PDHonline Course E472 (4 PDH)

Substations – Volume V – Circuit Interrupting Devices

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Substation Design
Volume V
Circuit Interrupting Devices

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This series of courses are based on the "Design Guide for Rural Substations", published by the Rural Utilities Service of the United States Department of Agriculture, RUS Bulletin 1724E-300, June 2001.

Preface

This course is one of a series of thirteen courses on the design of electrical substations. The courses do not necessarily have to be taken in order and, for the most part, are stand-alone courses. The following is a brief description of each course.

Volume I, Design Parameters. Covers the general design considerations, documents and drawings related to designing a substation.

Volume II, Physical Layout. Covers the layout considerations, bus configurations, and electrical clearances.

Volume III, Conductors and Bus Design. Covers bare conductors, rigid and strain bus design.

Volume IV, Power Transformers. Covers the application and relevant specifications related to power transformers and mobile transformers.

Volume V, Circuit Interrupting Devices. Covers the specifications and application of power circuit breakers, metal-clad switchgear and electronic reclosers.

Volume VI, Voltage Regulators and Capacitors. Covers the general operation and specification of voltage regulators and capacitors.

Volume VII, Other Major Equipment. Covers switch, arrestor, and instrument transformer specification and application.

Volume VIII, Site and Foundation Design. Covers general issues related to site design, foundation design and control house design.

Volume IX, Substation Structures. Covers the design of bus support structures and connectors.

Volume X, Grounding. Covers the design of the ground grid for safety and proper operation.

Volume XI, Protective Relaying. Covers relay types, schemes, and instrumentation.

Volume XII, Auxiliary Systems. Covers AC & DC systems, automation, and communications.

Volume XIII, Insulated Cable and Raceways. Covers the specifications and application of electrical cable.

Chapter 1
Power Circuit Breakers

By definition, a circuit breaker is a device that closes and opens an electric circuit between separable contacts under both load and fault conditions. The application of circuit breakers involves consideration of the intended function, expected results, benefits to the electric system, and characteristics of both the circuit breakers and the electric system. A photograph of a typical circuit breaker is shown on the right.

In some instances, protective devices of lesser capability and flexibility, such as fuses, circuit switchers, reclosers, etc., may be more desirable or preferred over more complex and costly circuit breakers.

Fuses are often desirable for transformer protection at any location where they are adequate for the thermal load and short-circuit conditions because of their lower cost and smaller space requirements compared to other devices. They are also desirable for their ease of coordination with circuit breakers and relays at other locations on the electric system. Fuses can also be applied as temporary maintenance bypass protection to permit maintenance of circuit breakers. Fuses are also used extensively for sectionalization and branch circuit protection in distribution systems.

Circuit switchers are less costly than circuit breakers and can be applied in much the same way as circuit breakers, subject to limitations in interrupting capability, with the same type of relay control as circuit breakers. Circuit switchers are also supplied without current transformers (circuit breakers are usually supplied with CTs), which are used in conjunction with relays to sense faults. They can be substituted for fuses in transformer bank protection to detect low-voltage-side faults that fuses may not be able to detect. This detection would utilize relay intelligence from the low-voltage side. Circuit switchers also provide excellent capacitor bank

switching and protection. In outlying areas of moderate short-circuit capacity, they can often be substituted for circuit breakers. They can be mounted similarly to air-break switches on a substation structure and thus require little or no additional space. The photo on the left shows a typical circuit switcher. This one is manufactured by S&C.

Reclosers are completely self-contained and provide excellent distribution circuit exit and feeder protection. Their ratings are adequate for both load and short circuit on most distribution circuits and overlap the ratings of more costly circuit breakers. Their operation is faster than most circuit breakers, and their sequence of open and close operations is very flexible. Reclosers are available in both single-and three-phase ratings so that they are very useful and adaptable for the entire distribution system at locations where reclosing operation is required.

Writing of specifications and selection of power circuit breakers and similar devices should be preceded by electric system studies to determine the parameters of application and operation that have to be satisfied. These include load flow, short-circuit, transient voltage, coordination, and protection studies. ANSI Std. C37.12, "American National Standard Guide Specifications for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis and a Total Current Basis," can be used directly as a model or checklist for the purchase specification. A manufacturer's standard design and construction would normally be considered acceptable.

It is recommended that those responsible for preparing power circuit breaker specifications become familiar with:

1. The C37 series of ANSI Standards covering ratings, testing, applications, specifications, etc.
2. Each specific application and proposed installation.
3. Each prospective supplier's product line of circuit breakers.

Types of Circuit Breakers

Breakers are usually classified as *dead tank* or *live tank* construction. *Dead tank* means that the circuit breaker tank and all accessories are maintained at ground potential, and the external source and load connections are made through conventional bushings. *Live tank* means that the metal and porcelain housing containing the interrupting mechanism is mounted on an insulating porcelain column and is therefore at line potential. This column, besides serving as an insulating support, may act as an access for the operating rod or linkage and, in the case of air circuit breakers, it acts as an air supply duct. Most circuit breakers above 242 kV are of “live tank” construction.

In addition to classification as live tank or dead tank construction, circuit breakers are also classified in terms of interrupting media. Breakers are also classified as three-pole, single-throw, and independent-pole operation. Three-pole single-throw breakers utilize one mechanical device to trip all three poles with a linkage to gang the operation together. With independent-pole operation, each pole is equipped with the mechanical means to trip its individual pole.

Each user must determine the ratings of circuit breakers required and then select a type of circuit breaker acceptable with regard to rating, performance expectations, compatibility with planned or existing substation configuration, and the ability to install, operate, and maintain the circuit breaker. Cost may also be an important consideration in the final selection.

Most, but not all, domestic circuit breakers in outdoor substations of 2.4 kV through 24.9 kV utilize a vacuum technology as the insulating dielectric to interrupt load and fault currents. Although outdoor vacuum breakers can be supplied for voltages up to 38 kV, SF_6 is more commonly used for voltages from 34.5 kV to 765 kV. SF_6 breakers are available in 15 kV to 242 kV ratings in single tanks and in 15 kV to 800 kV ratings in three, individual pole, tanks. Although SF_6 breakers are available in single-tank designs, the trend is toward a three-tank design. SF_6 breaker manufacturers have been able to reduce the size of the interrupting chambers, making the three-tank design more economical.

SF_6 circuit breakers are available with three operating mechanisms:

1. Pneumatic,
2. Hydraulic, and
3. Spring-operated.

Some circuit breaker manufacturers have models for each of the operating mechanisms. Although there are many differences, most circuit breakers require the bushings to be removed to expose the interrupting mechanism for inspection and maintenance.

Even though there are a number of oil circuit breakers still in service, with the developments in SF_6 and vacuum technology, oil breakers are being phased out.

Ratings

The rating of a circuit breaker is a summary of its characteristics that identifies its application on an electric system, its performance capabilities, and its adaptability. This summary of characteristics is given principally in terms of voltages, currents, and time as described in the rating tables, and in the following subsections.

Voltage

Voltage characteristics are defined in terms of RMS nominal, RMS rated maximum, rated voltage range factor, and rated dielectric strength. Nominal voltage, also known as voltage class, is used to identify the general voltage class or electric system voltage on which a particular circuit breaker was intended for application.

Rated maximum voltage is the maximum voltage for which the circuit breaker is designed and is also the upper limit for operation on an electric system. It is based on ANSI Std. C84.1, “American National Standard Voltage Ratings for Electric Power Systems and Equipment (60 Hz),” and ANSI Std. C92.2, “Preferred Voltage Ratings for Alternating Current Electrical Systems and Equipment Operating at Voltages above 230 Kilovolts Nominal.” It is the prime operating voltage reference and relates the rated short-circuit interrupting current and short-circuit interrupting kA or energy handling capabilities.

Rated voltage range factor, designated as “K,” defines the lower limit of operating voltage at which the required symmetrical and asymmetrical current interrupting capabilities vary in inverse proportion to the operating voltage. “K” is the ratio of rated maximum voltage to this lower limit of operating voltage. The rated maximum voltage either divided by K or multiplied by the reciprocal, 1/K will produce the lower limit of operating voltage. For 72.5 kV through 800 kV circuit breakers, where the voltage range factor is 1.0. This limits the maximum interrupting current capability at voltages lower than rated voltage to a value no greater than the interrupting current capability at rated maximum voltage. Breakers of 4.76 kV through 38.0 kV have a voltage range factor greater than 1.0, which permits operation at lower than rated voltage and a maximum interrupting current of K times rated interrupting current as described above. Table 2 shows a rated maximum voltage related to an interrupting kA, RMS rating.

For example, a circuit breaker rated 18 kA interrupting capacity, maximum operating voltage 15.0 kV, voltage range factor K = 1.30.

Calculate maximum interrupting current,

$I = 18 * 1.3 = 23$ kA.

Lower operating voltage limit,

$E = 15 / 1.3 = 11.5$ kV.

The rated dielectric strength of a circuit breaker is its voltage withstand capability with specified magnitudes and waveshapes of test voltage applied under specific test conditions. The schedule of dielectric tests for power circuit breakers includes values for low frequency and impulse. These values are fixed and are related directly to rated maximum voltage of breakers. Dielectric test values for outdoor AC high-voltage power circuit breakers are shown Table 1.

Table 1
Preferred Dielectric Withstand Ratings and External Insulation

Rated Max Voltage (kV, RMS)	Power Frequency 1 min. Dry (kV, RMS)	Power Frequency 10 secs Wet (kV, RMS)	Impluse Test 1.2x50 usec Wave: Full Wave Withstand (kV, Peak)	Impluse Test 1.2x50 usec Wave: Chopped Wave Min Time to Sparkover 2 usec Withstand	Impluse Test 1.2x50 usec Wave: Chopped Wave Min Time to Sparkover 3 usec Withstand	Switching Impulse: Withstand Voltage Term to Grd with Breaker closed (kV, RMS)	Switching Impulse: Withstand Voltage Term-Term On one phase with Breaker Open (kV, RMS)	Min Creepage Distance of Ext. Insulationn to Grd. (in)
4.76	19	n/a	60	n/a	n/a	n/a	n/a	n/a
8.25	36	n/a	95	n/a	n/a	n/a	n/a	n/a
15.0 15.0	36 50	n/a 45	95 110	n/a 142	n/a 126	n/a	n/a	n/a 9
25.8 25.8	60 60	50 50	150 125	194 n/a	172 n/a	n/a	n/a	15 15
27.0	60	n/a	125	n/a	n/a	n/a	n/a	n/a
38.0 38.0 38.0	80 80 80	n/a 75 75	150 200 150	n/a 258 n/a	n/a 230 n/a	n/a	n/a	n/a 22 22
48.3	106	95	250	322	288	n/a	n/a	28
72.5	160	140	350	452	402	n/a	n/a	42
123	260	230	550	710	632	n/a	n/a	70
145	310	275	650	838	748	n/a	n/a	84
170	365	315	750	968	862	n/a	n/a	93
245	425	350	900	1160	1040	n/a	n/a	140
362	555	n/a	1300	1680	1500	825	900	209
550	860	n/a	1800	2320	2070	1175	1300	318
800	960	n/a	2050	2640	2360	1425	1500	442

Current

Current characteristics are defined as follows. The *rated continuous current* of a circuit breaker is the designated limit of current in RMS amperes at rated frequency that it is required to carry continuously without exceeding design limitations. (Refer to Tables 2 and 3.)

Table 2
Preferred Ratings for Circuit Breakers
(72.5 kV and Below, Outdoor)

Voltage Class (kV, RMS)	Rating Factor (K)	Current Rating (A, RMS)	Short Circuit Current (kA, RMS)	Transient Recovery Voltage		Rated Interrupt Time (ms)	Trip Delay (Y, sec)	Rated Latching Current (kA, Peak)
				Peak Voltage (E_2 kV, Peak)	Time to Peak (T_2 usec)			
15.5	1.0	600 1200	12.5	29	36	83	2	33
15.5	1.0	1200 2000	20.0	29	36	83	2	52
15.5	1.0	1200 2000	25.0	29	36	83	2	65
15.5	1.0	1200 2000 3000	40.0	29	36	83	2	104
25.8	1.0	1200 2000	12.5	48.5	52	83	2	33
25.8	1.0	1200 2000	25.0	48.5	52	83	2	65
38.0	1.0	1200 2000	16.	71	63	83	2	42
38.0	1.0	1200 2000	20.0	71	63	83	2	52
38.0	1.0	1200 2000	25.0	71	63	83	2	65
38.0	1.0	1200 2000	31.5	71	63	83	2	82
38.0	1.0	1200 2000 3000	40.0	71	63	83	2	104
48.3	1.0	1200 2000	20.0	91	80	83	2	52
48.3	1.0	1200 2000	31.5	91	80	83	2	82
48.3	1.0	1200 2000 3000	40.0	91	80	83	2	104
72.5	1.0	1200 2000	20.0	136	106	83	2	52
72.5	1.0	1200 2000	31.5	136	106	83	2	82
72.5	1.0	1200 2000 3000	40.0	136	106	83	2	104

Table 3

Preferred Ratings for Circuit Breakers

(121 kV to 550 kV, Outdoor)

Voltage Class (kV, RMS)	Rating Factor (K)	Current Rating (A, RMS)	Short Circuit Current (kA, RMS)	Transient Recovery Voltage: Time to Peak (T2 usec)	Transient Recovery Voltage: Rated Rate R (kV/usec)	Transient Recovery Voltage: Rated Time Delay T1 (usec)	Rated Interrupt Time (ms)	Trip Delay (Y, sec)	Rated Latching Current (kA, Peak)
123	1.0	1200	20	275	2	1.7	50	1	52
123	1.0	1600 2000 3000	40	260	2	1.8	50	1	104
123	1.0	2000 3000	63	260	2	1.8	50	1	164
145	1.0	1200	20	330	2	1.7	50	1	52
145	1.0	1600 2000 3000	40	310	2	1.8	50	1	104
145	1.0	2000 3000	63	310	2	1.8	50	1	164
145	1.0	2000 3000	80	310	2	1.8	50	1	208
170	1.0	1200	16	395	2	1.7	50	1	42
170	1.0	1600	31.5	360	2	1.8	50	1	82
170	1.0	2000	40	360	2	1.8	50	1	104
170	1.0	2000	50	360	2	1.8	50	1	130
170	1.0	2000	63	360	2	1.8	50	1	164
245	1.0	1600 2000 3000	31.5	520	2	1.8	50	1	82
245	1.0	2000 3000	40	520	2	1.8	50	1	104
245	1.0	2000	50	520	2	1.8	50	1	130
245	1.0	2000 3000	63	520	2	1.8	50	1	164
362	1.0	2000 3000	40	775	2	1.8	33	1	104
362	1.0	2000	63	775	2	1.8	33	1	164
550	1.0	2000 3000	40	1325	2	1.6	33	1	104
550	1.0	3000	63	1325	2	1.6	33	1	164

The following notes are applicable to Tables 2 and 3.

For service conditions, definitions, interpretations of ratings, tests, and qualifying terms, see ANSI/IEEE Std. C37.04, ANSI Std. 37.06.01, ANSI/IEEE Std. C37.09, and ANSI/IEEE Std. C37.100. The preferred ratings are for 60-Hz systems. Applications at other system frequencies should receive special considerations. Current values have generally been rounded off to the nearest kiloampere (kA) except that two significant figures are used for values below 10 kA.

1. The voltage rating is based on ANSI C84.1, where applicable, and is the maximum voltage for which the breaker is designed and the upper limit for operation.

2. Rated closing and latching current (kA, peak) of the circuit breaker is 2.6 times the rated short-circuit current. (If expressed in terms of kA, RMS total current, the equivalent value is 1.55 times rated short-circuit current.)

3. The rated transient recovery voltage envelope is the "one-minus-cosine" (1-cosine) shape.

4. If the source of power to a circuit breaker is a single transformer or a bank of transformers and there are no substantial capacitors or loaded feeders connected to the source side of the circuit breaker, the transient recovery voltage may be more severe than those covered in these tables. T2 values for these applications are being developed.

5. The ratings in this column are the maximum time interval to be expected during a breaker opening operation between the instant of energizing the trip circuit and the interruption of the main circuit on the primary arcing contacts under certain specified conditions. The values may be exceeded under certain conditions as specified in ANSI/IEEE Std. C37.04, sub-clause covering "Rated Interrupting Time."

6. The rated transient recovery voltage envelope is the "exponential-cosine" shape.
   a. E_2 = 1.76 * rated maximum voltage;
   b. E_1 = 1.5/2/3 * rated maximum voltage.

For applications at altitudes higher than 3,300 ft, rated dielectric strength and rated maximum voltage shall be multiplied by an altitude correction factor for voltage, and current shall be multiplied by an altitude correction factor for current to obtain values at which applications may be made. See Table 4 for altitude correction factors.

Table 4 Altitude Correction Factors Voltage & Currrent		
Altitude	**Voltage ACF**	**Current ACF**
3,300	1.00	1.00
5,000	0.95	0.99
10,000	0.80	0.96

The rated short-circuit current of a circuit breaker is the highest value of the symmetrical component of the polyphase or line-to-line short-circuit current in RMS amperes measured from the envelope of the current wave at the instant of primary arcing contact separation that the circuit breaker is required to interrupt at rated maximum voltage and on the standard operating duty. It also establishes the highest currents that the breaker is required to close and latch against, to carry, and to interrupt. The relationship of rated short-circuit current to the other required capabilities is illustrated in Figure 1.

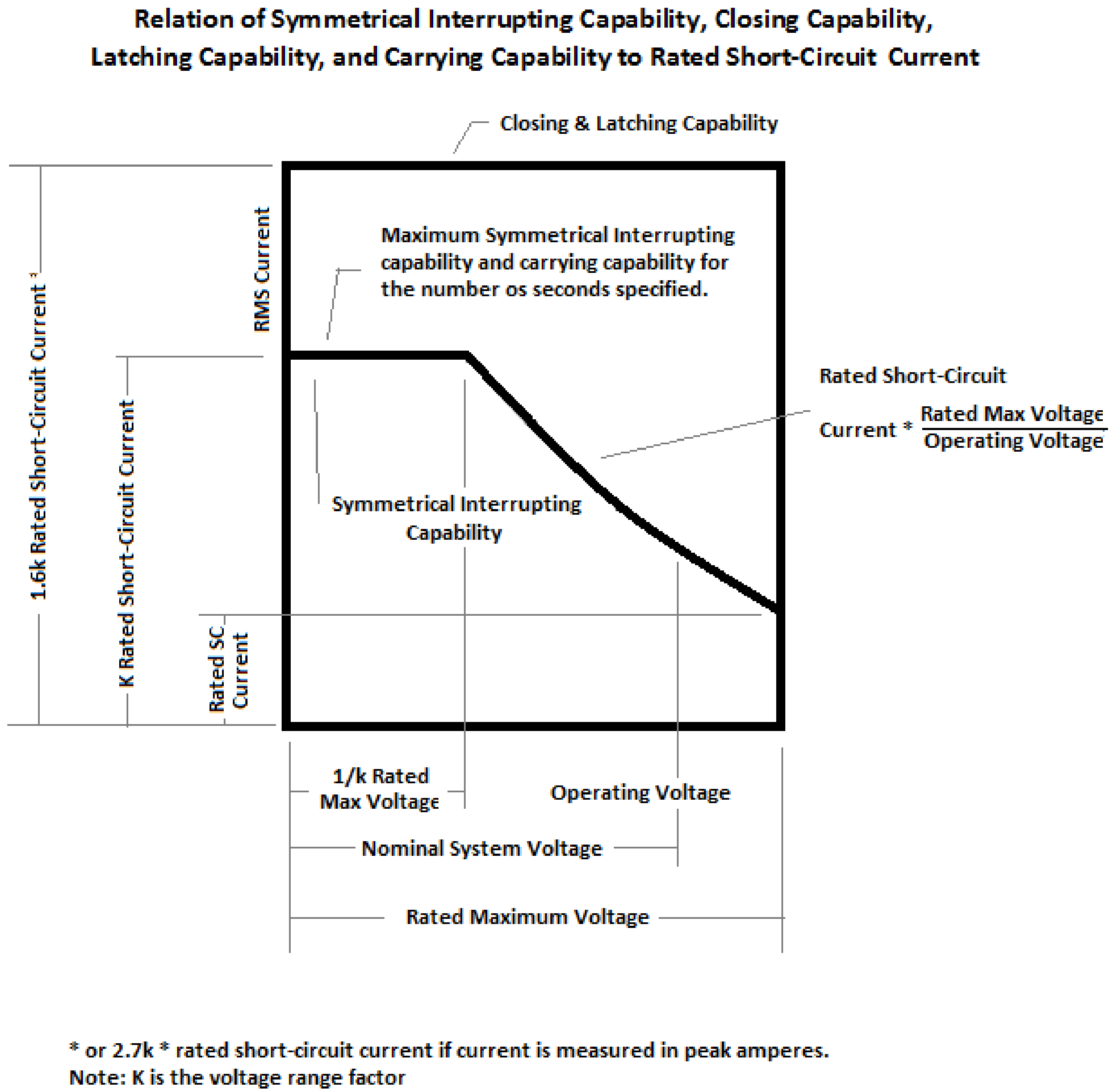

Figure 1

In addition to the current ratings defined above, symmetrically rated circuit breakers have related current capabilities. These related capabilities are essentially as follows:

Maximum symmetrical interrupting capability is K times rated short circuit. These related required capabilities are based on a relay time of one-half cycle, but may be used with any permissible tripping delay.

Required symmetrical interrupting capability of a circuit breaker for polyphase and line-to-line faults is the highest value of the symmetrical component of the short-circuit current in RMS amperes at the instant of primary arcing contact separation that the circuit breaker shall be required to interrupt at a specified operating voltage on the standard operating duty and irrespective of the direct current component of the total short-circuit current. The numerical value at an operating voltage between 1/K times rated maximum voltage and rated maximum voltage shall be determined using,

$$\mathbf{I_{SIC} = I_{SC} * \frac{Maximum\ Voltage}{Operating\ Voltage}}$$

Where,
I_{SIC} = Required Symmetrical Interrupting Capability, amps
I_{SC} = Rated short circuit current, amps

In no case shall the required symmetrical interrupting capability exceed K times rated short-circuit current. Required asymmetrical interrupting capability of a circuit breaker for polyphase and line-to-line faults is the highest value of the total short-circuit current in RMS amperes at the instant of primary arcing contact separation that the breaker shall be required to interrupt at a specified operating voltage and on the standard operating duty. The numerical value shall be equal to the product of a ratio “S”, specified below and illustrated in Figure 1, times the required symmetrical interrupting capability of the breaker determined for the operating voltage. The values of S shall be 1.4, 1.3, 1.2, 1.1, or 1.0 for breakers having primary arcing contact parting times of 1, 1.5, 2, 3, 4, or more cycles, respectively. The values of S for primary arcing contact parting times between those given above shall be determined by linear interpolation. The primary arcing contact parting time shall be considered equal to the sum of one-half cycle (present practical minimum tripping delay) plus the lesser of the actual opening time of the particular breaker, or 1.0, 1.5, 2.5, or 3.5 cycles for breakers having a rated interrupting time of 2, 3, 5, or 8 cycles, respectively.

Required symmetrical and asymmetrical interrupting capability of a circuit breaker for single line-to-ground faults shall be 1.15 times the corresponding values specified for polyphase and line-to-line faults. In no case are the capabilities for single line-to-ground faults required to exceed K times the symmetrical interrupting capability (that is, K times rated short-circuit current) and K times the asymmetrical interrupting capability, respectively, determined at rated maximum voltage.

Three-second short-time capability = K * rated short-circuit current

Closing and latching capability 1.6 K * rated short-circuit capability

Interrupting Time

The rated interrupting time of a circuit breaker is the maximum permissible interval between the energizing of the trip circuit at rated control voltage and the interruption of the main circuit in all poles on an opening operation, when interrupting a current within its interrupting capabilities. At duties below 25 percent of the asymmetrical interrupting capability at rated maximum voltage, the circuit has to be interrupted, but the time required for interruption may be greater than the rated interrupting time by as much as 50 percent for 5- and 8-cycle breakers and 1 cycle for 3-cycle breakers. For breakers equipped with resistors, the interrupting time of the resistor current may be longer. The interrupting time for a close–open operation at a specified duty should not exceed the rated interrupting time by more than 1 cycle for 5- and 8-cycle breakers and one-half cycle for 3-cycle breakers. When time is expressed in cycles, it should be on a 60-hertz basis.

Rated Permissible Tripping Delay

The rated permissible tripping delay of a circuit breaker is "Y" seconds and is the maximum value of time for which the circuit breaker is required to carry "K" times rated short-circuit current after closing on this current and before interrupting.

Other Factors Affecting Rating

The factors noted above form the basis of rating breakers. Other factors that may affect breaker capability include duty cycle, transient recovery voltage, reactive component of load, etc.

In particular, the *duty cycle* of the circuit breaker has to be considered in its application. The duty is the short-circuit current required to be interrupted, closed upon, etc. The cycle is a predetermined sequence of closing and opening operations.

The standard duty cycle to which circuit breaker ratings are related is one closing plus one opening operation, followed by a 15-second waiting period, followed by a second closing and a second opening operation (Note: the sequence is written as, "CO + 15 Sec + CO"). This duty cycle permits application of the circuit breaker at 100 percent of its rating. Numerous other operating cycles and time intervals can be used. If the number of operating cycles is greater and/or the time intervals are shorter than the standard duty cycle, derating of the breaker interrupting capability is necessary.

Operating Mechanisms

The operating mechanism of a circuit breaker has to be designed to ensure positive or definite opening of the circuit breaker, and circuit interruption has to occur whether the tripping or opening signal is received with the circuit breaker fully closed or in any partially closed position. The operating mechanism should also be capable of closing, reclosing and latching closed the circuit breaker when applied to the short-circuit current shown in the rating tables (See Tables 3 and 4).

Operating mechanisms can be provided with or for multiple-pole or independent-pole operation. The term *operation* is intended to cover tripping (opening), closing, and reclosing of the circuit breaker. Most circuit breakers in the United States utilize multiple-pole (three-pole) operation to serve and protect their entire service area by simultaneous opening or closing of their three poles.

Operating mechanisms are designed to have the closing function in a ready-to-close condition upon application of a closing signal. Simultaneous with the closing, the tripping function is placed in a ready-to-trip condition by electrical, mechanical, or both electrical and mechanical facilities in the operating mechanism. At the end of the previous closing operation, the closing function is again placed in a ready-to-close condition. This interaction of closing and tripping facilities permits any planned number of sequential closing and tripping actions to be performed.

The operating mechanism has to perform one complete closing operation including automatic cutoff of the closing power circuit after the initiating control device has been operated either manually or automatically and the first seal-in device in the control scheme has responded, even though the contacts of the initiating control device might be opened before the closing operation has been completed. Furthermore, a closing operation should not be performed at a control voltage lower than the minimum control voltage at which successful tripping can be performed.

Most circuit breakers use shunt (voltage) trip coils that have to be capable of tripping the circuit breaker when any voltage in the control voltage range is applied, even if the trip coil plunger is away from its normal maximum force position to the extent that it is in contact with the actuating trigger of the tripping system.

Other tripping solenoids include those operated by current from bushing or separate current transformers and those operated by a capacitor trip device discharge into the trip coil. The operating mechanism should incorporate a number of features specifically for maintenance and assembly operations. The mechanism has to have provisions that safeguard maintenance personnel from unintended operation. This is usually accomplished via fuse pullouts, permissive switches, or locking pins. Provisions are required for slowly closing the breaker to align the moving contacts. This is usually accomplished with a separate jacking device purchased with the breaker.

Operating mechanisms should be equipped with operation counters. Compressors should be equipped with elapsed running time meters. These two features are important to an effective maintenance program.

Solenoid Operating Mechanisms

Voltage (AC and DC)-operated solenoids were used almost entirely on all circuit breakers in the past. They were effective but relatively slow compared to present operating methods. They also required a large-capacity power supply (transformer or battery) because of their heavy current (ampere) demand, particularly on large, high-voltage circuit breakers. Solenoids are still used on some smaller circuit breakers where their lower operating power requirements are within available limits. Capacitor trip devices can also be provided to operate the solenoid.

Current-operated solenoids supplied with current from bushing-type or separate current transformers are available on the smaller circuit breakers and, like the capacitor trip devices, they are very useful in isolated areas where a separate operating power supply cannot be justified.

All other types of operating mechanisms (except manual) described below use small control solenoids of AC or DC operation to initiate the major closing operation performed by the pneumatic, hydraulic, or spring mechanisms.

Motor Operating Mechanisms

Motor operation of circuit breakers, like solenoids, was used mostly in the past on small circuit breakers and is still available from some suppliers. The motors can be AC or DC, usually of a high torque and high speed to drive a spring-loaded toggle over dead center and release to provide good closing speed.

Pneumohydraulic

Pneumohydraulic is a coined name for a combination of pneumatic and hydraulic operating mechanism. An air compressor provides high-pressure air (up to several thousand psi) to a cylinder with a piston used to drive hydraulic fluid into a piping system and servomechanism to provide closing and tripping operations when the appropriate control signals are applied.

The pneumohydraulic system is an energy storage system, integral with the circuit breaker, and is required to be of sufficient size to permit at least five complete closing–opening operations at rated short-circuit current, starting at normal working pressure and without replenishment of the compressed air energy store. It provides very high speed closing and tripping. This type of mechanism is normally available, from certain suppliers, on 121 kV and higher rated circuit breakers.

Operating mechanisms are designed for the rated control voltages listed with operational capability throughout the indicated voltage ranges to accommodate variations in source regulation, coupled with low charge levels, as well as high charge levels maintained with floating charges. The maximum voltage is measured at the point of user connection to the circuit breaker with no operating current flowing, and the minimum voltage is measured with maximum operating current flowing.

Pneumatic

Pneumatic operating mechanisms utilize compressed high-pressure air (or other gas) to apply closing and tripping forces directly to the mechanism. A variation of pneumatic operation is pneumatic closing with a tripping spring being compressed during the pneumatic closing operation. The pressure varies widely among suppliers from a few hundred to several thousand psi. Where the pneumatic energy storage is integral with the circuit breakers it has to be of sufficient size to permit at least two complete closing–opening operations at rated short-circuit current starting at normal working pressure and without replenishing the compressed air energy store.

Where the pneumatic energy storage is separate from the circuit breaker, it can be designed to any desired size for any desired combination of operations within the rating structure of the circuit breaker. It can also be utilized to operate (closing and tripping) several circuit breakers in a similar manner. It has almost unlimited flexibility for maintenance and emergency piping, valving, backup compressors, nitrogen bottles, temporary high-pressure hosing, etc.

This type of mechanism is available on most circuit breakers rated 23 kV and higher of the bulk air-blast and closed-cycle gas-blast types.

Motor-Charged Spring

Motor-charged spring operating mechanisms utilize a motor to compress a coil spring that holds this stored energy until a closing signal is received. Then the spring expands to close the circuit breaker and simultaneously to charge or compress a smaller coil spring, which is used to trip the circuit breaker. This trip spring may or may not be concentric with the closing spring, depending on the individual design. The energy storage capability of a motor-compressed spring operating mechanism has to be sufficient for an opening–closing–opening operation at rated short-circuit current, after which the spring-compressing motor should not require more than 10 seconds to compress the closing spring. Longer times are permissible through agreement between the purchaser and the manufacturer. In cases where the desired reclosing scheme depends on motor operation, a DC motor may be specified and supplied from a battery or rectifier. The above-described breaker mechanism provides high-speed closing and tripping. This type of mechanism is available on 2.4 kV through 72.5 kV circuit breakers.

Manual-Charged Spring

Manual-charged spring operating mechanisms have very limited application. They are available only from a few suppliers. Applications where reclosing operation is not required would be suitable for this type of operating mechanism. Compression of the spring to store the closing energy is accomplished by a hand jack that may be portable or integral with the operating mechanism. Energy storage required consists of only one closing and one tripping operation.

Manual Operating Mechanisms

Manual operating mechanisms are only available on small circuit breakers. They utilize a lever-operated toggle mechanism that releases energy from a relatively small spring. They may or may not have tripping capability. If they cannot trip, a backup protective device should be applied.

Tests

Tests performed on circuit breakers can generally be classified as follows:

1. Design tests
2. Production tests
3. Tests after delivery
4. Field tests
5. Conformance tests

These tests are fully described in ANSI/IEEE Std. C37.09, "American Standard Test Procedure for AC High Voltage Circuit Breakers." While a detailed discussion of these tests is beyond the scope of this course, a general outline of the tests involved follows.

1. Design Tests

Design tests consist of the following types of tests:

- Maximum Voltage
- Voltage Range Factor
- Continuous Current-Carrying Rated Frequency Tests
- Dielectric Strength Tests
- Short-Circuit Tests
    - Symmetrical interrupting capability (polyphase and line-to-line)
    - Assymetrical interrupting capability (polyphase and line-to-line)
    - Interrupting capability for single line-to-ground fault
    - Closing, latching, carrying, and interrupting capability
    - Short-time current carrying capability
    - Reclosing capability
- Transient Recovery Voltage
- Standard Operating Duty
- Tripping Delay
- Interrupting Time

- Reclosing Time
- Load Current Switching Capability
    - Low frequency withstand, dry and wet
    - Full wave impulse withstand
    - Impulse voltage test for interrupters and resistors
    - Chopped wave impulse withstand
    - Switching-impulse voltage withstand
- Capacitor Switching
- Rated Line Closing Switching Surge Factor
- Out-of-Phase Switching Current
- Shunt Reactor Switching
- Excitation Current Switching
- Mechanical Life
- Control Voltage Current (Nominal Control Voltage)

2. Production Tests

Production tests are normally made by the manufacturer at the factory as part of the process of producing the circuit breaker. If the breaker is completely assembled prior to shipment, some of the production tests are made after final assembly, but other tests can often be made more effectively on components and subassemblies during or after manufacture.

If the circuit breaker is not completely assembled at the factory prior to shipment, appropriate tests on components should be made to check the quality of workmanship and uniformity of material used and to ensure satisfactory performance when properly assembled at its destination. This performance may be verified by performing tests after delivery.

Production tests and checks include the following:

- Current and Linear Coupler Transformer Tests
- Bushing Tests
- Gas Container Tests (ASME Certification)
- Pressure Tests
- Nameplate Check
- Leakage Tests
- Resistor, Heater, and Coil Check Tests
- Control and Secondary Wiring Check Tests
- Clearance and Mechanical Adjustment Check Tests
- Mechanical Operation Tests
- Timing Tests

- Stored Energy System Tests
- Conductivity of Current Path Test
- Low-Frequency Withstand Voltage Tests on Major Insulation Components
- Low-Frequency Withstand Voltage Tests on Control and Secondary Wiring

3. Tests after Delivery
Tests made by the purchaser after delivery of the circuit breaker to supplement inspection in determining whether the breaker has arrived in good condition may consist of timing tests on closing, opening, and close–open, no-load operations, and low-frequency voltage withstand tests at 75 percent of the rated low-frequency withstand voltage. Polarity and ratio tests on the current transformers are also recommended.

4. Field Tests
Field tests are made on operating systems usually to investigate the performance of circuit breakers under conditions that cannot be duplicated in the factory. They usually supplement factory tests and, therefore, may not provide a complete investigation of the breakers' capabilities. Emphasis is usually placed on performance under the particular conditions for which the tests are made rather than on a broad investigation, and the schedule and instrumentation are adapted accordingly. Field tests may include transient recovery voltage performance, closing together two energized parts of a system operating at different levels of voltage and power factor, switching of full-sized shunt reactors or capacitor banks, contact timing for mechanically linked breaker poles or air supply linked poles where air lines may differ in length, measurement of resistances and voltage sharing or division of opening and pre-insertion resistors, etc.

5. Conformance Tests
Conformance tests are those tests specifically made to demonstrate the conformance of a circuit breaker with ANSI Standards.

Control and Auxiliary Power Requirements

Rated control voltages for power circuit breakers are defined in ANSI Std. C37.06. In addition, it will be necessary to provide auxiliary power at the breaker for use in conjunction with heater elements, compressor motors, compartment lights, etc.

Purchase Evaluation

When evaluating different types of breaker construction for a specific substation, it is important to include the cost of necessary auxiliary equipment such as maintenance jacks, gas handling equipment, oil handling equipment, tank lifters, etc. Environmental considerations of esthetics, noise, and oil spills may also affect the choice of breaker type. Others considerations may include size and weight of the breaker, operating mechanism, lead time, and terms and conditions of the sale.

Shipment and Installation

Immediately upon receipt, breakers should be examined for any damage en route. If damage is evident or indication of rough handling is visible, notify the carrier and the manufacturer promptly. Method of shipment will be dictated by many things including size of the breaker, destination, urgency of delivery, etc. In general, the small- to medium (138 to 230 kV)-size oil breakers will be shipped fully assembled. Most breakers can be shipped either by rail or by truck.

Detailed discussion of assembly and installation of circuit breakers is beyond the scope of this course. However, additional comments can be found in NEMA Std. SG4, “Instructions for the Installation, Operation and Care of Alternating-Current High-Voltage Circuit Breakers.” Manufacturers’ instructions are to be relied upon for the complete and proper installation of the equipment.

Chapter 2
Metal-Clad Switchgear

This chapter deals primarily with metal-clad switchgear for use in distribution substations. Metal-clad switchgear is defined as a type of metal-enclosed power switchgear with a number of necessary characteristics. These characteristics are fully defined in IEEE Std. C37.20.2, "Standard for Metal-Clad and Station-Type Cubicle Switchgear". Briefly, they are as follows:

- The main switching or interrupting device is removable.
- Major components of the primary circuit are enclosed and are separated by grounded metal barriers.
- All live parts are enclosed within grounded metal compartments with automatic shutters to block off energized parts when devices are disconnected.
- The primary bus is covered with insulating material throughout.
- There are mechanical interlocks for safety and proper operation.
- Secondary devices are essentially isolated from primary elements.
- A door to a circuit interrupting device may serve as a control panel or for access to some secondary elements.

Metal-clad switchgear serves the same system function as comparable elements in a conventional open bus-type substation. These elements may include main power switching or interrupting devices, disconnecting switches, buses, instrument and control power transformers, and control and auxiliary devices, as well as other devices.

Metal-clad switchgear is usually applied where appearance, land use, compactness, ease of installation, exiting low-voltage circuits, maintenance in foul weather, or safety require consideration. Its application has become more commonplace to house additional equipment including battery, chargers, low-voltage panels, compact microprocessor relaying, and supervisory control equipment. The outdoor single control house including the switchgear offers a more complete factory-wired and tested assembly. The advent of the "double-high" breaker configuration in the lower voltage and ampacity cases offers lower costs, yet requires specific layouts to avoid joint cubicle-forced maintenance outages. The cost difference between an open substation versus metal-clad switchgear depends on the final installed and operating costs, which will vary by application and site.

The main standards governing metal-clad switchgear are IEEE Std. C37.20.2, “IEEE Standard for Metal-Clad and Station-Type Cubicle Switchgear,” NEMA Std. SG-5, “Standards for Power Switchgear Assemblies,” and Std. SG-6, “Standards for Power Switching Equipment.” The indoor oilless circuit breakers (predominantly equipped with vacuum interrupters and higher voltage SF_6 gas interrupting media) are as applied with metal-clad switchgear and rated in accordance with ANSI Std. C37.06.

Metal Clad Switchgear Types

Metal-clad switchgear is available for both indoor and outdoor installations. The basic switchgear is the same for both types of installations. For outdoor installations, a weatherproof enclosure is provided. Weatherproof enclosures are made in several arrangements:

- Single-cubicle lineup, without an enclosed aisle
- Single line with enclosed aisle
- Double lineup, with a common enclosed center aisle

Any decision as to choice of indoor or outdoor type of switchgear should include a cost analysis. Usually weatherproof enclosures will cost less than indoor units (including the cost of a prefabricated or similar type of building and the additional labor and ancillary costs). Other factors, of course, may influence the decision such as joint use of any building for other purposes.

Metal-clad switchgear sections or cubicles are made for every recognized type of switching scheme, including straight bus (radial circuits), network, sectionalized bus, main and transfer bus, breaker-and-a-half, ring bus, double bus–double breaker, etc. The level of reliable bus configuration depends on the number of bus sections, redundant feeders, transformer sources, and alternative external local and remote switching features. Sections are made or can be adapted for almost any conceivable arrangement of the equipment usually required in circuits for feeders, transformers, generators, motors, reactors, and capacitors. Entrance provisions can be adapted to accommodate overhead through-roof bushings with insulated cable or bare bus bar circuits and non-segregated metal enclosed bus duct. Underground entrances are either by insulated cable through conduit circuits or wireways. Sections are made to accommodate all sorts of auxiliary equipment such as current and potential transformers, station power transformers, fuses, switches, surge arresters, etc.

Switchgear assemblies are also installed in locations that vary as to the degree of access and exposure to the general public. The categories are intended to provide differing degrees of protection to personnel from coming in contact with the enclosed live parts.

Category A: This category provides a degree of protection for unauthorized personnel performing deliberate unauthorized acts on the switchgear lineup.

Category B: This category provides a degree of protection against contact with the live parts by untrained personnel and unauthorized personnel, not subject to the deliberate acts of unauthorized personnel.

Category C: This category provides a degree of protection against contact with the live parts of equipment located within secure areas by authorized personnel.

Ratings

Rated nominal voltage of a switchgear assembly is the value assigned for identification. Standard ratings are 4.16, 7.2, 13.8, 25.0, and 34.5 kV. The 25 kV class circuits are served by either the more costly 34.5 kV class equipment or by some manufacturers' 25 kV class, which has now received ANSI Standards recognition.

Rated maximum voltage is the highest RMS voltage for which the equipment is designed and is the upper limit for operations.

Rated Frequency AC equipment are based on a frequency of 60 Hz.

Rated insulation levels consist of two items: (1) 60 Hz, one-minute withstand voltage, and (2) impulse withstand voltage or BIL. The standard values are shown in Table 5.

Table 5
Metal-Clad Switchgear Rated Insulation Levels

Rated Nominal Voltage (kV RMS)	60 Hz. 1 min. Withstand (kV)	BIL (kV)
4.16	19	60
7.2	36	95

13.8	36	95
25.0	60	125
34.5	80	150

Rated Continuous Current is the maximum current in RMS amperes at rated frequency that can be carried continuously by the primary circuit components, including buses and connections, without causing temperatures in excess of specified limits for any component. The standard ratings for the bus are 1200, 2000, and 3000 amperes. The continuous current ratings of the individual units shall correspond to the ratings of the switching and interrupting devices used.

Rated Short-Time or Momentary Current is the maximum RMS total current that can be carried momentarily without electrical, thermal, or mechanical damage. Standard ratings for a bus and its extensions should be matched to the breaker rated value, which can reach a maximum of 48 kA for 13.8 kV bus application.

Interrupting or switching capability of a particular device such as a circuit breaker, interrupter switch, fuse, etc., used in a switchgear assembly is determined by the rated capabilities of that device as listed in the appropriate standards.

Purchase Considerations

Metal-clad switchgear assemblies (breaker cells) for a particular job are normally purchased as a unit (including the breaker) from a single manufacturer because of the standardization and close coordination required among the various components such as interlocks and connections. The cells can be joined by either the switchgear breaker manufacturer or an OEM (original equipment manufacturer). Specifications can be supplied by a consulting engineer or drafted based on use of the manufacturer's guideline specifications. Any specification for metal-clad switchgear should include the following information or requirements.

The most common configuration is a single bus with a main incoming breaker, a tie breaker, and at least four feeder breakers sized to carry 50 percent of normal load. The tie circuit allows supply from another transformer and external feeder cross ties to allow feeder and main breaker removal for maintenance. The choice should be made based on system operating and reliability requirements and, ultimately, cost. The one-line diagram (somewhat matching the physical arrangement desired) should indicate bus configuration, ratings, nomenclature, and ancillary equipment including auxiliary transformers, instrument transformers, surge arresters, number of conductors per circuit, and entry means.

Anything affecting the circuit breaker requirements should be mentioned such as ultimate source fault capability, parallel transformer operation and capacity, normal/emergency feeder loading, reclosing duty, operating voltage, capacitor or reactor switching, etc.

The predominant bus material used is copper, since it provides strength and connection advantages over aluminum bus. Standard ratings match the continuous current rating of available circuit breakers. Judicious arrangements of “source” and “load” breakers can result in the lowest bus current requirements. Future expansion should be considered. The bus support and conductor insulation system should be track resistant. The bus insulation should be void free by using either a heat-shrink polymer or fluidized bed-applied epoxy. Indicate the bus configuration, whether 3-wire (with neutral external to the switchgear) or 4-wire (including either reduced or full-size neutral). The neutral bus should not be confused with mandatory copper ground bus used to bond switchgear cubicles and housing to the station ground.

Each transformer should be located on the one-line diagram and its requirements described. The potential transformers are applied in a wye-wye connection with a resulting 120/208 V secondary connection that is used commonly for metering and relay potentials. Current transformers are usually single-ratio type with accuracy ranges from C200 to C400 for most typical applications.

Instrument transformer circuits must be grounded. VT primary and secondary circuits should be separately grounded to avoid the tie between the primary and the secondary if the ground is lost. The CTs and VTs should be grounded at one location on each circuit.

To ensure that the metal-clad switchgear is wired by the manufacturer as desired and sufficient space is provided for all equipment, it is vital to detail the types of relays, control schemes, interlocks, metering, and interconnection features to be incorporated. This usually involves a cubicle-by-cubicle list of materials to be furnished. It may also include schematic diagrams when requirements are complex.

For circuit reliability, usually the switchgear is specified for DC control supply ranging from 48 to 125 volts DC. This control supply may be segmented by molded case breakers, fuse blocks, or fuse blocks with knife switches in several configurations at the cooperative’s choice to provide close, open, and breaker motor-spring charging power. Auxiliary power may be furnished from a fused transformer within the switchgear lineup or externally from a feeder that is not affected by the switchgear outage. The two most popular auxiliary voltages are 240/120 volts AC, 3-wire, single-phase, or 120/208 volts AC, 4-wire, three-phase to supply lighting, transformer fan, and LTC control, battery charging, and switchgear environmental control. The station battery can be supplied with the switchgear to power the switchgear control supply as well as other station higher voltage breakers.

Standard conditions are for operation in air at nameplate ratings within –30C and +40C and at altitudes not exceeding 3,300 feet. If a battery bank is housed within the switchgear, it is mandatory to supply enclosure environmental control by an air conditioner and resistance heating or a heat pump to keep the battery within its best operating range of from +10C to +26C.

Airborne dust and other contaminants may require additional filters and special paint finishes. Address these site-specific conditions depending on operating experience with other electrical equipment. In most applications, it is necessary to provide either non-switched or thermostatically controlled long-life resistance heaters to prevent condensation on the bus insulation and within the breaker during daily and seasonal atmospheric changes.

With a detailed and physically orientated one-line diagram, the manufacturer can usually submit acceptable arrangements that include cost savings not readily apparent to the cooperative. Plan, elevation, and cross-section sketches help the manufacturer interpret the specifications for any special arrangements and the inclusion of ancillaries.

The Bill of Materials should clearly state all requirements for equipment in each cubicle and include the number of spare breakers and test equipment to be provided, etc. State interface points at incoming bus connections, cable external connectors and insulating material, and enclosure grounding connectors.

Chapter 3
Automatic Circuit Reclosers

This chapter covers single- and three-phase alternating-current automatic circuit reclosers.

An automatic circuit recloser is a self-controlled protective device used to interrupt and reclose automatically an alternating-current circuit through a predetermined sequence of opening and reclosing followed by resetting, lockout, or hold closed. A photograph of a three-phase recloser is shown on the right.

Reclosers are installed to provide maximum continuity of service to distribution loads, simply and economically, by removing a permanently faulted circuit from the system or by instant clearing and reclosing on a circuit subjected to a temporary fault caused by lightning, trees, wildlife, or similar causes.

Unlike fuse links, which interrupt either temporary or permanent faults indiscriminately, reclosers are able to distinguish between the two types of faults, permanent and temporary. They give temporary faults repeated chances to clear or to be cleared by a subordinate protective device. If the fault is not cleared, the recloser recognizes the fault as permanent and operates to lock out or, in some applications, hold closed.

Automatic circuit reclosers are used in distribution substations and on branch feeders to protect distribution circuits and to switch them (see Figure 2). Their proper application requires a study of the load and short-circuit characteristics of both the protecting and the protected equipment. This includes high-voltage fuses or other protection in the supply to a substation transformer bank, a circuit breaker or reclosers at the distribution voltage supplying the feeder at the substation, various line reclosers, sectionalizers, line fuses, the wire arc burn-down characteristic at the fault location, ground resistance, etc.

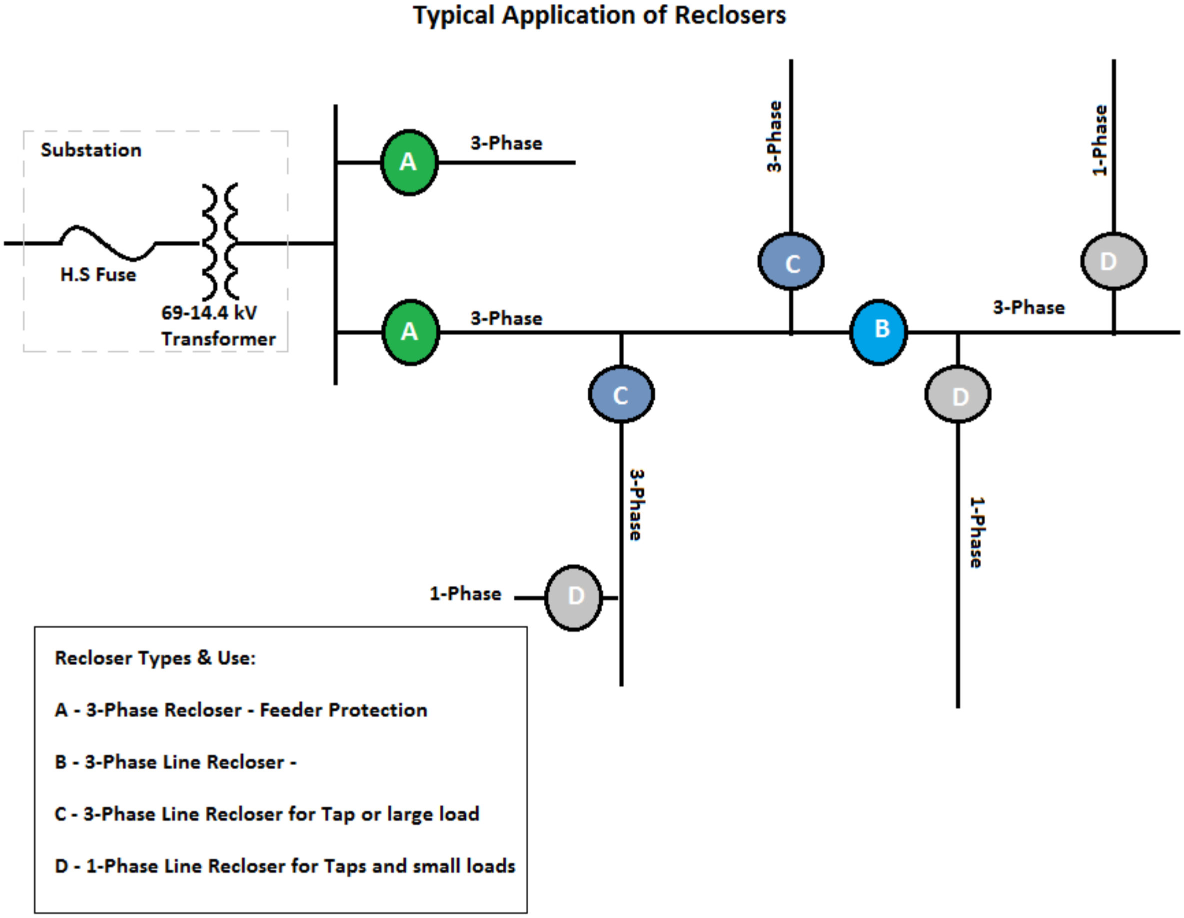

Figure 2

Reclosers are suitable for operation at their standard rating within an ambient temperature range of –30C to +40C and at altitudes not exceeding 3,300 feet. They may be applied at higher or lower temperatures, but performance may be affected and the manufacturer should be consulted regarding special considerations for such applications. They also may be applied at altitudes higher than 3,300 feet, provided that corrections (reductions) are made in impulse insulation level, rated maximum voltage, and rated continuous current. Correction factors (multipliers) are given in Table 6. Reclosers designed for standard temperature rise may be used above an altitude of 3,300 feet at normal current rating without exceeding ultimate standard temperature limits, provided that the ambient temperature does not exceed the maximum +40C limit reduced by the correction.

Table 6 Altitude Correction Factors for Automatic Circuit Reclosers			
Altitude	**Correction Factor (multiplier)**		
	Voltage Rating	**Current Rating**	**Ambient Temperature**
3,300	1.00	1.00	1.00
4,000	0.98	0.99	0.99
5,000	0.95	0.99	0.98
10,000	0.80	0.96	0.92
16,000	0.63	0.93	0.85

The rated interrupting current, current-related required capabilities, and rated interrupting time are not affected by altitude.

Applicable ANSI Standards (listed below) are comprehensive and valuable references when automatic circuit reclosers (ACRs) are being considered.

- ANSI/IEEE C37.60, "Requirements for Automatic Circuit Reclosers for Alternating-Current Systems"
- ANSI C37.61, "Guide for the Application, Operation and Maintenance of Automatic Circuit Reclosers"

Recloser Classifying Features

Single and Three Phase Configurations
Both single- and three-phase reclosers are available to satisfy application requirements.

Single-phase reclosers are used to protect single-phase lines, such as branches or taps of a three-phase feeder. They can also be used on three-phase circuits where the load is predominantly single phase. Thus, when a permanent phase-to-ground fault occurs, one phase can be locked out while service is maintained to the remaining two-thirds of the system.

Three-phase reclosers are used where lockout of all three phases is required for any permanent fault. They are also used to prevent single phasing of three-phase loads, such as large three-phase motors. Three-phase reclosers have two modes of operation.

The first, single-phase trip and three-phase lockout, consists of three single-phase reclosers mounted in a single tank, with mechanical interconnection for lockout only. Each phase operates independently for overcurrent tripping and reclosing. If any phase operates to lockout condition due to a permanent fault, the mechanical linkage trips open the other two phases and locks them open. Thus, extended single-phase energization of three-phase loads is prevented. This type of operation is provided for smaller recloser types.

Larger reclosers make use of the second mode of operation: three-phase trip with three-phase lockout. For any fault—single-phase-to-ground, phase-to-phase, or three-phase—all contacts operate simultaneously for each trip operation. The three phases, mechanically linked together for tripping and reclosing, are operated by a common mechanism.

<u>Control Intelligence</u>

The intelligence that enables a recloser to sense overcurrents, select timing operation, time the tripping and reclosing functions, and finally lock out, is provided by its control. There are two basic types of control schemes used: integral *hydraulic* control or *electronic* control located in a separate cabinet. A recloser employs one of these controls.

Hydraulic recloser control is used in single-phase reclosers and in smaller ratings of three-phase reclosers. It is built as an integral part of the recloser. With this type of control, an overcurrent is sensed by a trip-coil connected in series with the line. When the overcurrent flows through the coil, a plunger is drawn into the coil to trip open the recloser contacts. Timing and sequencing are accomplished by pumping oil through separate hydraulic chambers or ducts.

Electronic recloser control is used with some single-phase reclosers and larger three-phase reclosers. Compared to the hydraulic control, it is more flexible, more easily adjusted, and more accurate. The electronic control, housed in a cabinet separate from the recloser, conveniently permits changing timing, trip current levels, and sequences of recloser operations without de-energizing or untanking the recloser. A wide range of accessories are available from metering capabilities on some models to modifying the basic operation, solving many different application problems.

Line current is sensed by special sensing current transformers in the recloser. The recloser and control are connected by a multiconductor control cable that carries sensing transformer secondary currents to the control and the necessary trip and reclose signals from the control to the recloser. A DC battery either supplies the control or provides backup, ensuring adequate operating power under all fault conditions. Most reclosers require an external AC source either to charge the DC battery or provide control power.

Tripping

Series coil and non-series coil tripping are characteristics of individual classifications of reclosers.

Series coil tripping is used on hydraulically controlled single-phase reclosers and three-phase reclosers. Sensing of fault current is provided by a series-connected solenoid coil (magnetic actuator) that carries its rated line current. When a fault occurs, tripping is initiated by the solenoid plunger. The plunger, normally held at rest by the closing springs, is pulled into the coil and causes overtoggling of trip springs in the operating mechanism that opens the recloser contacts. Tripping simultaneously charges closing springs that then close or reclose the recloser when the proper closing signal is present, thus making the recloser ready for another tripping operation.

Non-series coil tripping is used on some single-phase vacuum reclosers and some three-phase reclosers. It may consist of a tripping solenoid, energized from an external power supply, that over-toggles tripping springs in the same way as performed by the series trip solenoid. It may also consist of a tripping spring simply released by a small tripping solenoid also externally energized. In both cases, the tripping spring is previously charged by a closing solenoid or closing motor during a closing or reclosing operation of the recloser. Other technologies do not utilize spring charging, relying on the solenoid to perform the tripping operation.

Closing

Various methods of closing and reclosing are available, depending on the recloser selected. Spring closing is utilized on most single-phase and some three-phase reclosers. In each case, the closing spring is charged during a previous tripping operation.

Solenoid closing is utilized on some single-phase and some three-phase reclosers. The solenoid coil may be high-voltage AC and connected line to grounded neutral or it may be low-voltage DC energized from a battery. A low-voltage rectifier accessory is also available to permit use of local AC power supply for closing. Some methods utilize solenoid closing to charge the tripping springs in preparation for the next tripping operation.

Motor closing is utilized on some three-phase reclosers. The motor charges the closing springs and forces their overtoggle to close the recloser. The closing spring action simultaneously charges the tripping springs. The motor is energized from an external power supply.

Interrupter Types

The term Type is a manufacturer's designation to identify each particular group or family of reclosers that it produces. It covers the major classifying features and certain rating and performance characteristics.

Reclosers utilize either oil, vacuum, or SF_6 as the interrupting medium. In the past oil interruption was utilized on most single-phase and some three-phase reclosers. Reclosers utilizing oil for current interruption use the same oil for basic insulation. Most reclosers with hydraulic control also use the same oil for timing and counting functions.

Vacuum interruption is now utilized on a most new single-phase and three-phase reclosers. It has the advantages of lower maintenance frequency and minimum external force reaction during interruption. Some vacuum reclosers may utilize oil as the basic insulating medium, depending on the recloser selected.

SF_6 interruption is utilized on some three-phase reclosers. In addition to having the same advantages as vacuum interruption, SF_6 is a better insulating medium than oil or air.

Recloser Ratings

Automatic circuit reclosers are rated in terms of various voltages, frequency, continuous current, minimum tripping current, interrupting current, and making current. In operating a recloser, the limitations imposed by a given recloser rating should not be exceeded in any respect; otherwise, excessive maintenance or unsatisfactory operation may be experienced.

Nominal voltage specifies the nominal system voltage to which the recloser is intended to be applied.

Rated maximum voltage indicates the highest voltage at which the recloser is designed to operate. Voltage ratings of automatic circuit reclosers are shown in Tables 7 and 8. Some reclosers can be operated at system voltages lower than rated voltage. Series coil, hydraulically operated reclosers can be applied at a lower voltage without modification, and in such cases may gain an increase in interrupting current capability. Non-series coil—shunt coil closing, spring tripping—reclosers can be applied at a lower voltage by installing a closing coil of the appropriate system voltage rating. No change is necessary if the closing coil is low voltage and is supplied from an external AC or DC auxiliary power source. Consult manufacturers and their literature for proper application of reclosers at voltages lower than rated voltage.

Rated impulse withstand voltage of reclosers is a performance characteristic specified in ANSI/IEEE Std. C37.60 as a test requirement. This test demonstrates the ability of the recloser to withstand lightning and other fast impulse voltages. The voltage wave is a standard 1.2 x 50 μs wave and may be either positive or negative polarity.

The *rated frequency* of reclosers is 60 Hz. Consult the manufacturer if operation at other frequencies is being considered.

The *rated continuous current* is the magnitude of current in RMS amperes that the recloser is designed to carry continuously. The present continuous current ratings of automatic circuit reclosers are shown Tables 7 and 8. In many cases, the basic continuous current rating of a given recloser is limited by the series trip solenoid coil rating installed in the recloser. Therefore, as load current requirement increases, it is only necessary to replace the solenoid coil with one having a larger rating.

Table 7

Oil Circuit Recloser Ratings

			Low Frequency Insulation Level Withstand Test (kV/RMS)		Current Rating (amps)		Standard Operating Duty Percent of Interrupting Rating						
							15-20		45-55		90-100		
System Voltage (kV/RMS)	Max Voltage (kV/RMS)	Impulse Withstand Voltage (kV, Crest)	1 Min Dry	10 s Wet	Cont 60hz	Sym Inter Rating @ Max Volts	X/R Min	No. Of Unit Ops.	X/R Min	No. Of Unit Ops	X/R Min	No. of Unit Ops	Total No. of Unit Ops.
Single Phase Reclosers													
14.4	15.0	95	35	30	50	1250	2	40	4	40	8	20	100
14.4	15.5	110	50	45	100	2000	2	32	5	24	10	12	68
14.4	15.5	110	50	45	280	4000	3	32	6	20	12	12	64
14.4	15.5	110	50	45	560	10000	4	28	8	20	15	10	58
24.9	27.0	150	60	50	100	2500	2	32	5	24	12	12	68
24.9	27.0	150	60	50	280	4000	3	32	6	20	13	12	64
34.5	38.0	150	70	60	560	8000	4	28	8	20	15	10	58
Three-Phase Reclosers													
14.4	15.0	95	35	30	50	1250	2	40	4	40	8	20	100
14.4	15.5	110	50	45	100	2000	2	32	5	24	10	12	68

14.4	15.5	110	50	45	280	4000	3	32	6	20	12	12	64
14.4	15.5	110	50	45	400	4000	3	32	6	20	12	12	64
14.4	15.5	110	50	45	560	8000	3	28	7	20	14	10	58
14.4	15.5	110	50	45	560	16000	4	16	8	8	16	4	28
14.4	15.5	110	50	45	560	16000	4	28	8	20	16	10	58
14.4	15.5	110	50	45	1120	16000	4	28	8	20	16	10	58
24.9	27.0	150	60	50	100	2500	2	32	5	24	12	12	68
24.9	27.0	150	60	50	560	8000	4	28	8	20	15	10	58
24.9	27.0	150	60	50	1120	8000	4	28	8	20	15	10	58
24.9	27.0	150	60	50	560	12000	4	28	8	20	15	10	58
34.5	38.0	150	70	60	400	6000	4	28	8	24	15	10	62
34.5	38.0	150	70	60	560	16000	4	28	8	20	15	10	58
34.5	38.0	150	70	60	1120	12000	4	28	8	20	15	10	58
46.0	48.3	250	105	95	560	10000	4	28	8	20	15	10	58
69.0	72.5	350	160	140	560	8000	4	28	8	20	16	10	58

Table 8

Vacuum Recloser Ratings

System Voltage (kV/RMS)	Max Voltage (kV/RMS)	Impulse Withstand Voltage (kV, Crest)	Low Frequency Insulation Level Withstand Test (kV/RMS)		Current Rating (amps)		Standard Operating Duty Percent of Interrupting Rating						Total No. of Unit Ops.
							15-20		45-55		90-100		
			1 Min Dry	10 s Wet	Cont 60hz	Sym Inter Rating @ Max Volts	X/R Min	No. Of Unit Ops.	X/R Min	No. Of Unit Ops	X/R Min	No. of Unit Ops	
Single Phase Reclosers													
14.4	15.5	110	50	45	200	2000	2	52	5	68	10	18	138
Three-Phase Reclosers													

14.4	15.5	110	50	45	200	2000	2	52	4	68	10	18	138
14.4	15.5	110	50	45	400	6000	3	48	7	60	14	16	124
14.4	15.5	110	50	45	560	12000	4	44	8	66	15	16	116
14.4	15.5	110	50	45	800	12000	4	44	8	56	15	16	116
14.4	15.5	110	50	45	560	16000	4	44	8	52	16	16	112
14.4	15.5	110	50	45	800	16000	4	44	8	52	16	16	112
14.4	15.5	110	50	45	1120	16000	4	44	8	52	16	16	112
24.9	27.0	125	60	50	560	10000	3	44	7	56	14	16	116
34.5	38.0	150	70	60	560	12000	4	44	8	56	15	16	116

The *rated minimum tripping current* is the minimum current at which a magnetically operated series coil recloser will perform a tripping operation. Standard tripping pickup is 200 percent of the continuous current rating of the recloser coil. Some reclosers are adjustable above or below the standard tripping pickup value.

The minimum tripping current for shunt trip hydraulically controlled reclosers is as described for series reclosers. With electronically controlled reclosers, the minimum trip rating is variable and has no relation to the rated continuous current. Information on specific reclosers should be obtained from the manufacturer.

The differential between minimum trip and continuous current ratings normally provides sufficient margin for load inrush current pickup after an extended outage on a feeder circuit.

The *rated interrupting current* is the maximum RMS symmetrical current that a recloser is designed to interrupt under the standard operating duty, circuit voltage, and specified circuit constants. This rating is stated on the nameplate. It is based on the capability of reclosers to interrupt the corresponding asymmetrical current in circuits having minimum X/R values as given in Tables 7 and 8 with a normal frequency recovery voltage equal to the rated maximum voltage of the recloser.

X/R is the ratio of reactance to resistance of a circuit at rated frequency. The RMS value of asymmetrical fault current at any time after initiation of the fault is dependent upon the instantaneous voltage existing at the moment the fault is initiated and upon the decrement of the direct current component, which is determined by the X/R value of the circuit. Multiplying factors that produce the maximum RMS value of asymmetrical current at one-half cycle corresponding to the rated interrupting current can be found in ANSI/IEEE Std. C37.60-1981

The *rated making current* is the same value as the rated interrupting current, including the corresponding asymmetry. The recloser has to be capable of closing and latching closed against the rated making current and holding closed until a tripping sequence is initiated.

Construction

Most automatic circuit reclosers consist of five major components:

1. Tank,
2. Bushings,
3. Mechanism,
4. Interrupter, and
5. Controls.

1. Tank

The tank is that part of the recloser that houses the interrupter and tripping and closing mechanisms. The tank is usually made of steel and is rectangular for a three-phase recloser and cylindrical for a single-phase recloser. The top is usually an aluminum casting that supports the various components. Some new technologies do not utilize tanks. The interrupter may be enclosed in an epoxy bushing while the operating mechanism is enclosed in a steel housing.

2. Bushings

The bushings are the insulating structures including through-conductors with provision for mounting on the top of the recloser.

3. Operating Mechanism

The operating mechanism of an automatic circuit recloser provides the power to open, close, reclose, lock out, or hold closed the main contacts. The tripping mechanism is the device that releases the holding means and opens the main contacts. In most cases, the opening force is furnished by springs that are charged by the closing mechanism.

The closing mechanism is a solenoid coil, springs, or a motor and gear arrangement. The closing force serves to close the main contacts and at the same time charges the opening springs. The lockout mechanism is the device that locks the main contacts in the open position following the completion of the sequence of operation. The hold-closed mechanism is the device that holds the main contacts in the closed position following the completion of a predetermined sequence of operation. It holds the main contacts closed as long as current flows in excess of a predetermined value. When the current is reduced below this value, the hold-closed mechanism resets to its initial position.

4. Interrupter

The interrupter is that part of the recloser that contains separable contacts that operate within an interrupting unit. The physical configuration and method of interruption vary with manufacturer and recloser classification.

5. Control

Reclosers are provided with sequence control devices and operation integrator to change the recloser from instantaneous operations to time-delay operations and to lock out the recloser after a prescribed number of operations. Individual tripping operations of a recloser can be made to follow instantaneous or time-delay, time–current characteristics. Reclosers are normally set for one of the following sequences of operations:

- Four time-delay operations
- One instantaneous operation followed by three time-delay operations
- Two instantaneous operations followed by two time-delay operations

A number of different sequence control devices may be roughly classed into three types: hydraulic, mechanical, or electronic. In the hydraulic type, an oil pump attached to the recloser plunger raises a trip piston a certain distance with each operation of the recloser. This trip piston establishes the sequence of fast and delayed tripping operations and eventually locks the recloser open. In the mechanical type, the trip piston is mechanically operated by the lift rod one notch at a time to accomplish this sequencing. The electronic type of control utilizes solid-state circuitry to provide the intelligence for performing all the command functions or automatic operation. Consult manufacturers' literature for ratings and available arrangements of electronic components.

Recloser Operation

When an overcurrent of sufficient magnitude flows through the trip coil or sensing current transformers, the tripping action is initiated and the contacts are opened. The recloser contacts then reclose following a predetermined length of time (see Figure 3). By the time the recloser has reassessed the circuit, the sequence control device has moved to count the trip operation. If the fault still persists on the circuit when the recloser closes, the tripping and reclosing sequence is repeated a predetermined number of times, as established by the sequence control device, until the recloser goes to either the lockout or the hold-closed position. If the fault has cleared from the circuit during any open-circuit period, however, the recloser closes and remains closed, and the sequence control device resets so that it is in position for the next sequence of operations (see Figure 4).

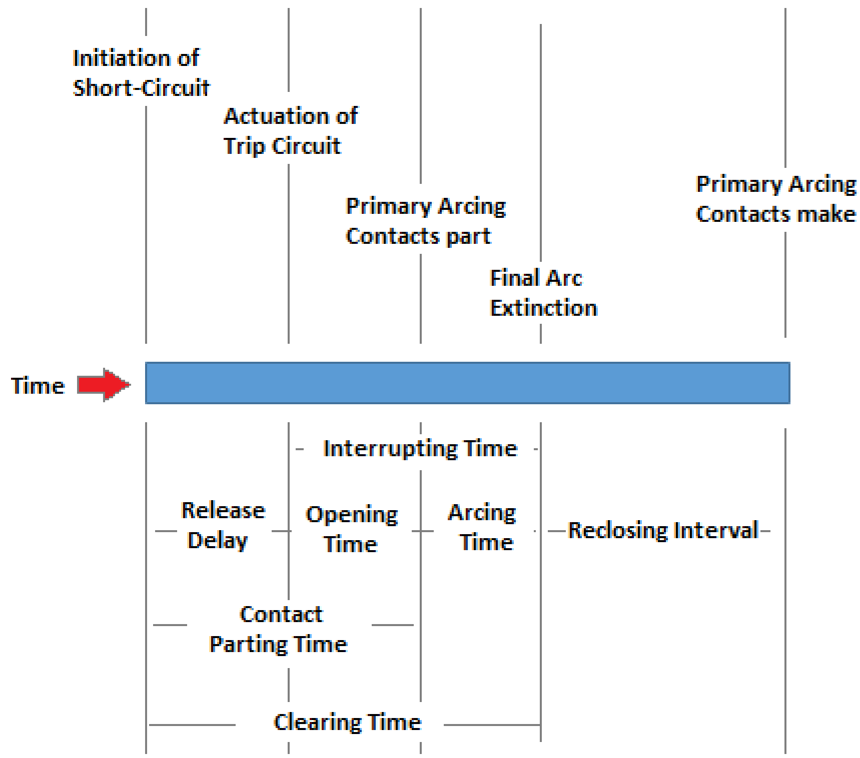

Figure 3

<u>Manual Tripping</u>
An automatic circuit recloser can be tripped manually by moving the manual-operating handle to the trip position by means of a hookstick, or by moving the control switch to the trip position if the recloser is provided with remote control. If the recloser has a non-reclosing lever, the non-reclosing lever should be pulled down as far as it will go in order to cut out the automatic reclosing before the recloser is manually tripped.

<u>Manual Closing</u>
An automatic circuit recloser can be closed manually by moving the manual-operating handle to the close position by means of a hookstick or, if the recloser is provided with remote control, by moving the control switch to the close position. If the recloser has a non-reclosing lever, the non-reclosing lever should be pulled down as far as it will go in order to cut out the automatic reclosing before the recloser is closed manually. After the automatic circuit recloser has been successfully closed, the automatic reclosing should be placed in service.

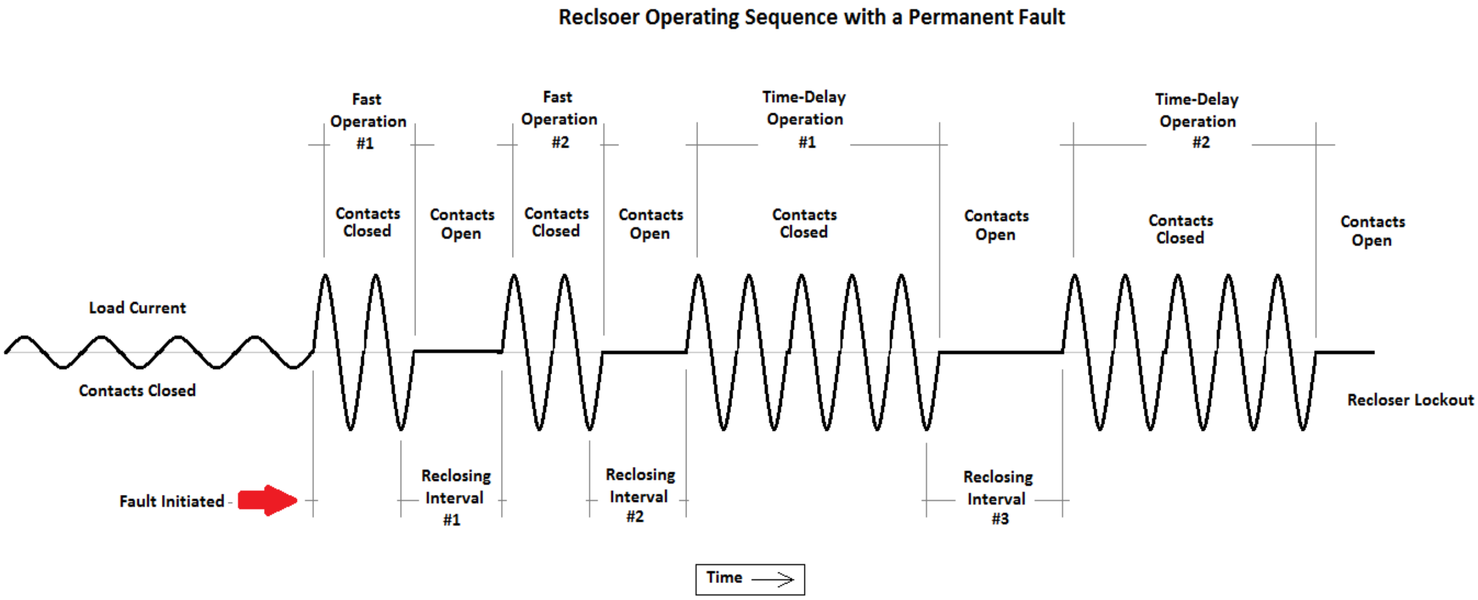

Figure 4

Manual Reclosing After Lockout Operation

Many reclosers in service are designed to lock out following a selected sequence of tripping and automatic reclosing operations. The theory behind this type of application is that, if a fault is temporary, it will be cleared during the instantaneous operation of the recloser. If the fault is permanent, the recloser goes into time-delay tripping operation and permits sectionalizing devices, such as fuses beyond the recloser, to open and isolate the fault. If a permanent fault should occur between the recloser and the next sectionalizing device out on the line, the recloser then goes to lockout and isolates the fault.

When a recloser appears to be locked out, the operator is always faced with the possibility that the recloser itself may have failed. The following procedure is recommended for reclosing of the recloser after a lockout operation. Make a careful visual inspection for evidence of distress such as throwing of oil or damaged bushings.

Close the recloser with a hookstick, keeping the hook in the operating ring momentarily so that the recloser can be opened manually in case local trouble or failure becomes evident. If no local trouble develops and the recloser again locks out after going through its proper sequence, it should not be reclosed again until the entire circuit on the load side to all sectionalizing devices has been patrolled and cleared if necessary.

Manual Reclosing After Hold-Closed Operation

The recloser that is designed for hold-closed operation performs much the same function as the recloser that goes to lockout. It is normally set to trip instantaneously twice to permit a temporary fault to clear. If the fault is permanent, the recloser latches closed to permit the sectionalizing device nearest the fault to operate and isolate the fault. However, a fuse at the recloser opens the circuit when a permanent fault occurs between the hold-closed recloser and the next sectionalizing device out on the line. The fuse in series with the hold-closed recloser is normally installed on the supply side of the recloser so that it also protects against electrical failure in the recloser itself. To reclose a recloser after a hold-closed operation, the following procedure is recommended.

Make a careful visual inspection for evidence of distress such as throwing of oil or damaged bushings. If inspection indicates that everything is in order, the operator should first open the recloser with a hookstick, and then replace the fuse and close the cutout to check the recloser on the supply side. If everything is in order, the operator should open the series cutout and close the recloser; then close the series cutout. If there is no local trouble and service is still not restored, then the load side to all sectionalizing devices should be patrolled to determine the cause of the tripout.

Load Pickup

The inrush current experienced in closing a recloser after a lockout operation may occasionally introduce some difficulties in getting the recloser to latch closed. The highest inrush current can originate from automatic starting motors or magnetizing current of transformers; however, these types of inrush currents are normally short lived (on the order of 3 to 30 cycles). Some makes of reclosers may operate on the instantaneous trip due to this inrush current and may have to open and automatically reclose, until the sequence of operation comes to the time-delay trip, before the recloser will stay closed. Other makes of reclosers, when reclosed after lockout, do not operate on the instantaneous trip but have one time-delay trip operation to lock out, which will normally override the inrush current and pick up the load. A cold-load pickup accessory is available on electronic controls for three-phase reclosers. This accessory temporarily increases the minimum pickup current to a sufficient value (usually double) to override the cold-load inrush current and allow the recloser to latch closed.

Careful observation will indicate whether failure to hold the load is caused by a fault or by heavy overload. Instant and perhaps violent action would indicate a fault, whereas some delay might mean overload due to inrush current. In the latter case, sectionalizing to drop part of the load, rather than a patrol, may be necessary. In any case, if nothing is found on patrol, then sectionalizing is indicated.

Maintenance and Inspection

Before installing a recloser, check for external mechanical damage, oil level, operating sequence as specified, and the record reading on the operation counter. Periodic inspection and maintenance are essential to ensure efficient, trouble-free service of an automatic circuit recloser. Once an automatic circuit recloser is installed, it should be placed on a periodic schedule of test and inspection. Frequency of maintenance should be based on the manufacturer's recommendations, elapsed time in service, and number of operations. Many of the new vacuum technologies do not require the frequency of scheduled maintenance that traditional oil circuit reclosers do. Such test and inspection should cover timing tests and checking of bushings for cracks and of the tank for oil leakage, as well as recording the counter reading. Internal inspection should include contact maintenance or replacement; a check of all gears, linkages, timing devices; test of the oil, etc.

Mounting

Most reclosers, both single- and three-phase, are suitable for mounting on poles and substation structures. Single-phase reclosers can be mounted singularly or in clusters. Three-phase reclosers have mounting frames that are suitable for base mounting, pad-mount enclosure installation, or modification for pole or substation structure mounting.

Summary

This course has reviewed the most common types of interrupting equipment used in substations, namely circuit breakers, metal-clad switchgear, and reclosers. These devices may use different interrupting mediums such as air, oil, vacuum, or SF_6 and they may have different interrupting capabilities and characteristics. However, they all have the same intended purpose which is to safely interrupt the flow of current in a substation.

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