a SCADA system should be similar to substation operation by control switch. An ‘‘open’’ command should disable all autoreclosing even when issued on an open breaker. The latter requirement is valuable during system restoration following a wide area event such as a blackout. The operator should be able to close either end of the line first regardless of the automatic conditions. The maximum voltage difference and synch angle should be determined and, if possible, the synch check relay could need to be adjusted to allow closing.~~

~~6.2.8 Adaptive autoreclosing~~

~~As indicated in 6.2.6, the use of substation computers, IEDs, and PLCs for substation relaying and control is increasing. The use of a computer allows adaptive relaying and control features that have never been used before.~~

~~An industry survey by the IEEE Power System Relaying Committee [B9] indicates that several adaptive autoreclosing schemes have been in use or are being proposed. They include:~~

~~e) Allow the substation computer to be the only autoreclosing device for the entire substation. (IEEE Power System Relaying Committee [B9].)~~

6.3 Application considerations

6.3.1 Blocking of autoreclosing

Blocking requirements for autoreclosing will vary and depend on specific design features incorporated into the transmission system. In addition to those found in 4.6, below is a list of conditions that may require blocking or disabling of autoreclosing for transmission circuits:

~~Autoreclosing is normally blocked:~~

~~b) Following any manual trip operation of a circuit breaker.~~

~~c) For all breakers tripped by a bus differential relay operation.~~

~~d) For a transformer differential relay operation associated with a line terminal, or a transformer tapped onto the line until the transformer is isolated.~~

~~e) For a breaker failure relay operation within the zone of operation of the breaker failure relay.~~

~~In addition, the following conditions should be considered for blocking autoreclosing:~~

~~1) *Hot line maintenance*. For securing of personnel safety, autoreclosing should be blocked while line crews perform hot-line maintenance.~~

a) Three-phase faults. Three-phase faults are rare on EHV (~~765~~-345 kV and above) and are unlikely to be of a temporary nature. These faults most often result from ground straps left in place after breaker maintenance or downed line structures; therefore, blocking of autoreclosing could be considered. Since temporary three-phase faults are more probable for lower voltage transmission lines, autoreclosing may be desirable if system stability and generation are not negatively affected.

~~6.2.1.4 Out-of-step and power swing conditions~~

b) Power swing and out-of-step conditions. On detection of ~~a breaker has tripped due to~~ a power swing or out-of-step condition ~~relay, consider blocking autoreclose until system stability can be re-established~~. ~~All~~ autoreclosing should be blocked, because ~~following an out-of-step or power~~ an autoreclosure could further agitate an already disturbed system condition. This action should be taken whether the out-of-step or power swing relay is ~~operation~~ used to block tripping or initiate ~~causes~~ stripping of the breaker.

~~3) *Breaker failure to trip or trip circuit monitor alarm*. If a relay trip has occurred, but the breaker stays closed longer than the expected breaker trip time (e.g., 6–10 cycles), block autoreclosing and initiate tripping of the backup breaker. Also, if trip circuit logic is available, then use this logic to block autoreclose if an open trip circuit is detected.~~

~~4) *Breaker failure to close*. If an attempt is made to autoreclose, and the breaker does not close (based on 52 auxiliary contact) or fails to close within the expected close time, or if a discontinuity (open circuit) is detected, then further attempts to autoreclose are blocked.~~

6.3.2 Turbine-generator considerations

Manual closing or autoreclosing without synchronization supervision may subject ~~at line terminals that are in close electrical proximity to them~~ turbine-generators to excessive shaft torques and winding stresses with resultant loss of life of the turbine-generator system. These effects should be studied and evaluated before unsupervised autoreclosing is allowed ~~initiated by tripping~~. It is preferable to re-energize a line at a terminal remote from the generator bus, check synchronism between the generator bus and line, and then close the breaker at the generator end.

In past years, considerable research and analysis focused on the stresses in the shafts and components of turbine-generators due to switching operations. There is little documentation of actual damage to, or failure of, turbine-generators resulting from autoreclosing or switching. The effects of these induced stresses are cumulative and can be caused by normal switching operations or system faults. Therefore, autoreclosing can be a contributing factor to machine failure, but not necessarily the sole contributor.

An unsuccessful autoreclose attempt (particularly for three-phase faults) close-in to a generating plant can contribute to accelerated torsional fatigue on the turbine-generator shafts (IEEE Std C50.13 [B61], ~~ANSI C30.13-1977~~ IEEE Committee Report [B47], Jackson et al [B63], and Hsu et al [B86]). This can be dealt with by not autoreclosing near generating plants or by blocking the autoreclose for close-in or three-phase faults. Consideration should be given as well to the natural oscillatory frequency of the transmission line as autoreclosing can result in a resonant condition, which could contribute to other system problems.

The operation of closing a breaker in the power system ~~can result in the~~ creates ~~of~~ power transients and current oscillations, which can stress or damage generating units ~~located electrically close to that breaker~~. These transients affect various components of the turbine-generator. The concern is the average initial power difference, ΔP, which occurs when the breaker is closed, and its effect in producing torsional stresses, primarily in the rotational members of the turbine-generator. (ΔP is the difference between the generator real power output level just prior to breaker closing, and the generator real power level just after breaker closing.) For this condition, a ~~permissible~~ limit for ΔP ~~or I~~ at the generator terminals of 0.5 per unit based on the rated load and power factor typically results in acceptable performance. Regardless of the cause of initial disturbance, autoreclosing times in excess of 10 s appear long enough to allow the oscillations from the initial disturbance to die out.

Abnormally high stresses are imposed on the turbine-generator shafts due to high-speed autoreclosing [B1]. ~~Turbine-generators when subjected to high-speed autoreclosing can resonate at the natural frequencies of the turbine and shaft.~~ These transient torques will cause cyclic stress variations in the generator shaft resulting in cumulative fatigue damage when they exceed material fatigue limits. This results in reduced component life of shafts, retaining rings, and rotors. In extreme cases, these torsional vibrations have led to growing oscillations resulting in shaft damage. Some of the more recent papers on the subject of shaft fatigue as a result of high-speed autoreclosing (IEEE ~~ANSI~~ Std C50.13 ~~30.13~~-~~1977~~ [B61]) suggest that simple measures such as ΔP ~~or I~~ cannot be correlated directly.

Transient torque studies that quantify the impact of high-speed autoreclosing can be performed to calculate the impact on the turbine-generators. This study would require a detailed turbine-mass representation and is generally performed using the Electromagnetic Transient Program (EMTP). This study can then provide a basis for evaluating the need for torsional monitors/relays on the turbine-generators.

The torsional monitoring devices monitor the turbine-generator shaft for torsional oscillations by providing torsional mechanical response evaluation, shaft torsional stress, and fatigue evaluation, and can be used by the operator to assess torsional impact of an event on a unit. The torsional protective devices continuously monitor the turbine-generator shaft and provide trip output contacts when shaft fatigue reaches predetermined levels.

In some cases, generation may exist at both ends of a transmission line. While the basic premise is to avoid any reclosing near generation in order to reduce stress on the generator, the impact to the transmission system must also be considered. Stability analyses, along with additional data, can be used as a tool to help determine which end, if any, should be permitted to close on a dead line. Many other factors, such as system configuration, generation size, and infeed sources contribute to the decision. Regardless of the analysis, the transmission owner and the generation owner should both be aware of the analysis used to determine if autoreclosing is appropriate.

In consideration ~~As a result~~ of the ~~apparent~~ risk to turbine-generator life, autoreclosing practices ~~most utilities~~ may be modified to incorporate one or more ~~their autoreclosing practices to some form~~ of the following:

a) Autoreclose by synchronism check only

b) Allow a minimum of a 10s delay prior to any dead-line autoreclose attempt

c) Use single-phase tripping/reclosing ~~and~~

d) Allow three-phase autoreclose on single-phase faults only

e) Autoreclose lines with tapped generation only under dead-line conditions

f) Use no autoreclosing near generation

6.3.3 Other system elements

Risks versus benefits should be evaluated before applying autoreclosing following faults on transformers, buses, or cables. For these system elements, it is generally not advisable to autoreclose since the probability of a fault being permanent is high and the probability of aggravating equipment damage is increased. Under specific circumstances, however, the benefits of autoreclosing could justify its use.

6.3.4 Multiple-breaker line terminations

~~6.1.1.8 Multiple circuit breaker line termination~~

Multiple-breaker line terminations, such as ring bus, double bus/double breaker, or breaker-and-a-half schemes, can provide flexibility in operating the transmission system. However, since simultaneous closing times are difficult to achieve, autoreclosing into a permanent fault by more than one breaker at the same line terminal could result in the fault being maintained on the system for a longer than intended period and can be followed by an incorrect breaker failure operation. In addition, this action could increase the severity of the system disturbance. The suggested mode of autoreclosing at a terminal with more than one breaker per line is to autoreclose with a preselected breaker. Following the successful autoreclose operation of the preselected breaker, the other breaker(s) associated with the line terminal may be autoreclosed on a time-delayed basis, or closed by other means. Supervision by synchronism check or voltage relays of the remaining breaker(s) at this terminal may need to be considered in the closing circuit. ~~For example, if a breaker is out of service for maintenance, operators can energize the line from the in-service breaker. In some cases, multiple-breaker lines can simply be a more economical alternative for designers. In any case, protection engineers need to apply relaying to trip two breakers for a line fault and to provide restoration of power to the faulted circuit by autoreclosing two breakers in an orderly manner.~~

The same considerations for high-speed and time-delayed autoreclosing, single and multiple-shot, and supervision of autoreclosing can be applied to multiple-breaker termination applications as lines terminated with a single breaker. These considerations are typically applied to the "lead" breaker (e.g., Breaker 1 in Figure 7). If the lead breaker autoreclose attempt is successful and the lead breaker remains closed, the "follow" breaker (Breaker 2 in Figure 7) is autoreclosed on a time-delayed basis. This operation can be supervised by "live-line/live-bus." In the event that the lead breaker autoreclose attempt is not successful and the lead breaker is tripped prior to the autoreclosure of the follow breaker, the autoreclosing logic and time delays at this line terminal may allow the follow breaker to become the first breaker to close in a time-delay mode (with supervision) if the remote terminal autorecloses to energize the line ~~first.~~

In these applications, it may be desirable to include selection logic that transfers the lead autoreclosing function from an out-of-service breaker (e.g., Breaker 1) to the remaining breaker (Breaker 2). This logic can also include a transfer of the lead breaker selection, following a successful autoreclose operation, to the other breaker to equalize the wear on the interrupter.

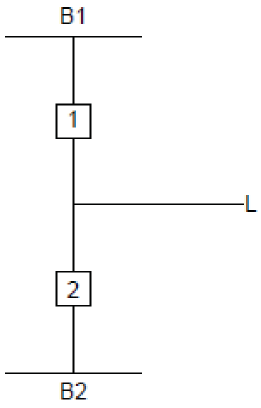


Figure 7 —Multiple-breaker line termination

6.3.5 Special considerations for series compensated lines

Series capacitor installations are most likely to be used on EHV transmission lines to increase power transfer. The introduction of this type of compensation may require modification in autoreclosing practices. Each installation requires close examination by the operating and protection engineers.

There are various configurations of series capacitor bank protective components. The protective components typically consist of metal oxide varistors (MOV) across the capacitor bank to prevent excessive voltage, a bypass breaker to protect both capacitors, and MOVs during overload and overvoltage conditions. In addition to these, there could be a triggered air gap to protect MOVs and capacitors under severe overvoltage situations. There are legacy installations with self-triggered air gap and a bypass breaker configuration across series capacitors. For further details on series capacitor banks, please refer to IEEE Std 824TM and IEEE Std C37.116.

Autoreclosing philosophies on lines with series compensation vary among utilities. Issues such as system stability, single-phase or three-phase tripping ~~autoreclosing~~, communication means, and short-circuit levels could be the determining factors for adopting a particular autoreclose philosophy. When single-phase tripping and reclosing is used, series capacitors are bypassed either only on the faulted phase or on all three phases to reduce the secondary arc and TRVs on breakers. For details, refer to IEEE Std C37.116.

~~On lines with single-phase tripping and series compensation, to aid in secondary arc extinction, the series capacitors are bypassed during the single-phase autoreclosing dead time. The capacitor controls bypass the bank within six cycles of the last line terminal's opening and automatically reinsert the capacitor bank after the last circuit breaker closes. In addition to the benefit of helping extinguish the secondary arc, the automatic bypassing avoids exposing the capacitor bank to an unsuccessful autoreclose situation.~~

~~On newer series compensation capacitor bank controls, it is possible to bypass the automatic sequence (by supervisory control) and pick up the line with the capacitor bank in service, which reduces the Ferranti rise on the open end of the transmission line. This is helpful when it is difficult for control center staff to lower the sending end voltage, prior to line closing, during some operating conditions.~~

6.3.6 Guidelines for setting synchronism-check angles

Synchronism-check (sync-check) is used to supervise reclosing between two portions of a system that are connected through ties in parallel with the path being closed. Sync-check refers to the determination that acceptable voltages exist on the two sides of the circuit breaker, and the phase angle and frequency difference (slip) between them is within a specified limit for a specified time.* Closing the circuit breaker under undesirable conditions may have an adverse impact on equipment such as turbine-generator shafts and circuit breakers and may also have an adverse impact on system stability. The settings on a sync-check relay are selected to prevent reclosing when reclosing under live-bus/live-line conditions would adversely impact equipment or system operation.

Sync-check relays respond to three characteristics associated with the voltage phasors on either side of the open circuit breaker: slip, phase angle difference, and magnitude difference. In some relays, particularly microprocessor-based designs, limit settings can be applied to each of these characteristics independently. In other relays, particularly older electromechanical types, the characteristics are interdependent such that separate limits cannot be set. The following guidance is provided relative to limit settings for each of these characteristics.

— Slip: The difference in frequency between bus-side and line-side voltages should normally be zero, indicating that the systems on each side of the open breaker are synchronously tied by at least one other interconnection. A low, non-zero value of slip is generally allowed so that the breaker can be used to manually re-synchronize two systems that are separated, but both operating at or near nominal frequency, with the sync-check relay providing protection for this breaker closure.

— Phase angle difference: The difference in angle between the line-side and bus-side voltage phasors on opposite sides of an open transmission line breaker is due to the active power flow in the line prior to its trip, and subsequent system repositioning. The angular difference is approximately proportional to the prior MW flow and is a predictor of the flow that will occur when the breaker is closed if system generation changes are not made. Closure of a breaker with high angular difference could result in power transients and current oscillations. This closure can also cause damage to generating units located electrically close to that breaker. Components that are most impacted are the turbine-generator shaft, particularly the coupling between the turbine and the generator. A convenient measure of this impact is the average initial power difference, ΔP, which occurs on the generator when the breaker is closed. A process for determining the ΔP at nearby generators is provided below. This analysis can provide an acceptable upper limit on angular difference which can be used in applying angle difference settings to the sync-check relays.

— Voltage magnitude difference: The voltage magnitudes on the bus-side and line-side of the open breaker may be different due to the level of reactive power (MVAr) flow in the line prior to its trip and subsequent system repositioning. Depending on the sync-check relay type and operating principle, the voltage magnitude difference may be monitored in various ways. Some relays use the phase-to-neutral voltage limit setting that is associated with the live-line logic and allow reclosing as long as both voltages are above this limit. This method does not provide monitoring of the voltage difference, but merely gives a permissive indication to the phase angle and slip logic that both voltages are present. Other relays have the capability to set an average voltage magnitude difference, independent of the live-line/dead-line settings and the phase angle across the open breaker. Yet other relays are capable of calculating an actual phasor voltage difference across each pole of the open breaker. The phasor voltage difference setting is dependent on the maximum phase angle difference setting.

Selection of the sync-check angle limit is difficult by any calculation. This is because the angle presented to the sync-check relay and the system impact associated with closing the circuit breaker may vary significantly depending on system operating conditions. Many utilities set the sync-check angle limit using a standardized conservative value of 20°–30° and adjust this setting upward if network conditions prevent reclosing, while others use a more liberal angle of 60°. It is generally not a good idea to allow reclosing at angles greater than 60°, although reclosing at higher angles may be acceptable under some conditions while reclosing at angles less than 60° may result in undesirable system impacts. The use of a standardized setting may be acceptable when sync-check is applied on lower voltage systems; however, this practice is not recommended on EHV systems or in proximity to generation where system impacts may be significant.

When reclosing is utilized on EHV systems or in proximity to generation, the sync-check angle limit should be determined through system studies. The impact on turbine-generator shafts resulting from live-bus/live-line reclosing is proportional to the angle across the breaker and inversely proportional to the impedance in the path that is being closed. Both the angle and impedance of the path being closed, relative to the parallel system, may vary for different operating conditions. Thus, it is important to evaluate a range of system conditions to identify the worst potential system impact for credible operating conditions. Typically the conditions evaluated are limited to reclosing the line under consideration with one or two other parallel lines open. The dispatch conditions of nearby generation may also significantly impact the voltage angle. Therefore, analysis also typically includes sensitivity to system transfer levels, system load levels, and the status of generators in proximity to the line under consideration. The conditions studied are selected based on knowledge of the system and engineering judgment.

Analysis can be performed using a power flow program to examine reclosing for a range of expected conditions considering the factors stated above. The apparent angle across the open breaker will be a factor of transfers across the system and the equivalent impedance of the parallel ties between the two parts of the system. This voltage across the open breaker contacts will be a combination of the actual angular difference and the difference in the voltage magnitudes on either side of the open breaker. Provided the two portions of the system are connected and are at or near a steady-state condition, the rate of angle change (slip frequency) will be very low. The range of potential angle should be calculated for the worst credible operating condition for which reclosing is expected.

Setting the sync-check angle limit greater than the maximum possible angle means that reclosing is not restricted by phase angle; however, it will not mean that the system can adequately absorb the impact of reclosing. The second step in assessing the sync-check angle limit is to assess the impact on turbine-generator shafts associated with reclosing. In some portions of the system, this assessment may be unnecessary (it even may be permissible to reclose without a sync-check relay) because the maximum angle possible is small or there is sufficient impedance in the path being closed to prevent a significant system impact. This is particularly true on lower voltage systems in the absence of local generation. However, where generation is located close to the line being reclosed and the maximum possible sync-check angles are high, the impact on turbine-generator shafts should be assessed. The impact to the generators can be determined using a power flow program solution that maintains fixed generator flux linkages to assess the change in generator electrical power that occurs when the circuit breaker is closed. The sync-check angle limit should be selected to limit the potential for generator shaft damage. Limiting the change in electrical power, ΔP, to 0.5 per unit or less on the generator MVA base typically results in acceptable performance [B47]; however, the acceptable level varies for different turbine types, and consultation with the generator manufacturer may be necessary.

Experience has shown that for most sync-check angle limits used by utilities, the impact of the reclosing is less than closing into a fault and is therefore not of concern. However, when considering the potential impact on turbine-generator systems, it is appropriate to assess the impact associated with intentional reclosing differently than the impact of faults (which are unavoidable). The necessary trade-off is to balance the potential impact associated with reclosing under stressed system conditions against the potential impact on reliable system operation if the sync-check setting prevents reclosing.

If the angle across the circuit breaker is not initially within the sync-check angle limit, it is possible that the angle limit will be met at some later time due to a change in generation dispatch or changes to the system topology (such as reclosing of other lines following a major system disturbance). Logic may disable the autoreclosing scheme if acceptable autoreclosing conditions are not met within a pre-defined time duration, or the logic may wait indefinitely for acceptable conditions. Both practices have advantages and disadvantages. Limiting the time duration in which a live-bus/live-line reclose attempt is allowed avoids having the reclose attempt occur at a future time in an unpredictable and potentially undesirable fashion; however, this practice may prolong system restoration. The practice of waiting indefinitely may be useful for reducing restoration time following a major disturbance by allowing reclosing as soon as acceptable conditions exist; however, the unexpected closing of breakers during system restoration can upset the balance of generation and load, which could result in subsequent outages and extend the time of restoration. When this latter practice is used, it should be based on analysis of the potential system conditions for which autoreclosing may occur in order to manage risk to equipment and system reliability. Regardless of which practice is used, the system operators need to be aware of how their system is designed and need to be adequately trained to respond appropriately during a system-wide outage event.

6.3.7 Leader-follower autoreclosing of transmission lines

The leader-follower autoreclosing scheme is typical of transmission-line autoreclosing practices. , The leader is defined as the line terminal that autorecloses first, and the follower is the line terminal that recloses second. This should not be confused with lead-follow terminology used to describe multiple breakers of multi-breaker terminals in 6.3.4.

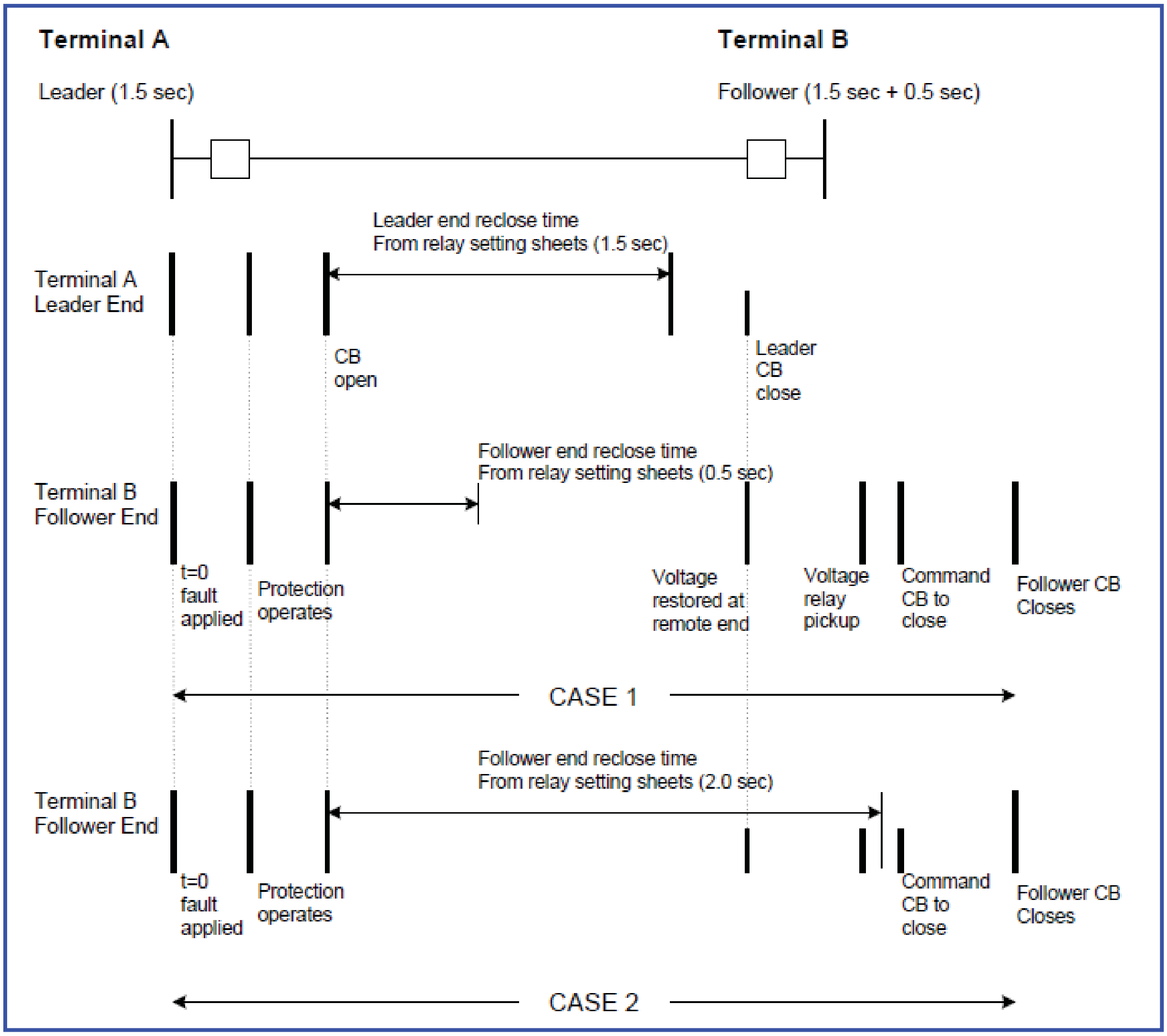
In this scheme, the leader end is typically selected as the weaker source of the two ends of a transmission line and is used to "test" the line. This practice is used to verify ~~ensure~~ the fault has been cleared while imposing the least disturbance to generation ~~the power system~~. (However, it should be noted that testing from the weaker end may result in a greater voltage drop and disturb sensitive loads.) If the leader end autoreclose attempt is successful, the follower end autoreclose attempt ~~being~~, which is supervised by voltage and/or synchronism-check functions, is then enabled and autorecloses. This scheme can be utilized to restore either a network line section, or a tie line between two systems.

Figure 9 illustrates the sequence of events for a typical leader-follower scheme. In the two cases illustrated, timing of the reclosing relays at both ends of the line is initiated by the operation of the protection, and the timing of the leader ~~or Master~~ terminal reclosing relay is set for 1.5 s. In Figure 8, Case 1, the time delay of the reclosing relay at the follower terminal is set to 0.5 s (significantly less than that at the lead terminal) and is supervised by a voltage relay. When the voltage relay senses that voltage has been restored at the follower end, autoreclosing is permitted. A short time delay may be incorporated into the voltage relay so ~~ensure~~ that the voltage level is present for a period of time prior to closing to prevent any transient influences.

If the follower end autoreclose timing is significantly longer than the ~~master~~ leader terminal ~~end~~ setting, the follower end timing diagram would be as shown in Case 2 of Figure 8. In this case, the voltage relay senses the presence of the restored voltage ~~and~~, then the reclosing relay times out and initiates autoreclosure of the breaker.

A network line (a line where the terminals are effectively tied together by other parallel lines) may use only the presence of voltage to initiate autoreclosing when there are enough ~~as the~~ other network connections so ~~ensure~~ that the voltage phase angle difference across the open breaker is small. ~~Whereas~~ A tie line (a line where there are no other parallel lines connecting the system tightly together) normally requires the use of synchronism-check relays so ~~ensure~~ that the voltage phase-angle difference across the breaker is within acceptable margins.

~~The~~ EHV autoreclosing practices are essentially the same, whether or not series capacitors are applied. However, overvoltage protection can be included if the follower terminal ~~end~~ voltage is too high to permit autoreclosing safely. In this instance, a transfer trip of the leader terminal ~~end~~ of the line would be initiated by the overvoltage relays.



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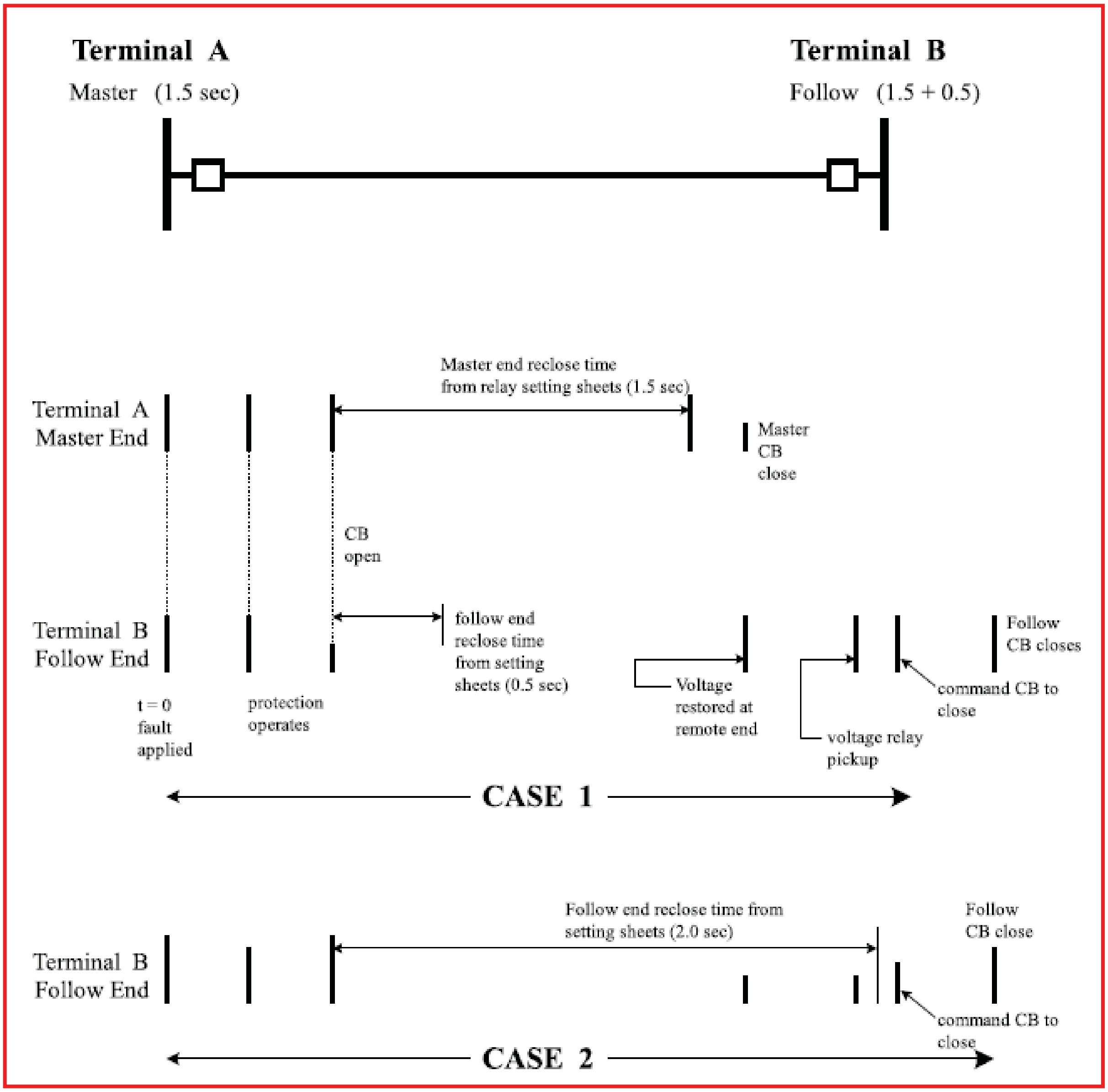

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Figure 8 —Leader-follower reclosing scheme timing

6.3.7.1 Weak source/strong source considerations

As indicated above, the leader end is typically selected as the weaker of the two ends to test the line in the leader-follower transmission line autoreclosing practices. The weaker end is defined as the terminal with larger Thevenin impedance with the line disconnected. This is preferable because if the line fault is permanent in nature, an autoreclose into the fault from the weaker end should result in less stress, thermal and mechanical, to the power equipment and less disturbance to the power system, as compared to the "test" from the stronger end. However, the terms weak source and strong source are only relative in nature.

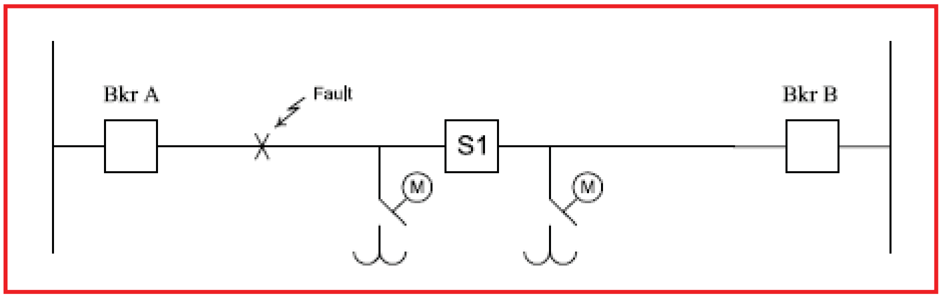
At some locations, on lines with tapped loads, designating the stronger source as the leader end to test the line may be preferred. At certain locations under various system operating conditions, successful autoreclose from the weaker end on lines with tapped loads may lead to slower voltage recovery and other power quality problems. This is due to the active demand and, in particular, the reactive demand when energizing and picking up de-energized loads and transformers.

A study should be performed to select the leader end for autoreclose on lines with tapped loads. Of course, this is largely dependent on the Thevenin impedance of the line terminals under various system operating conditions and the size and the type of the tapped loads. However, in most applications, the decision to use the stronger source as the leader end is the result of operating experience, system monitoring, and post fault analysis.

~~6.3.3.1 Application considerations—example 1~~

~~Reclosing relays and automatic sectionalizing equipment are used together to isolate faulted sections of transmission lines. In sectionalizing applications the transmission line usually feeds tapped loads. By sectionalizing the line, maximum load can be maintained when a permanent fault occurs on the line. Successful sectionalizing requires that both autoreclosing and reset times of the reclosing relays associated with the line breakers and the line sectionalizing equipment coordinate.~~

~~When applying reclosing relays with sectionalizer (S1) and/or motor operated disconnects, the autoreclose time of the breaker reclosing relay needs to be longer than the opening time of the sectionalizer and the motor operated disconnect switch combined. The opening time of the sectionalizer needs to include the operating time of the initiating devices. If the controlling device is a time delay undervoltage relay, then its operating time should be accounted for so that the line is not re-energized while the sectionalizer or the motor operated disconnects are opening. (See Figure 6.)~~



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~~Figure 6—Line sectionalizing scheme 1~~

~~In this example, the line breakers are equipped with reclosing relays having a single autoreclosing shot and a 10 s reset time. The sectionalizing switch in the center of the line is designed to open for a loss of voltage and close after a time delay when voltage has been restored on both sides.~~

~~a) Fault occurs between breaker A and S1.~~

~~b) Source breakers A and B open for the fault.~~

~~c) S1 opens on loss of potential.~~

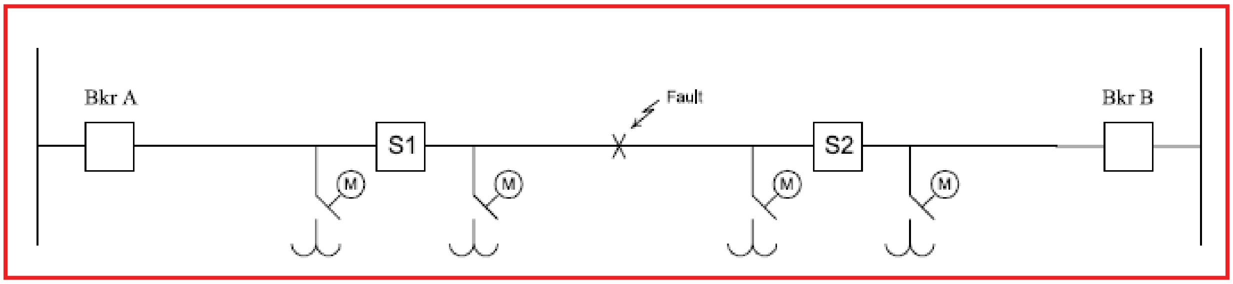
~~d) Breaker A autorecloses to re energize the line up to S1.~~

  ~~1) If the fault is transient, breakers A and B both autoreclose, followed by S1 reclosing when voltage is present on both sides.~~

  ~~2) If the fault is permanent, breaker A autorecloses and trips to lockout. Breaker B autorecloses and holds as S1 is still open, therefore isolating the fault from terminal B. S1 stays open until the fault is isolated and breaker A is closed.~~

~~6.3.3.2 Application considerations—example 2~~

~~When applying reclosing relays with series sectionalizers that autoreclose on voltage restoration, the reset time of the reclosing relays associated with the line breaker should be shorter than the closing time of the sectionalizer. This prevents the line breaker from locking out in the event that the fault is between the series sectionalizers. The sequence of operation for this type of sectionalizing scheme would be as shown in Figure 7.~~



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~~Figure 7—Line sectionalizing scheme 2~~

~~In this example, the line breakers are equipped with reclosing relays having a single autoreclosing shot and a 10 s reset time. The sectionalizing switch S1 is designed to open for a loss of voltage and close after a time delay when voltage has been restored on the breaker A side. The sectionalizing switch S2 is designed to open for a loss of voltage and close after a time delay when voltage has been restored on the breaker B side. The scheme operates as follows:~~

~~a) Fault occurs between S1 and S2.~~

~~b) Source breakers A and B open for the fault.~~

~~c) S1 and S2 open on loss of potential.~~

~~d) Breakers A and B autoreclose to re energize the line up to S1 and S2.~~

~~e) The reclosing relays at both breakers A and B reset after a time delay.With restoration of potential on its source side, S1's reclosing relay autorecloses S1 after a time delay; breaker A senses the fault again and opens, S1 opens and locks out due to loss of potential before its reclosing relay has reset.~~

~~g) Breaker A autorecloses and remains closed. Note that if the reclosing relay had not reset breaker A would have opened and locked out.~~

~~h) With restoration of potential on its source side, S2's reclosing relay autorecloses S2 after a time delay; breaker B senses the fault again and opens, S2 opens and lock out due to loss of potential before its reclosing relay has reset.~~

~~i) Breaker B autorecloses and remains closed.~~

~~j) The faulted section of the line has now been sectionalized.~~

~~For faults between either breaker A and S1 or breaker B and S2, the respective source breaker operates to lock out and the respective sectionalizer opens between the first and second autoreclosing of the source breaker. The sectionalizer does not autoreclose until the potential has been restored on the source breaker side of the sectionalizer.~~

6.3.8 Transformer considerations

Transformers present unique autoreclosing characteristics. As indicated in IEEE Std C37.91~~-2000~~ [B58], ~~and in 6.3.4,~~ there is no single policy about re-energizing transformers automatically. The main consideration is whether a fault has occurred in the transformer itself or on the line terminals leading into the transformer.

~~6.3.4 Lines terminated with Transformers~~

It is a standard practice not to re-energize a faulted transformer intentionally prior to the unit being inspected and repaired as necessary. Therefore, when a transformer without a local interrupting device is connected directly to a transmission line, it is necessary for the transformer protective relays to prevent the line terminals from autoreclosing. This is normally accomplished by the transformer relays operating a lockout that initiates a signal via some communications medium to trip and prevent autoreclosing of the line terminals until the transformer is isolated.

Two different arrangements are discussed:

— Transformers in-series with a transmission line

— Transformers tapped on a transmission line

6.3.8.1 Transformers in-series with transmission line

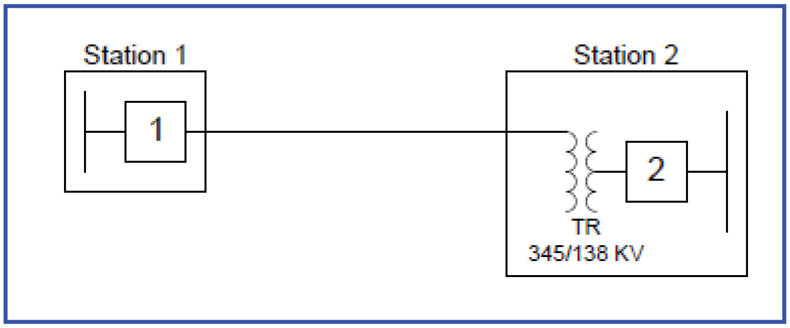

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Figure 9 —Transformer in-series with transmission line

In order to facilitate a transmission through-connection between two networks at different transmission voltages, a transformer can be installed in-series with the transmission line. Such a transformer must be rated to carry the maximum expected through-load between the two terminals. See Figure 8.

Under this arrangement, there is no 345 kV breaker at station 2. Therefore, along with tripping and locking out local breaker 2, the transformer protection for the 345 kV/138 kV transformer should trip and lockout remote breaker 1 at station 1 to avoid unnecessary automatic reclosing into a bank fault.

It may be acceptable, however, for both breaker 1 and breaker 2 to autoreclose for faults on the transmission line.

6.3.8.2 Transformers tapped on a transmission line

More common than the series arrangement is the tapped transformer arrangement. These transformers are located along a transmission path to meet distribution requirements and most often serve radial load. See Figure 10.

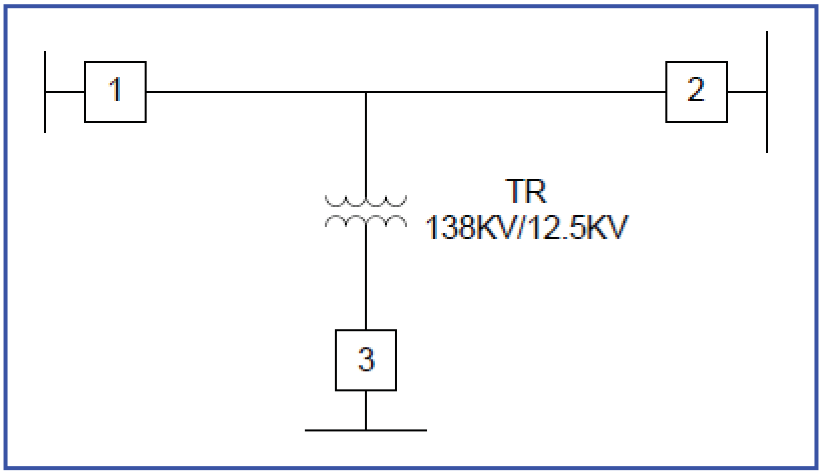

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Figure 10 —Transformer tapped on transmission line

These transformers may or may not have high-side interrupting devices to clear transformer faults. If no such device is available, remote breaker 1 and breaker 2 must be tripped to clear bank faults.

In some cases, bank protection may trip and lockout remote breaker 1 and breaker 2 as for the series arrangement.

However, if autoreclosing is to be allowed, control logic needs to ensure that the trip signal has been reset and a failure or fade in the communication channel has not occurred before enabling the autoreclosing. One method to accomplish this is to block autoreclosing on the receipt of a trip signal, but not enable the autoreclose until after the trip has reset and a communication channel normal or guard signal is received.

One common practice is to use a device such as a motor-operated air switch to isolate the faulted transformer after the line terminals have cleared (see Figure 11). In this application, the transformer protective relays operate a lockout relay that initiates a transfer trip signal to trip and prevent reclosing of the line terminals and ~~also~~ open the motor-operated switch. The lockout relay can also operate a high-speed ground switch that closes so ~~ensure~~ that the transformer fault may be quickly detected should the communications path fail to allow direct tripping of the line terminals. If everything works properly, the line terminals will be open prior to the grounding switch blade being closed. The opening of the motor-operated air switch is often supervised by a voltage relay to verify ~~ensure~~ that the remote terminals have cleared prior to attempting to isolate the faulted transformer. As a final backup to isolate a faulted transformer, the motor operator can be opened after a time delay ~~of typically 3 to 5 s~~ in the event that the line voltage monitoring relay fails to drop out. Isolation of the faulted transformer resets the transfer~~-~~ trip signal, thereby enabling the remote line terminals to autoreclose.

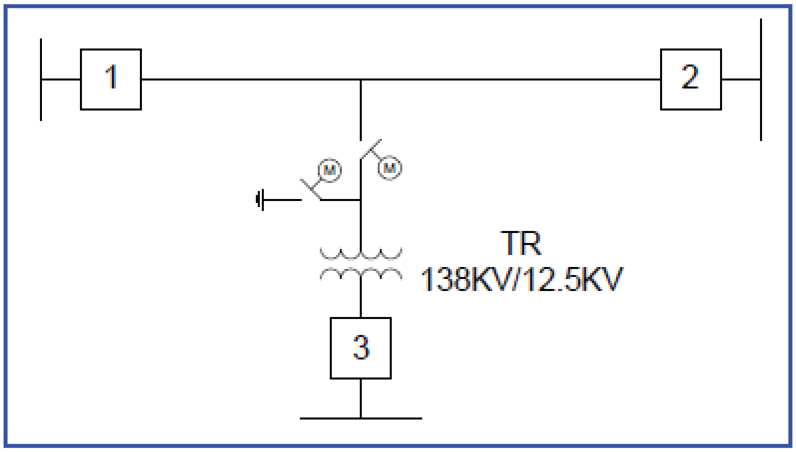

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Figure 11 —Tapped transformer with motor-operated air switch and grounding switch

In locations where a tapped transformer has a motor-operated air switch or a limited interrupting capable circuit switcher, and there is no communications path to permit tripping and prevent autoreclosing of the remote terminals, the first dead-line autoreclosing attempt at one line terminal should be delayed long enough to permit the operation of the transformer disconnecting device. ~~Typical dead line autoreclosing delay times are 5 s where a circuit switcher is utilized and 10 to 15 s where a motor operated air switch is utilized.~~

In situations when the line fault can be sourced by the transformer ~~At~~, the transformer circuit breaker autoreclosing is typically voltage supervised to minimize stress on the transformer and is not initiated by the transformer protective relays. Transformer protective relays are typically a differential relay(s) (device 87T), or sudden pressure relay (device 63) that initiate tripping through a lockout relay (device 86T). When a transformer protection relay operates, it is assumed that the fault occurred within the transformer rather than in the leads; therefore, autoreclosing should not be initiated. When the line relays operate, the line should not be tested through the transformer to see if the fault still exists. The initial testing is done at the remote line terminal. Autoreclosing at the transformer is set to close after the remote end closes and remains closed. The conditions for allowing reclosing at the transformer can be as follows:

— Live-line/transformer-dead bus with delay

— Live-line/transformer-live bus with delay

— Live-line/transformer-live bus with synchronism-check

As an example, consider the following in Figure 12: A 138 kV two-terminal line with a tapped 138 kV/12.5 kV transformer located in the middle; ~~one main terminal has R_{DT1} (autoreclosing with dead line supervision and time delayed T1), the other main terminal is R_{AST1} (autoreclosing with synch check and synchronism maintained for time T1), and the 12.5 kV transformer breaker is R_{AT1} (autoreclosing with live line supervision and time delayed T1~~. Assume that a fault has occurred on the line and the main terminals as well as the transformer low-voltage breaker have all tripped. Normal autoreclosing would occur when the breaker 1 ~~R_{DT1} end~~ confirmed that the line was dead and the initiated autoreclosing was successful. Breaker 2 ~~The R_{AST1} terminal~~ would be autoreclosed after determining that live voltage was present and in synchronism. Breaker 3 would autoreclose after the transformer was energized, with a delay time ~~and then the transformer R_{AT1} (autoreclosing with live supervision on the secondary side of the transformer and time delayed by T1) would autoreclose in on the line. The delay time used for the transformer is~~ customarily set longer than the times for the main terminals. The transformer was never subjected to any additional stress that could have occurred if the fault was permanent and the transformer was used in an attempt to re-energize the line.

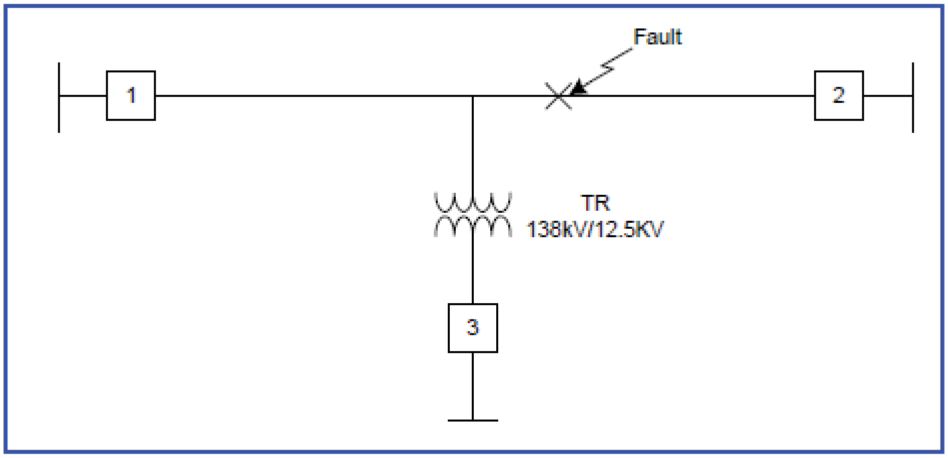

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Figure 12 —Autoreclosing with tapped transformer

Autoreclosing of the low-voltage circuit breakers on a transformer that is tapped on a transmission line should be supervised by voltage sensing. Autoreclosing of these breakers can be initiated by the receipt of a transfer trip signal followed by the reset of the transfer trip. Autoreclosing is completed if the transfer trip is reset and the transformer is re-energized. Transformer re-energization is typically detected by voltage sensing, either three-phase or single-phase, which ~~that~~ monitors the transformer secondary voltage. Autoreclosing of the low-voltage circuit breakers is typically delayed by several seconds after the secondary voltage is detected to verify that the primary supply is stable.

6.3.9 Multiple-terminal lines

High-speed autoreclosing can be applied to all terminals of a multiple-terminal line if the line protection scheme provides simultaneous clearing of faults at all terminals and autoreclosing all terminals into a permanent fault is not detrimental to system stability. High-speed autoreclosing requires a minimum dead time that is generally more difficult to obtain on multiple-terminal lines as compared to two-terminal lines. The result is that high-speed autoreclosing on multiple-terminal lines is normally not permitted unless the pilot scheme is operational and all terminal protective relays are able to detect any line fault at its inception. This gives reasonable assurance that all terminals will clear simultaneously. On multiple-terminal lines where high-speed autoreclosing is to be used, it could be advisable to high-speed autoreclose at one terminal and allow the other terminals to sync-check autoreclose.

On multiple-terminal lines where high-speed autoreclosing is not used, delayed dead-line autoreclosing is normally used at either one, or possibly ~~only~~ two, of the terminals. If dead-line reclosing is used at different terminals, the time delays are usually different to allow sequential reclosing attempts of the line. When an autoreclose attempt is successful, sync-check autoreclosing is then used to restore all remaining terminals. The dead-line autoreclosing sequence and sync-check logic should be based on the same criteria ~~selection parameters~~ as a two-terminal line ~~with sync-check autoreclosing used at all terminals. Reclosing logic that utilizes dead line and sync check functions should be used to allow the sync check supervised closure where a dead line autoreclosure attempt failed initially and a subsequent delayed dead line autoreclosure at another terminal was successful.~~

~~6.3.7 Cable circuits and hybrid lines~~

~~Transmission lines that utilize cable present a special concern as to whether or not to incorporate autoreclosing. Faults inside cables are permanent and the use of autoreclosing may not be prudent.~~

~~If the line is completely cable, it makes no sense to autoreclose into what is a permanent fault. There is no need to cause more damage and increase the stress to adjacent portions of the power system. Therefore, the use of autoreclosing on transmission lines entirely made of cable is not recommended (IEEE Power System Relaying Committee [B10]).~~

~~If the line is a hybrid cable and overhead line, autoreclosing could possibly be used if additional relaying is installed on the cable portion. By using a pilot relay scheme, faults in the cable section could be exactly identified. Should a fault occur within the cable, then autoreclosing would be blocked. Pilot schemes such as current differential, phase comparison, or pilot wire lend themselves to this approach. There would be added expense as there would be a need for a communication channel for transfer trip/autoreclose inhibit and freestanding current transformers at the overhead/cable terminals. At least one utility is using a current differential scheme with fiber optic communications to trip and block autoreclosing for cable faults on a 345 kV hybrid line (Sufana et al. [B14]).~~

6.3.10 Gas-insulated bus

Normally, autoreclosing would not be used on a gas-insulated bus to minimize contamination and burn through of the containment wall due to the fault. However, if a portion of the bus is included in the transmission line protection, such as the portion between the breakers on a breaker-and-a-half or a ring bus configuration, the autoreclosing practice for the transmission line would normally be followed. The gas-insulated bus section could have separate protection; in which case, sensing would be available to block autoreclosing for faults within the bus section. In cases where the gas-insulated bus is at a generating station and autoreclosing requires the line to be energized from the remote end, it is necessary to send a transfer trip signal to the remote terminal to block autoreclosing for faults in the gas bus section. If there are tapped loads on the transmission line, a motor- operated air break switch can be installed near the gas bus termination. When the switch opens, it causes the direct transfer trip signal to be removed and allows the line to autoreclose at the remote end.

6.3.11 Transmission line reclosing and interfacing with automatic sectionalizing schemes

Placing several load tap points along a transmission line creates a unique set of problems if the utility desires that at least some of the tapped loads should remain energized after a permanent fault. This may be accomplished through the use of motor-operated disconnects or other transmission line sectionalizing devices placed at key points in the line to open and isolate the faulted section of the line, allowing automatic reclosing to re-energize the load on the unfaulted line section. This sectionalizing or flip-flop scheme generally consists of line voltage monitoring devices such as CVTs or VTs and appropriate voltage relays, control relays, timing equipment, and batteries to sense the line voltage on either side of the sectionalizing scheme and to open the sectionalizing devices in a predetermined order when the line is dead between reclosing attempts. Two sectionalizing schemes will be discussed. The first method uses one sectionalizing device and two reclose attempts. The second method uses two sectionalizing devices and three reclose attempts. Other sectionalizing scheme designs are possible, but the following two examples will provide the principles upon which transmission line sectionalizing schemes generally operate.

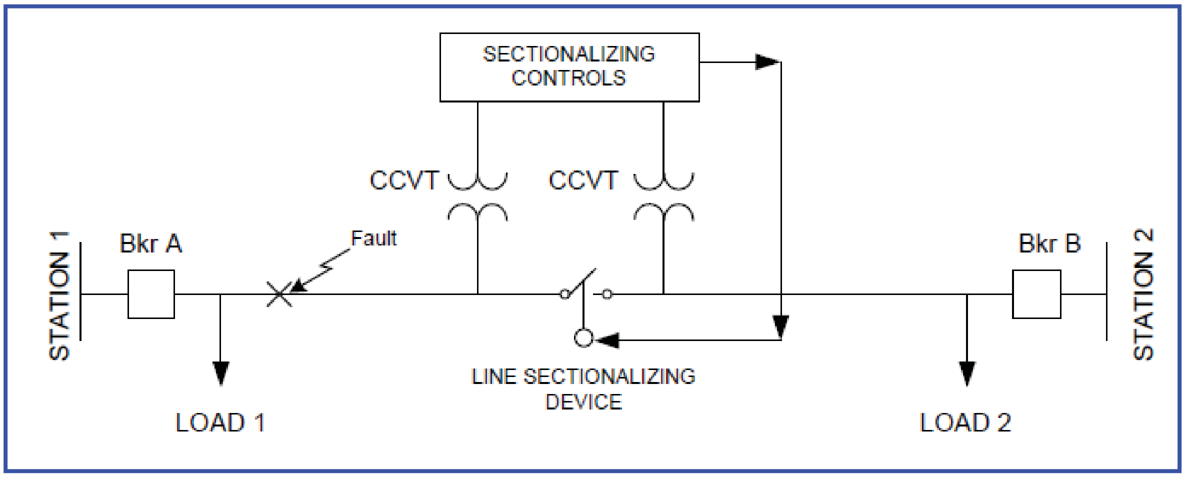

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Figure 13 —Sectionalizing scheme with one sectionalizing device

Refer to Figure 13 for an explanation of the first method. Under normal conditions, the line is connected through from station 1 to station 2 with the sectionalizing device closed and load 1 and load 2 being served. When the shown fault occurs on the line, both breaker A and breaker B will trip and reclose on the first shot of reclosing to try to restore the entire line to service. If the fault is permanent and the first shot of reclosing is unsuccessful, the line sectionalizing controls will sense a dead-line on both sides of the sectionalizing device and then open the sectionalizing device after a small time delay. Then, the second reclosing open interval timer will time out and both ends of the line will reclose on the second shot. Since the fault is on the station 1 side of the line sectionalizing device, breaker A will again trip and go to lockout. Breaker B will successfully reclose and return load 2 to service. When the item causing the fault has been cleared from the line, the line sectionalizing device can be closed to return load 1 and the line up to breaker A to service. Paralleling will then be made with breaker A. If the fault is on the station 2 side of the sectionalizing device, then the process is similar such that load 1 will be returned to service. Typical reclosing times and sectionalizing device operating times are given below.

Table 2 —Breaker open interval times

Open interval #	**Breaker A and B**
1	20–45 cycles[a]
2	10 s[a]

[a] The times in the table assume that the line sectionalizing device is a motor operated disconnect that requires 5 s to travel from closed to open or vice versa. The times above also assume a 5 s margin between when the completion of the sectionalizing and the breaker open interval timing out. These times are to illustrate operation only and should not be considered actual settings for any particular line without engineering judgment.

Table 3 —Sectionalizing device typical operating times

Sectionalizing device	Time to open upon a dead-line
1	5 s[a]
[a]See note in Table 2.	

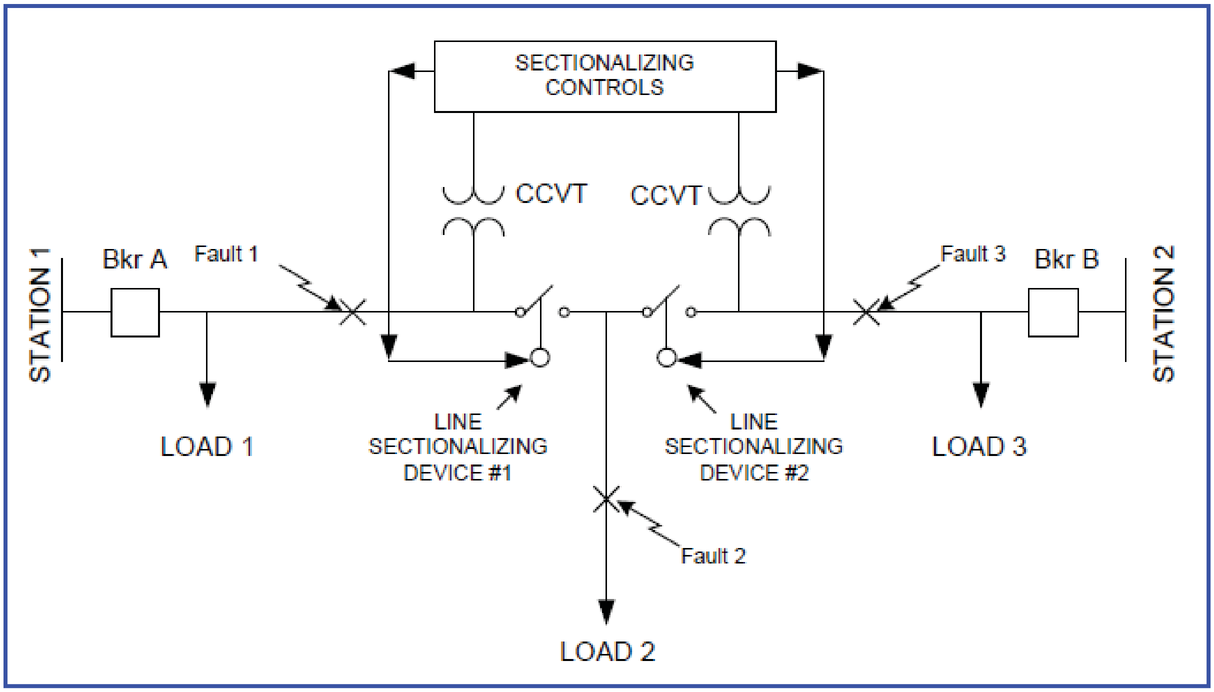

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Figure 14 —Sectionalizing scheme with two sectionalizing devices

Refer to Figure 14 for an explanation of the second method. Under normal conditions, the line is connected through from station 1 to station 2 with the sectionalizing devices closed and load 1, load 2, and load 3 being served. When a fault occurs on the line, both breaker A and breaker B will trip and reclose on the first shot of reclosing to try to restore the entire line to service. When the sectionalizing controls sense that the line is dead for a permanent fault 1, sectionalizing device 1 opens to allow the second reclose attempt from breaker B to pick up load 2 and load 3. Breaker A advances through its reclosing sequence to the lockout state due to the permanent fault 1.

If the line remains dead due to a permanent fault 3, the sectionalizing controls will close sectionalizing device 1 after a short delay and open sectionalizing device 2 before breaker A recloses the second time to pickup load 1 and load 2. Breaker B advances through its reclosing sequence to the lockout state due to the permanent fault 3.

If the line still remains dead due to a permanent fault 2, the sectionalizing controls open sectionalizing device 1 for the second time (device 2 remains open). Breaker A and breaker B then reclose for the third time to pickup load 1 and load 3.

In the second scheme, typical open interval times for breaker A and breaker B are given below.

Table 4 —Breaker open interval times

Open interval #	**Breaker A**	**Breaker B**
1	20-45 cycles	20-45 cycles[a]
2	20 s	10 s[a]
3	30 s	30 s[a]

[a] The times in the table assume that the line sectionalizing device is a motor operated disconnect that requires 5 s to travel from closed to open or vice versa. The times above also assume a 5 s margin between when the completion of the sectionalizing and the breaker open interval timing out. These times are to illustrate operation only and should not be considered actual settings for any particular line without engineering judgment.

Table 5 —Sectionalizing device typical operating times

Sectionalizing device	Time to open upon a dead-line
1	5 s[a]
2	15 s[a]
[a]See note in Table 4.	

Timing of sectionalizing schemes is critical and the timers at the sectionalizing point should not be allowed to reset for momentary re-energizations of the transmission line during reclose attempts. The transmission line, in effect, becomes the path through which the reclosing timers remain in loose synchronism. If any timer at the sectionalizing point or at station 1 or station 2 becomes out of synchronism or resets prematurely during the sectionalizing cycle, the sectionalizing scheme will not operate properly.

~~6.3.9 Generators~~

~~In addition to the considerations discussed in 6.1.1.6, the application of autoreclosing may need to be considered at or near a generating plant for system or machine stability purposes. The system operating conditions and configuration could allow the advantages of autoreclosing to overcome the risks associated with such an operation.~~

~~6.3.12 Lines with series compensation~~

~~Depending on the type and the design of the series capacitor platform, autoreclosing issues differ. For instance, if the series bank is of the gapped scheme only, without nonlinear arrestors, then it is desirable to delay autoreclosing sufficiently to allow capacitors to discharge and hence eliminate the possibility of false tripping on autoreclosing.~~

~~However, for capacitors with both gap and ZnO schemes, additional delays for autoreclosing may not be necessary. In this case, autoreclosing can be achieved after the successful extinction of the secondary arc clearing. One way to accelerate autoreclosing time is with the approach of closing the capacitor bypass switch to permit a temporary removal of capacitors when autoreclosing~~

~~6.3.13 Shunt capacitors on bus~~

~~Shunt capacitors that can be applied at a bus should not be a consideration for autoreclosing because their control circuits are designed to trip automatically prior to an autoreclose attempt.~~

~~6.3.14 In-line breaker~~

~~A single in-line breaker presents an unusual situation where dead line autoreclosing is applied in two directions on one breaker. The recommendation here is to use hot bus-dead line and sync check autoreclosing with dedicated single shot autoreclosing for each function. The hot bus aspect ensures that a reliable voltage source is present prior to autoreclosing. If for some reason there had been a relay miscoordination at the remote source such that this source tripped for the line fault, then remote source dead line autoreclosing could result in the source locking out when both lines are picked up and the fault re-established~~

~~Another consideration is that a single autoreclosing relay should not be used for both of the dead line relays. If utilized for both, consecutive faults occurring on each line within the reset time of the autoreclosing relay will lock the in-line breaker out.~~

7. New technologies/special applications

7.1 Ethernet based applications to autoreclosing

With the advent of IEC 61850 [B46], DNP3, IEEE Std 1815 [B54], and many other standards for IEDs that are Ethernet related, all manner of protection and control logic can be developed. Without the need to have extensive wiring and through the use of the substation Ethernet connections, autoreclosing functions can be enhanced in addition to all of the other protection and control functions.

Here are several examples of how these various protocols and standards could be used in autoreclosing logic schemes:

a) Health and welfare type messages in addition to the normal control type functions. These health and welfare messages could be:

1) The temperature, gas, and oil for signs of contamination or hot spots

2) Breaker contact wear monitoring

3) Rate of decay of a leaky SF_6 breaker's interrupting tank

4) Insufficient air in the closure tank that provides breaker closing

5) Real-time breaker travel test with each operation that senses if the phase openings or closings are within specifications

b) The logic used for auto reclosing could also be changed in real time. Here are several examples:

1) Consider the case of a ring bus and the reclosing that might be used. For Figure 15 below, assume that line M has breaker 2 and breaker 3. One of the two line breakers (i.e., breaker 2) would be considered the lead breaker to close for an autoreclose attempt, perhaps with some sort of sync-check supervision. By the use of IEDs, it would be possible for the logic to be very quickly changed to allow for breaker 3 to become the lead breaker.

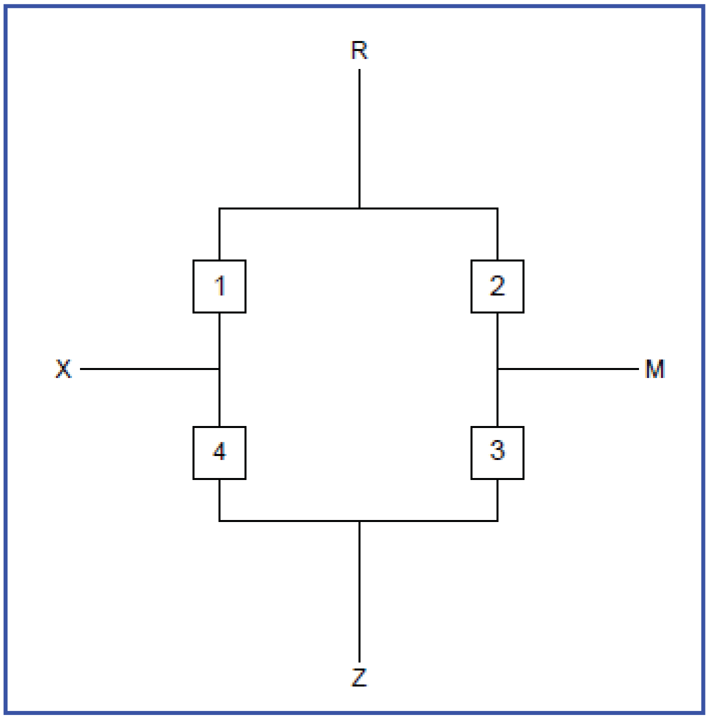

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Figure 15 —Ring bus

2) The circuit breaker itself would not necessarily have to tell the rest of the network to change the autoreclose logic; it would also be possible for any connected equipment to do the same. Consider the case of a line terminated in a transformer (see 6.3.8.1). If the relay protection for the transformer or the transformer itself (through the use of diagnostic sensors within the tank) detects a problem, the rest of the network could be told that the autoreclosing for the transformer is being changed.

3) Engineering changes to the autoreclosing could easily be performed from a remote location. This would not just be timing changes; this could be the complete logic right down to what relay is allowed to initiate a reclose and with what type of voltage supervision. Again, major rewiring would not be needed; only the software logic would need to be changed.

4) The voltage supervision source to be used can literally be changed on the fly. In the substation of the future, the bus voltage and line currents would also be available on the network, not just the control functions. So if a VT normally used for a line's sync-check is unavailable for some reason, the autoreclosing logic could be told what VT to use on a temporary basis. Obviously the unavailable VT would also effect the relay protection, but the protection could also be told what voltage source to use on a temporary basis.

7.2 Coordination of fast valving and high-speed reclosing

Fast valving is a high-speed control scheme used on some larger thermal generating units to assist in maintaining transient stability by rapid closing and opening of steam valves in a prescribed manner to reduce machine accelerating power following the recognition of a severe transmission system fault. The scheme initiates a fast, temporary reduction of steam pressure applied to a generator turbine, reducing generator electrical power output by as much as 50% for a short amount of time. The scheme can then return the turbine steam valves to normal position and full generator electrical output power is restored within a specified timeframe, which is usually five to ten seconds.

A fast valving scheme is typically implemented to improve generator stability performance and line availability. The fast valve schemes are usually limited to a finite number of operations within a given time period, and they are normally initiated by specific system events (such as a line trip) and supervised by system configurations (such as generator output level or transmission circuit availability). It is evident that the fast valve control schemes can be rather complex and that system control integrity and redundancy is crucial.

Line autoreclosing and generation fast valving schemes need to be coordinated to provide for proper operation. The timing of the scheme needs to be coordinated with the line autoreclose reset time, the fast valve scheme reset time, and system stability performance.

7.3 Sychrophasor applications

7.3.1 Fault location to supervise reclosing on mixed lines

Transmission lines that consist of both overhead and underground sections are referred to as mixed, or hybrid, lines. They are common in some metropolitan areas and usually do not have reclosing applied. Some applications may have a considerably shorter underground section as compared with the overhead sections. In these cases, autoreclose may be desired to recover from temporary overhead faults, thus helping to minimize outage durations. However, line outages caused by underground faults should not have reclosing applied for three main reasons:

— A cable fault is typically permanent

— Public safety may be jeopardized, since the fault may have been caused by construction crews operating machinery in the vicinity of the cable

— Reducing the chance of damaging the cable to the point that extracting the cable from the conduit is extremely difficult

The difficulty on a hybrid line is to be able to determine if the fault is in the overhead section, where reclosing should be permitted, or in the underground section, where reclosing is prohibited.

Fault locating algorithms based on utilizing synchrophasor measurements are in development. Fault location based on synchrophasor measurements at one end of the line does not provide good results since the algorithms require the use of the zero sequence impedance. This impedance includes the earth resistivity of the current return path, which varies based on soil type and weather conditions, thus preventing an accurate fault location. Conversely, fault location based on using synchrophasors and differential relaying principles has the potential to better identify fault location. Using phasor measurement units (PMUs) that are located at each end of the line may allow the use of the positive sequence network, eliminating the need to rely on the variable zero sequence impedance. Since the positive sequence network is used for every fault, the type of fault is irrelevant, and fault location can be more accurate. The algorithm is thought to not be affected by fault resistance, load flow, or the non-homogenous nature of the system.

Using PMUs to better determine fault location on hybrid lines may result in selective reclosing, and thus decreased outage durations.

7.4 Autoreclosing (load restoration) after underfrequency load shedding

Automatic underfrequency load shedding (UFLS) is performed quickly to arrest power system frequency decline by decreasing the connected load to match available generation. The matching of load and generation is achieved by tripping feeders or lines.

When the system returns to normal, the tripped load could be restored either manually or via automatic restoration methods. In many regions, manual restoration is preferred. However, it would be possible to configure frequency supervision in reclosing devices to autoreclose feeders tripped by UFLS.

Load restoration after an underfrequency event is discussed in detail in IEEE Std C37.117 [B60].

7.5 Point-on-wave (POW) and staggered pole autoreclosing

Point-on-wave (POW), or controlled autoreclosing, is sometimes applied with autoreclosing. This form of autoreclosing involves processing information from voltage transformers on each side of the circuit breaker so as to enable each pole to autoreclose at the optimum moment to reduce overvoltages and stress to equipment.

POW autoreclosing is applied in combination with line-connected surge arresters to reduce switching surges, particularly if breaker closing resistors are not applied. It is most often applied to high-voltage transmission lines equipped with shunt reactors and subject to a resonant discharge upon line de-energization. With the application of POW autoreclosing, overvoltages can generally be kept below two per unit.

A typical POW device monitors the voltages across the breaker, factors the breaker closing time, and provides a close output to close the breaker poles at the POW that will result in a minimum overvoltage. Typically, for a transmission line, it is optimum to close the first breaker pole at source-side phase-to-neutral voltage zero, or at a point when the voltages on each side of the breaker are momentarily equal (synchronous), and to autoreclose the subsequent two poles at set intervals of time; 120 electrical degrees (5.6 ms) would be a typical time interval.

Another form of controlled autoreclosing is staggered pole autoreclosing. For staggered pole autoreclosing, the first pole autorecloses at random relative to the source-side voltage. The second and third poles are each in turn delayed by a set time (typically 8 ms). Staggered pole autoreclosing does not require a complex device as that for POW. It will nevertheless provide a significant reduction in voltage surge; in some instances only slightly less than that with POW.

A utility can elect to apply POW or staggered pole autoreclosing. Some utilities apply a combination of both methods so that the interval between autoreclosing each phase should not be less than a minimum setting (typically 8 ms).

Breaker closing times are a critical factor in applying POW autoreclosing since the time has to be accurately determined in advance to provide optimum autoreclosing of each phase. Breaker close time repeatability, variations in ambient temperature, dc control voltage variations, and time between operations can all affect the breaker closing time. In some cases, breaker ambient temperature compensation is included with POW operation. Some variation in breaker close time can nevertheless be tolerated since small deviations from optimum closing (typically on the order of 2 ms) can still achieve acceptable results.

The application of this technology provides a viable alternative to traditional breaker closing resistors in achieving reduced transmission line overvoltages during ~~on~~ autoreclosing. There is ongoing development in the area of intelligent POW devices. However, further discussion on the many aspects of POW autoreclosing is beyond the scope of this guide.

7.6 Multi-Phase Autoreclosing (MPAR)

As discussed in 6.2.4, some utilities use single-phase-tripping/reclosing. This reclosing scheme opens and then recloses only the faulted pole of all breakers on the protected line for single line-to-ground faults, and opens all three poles for all other types of the fault. This approach can be implemented in many relays, usually hard-coded, and is used around the world and is well-suited for single-circuit protection application. Even for double-circuit lines, this approach is traditionally used by having two separate relay systems tripping and reclosing its own protected line as if this is a single-circuit line.

However, on the double-circuit transmission lines, the approach can be different. Even if two phases are faulted and tripped on one line, there is a possibility that on the parallel circuit all three phases remain in service, or if a cross-country fault occurs on both circuits, at least there are two different phases unfaulted on both parallel lines. Having at least two different phases remaining healthy during a disturbance would allow maintaining system synchronism and stability. Maintaining power transfer during different types of faults and preventing separation of parts of the system may improve system stability. This is achievable with modern protective relays and communications between relays to share the fault type information between relays.

Consequently, for such schemes there will be special requirements for reclosing. Depending on the fault type, tripped poles, and reclosure mode, different reclosure responses are required. Reclosing relays must be able to support different reclosure modes: pure three-phase, single-phase and three-phase, and at least two multi-phase modes for double circuit lines. For example, if an A-B fault occurs on line #1 with a simultaneous A-C fault on parallel line #2 (see Figure 16) only those affected poles should be tripped, provided that the reclosing mode is multi-mode M2 (2 phases). Accordingly, reclosing should be performed for the same mode. Breakers selected for mode M3 (3 phases), should trip three-phase, and then three-phase delayed reclosing should be performed.

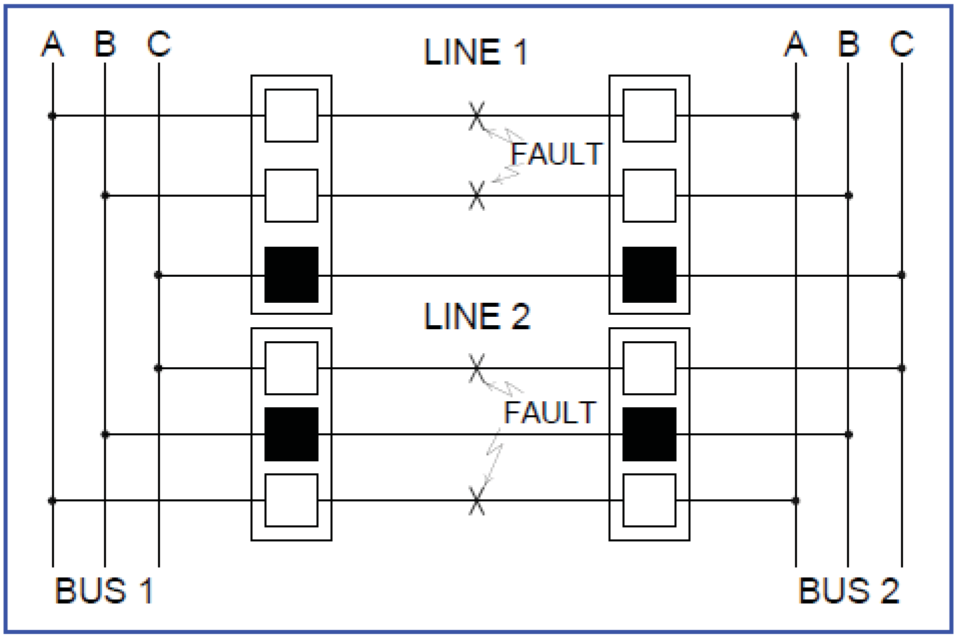

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Figure 16 —Multi-phase tripping/reclosing

There are usually three to four distinct modes of tripping and reclosing operation, which can be chosen with panel control switches or with relay pushbuttons. Depending on the mode of operation and on the phases tripped on both lines, reclosure has 3 different dead time delays to close breakers:

— 1P initiation, which is high-speed reclosure on order of 0.5 s to 0.8 s.

— M initiation, which is medium-speed reclosure, performed when multi-phase conditions are satisfied on order of 1 s.

— 3P initiation, which is the slowest 3-phase reclosure, performed after 3-phase tripping on order of 1.2 s to 1.5 s.

Additionally, each reclosure system performs the following:

— Monitors status of remote breaker poles on the protected line

— Monitors status of the parallel line breaker poles and controls two breakers

— Monitors leader-follower selection with selectable sequence of operation

— Monitors breaker fail operation

7.7 Pulseclosing

An alternative and patented approach to conventional reclosing, called pulseclosing, has recently been developed and deployed at medium-voltage. Pulseclosing produces a minor loop or pulse of current by initiating a rapid, single-phase, controlled POW close-open operation using conventional vacuum bottle contacts. This POW operation is initiated after a system voltage peak such that the duration of the resulting minor loop of current is between approximately ¼ and ½ cycles.

The resulting minor loop of current is then analyzed to determine if it represents a fault condition. If the analysis indicates a fault is still present, reclosing is suspended until a subsequent pulseclosing operation indicates the absence of the fault, or lockout is reached. The time intervals between subsequent pulseclosing operations are selectable and correlate with the open intervals between conventional reclosing operations.

When pulseclosing is performed in response to a multi-phase fault not involving ground, the POW, rapid close-open operation is based on phase-phase system voltage. Consequently, the resulting minor loop of current does not indicate a fault condition until pulseclosing the second phase. While the second phase never recloses under this condition, the first phase has, and now must be reopened as a result of the fault declaration.

As the energy represented by the minor loop or pulse of current is appreciably less than that resulting from conventional reclosing, a fuse that has initially been prevented from clearing a downstream fault will not be cleared by pulseclosing. Consequently, a conventional closing operation, which occurs at or near a system voltage peak on a phase-by-phase basis, is required to blow the fuse.

7.7.1 Pulsefinding

Pulseclosing also enables automated recovery from intentional miscoordination of series fault-interrupters. Where series pulseclosing devices have intentionally been miscoordinated and would all trip should they all sense a fault, the low energy of the minor loop of current does not reinitiate a simultaneous trip of these devices.

Annex A

(informative)

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Annex B

(informative)

History of automatic reclosing

The first stations to be automated were those for the ac to dc conversion for urban and interurban electric railways starting around 1913. The stated purpose was "to effect large savings by eliminating the cost of operators." As these controls were refined and became more sophisticated, it was noted that the automatic switching equipment could perform the necessary operations both faster and more accurately than the human operator. Next, the Edison three-wire dc light and power feeders were automated, and then the small hydrogenerating plants were automated. Supervisory, or remote control, also came into the picture, controlling stations from either a manned station or dispatch center.

Autoreclosing (automatic reclosing) came into general use in the 1920s. In a 1925 paper, a writer from Alabama Power stated that~~,~~ when his company began using autoreclosing in 1922, there were no commercial reclosing relays on the market, so his company designed and built its own reclosing relay, called the Seale relay after its designer, Jack Seale. A discusser of this paper stated that an induction relay, a timing relay, and a motor-driven drum timer were all commercially available before 1922.

SPECULATION—these three devices could have been the G.E. type HG-13, the G.E. type MD-2, and the Westinghouse type GR, respectively. Some sources show the GR being put on the market in 1919. The Seale relay used an induction disk motor driving a cam wheel to initiate a reclosure; an auxiliary relay was integrated inside the case. A number of G.E. type HG-13 single-shot reclosing relays were installed in the Georgia Power Company's East Point substation in the mid-1920s.

A report to the AIEE Summer Convention in Denver, June 25–29, 1928, contained a bibliography of papers covering the period of 1913 through 1928. Included in this bibliography were reports on autoreclosing practices of circuit breakers made to the Transmission and Distribution Committees and to the Relay Subcommittee of the Protective Devices Committee. It was noted in this report that the Standard for Automatic Stations No. 26, adopted by AIEE in 1928, contained the latest list of functional (device) numbers. It was also stated that device numbers had been in use for about 15 years, which would put the origin of this practice around 1913, when the first stations were automated.

In the IEEE PSRC Report on automatic reclosing of transmission lines [B53], the authors allude to the development~~,~~ in the late 1930s and 1940s of “transmission circuit breakers with high-speed mechanisms” as the key to high-speed autoreclosing of HV transmission circuits. To elaborate, Dr. J. Slepian’s work on arcs led to the development of the De-Ion circuit breaker interrupter, reported in 1929 and 1930, which made the efficient interruption of the ac arc in oil possible. Before this interrupter was developed, the sheer volume of the oil in the breaker was depended on to interrupt the arc; high oil pressures were generated such that oil-throwing from the breaker tank vents was not unusual, nor was flame-venting unknown. As the De-Ion interrupter made arc extinction manageable, the development of pneumatic mechanisms for circuit breakers increased the operating speeds and reduced control power requirements.

Many papers were written in the 1930s extolling the virtues of high-speed autoreclosing: increased system stability, reduced customer outages, and the possible deferment of additional transmission lines. The prevailing philosophy was to use three reclosure attempts (shots) to restore service: one high-speed, followed by two delayed shots. Numbers were given in these papers showing the effectiveness of this scheme. Gillies in his 1954 paper [B39] took these numbers and came up with the following percentages for the effectiveness of three-reclose shots:

	First shot	**Second shot**	**Third shot**
Percentage successful reclosures	90	4	1

These numbers are typical for transmission circuits, illustrating that the first shot has the greatest effectiveness, with little gain from the second and third shots. About 5% of the lines did not successfully reclose and locked out.

As the reclosing relay developed from the crude devices of the 1920s to the motor-driven reclosers of the 1930s and 1940s, miniaturization was practiced, producing synchronous motor timers and solid-state timers; however, they still required external control logic, voltage check, and synchronism check relays. The reclosing relay reached the apex of its development as a stand-alone device in the microprocessor-based relays of the 1980s and 1990s with built-in programmable logic, voltage check, and sync-check. Even as these relays supplanted their predecessors, technology marched on, superseding these relays by including the reclosing and check functions in other protective relays, thus no longer needing a stand-alone reclosing relay.

Annex C

(informative)

Sample method to indicate autoreclosing mode and timing

As mentioned in 4.2, a standardized method of indicating the autoreclosing mode and timing is desirable ~~required~~. Figure C.1 illustrates one example ~~the standard~~ method ~~used~~ to indicate the autoreclosing interval times ~~that will be utilized in this guide~~. This method uses the point of breaker position recognition by the reclosing relay as the beginning of the timing measurement, which is the first instance previously described.

The following examples provide a shorthand method that may be useful to describe common autoreclosing modes ~~in use today~~ on a single line diagram or other system operational drawing. ~~These include the following:~~

To clarify what source is used for the voltage supervision, it might be useful to use the letter B for Bus and L for Line. Further an indication for the voltage status of D for Dead and A for Alive or Live (or H for Hot) could be used. Thus

DL=Dead-line

AL=Alive-line or HL= Hot-line

DB=Dead-bus

AB=Alive-bus or HB= Hot-bus

DLDB= Dead-line-Dead-bus

ALDB= Alive-line-Dead-bus or HLDB= Hot-line-Dead-bus

DLAB= Dead-line-Alive-bus or DLHB= Dead-line-Hot-bus

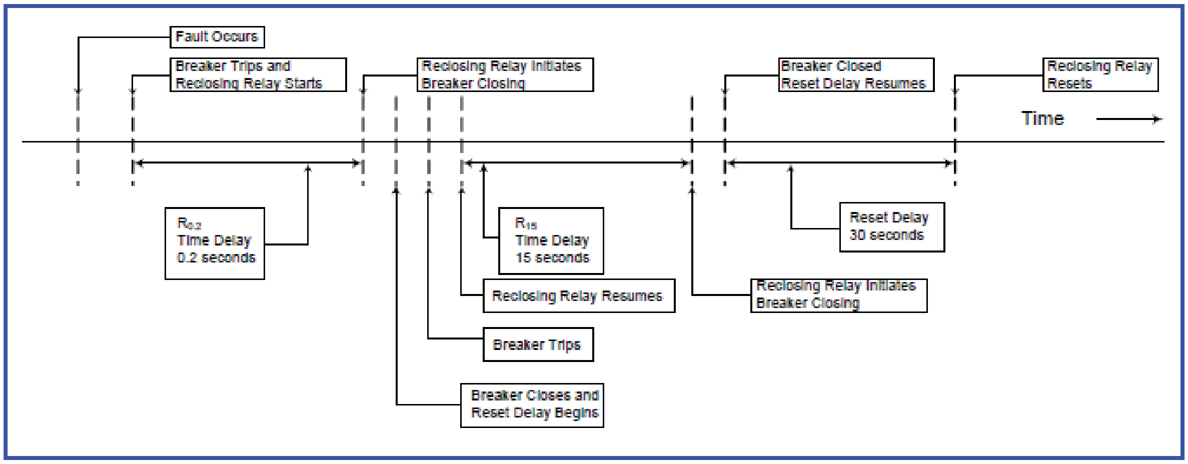
ALAB=Alive-line-Alive-bus or HLHB= Hot-line-Hot-bus

The following are samples that use this shorthand method:

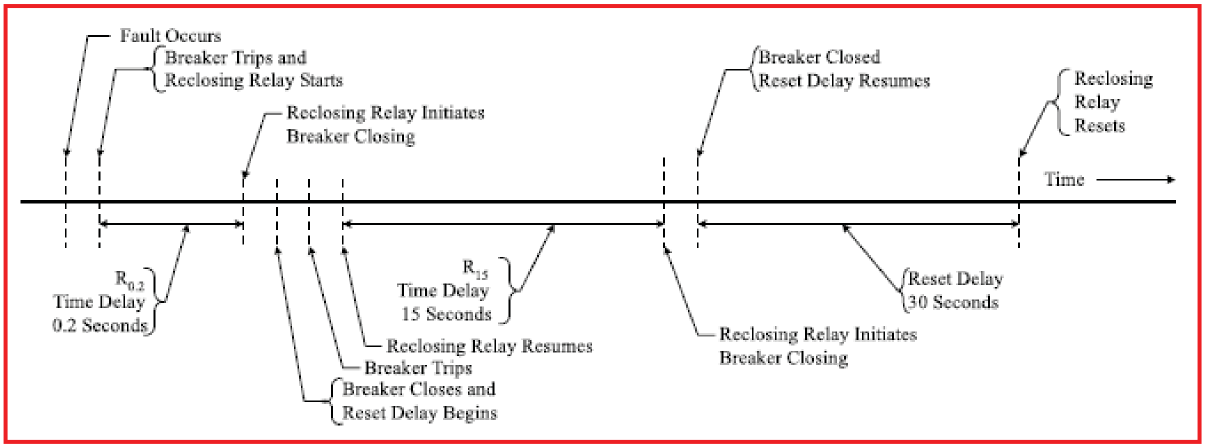
R	Autoreclosing with no voltage supervision and no external time delay.
R_{T1}	Autoreclosing with no voltage supervision and time delay T1. For example, R2 could be autoreclosing with no voltage supervision and a time delay of 2 s.
R_{DLT1}	Autoreclosing with dead-line supervision and time delay T1. For example, RDL1 could be autoreclosing with dead-line voltage supervision and a time delay of 1 s.
$R_{HL\cancel{A}T1}$	Autoreclosing with live-line supervision and time delay T1. For example, RHL0.5 could be autoreclosing with dead-line voltage supervision and a time delay of 0.5 s.
R_{DBAT1}	Autoreclosing with line dead before becoming alive; alive for time T1. This type of reclosing might be incorporated where a backfeed source might re-energize the line and is known to provide a stable phase angle.
$R_{ALABST1}$ or $R_{HLHB\cancel{A}ST1}$	Autoreclosing with Alive-line/Alive-bus (or Hot-line/Hot-bus) with sync-check and synchronism maintained for time T1.

R_{DT1} R_{T2}	Autoreclosing with the first attempt having dead-line supervision and time delay T1. Second attempt with no voltage supervision and time delay T2. From Figure C.1, T1 is 0.2 s and T2 is 15 s as measured from recognition of the breaker opening following the second trip.
R_{DLDBT1} R_{DLDBT2}	Autoreclosing with the first attempt having dead-line dead-bus supervision and time delay T1. Second attempt with dead-line dead-bus supervision and time delay T2.

The autoreclosing sequence illustrated in Figure C.1 involves two autoreclosing attempts (R0.2R15), followed by a reset of the reclosing relay. In this example, it is assumed that the initial autoreclose of the breaker was not successful and the fault detection devices retripped the breaker. The initial autoreclosing delay setting provides a delay time of 0.2 s (R0.2) from the sensed closure of a breaker auxiliary contact, indicating the breaker is open, to the initiation of the closing coil of the breaker. The second autoreclosing delay provides a similar interval of 15 s (R15). The reset interval will begin each time the breaker closes. In the sequence shown in Figure C.1, the reset timing function is halted and reinitialized when the breaker trips. The autoreclosing relay will reset to its initial state provided that the breaker does not open during this (reset) interval. The reset delay for this example is 30 s.



(New)



~~(Deleted)~~

Figure C.1—Autoreclosing time line

IEEE Std ~~ANSI~~ C37.06 ~~-2000~~[5] indicates that the minimum autoreclosing time delay should be ~~20 cycles~~ (0.3~~33~~ s) to allow fault arc products to dissipate. A breaker manufacturer may incorporate this delay into an operational mechanism of the breaker. This internal delay may need to be taken into consideration when setting the delay of a critical high-speed autoreclosing attempt.

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[5] ~~Information on references can be found in Clause 2.~~

Figure C.1 includes more detail perhaps than necessary for this description, and is not drawn to scale. The detail shown indicates that there are a number of events that must take place in clearing a fault, some of which need to be considered when determining delay settings for the reclosing relay. Other details, which need to be considered, are the time required to open and close the controlled breaker, and that the reclosing relay must recognize the position of the breaker by monitoring an auxiliary contact on the mechanism. In some electromechanical reclosing relays, there is a short delay as the internal logic sets itself for timing. In numerical/electronic/microprocessor designs, a short period is allowed to recognize the position of the breaker status ~~sending~~ contact (debounce time). While these intervals may be short enough to be neglected in the longer delay settings, they are still a part of the overall sequence of events and may need to be considered when fast autoreclosing is desired.

Figure C.1 is a general example and does not represent ~~It should also be noted that Figure 1 is typical and the reader needs to be aware of~~ how the timing functions of all reclosing relays are initiated and reset. Reclosing relay characteristics, such as ~~Care needs to be taken to assure that~~ reset time initiation, cancellation, successful reclosing sequence completion, pausing or stalling, and lockout logic must be well understood before applying settings ~~considered~~. The operation of the relay can vary according to its manufacturer, vintage, built-in logic, and programmable ~~(applied)~~ logic ~~scheme variables~~.

Reclosing relays can be in one of three distinct states: Timing or Cycling, Reset, and Lockout. Figure C.1 illustrates the definitions to be used within this guide relative to the timing of a reclosing relay. The fault clearing sequence begins with the inception of a fault, followed by the controlled breaker being tripped. When the controlled breaker opens, the reclosing relay starts timing toward its initial autoreclose attempt (the relay is in its timing or cycling state). At the completion of this delay, the reclosing relay closes its output contact and initiates breaker closing. At this point, the reclosing relay starts its reset timer. In the illustrated sequence, the fault is not cleared and the protection initiates a second trip. The reset timer is stopped and reset, and the reclosing relay begins timing toward a second autoreclosing attempt that ultimately initiates a second breaker closing operation. Since the fault has now been cleared and the breaker remains closed for the interval of the reset delay timer, the reclosing relay resets itself to its initial state (also known as the reset state).

If the fault persists and the number of programmed autoreclosing attempts expires, the reclosing relay advances to its lockout state, leaving the breaker open. The autoreclosing function is now locked out until the breaker is closed by other means. Depending on the design of the reclosing relay, the relay may then reset immediately or after a reset time delay. This may be the same reset delay used for successful reclose, or a different delay used exclusively from the lockout condition. In the event that the breaker is manually closed and fails to remain closed, care should be taken in the reclosing circuitry/logic to prevent the reclosing relay from operating. One technique available with microprocessor based relays that combine both protection and autoreclosing functions is to block reset if an overcurrent condition is detected when the breaker is closed. This can prevent breaker pumping for impedance limited faults that may take the time overcurrent element longer to trip than the reset time delay used from lockout.

Annex D

(informative)

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