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

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

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Power System Relaying Committee
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Abstract: Guidelines for the application of automatic reclosing facilities to circuit breakers are established. Decisions concerning the use of such facilities in specific cases are left to the user.
Keywords: automatic operation, circuit breaker, distribution, reclosing, transmission

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Introduction

(This introduction is not part of IEEE Std C37.104-2002, IEEE Guide for Automatic Reclosing of Line 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 temporary fault have evolved over many years. This newly developed 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.

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

1. Overview

1.1 Scope

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 purpose of this guide is to establish guidelines for the application of automatic reclosing facilities to circuit breakers. This 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. 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. References

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.

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

IEEE Std C37.04™-1999, IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers.[2,3]

IEEE Std C37.010™-1999, IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis.

IEEE Std C37.2™-1996 (Reaff 2001), IEEE Standard Electrical Power System Device Function Numbers and Contact Designations.

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.

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

IEEE Std C37.90™-1989 (Reaff 1994), IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus.

IEEE Std C37.100™-1992 (Reaff 2001), IEEE Standard Definitions for Power Switchgear.

3. Definitions

For purposes of this guide, the following terms and definitions apply. IEEE 100™ [B6][4] should be referenced for terms not defined in this clause.

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

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

3.2 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.

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

3.4 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.

3.5 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 the autoreclosing attempt.*

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

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

3.7 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.

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

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

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

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

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

3.13 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.*

3.14 synchronism check: Refers to the determination that acceptable voltages exist on the two sides of the breaker and the phase angle between them is within a specified limit for a specified time.*

3.15 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

4.1 Basics

As most faults on overhead electrical systems are temporary in nature, the use of autoreclosing aids in the restoration of the system. To apply autoreclosing properly, several concerns need to be addressed. Some of the most frequently asked fundamental questions are as follows:

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

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

4.2 Timing nomenclature

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 sequence of 15 s and 30 s may be designated as $R_{15}R_{30}$. The 30 s may indicate the time after the first autoreclose attempt failed and the breaker tripped a second time or the total elapsed time from the initial trip. In the first instance, this means that the second attempt would happen at the 45+ s point after fault initiation. In the second interpretation, this means that the second attempt would occur 30 s after fault initiation. A standardized method of indicating the autoreclosing mode and timing is required. Figure 1 illustrates 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 shorthand method may be used to describe common autoreclosing modes in use today on a single line diagram or other system operational drawing. These include the following:

R	Autoreclosing with no voltage supervision and no external time delay.
R_{T1}	Autoreclosing with no voltage supervision and time delayed T1.
R_{DT1}	Autoreclosing with dead-line supervision and time delayed T1.
R_{AT1}	Autoreclosing with live-line supervision and time delayed T1.
R_{DBAT1}	Autoreclosing with line dead before becoming alive; alive for time T1.
R_{AST1}	Autoreclosing with synch check and synchronism maintained for time T1.
$R_{DT1}R_{T2}$	Autoreclosing with the first attempt having dead-line supervision and time delayed T1. Second attempt with no voltage supervision and time delayed T2. From Figure 1, T1 is 0.2 s and T2 is 15 s as measured from recognition of the breaker opening following the second trip.

The autoreclosing sequence illustrated in Figure 1 involves two autoreclosing attempts, 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 ($R_{0.2}$) 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 (R_{15}). The reset interval will begin each time the breaker closes. In the sequence shown in Figure 1, the reset timing function is halted and reinitialized when the breaker trips. The autoreclosing relay will reset to its initial state providing that the breaker does not open during this (reset) interval. The reset delay for this example is 30 s.

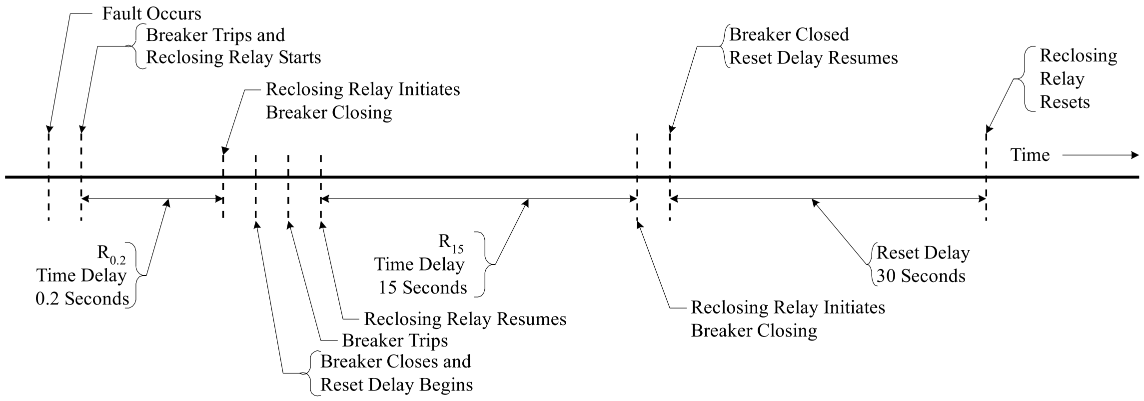

Figure 1—Autoreclosing time line

ANSI C37.06-2000[5] indicates that the minimum autoreclosing time delay should be 20 cycles (0.333 s). 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.

Figure 1 includes more detail perhaps than necessary for this description, and is not drawn to scale. The detail shown is to indicate to the reader 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 relays there is a short delay as the internal logic sets itself for timing. In electronic designs, a short period is allowed to recognize the position of the 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. It should also be noted that Figure 1 is typical and the reader needs to be aware of how the timing functions of the relay are initiated and reset. Care needs to be taken to assure that reset time initiation, cancellation, successful reclosing sequence completion, pausing, and lockout logic are considered. The operation of the relay can vary according to its manufacturer, vintage, and programmed (applied) logic scheme variables.

Figure 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. 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 and initiates closing of the breaker. 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 states.

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 reclosing relay is now 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 the reset time delay. In the event that the breaker is manually closed and fails to remain closed, care should be taken in the reclosing circuitry to prevent the reclosing relay from operating.

4.3 Autoreclosing 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, 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 is required to ensure that circuit breakers autoreclose only when intended. The control circuitry 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 52b contact, then a slip contact of the circuit breaker control switch is installed in series with the close initiation. This contact of the

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

circuit breaker control switch disengages when the circuit breaker is manually opened. It engages when the circuit breaker is closed manually. 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 following a manual closure. 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.

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.

Autoreclosing is also *locked out*, or terminated, after the programmed number of attempts to re-energize the line are tried and unsuccessfully completed. 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.

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.

4.3.2 Voltage supervision of autoreclosing

Autoreclosing is often supervised by voltage permissives. These voltage permissives are often single phase, connected phase-to-phase, or phase-to-neutral. If a line has tapped terminals and these terminals can backfeed the line, then the main terminal, which re-energizes 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 need to be delayed longer to permit all terminals to clear the fault.

A method to 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 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 the source of backfeed is a delta-connected transformer. If a single phase-to-ground fault occurred with backfeed from such a source and single phase sensing was utilized, then two phases may have high voltage and one phase 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 backfeed 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 should be by two relays connected to different phases or dropout of a single relay should be monitored or alarmed.

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, 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 ensure that the primary supply is stable.

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 comprised of 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 that distribution source transformer size increased as well as the number of supplied feeders. It is known that when transformers are subjected to any fault on the secondary that the transformer windings are stressed. 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 Dead time

Several factors are important to consider before attempting to autoreclose any circuit breaker that has just tripped for a fault. An autoreclose attempt without sufficient time delay to allow the dielectric to re-establish its strength results in an unsuccessful 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.

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 5.4.5.

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. 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 (s)
Initial trip to 1st reclose (R_{T1})	0–5
2nd trip to 2nd reclose (R_{T2})	11–20
3rd trip to 3rd reclose (R_{T3})	10–30

5.2.3 Lockout reset time

A reset timer can be provided in a reclosing relay that resets the relay after successful autoreclosure of the circuit interrupting device. If the autoreclosure is not successful, the relay moves to the lockout position so that the interrupting device cannot be automatically closed. The lockout condition is useful in preventing excessive wear on the interrupting device from multiple operations due to frequent transitory faults on the distribution feeder, which can be caused by wind, tree contact, or lightning during storm conditions. Lockout is also useful in preventing a circuit interrupting device from inadvertently autoreclosing when it is closed manually into a faulted distribution line. The lockout condition is automatically reset after the breaker is closed manually or remotely and remains closed for the preset period of time to assure a fault does not exist at the instant of closure.

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.

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 tend 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. 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. This additional security can be provided by dead-line autoreclosing logic, synchronizing check, or transfer trip protection.

5.2.6 Substation controller

A substation controller consists of an intelligent device to control operations of the circuit breakers at the distribution 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.

5.2.7 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 distribution substation.

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).

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 in order to assure that proper coordination will exist.

5.3.2 Sectionalizers

A sectionalizer is a protective device, used in conjunction with a recloser, or breaker and reclosing relay, which isolates faulted sections of lines. The sectionalizer does not interrupt fault current. Instead, it counts the number of operations of the interrupting device upstream and opens while the interrupting device is open.

Reclosing relays and automatic sectionalizing 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.

If the sectionalizing sequence is to be successful, the autoreclosing times associated with the feeder breakers need to coordinate with the line sectionalizer 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), it will open on the next loss of voltage 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 is 20 s, 20 s, and then lockout (R_{20} R_{20}). The downstream sectionalizer is set to count two current pulses before opening and has a reset time of 25 s.

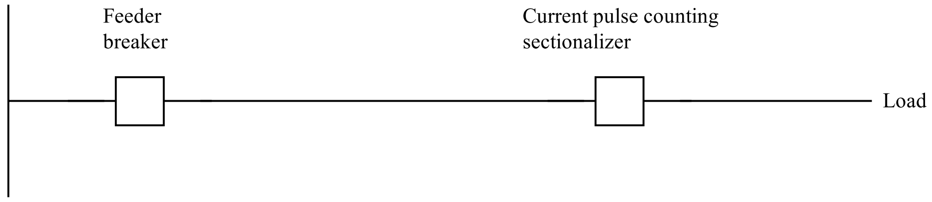

Figure 2—Pulse-counting sectionalizing scheme

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.

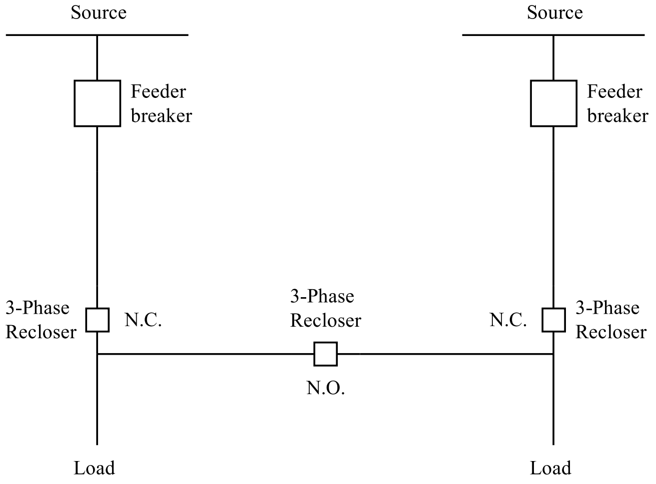

Figure 3—Loop sectionalizing scheme

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 transient 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 transient, all customers are restored, including those beyond the fuse, when the breaker initial 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 these instantaneous overcurrent elements are not in service during the initial trip of the feeder, and the time overcurrent elements are set to coordinate 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 4 a). An example of the coordination for this circuit is shown in Figure 4 b). 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 overcurrrent elements in the two interrupting devices.

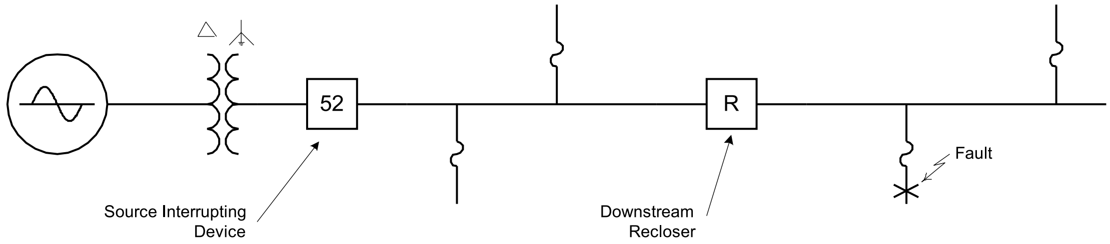

Figure 4a)—One-line diagram

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

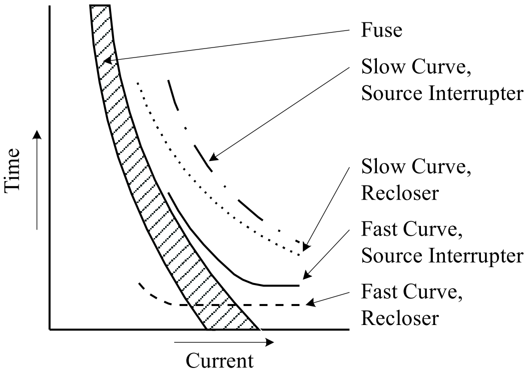

Figure 4b)—Typical circuit coordination with sequence coordination

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 4 c).
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 4 a). 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

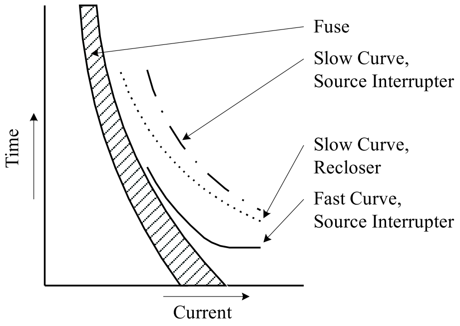

Figure 4c)—Coordination diagram without sequence coordination following fast trip(s) of downstream recloser

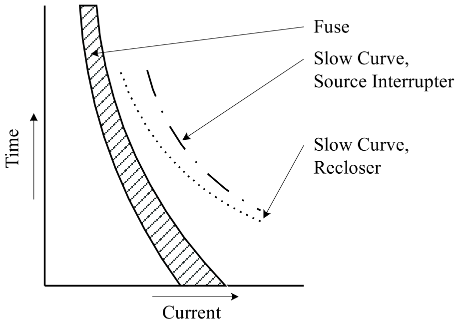

Figure 4d)—Coordination diagram with sequence coordination following fast trip of downstream recloser

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 4 d). With this sequence, the customers tapped between the two interrupters have no interruptions for the permanent fault event.

5.3.5 Distribution bus autoreclosing

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 (5 s) and not supervised except for buses that can be fed from another source. These other sources could be dispersed generation on the line breakers, 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.

5.3.6 Autoreclose blocking

Blocking or disabling of autoreclosing on distribution circuits may be required for various circumstances. Requirements will vary depending on specific design features incorporated into the distribution system. The following are several conditions for which autoreclosing is blocked:

a) *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 4.3.2.)
b) *Bus faults*. Autoreclosing of lines can be blocked for bus faults. (See 5.2.4 and 5.3.5 for possible exceptions.)
c) *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.
d) *Downed conductor protection*. Autoreclosing can be blocked when protective systems designed to 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. [B13].)
e) *Voltage unbalance*. Autoreclosing can be blocked if a voltage unbalance condition is detected at the station. A source-side open circuit can cause such unbalances. Restoring service under unbalanced conditions could cause damage to customer equipment.
f) *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.
g) *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 are blocked until the failed breaker is isolated and the bus is restored.
h) *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.
j) *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.
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.
l) *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.

5.3.7 Load tap changer (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. It is a common practice to block the LTC controls while an autoreclosing sequence is in progress.

5.4 Special application considerations

5.4.1 Dispersed generation and other sources

Distribution systems to which dispersed generation is connected provide utilities with special concerns. The presence of generation can require special studies on the part of the utility.

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 reliability to other customers, a communication-aided protection package could be needed.

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.

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.

5.4.2 Lines with cables

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

If the line is completely cable, it makes no sense to autoreclose into a permanent fault. There is no need to subject the circuit breaker, bus, substation transformer, and more importantly the customer to additional damage. Therefore, the use of autoreclosing on feeders entirely made of cable is not recommended.

If the line is partially cable and partially overhead, autoreclosing could be used if the 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.

Depending on the location and length of the cable section relative to the total feeder length, some utilities elect to 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 transient 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.

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

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

a) is set for more than two operations, or
b) 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.

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,

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
		$R_{T2} = 15$	
		$R_{T3} = 30$	

asymmetrical current, or rotating machinery considerations, which could also modify the interrupting capability of the breaker.

These capability factors are defined in the standards for the 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 modern technologies such as SF6 puffer or vacuum circuit breakers as the dielectric recovery time is less than the 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.

5.4.5 Effects of autoreclosing on disk type overcurrent relays (ratcheting)

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 the fault and removes the fault current flow before the disk type overcurrent relays reach their trip point. A minimum safety margin is normally provided 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 an instantaneous reset of the timing function as well as other selective reset characteristics, which is normally considered in the coordination process.

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. Lengthening of the reset time on the reclosing relay prevents the excessive operations, but could cause undesirable lockout operations.

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 minute window.

5.4.7 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 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.
c) 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.
d) 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.)
e) Use of an overcurrent 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.
f) Use of an overcurrent 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.
g) 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.
h) Breaker failure to close. If an attempt to autoreclose a breaker is made, and the breaker does not close (based on 52 auxiliary contact sensing) within the expected close time, block further attempts to autoreclose.

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.

5.4.8 Capacitors

Shunt capacitors are applied to distribution buses and lines to provide 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 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.)

6. Autoreclosing for transmission systems

6.1 Transmission systems overview

The loss of a single line in the transmission system can have a 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 reduced the impact that autoreclose attempts have on the system.

In addition to methods, many elements common in transmission require consideration of their effects on the application of autoreclosing. For example, a network transmission line 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 is 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.

6.1.1.2 Number of operations

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 adverse effects on customers and their equipment.

6.1.1.3 Blocking of autoreclosing

Autoreclosing is normally blocked:

a) During the reception of a transferred trip signal. In some schemes, a timer is initiated by the receipt of the transferred trip signal. If this timer times out, operation of the reclosing sequence is prevented.
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.
2) *Three-phase faults*. Three-phase faults are rare on EHV (765–345 kV) and are unlikely to be of a transient nature. These faults most often result from ground straps left in place after breaker maintenance or downed line structures; therefore, blocking of autoreclosing should be considerd. Since transient three-phase faults are more probable for lower voltage transmission lines, autoreclosing may be desirable if system stability and generation are not affected.
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.
5) *Faults on buses, transformers, or underground cables*. These faults are most likely permanent in nature; autoreclosing a breaker could aggravate electrical equipment damage. Consider the risks and benefits of autoreclosing versus blocking all autoreclosing.
6) *Power swing and out-of-step conditions*. If a breaker has tripped due to power swing or out-of-step relay, consider blocking autoreclose until system stability can be re-established.

6.1.1.4 Breaker failure operations

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

6.1.1.5 Autoreclose supervision

Various forms of autoreclose supervision can be 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, which 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.

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 or voltage magnitude across the breaker contacts to be closed. The setting of the synchronism check relay is based on the angular difference between the two voltages and is designed to minimize the shock to the system when the breaker is closed.

Receipt of transfer trip signal—lines that have transformers or reactors connected without a breaker should not be autoreclosed for faults in 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, it is necessary to distinguish between a 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.

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 apply three relays (one per phase) to provide for added reliability. Three-phase monitoring can be used for dead-line checking on distribution lines with distributed generation, when fuses are applied between the substation and generation. It should also be noted that particularly for high-voltage transmission lines with line reactors, after a line tripout on a line-to-ground fault the trapped charge is expected to maintain near rated voltage for a considerable time. 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 ensure 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 following terminal 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.

6.1.1.6 Turbine-generator considerations

Manual closing or autoreclosing without synchronization supervision at line terminals that are in close electrical proximity to turbine-generators can subject them 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 autoreclosing is 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 stresses induced 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 three-phase faults) close in to a generating plant can contribute to accelerated torsional fatigue on the turbine-generator shafts (ANSI C30.13-1977 [B1], IEEE Committee Report [B8], and Jackson et al. [B12]). This can be dealt with by not autoreclosing near generating plants or by blocking the autoreclose for close-in faults 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 resonance condition, which could contribute to other system problems.

The operation of closing a breaker in the power system can result in the creation of power transients and current oscillations, which can stress or damage generating units located electrically close to that breaker. These transients effect various components of the turbine-generator. The concern is the average initial power, ΔP, which occurs when the breaker is closed, and its effect in producing torsional stresses, primarily in the rotational members of the turbine-generator. For this condition, the permissible limit for ΔP or ΔI at the generator terminals are 0.5 per unit based on the rated load and power factor. 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.

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 (ANSI C30.13-1977 [B1]) suggest that simple measures such as ΔP or ΔI 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 Electro Magnetic 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.

As a result of the apparent risk to turbine-generator life, most utilities have modified their autoreclosing practices to some form of the following:

a) Autoreclose by synchronism check only
b) Allow a minimum of a 10-s delay prior to any autoreclose attempt
c) Use single pole tripping and allow autoreclose on single phase faults only
d) Autoreclose lines with tapped generation only under dead-line conditions
e) Use no autoreclosing near generation

6.1.1.7 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.

6.1.1.8 Multiple circuit breaker line termination

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.

6.1.1.9 Special considerations for series compensated lines

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.

6.2 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 (IEEE PSRC Report [B11]). Given the high success rate of autoreclose attempts for transient faults, it makes sense to attempt a high-speed autoreclose.

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

a) Provides fast restoration of power to customers
b) Can help to maintain system stability
c) Restores system capacity and reliability

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 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.

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.
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. [B12]). 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 6.1.1.6.)

6.2.1.1 Deionizing time

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. This deionization time depends on the voltage, the conductor spacing, the magnitude of fault current, and the weather conditions (Westinghouse Electronic Corporation [B16]). Under normal conditions, a good minimum delay can be established using Equation (1) for deionization of air at the fault location:

$$t = 10.5 + V_{L-L}/34.5 \tag{1}$$

where

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

This time can increase if a nearby adjacent parallel line helps to sustain the arc or if single 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. For other types of circuit breakers, a delay needs to be added to either the breaker time or the autoreclose time.

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 autoreclosing operation. 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. When there is a question regarding this feature, the breaker manufacturer should be consulted.

6.2.1.3 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 attending its use. The risk is that stability could be endangered rather than benefited 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 to ensure that high-speed autoreclosing does not endanger stability.

6.2.1.4 Out-of-step and power swing conditions

All autoreclosing should be blocked following an out-of-step or power swing relay operation. This action should be taken whether the out-of-step or power swing relay is used to block tripping or causes tripping of the breaker as an autoreclosure could further agitate an already disturbed system condition.

6.2.1.5 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 autoreclosure, 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 will fall in the range 0.5–1.5 s. 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.

6.2.2.2 Phase angle, frequency, and voltage considerations

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 frequency differences, 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 ensure undesired autoreclosing modes 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) hot bus–dead line, c) hot line, or d) 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.

6.2.3 Selective autoreclosing

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.

Most, if not all, selective autoreclosing schemes use the operation of specific relays or relay elements to initiate the scheme. The advent of microprocessor relays with the ability to assign specific relay elements to output contacts has allowed for very selective autoreclosing. Almost any element of the microprocessor relay can now be used in site-specific schemes.

There are a large variety of schemes used today. Some schemes only allow autoreclosing on pilot trips where it is likely that a similar pilot trip will occur if the fault re-establishes on autoreclose. Others 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, out-of-step tripping, or where sensitive or critical loads can be affected.

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 weighted 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 vice versa.

6.2.4 Single-shot- and multiple-shot autoreclosing

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.

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 access 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 nonpilot and additional time is required to allow for time-delayed tripping of one or more terminals.

6.2.5 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 multiphase 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.

Consider 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 can also serve the purpose of suppressing the ground fault secondary arc current. Typical single pole autoreclose times applied by utilities are in the order of 0.5 to 1.0 s.

Single pole 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 pole 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:

a) Inhibit autoreclosing until the fault arc is extinguished. This would require the use of line-side voltage transformers. (Horowitz et al. [B5] and IEEE Power System Relaying Committee [B9].)
b) Block autoreclosing for multiphase faults. This necessitates the use of single pole switching. (IEEE Power System Relaying Committee [B9].)
c) Initiate immediate autoreclosing for undesirable trips. A substation SCADA computer could initiate immediate reclose when fault data indicate an incorrect relay operation.
d) Change the synchronism check angle if synch 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 [B9].)
e) Allow the substation computer to be the only autoreclosing device for the entire substation. (IEEE Power System Relaying Committee [B9].)

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 even autoreclosing inhibited. Lower current faults could allow for a shorter delay time. High-resistance faults may have the autoreclosing inhibited (Rockefeller et al. [B13]). 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. [B5]).

It should also be possible to adjust the autoreclosing mode for each line based on a systemwide 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.

6.2.9 Point-on-wave 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.

Point-on-wave autoreclosing is applied in combination with line-connected surge arresters to reduce switching surges, particularly if breaker closing resistors are not being 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 point on wave autoreclosing, overvoltages can generally be kept below two per unit.

A typical point-on-wave device monitors the voltages across the breaker, factors the breaker closing time, and provides a close output to close the breaker poles at the point on wave, which 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 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 point on wave. It will nevertheless provide a significant reduction in voltage surge; in some instances only slightly less than that with point on wave.

A utility can elect to apply point on wave or staggered pole autoreclosing. Some utilities apply a combination of both methods to ensure 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 point on wave autoreclosing since the time has to be accurately determined in advance to ensure 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 point-on-wave 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 on autoreclosing. There is ongoing development in the area of intelligent point-on-wave devices. However, further discussion on the many aspects of point-on-wave autoreclosing is beyond the scope of this guide.

6.3 Application considerations

6.3.1 Radial 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, the second autoreclosing shot should be 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.

6.3.2 Leader–follower autoreclosing of transmission lines

The leader–follower autoreclosing scheme is typical of transmission-line autoreclosing practices. In this scheme, the leader end is selected as the weaker of the two ends, and is used to "test" the line. This practice is used to ensure the fault has been cleared while imposing the least disturbance to the power system. If the leader-end autoreclosure is successful, the follower end autoreclosure, being 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 5 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

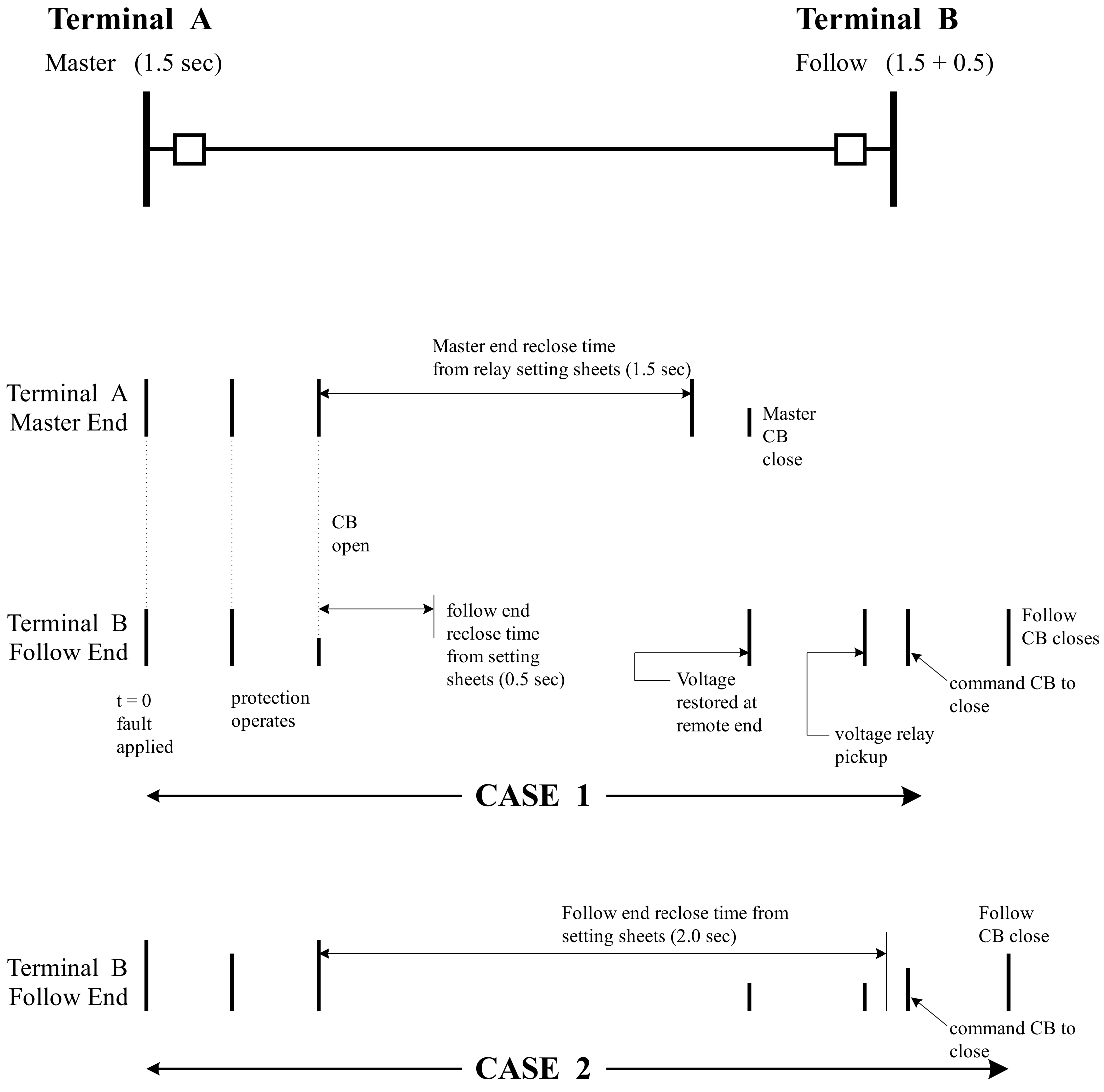

Figure 5—Leader–follower reclosing scheme timing

protection and the timing of the leader or *Master* terminal reclosing relay is set for 1.5 s. In Figure 5, Case 1, the time delay of the reclosing relay at the *follow* 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 to 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 (lead) end setting, the follower end timing diagram would be as shown in Case 2 of Figure 5. 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 as the other network connections 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 to 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 follow end voltage is too high to permit autoreclosing safely. In this instance, a transfer trip of the *leading end* of the line would be initiated by the overvoltage relays.

6.3.3 Lines with automatic sectionalizing

A line with automatic sectionalizing can be either radial or connected to source buses at either or both ends. An ideal practice would require a potential device on each end of the line to permit voltage supervision of autoreclosing as indicated in 6.2.2.2 and 6.3.2. 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 transient in nature. If the second shot fails, a fault between the source and sectionalizing point is indicated and the line is locked out.

Lines that have 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. Loss of the primary supply will start the transfer timer. If the line 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 accommodate the autotransfer abort; if the first attempt is unsuccessful, then the second attempt should not be made until the autotransfer scheme has had time to complete its transfer function.

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.)

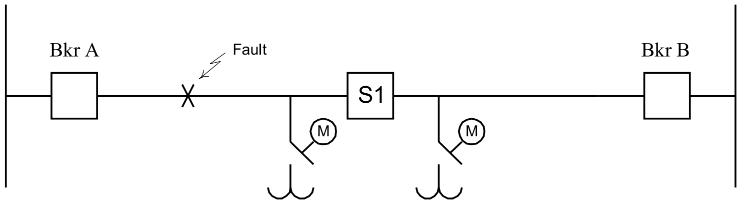

Figure 6—Line sectionalizing scheme 1

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.

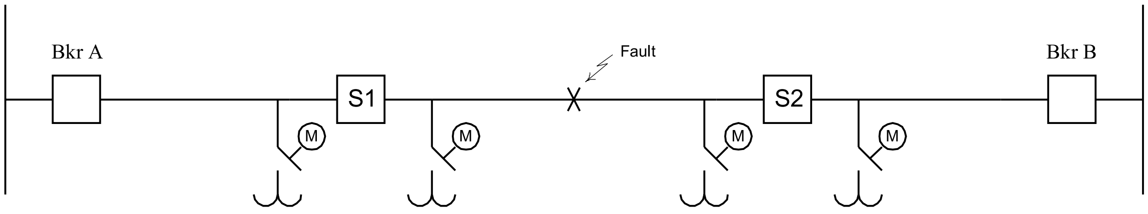

Figure 7—Line sectionalizing scheme 2

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.
f) 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.

6.3.4 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.

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. 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 opens the motor-operated switch. The lockout relays can also operate a high-speed ground switch that closes to 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 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.

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.

6.3.5 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 that autoreclosing of 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 to be used, delayed dead-line autoreclosing is normally used at only two of the terminals 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. The dead-line autoreclosing sequence should be based on the same selection parameters as a two-terminal line.

6.3.6 Multiple-breaker line terminations

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. 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 8). If the *lead* breaker remains closed, the *follow* breaker is autoreclosed on a time-delayed basis. This operation can be supervised by “live-line–live-bus.” In the event that 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 (Breaker 2 in Figure 8) to become the first breaker to close in a time-delay mode (with supervision), if the remote terminal autorecloses first.

In these applications, it is desirable to include a selection logic that transfers the *lead* autoreclosing function from the *out-of-service* breaker to the remaining breaker. 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.

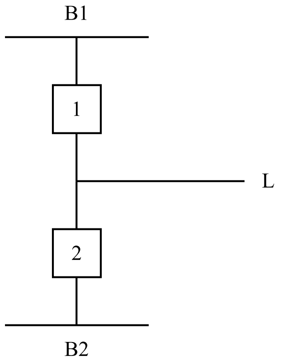

Figure 8—Multiple-breaker line termination

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]).

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. [B14] and Truax et al. [B15]).

6.3.8 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 direct 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.

6.3.9 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.

6.3.10 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 shall 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 major damage.

6.3.11 Transformers

Transformers present unique autoreclosing characteristics. As indicated in IEEE Std C37.91-2000 [B7] 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.

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:

a) Live line–dead transformer with delay.
b) Live line–live transformer with delay.
c) Live line–live transformer with synchronism.

As an example, consider the following: 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 R_{DT1} end confirmed that the line was dead and the initiated autoreclosing was successful. The R_{AST1} terminal would be autoreclosed after determining that live voltage was present and in synch 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.

6.3.12 Lines with series compensation

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

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.

Autoreclosing philosophies on lines with series compensation vary among different utilities. Issues such as system stability, single-phase or three-phase autoreclosing, communication means, and short-circuit levels could be the determining factors for adopting one particular autoreclosure philosophy.

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.

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’’ [B11], 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 [B4] 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 synch 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)

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