Abstract - This paper summarizes the methods that are typically used in industry to evaluate the service-life of low-voltage power circuit breakers and molded-case circuit breakers. It reviews the electrical ratings and endurance requirements set forth in manufacturing standards, the ways that these endurance requirements can be used to develop expectations of circuit breaker life, the methods of maintenance inspections and the interpretations of these inspections.

Index Terms - Low-voltage power circuit breakers, molded-case circuit breakers, circuit breaker maintenance.

I. INTRODUCTION
Manufacturing standards for low-voltage power circuit breakers and molded-case circuit breakers are created primarily for the purpose of setting performance criteria of manufactured products. These performance criteria can also help users anticipate the need for refurbishment or replacement, especially if a history of significant in-service events, maintenance testing and maintenance inspections has been kept.

II. SWITCHGEAR RATINGS AND ENDURANCE REQUIREMENTS
The four basic electrical ratings for switchgear components and assemblies are:
1. Maximum Voltage Rating or Nominal Voltage Class.
2. Continuous Current Rating.
3. Rated Short-Circuit Current (Circuit Breakers).
4. Short-Circuit Current Ratings (Switchgear Assemblies).

A. Maximum Voltage Rating or Nominal Voltage Class
Low-voltage power circuit breakers are marked with the maximum system voltage at which they can be applied. Standard maximum voltage ratings are 635 volts, 508 volts, and 254 volts. A low-voltage breaker can be used in a circuit that has a nominal voltage rating less than the breaker's maximum voltage rating. For example, a 635-volt rated circuit breaker can be applied in a 208, 240, 480, or 600 volt rated circuit. For fused breakers, the 635-volt maximum voltage rating becomes 600 volts to match the voltage rating of the fuses.

B. Continuous Current Rating
The continuous current rating of a circuit breaker, isolator switch, load-break switch, switchgear assembly, or motor control center is the number of amperes that the device can carry continuously without the temperature of any insulation component becoming greater than its rated temperature. For low-voltage power circuit breakers and molded-case circuit breakers, the continuous current rating of the breaker's frame is called the frame size. For any low-voltage power circuit breaker that can accept a replaceable trip device, installation of a trip device that has a continuous current rating that is less than the frame size reduces the continuous rating of the circuit breaker. It is not permissible to install a trip device that has a continuous current rating that is greater than the breaker's frame size.

C. Rated Short-Circuit Current (Circuit Breakers)
A low-voltage circuit breaker has one or more rated short circuit-current values, often called interrupting ratings or interrupting capabilities. These interrupting ratings are the maximum values of available (prospective) currents at which the breaker is able to perform its short-circuit current duty cycle at different maximum voltage values. Available current is defined in manufacturing standards as the expected root-mean-square (rms) symmetrical value of current at a time ½ cycle after short circuit initiation. Note: The short circuit duty cycle is a specific test that is performed on a prototype model of a circuit breaker. A detailed explanation of this test can be found in ANSI/IEEE standard C37.

Table I is an example of the information concerning interrupting capabilities that might appear in a manufacturer's instruction book. Every different model of circuit breaker will have a different set of interrupting current capabilities.

<table>
<thead>
<tr>
<th>Frame Size (amperes)</th>
<th>Interrupting Ratings (RMS Symmetrical Amperes) With Instantaneous Trip</th>
<th>Short Time Ratings - 30 cycles (With Short-Delay Trip)</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>208-240 V 42,000 30,000 30,000 30,000 50,000 50,000 50,000 50,000 42,000 42,000</td>
<td>208-240 V 30,000 30,000 30,000 42,000 42,000</td>
</tr>
<tr>
<td>1600</td>
<td>65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000</td>
<td>85,000 85,000 85,000 85,000 85,000 85,000</td>
</tr>
<tr>
<td>2000</td>
<td>65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000 65,000</td>
<td>85,000 85,000 85,000 85,000 85,000 85,000</td>
</tr>
<tr>
<td>3200</td>
<td>85,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000</td>
<td>85,000 85,000 85,000 85,000 85,000 85,000</td>
</tr>
<tr>
<td>4000</td>
<td>130,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000 85,000</td>
<td>85,000 85,000 85,000 85,000 85,000 85,000</td>
</tr>
</tbody>
</table>

The interrupting capability of a low-voltage breaker varies with the applied voltage. For example, a 1600 ampere-rated breaker applied at 240 volts might have an interrupting capability of 65 kA at 240 volts, whereas the same breaker applied at 480 volts would have an interrupting capability of 50 kA. The interrupting capability also changes if the breaker's automatic trip device has a short-time trip function rather than an instantaneous trip function. For example, a 4000 ampere-rated circuit breaker that has an instantaneous trip might have an interrupting capability of 130 kA at 240 V, whereas the same breaker equipped with a short-time trip has an interrupting capability of 85 kA at 240 V.

Any low-voltage power circuit breaker that is equipped with current limiting fuses, which are also called current limiters, has a short-circuit current rating equal to 200 kA.

Rated short-circuit current is also influenced by the ability of a circuit breaker to close and latch against, carry, and subsequently interrupt, a fault current. Closing and latching capabilities, sometimes called momentary rating, relate to the breaker’s ability to withstand the mechanical and thermal stress of the first half-cycle of a fault current. Low-voltage power circuit breakers and molded case circuit breakers display no nameplate information concerning momentary rating. These types of breakers are traditionally applied according to their interrupting current capability. The reason that momentary ratings do not appear on their nameplates is that very few low-voltage power systems are capable of producing fault currents whose asymmetrical value is greater than 1.6 times the symmetrical value. For those few systems that have a greater asymmetrical value, a circuit breaker of higher interrupting current rating is applied.

Note: ANSI/IEEE C37.04-1997 [1] explains the way that the required symmetrical interrupting capability, required asymmetrical interrupting capability, required interrupting capability for single line-to-ground faults, required short-time current capability, and required reclosing capability are combined to determine the short-circuit current rating of a circuit breaker.

D. Short-Circuit Current Ratings (Switchgear Assemblies)

A panelboard has a short-circuit current rating shown on its nameplate. A panelboard is not allowed to be applied in any circuit whose available fault current is greater than its short-circuit current rating. The short-circuit current rating of a panelboard is limited to the lowest value of rated short-circuit current for any circuit breaker that is installed within the panelboard. [2]

The short-circuit withstand rating of a motor control center is the average rms current that its busses can carry for two seconds. A motor control center is not allowed to be applied in any circuit whose available fault current is greater than its short-circuit withstand rating.

The rated momentary current of metal-enclosed or metal-clad switchgear represents the maximum rms current that it is required to withstand during a test of 10 cycles duration. This test is conducted on a prototype model.

The rated short-time current of metal-enclosed or metal-clad switchgear is the average rms current that it can carry for a period of two seconds.

E. ANSI/IEEE C37.16 Endurance Requirements

The ANSI/IEEE Standard for Switchgear C37.16-1998 [1] provides requirements for the endurance of low-voltage power circuit breakers and AC power circuit protectors. Although primarily used by manufacturers who have an interest in assuring a durable product, these endurance requirements can also help equipment users to anticipate the need for maintenance or replacement.

In order to verify that a particular design of circuit breaker meets the endurance requirements, a manufacturer performs all endurance tests on a single circuit breaker. Table II appears in the Standard and represents the number of times that the circuit breaker is required to make and subsequently break line currents that are 600% of the breaker's rated continuous current. The test method includes specifications for how much time can elapse between switching operations. The breaker components that are most likely to become worn during this endurance test are arcing tip and arc chutes.

<table>
<thead>
<tr>
<th>Circuit-Breaker Frame Size (amperes)</th>
<th>Number of Make-Break Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Col. 1</td>
</tr>
<tr>
<td>1</td>
<td>225</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
</tr>
<tr>
<td>4</td>
<td>1600</td>
</tr>
<tr>
<td>5</td>
<td>2000</td>
</tr>
<tr>
<td>6</td>
<td>3000</td>
</tr>
<tr>
<td>7</td>
<td>3200</td>
</tr>
<tr>
<td>8</td>
<td>4000</td>
</tr>
</tbody>
</table>

*Not applicable.

Table III also appears in the Standard and represents the number of open-close or close-open operations that the breaker's operating mechanism is required to endure when making and breaking 100% of its rated current (Electrical Endurance) and no current (Mechanical Endurance). The components that are most likely to become worn during this endurance test are latches, cam, rollers, bearings, pins, clamps and threaded hardware. In order to pass this test, adjusting, cleaning, lubricating and tightening are allowed at the intervals shown in column 2. The numbers in this column contain a clear implication that maintenance is required in order to allow a circuit breaker's operating mechanism to realize its full lifetime. When frequent mechanical operations are expected for a circuit breaker application, an operations counter is typically specified as an optional accessory. Motor starting duty or use in an automatic transformer system are the most common examples of applications that will result in frequent operations.
The main contacts should not touch as the stored-energy of the breaker's mechanism discharges. Trip-free operation is verified by attempting to close the interrupters while maintaining a trip signal at the same time. The main contacts should not touch as the stored-energy of the breaker's mechanism discharges.

**TABLE III**

<table>
<thead>
<tr>
<th>Circuit-Breaker No.</th>
<th>Frame Size (amperes)</th>
<th>Number of Make-Break or Close-Open Operations</th>
<th>Electrical Servicing Endurance</th>
<th>Mechanical Servicing Endurance</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Col. 1</td>
<td>Col. 2</td>
<td>Col. 3</td>
<td>Col. 4</td>
<td>Col. 5</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>225</td>
<td>2 500</td>
<td>4 000</td>
<td>10 000</td>
<td>14 000</td>
</tr>
<tr>
<td>2</td>
<td>600</td>
<td>1 750</td>
<td>2 800</td>
<td>9 700</td>
<td>12 500</td>
</tr>
<tr>
<td>3</td>
<td>800</td>
<td>1 750</td>
<td>2 800</td>
<td>9 700</td>
<td>12 500</td>
</tr>
<tr>
<td>4</td>
<td>1 600</td>
<td>500</td>
<td>800</td>
<td>3 200</td>
<td>4 000</td>
</tr>
<tr>
<td>5</td>
<td>2 000</td>
<td>500</td>
<td>800</td>
<td>3 200</td>
<td>4 000</td>
</tr>
<tr>
<td>6</td>
<td>3 000</td>
<td>250</td>
<td>400</td>
<td>1 100</td>
<td>1 500</td>
</tr>
<tr>
<td>7</td>
<td>3 200</td>
<td>250</td>
<td>400</td>
<td>1 100</td>
<td>1 500</td>
</tr>
<tr>
<td>8</td>
<td>4 000</td>
<td>250</td>
<td>400</td>
<td>1 100</td>
<td>1 500</td>
</tr>
</tbody>
</table>

*Servicing shall consist of adjusting, cleaning, lubricating, and tightening.

Two comments are made in the Appendix section of Standard C37.16 that relate strongly to equipment maintenance:

1. "The circuit breaker should be in a condition to carry its rated continuous current at maximum rated voltage and perform at least one opening operation at rated short-circuit current. After completion of this series of operations, functional part replacement and general servicing may be necessary." [1]

2. "If a fault operation occurs before the completing of the listed operations, servicing may be necessary, depending on previous accumulated duty, fault magnitude, and expected future operation." [1]

The implication for maintenance is that a power circuit breaker is first put into service and during maintenance inspections. A digital low-resistance ohmmeter (DLRO), Ducter, Micro-ohmmeter or a millivoltmeter used with a primary current injection test set can measure primary circuit resistance.

The following faults cause primary circuit resistance to become greater:

1. The loosening of any electrical connection in the primary circuit.
2. A reduction of spring pressure within the fixed main contacts assembly of the interrupter.
3. Chemical contamination, particles of dirt or grit, or oxidation of the surfaces of main contacts.
4. Mechanical damage on the surfaces of main contacts.

A manufacturer's instructional literature sometimes specifies a maximum value of primary circuit resistance for a specific model of circuit breaker. An example of these specifications is given in Fig. 1.

**6.6 PRIMARY CIRCUIT RESISTANCE CHECK**

If desired, the d-c resistance of the primary circuit may be measured as follows: close the breaker, pass at least 100 amps d-c current through the breaker. With a low resistance instrument, measure resistance across the studs on the breaker side of the disconnects for each pole. The resistance should not exceed 60 μΩ, 40 μΩ and 20 μΩ for 1200 amp, 2000 amp and 3000 amp breakers respectively.

Fig. 1: Example of Manufacturer's Recommendation for Primary Circuit Resistance

If no specification is given in a manufacturer's instructional literature, primary circuit resistance readings can be evaluated by comparing readings of the past with present readings to detect a trend. A reading that increases by a factor of two is considered a significant sign of deterioration. Primary circuit resistance measurements are generally made before and after cleaning operations are performed on the main contacts.

**B. Operating Mechanism Inspections**

The operating mechanism of a circuit breaker is typically inspected by:

1. Closing and opening the breaker's interrupters several times to verify consistency of operation.
2. Verifying the trip-free function (when applicable).
3. Adjusting the trip latch overlap (when applicable).
4. Adjusting the spring-release or close latch overlap (when applicable).

Consistency of operation is defined by the mechanism's ability to successfully latch closed and trip open every time a manual or electrical signal is initiated. Trip-free operation is verified by attempting to close the interrupters while maintaining a trip signal at the same time. The main contacts should not touch as the stored-energy of the breaker's mechanism discharges. Note: The trip-free feature is not incorporated into every circuit breaker. Some primary circuit resistance are typically measured before a circuit breaker is first put into service and during maintenance inspections. A digital low-resistance ohmmeter (DLRO), Ducter, Micro-ohmmeter or a millivoltmeter used with a primary current injection test set can measure primary circuit resistance.

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circuit breaker’s main contacts will momentarily touch if a closing signal is initiated at the same time as a tripping signal.

The specific procedure for adjusting trip latch overlap or close latch overlap is different for each model of circuit breaker. If these latches are not correctly adjusted, a circuit breaker might not latch when a close signal is initiated (a rapid close-open action) or might fail to trip when a trip signal is initiated. Note: Not all power circuit breakers have a trip latch or close latch adjustment.

C. Contact Pressure and Alignment Inspections

The manufacturer’s instructional literature usually contains specific procedures of inspecting and adjusting the pressure and alignment of the main and arcing contact of a power circuit breaker. Pressure inspections do not necessarily involve an actual measurement of force or pressure. More typically, dimensional measurements are specified that assure contact springs are compressed an adequate amount. Additionally, springs are visually inspected to verify that they have a normal color. Discoloration indicates that the metallurgical properties of a spring are compromised.

Alignment checks are typically dimensional measurements that assure sufficient penetration of moving contacts into the areas of fixed contacts. Fig. 2 (c) and Fig. 2(d) illustrate examples of the dimensional checks that are specified in the instructional literature of a low-voltage power circuit breaker.

D. Contact Erosion Inspections

Air circuit breakers and magnetic-air circuit breakers have separately replaceable sets of arcing and main contacts. The arcing contacts are expected to evaporate at a rate that depends on the number of interruptions and the amount of current that is interrupted. For the contacts shown in Fig. 2 (a), dimension A will become smaller and dimension C will become larger as arcing contacts erode. The main contacts are not expected to erode.

Fig. 2 (a): Erosion Inspection

Fig. 2 (b): Erosion Inspection

E. Lubrication of the Mechanism

Almost all power circuit breakers require periodic renewal of lubrication in their operating mechanism. There are four factors that determine the frequency that lubrication should be renewed:

1. The continuous current rating of the circuit breaker
2. The number of close-open operations since the most recent renewal
3. The time since the most recent renewal
4. The circuit breaker’s operational environment

Manufacturing Standard ANSI/IEEE C37.16 establishes endurance requirements for low-voltage power circuit breakers. These requirements relate the minimum number of close-open operations that a breaker must be able to accomplish before requiring service. One of the limiting factors is the need to renew lubrication in a circuit breaker’s mechanism. In general, the greater the continuous current rating of the breaker, the fewer operations before required service. The manufacturer’s instructional literature is allowed to suggest a greater number of operations than the number given in the manufacturing standard. For example, although an 800 ampere-rated circuit breaker is required by the manufacturing standard to endure 500 operations before service is needed, a manufacturer’s instruction book might indicate that an 800 ampere would require renewal of lubrication after 1750 operations.

If a circuit breaker operates only a few times each year, a 500- or 1750-operation count might never happen within the useful life of the breaker. A need to renew lubrication
will, however, develop owing to the fact that lubrication materials deteriorate when exposed to air. This deterioration is accelerated by environmental conditions such as elevated air temperature or the existence of airborne contaminants. No formula exists that can be used to calculate a period of time before renewal of lubrication is needed. Most users establish programs to lubricate critical circuit breakers based on an established time interval. Malfunctions have been attributed to a failure of lubrication for circuit breakers having as little as five years of normal service. The lubrication points that typically require critical attention are a circuit breaker’s trip latch, spring-release latch, and cam-follow roller. In all cases, the manufacturer’s instructional literature should be consulted to determine which components require lubrication.

There is a large variety of materials that are used to lubricate a circuit breaker’s mechanism. More than one type of lubrication material might be used in the same mechanism at different specific points. Additionally, the material that is recommended for renewal of lubrication is sometimes not the same material that was installed at the factory. For example, many models of circuit breakers have molybdenum disulfide in a lithium base installed at the factory, but the breaker’s instruction book recommends light machine oil to be applied to these same lubrication points for maintenance. In all cases, it is important to use the material that is specified in a circuit breaker’s instruction book. Although newer and better lubrication materials become available, circuit breaker manufacturers seldom re-qualify circuit breakers using new lubricants by conducting standard endurance tests after the time of initial introduction for sale.

F. Lubrication of Current-Carrying Components

A manufacturer’s instruction book sometimes recommends renewal of lubrication for specific current-carrying components of a circuit breaker. These components might include:
1. Main contacts
2. Primary-circuit finger clusters
3. Bus studs

Care must be taken when determining which current-carrying components should be lubricated and which should not.

G. Insulation Resistance Tests

Insulation resistance measurements of the primary insulation of a power circuit breaker can be used to detect deterioration such as absorption of moisture, contamination, or thermal aging. There is no practical method for evaluating the condition of this insulation on the basis of a single measurement of megohms. Measurements taken over a period of months or years can reveal a deteriorating trend. A change representing a factor of ten over a period of a year is considered a reason to conduct additional inspections of an insulation system such as visual inspections or applied-potential tests.

Insulation resistance tests are useful just before returning a circuit breaker to its switchgear compartment to confirm that moisture has not condensed on insulation surfaces. A typical criteria for returning a breaker to service is that its insulation resistance is not less than a tenth of the value that has been recorded for previous measurements when the insulation was known to be dry.

H. AC Dielectric Withstand and Low-Frequency Withstand Tests

An AC dielectric withstand test, sometimes called a low-frequency withstand test, an applied potential test, or a high potential test, can be used to detect a gross failure of an insulation component, the presence of a foreign object within an insulation system, or insufficient clearance between conductors. Manufacturer’s literature typically recommends that an AC dielectric withstand test should be conducted on a circuit breaker before initially placing it into service, after repairs, and on a periodic basis as part of a maintenance inspection.

There are several correct methods for conducting a dielectric withstand test. The method outlined in ANSI/IEEE standard C37.50-1989 includes the following basic points of application of a test voltage while the circuit breaker’s main contacts are open: [3]

1. Voltage is applied to all upper and lower primary terminals with respect to the metal parts that are normally grounded.
2. Voltage is applied to all primary terminals with respect to the secondary terminals.
3. Voltage is applied to all upper primary terminals with respect to all lower terminals of the breaker.

For convenience, the requirements of the first two tests described above are satisfied in a single test by first connecting the secondary terminals to the metal parts that are normally grounded.

The following are points of application of a test voltage while the circuit breaker’s main contacts are closed:

1. Voltage is applied to all primary terminals with respect to the metal parts that are normally grounded.
2. Voltage is applied to all primary terminals with respect to the secondary terminals.
3. Voltage is applied to primary terminals of different phase circuits.

Fig. 3 illustrates four hookups that can be used for conducting the withstand tests described above.

Fig. 3 (a): Hookup 1 for Withstand Test
Low-voltage power circuit breakers are tested at the factory using 2,200 volts AC applied for 60 seconds. For maintenance testing, 60% of the factory test voltage or 1320 volts would typically be used. The manufacturer's instructional literature might recommend a different magnitude of voltage.

I. Arc Chute and Interphase Inspection

The arc chutes and interphase barriers of a circuit breaker are inspected visually to detect broken or contaminated components. Broken components are replaced. The contamination that is caused by arc products can be cleaned by various methods such as sand blasting or using a flexible aluminum-oxide coated paper disc. Soot and dust is typically removed with a pressure-regulated jet of air. Note: Some arc chutes contain asbestos components such as rope, cement, or shields. Arc chutes having asbestos components should not be cleaned with a jet of air.

J. Primary Current Injection Tests of Automatic Trip Devices

The correct functioning of the automatic trip devices of low voltage power circuit breakers and molded-case circuit breakers can be tested using primary current injection. Because primary current injection testing is a relatively expensive service, it is usually performed only on circuit breakers that are components of a critical process or engineered safety system. Circuit breakers that have thermal-magnetic or electro-pneumatic tripping devices are more likely to be tested using primary current injection because it is the only means available for verifying their correct functioning. Circuit breakers that have solid-state tripping systems can be tested using secondary current injection, a less expensive procedure. However, because secondary current injection cannot verify the correct functioning of the current sensors of a solid-state trip system, primary current injection is used occasionally to supplement a program of periodic secondary-current testing.

The method of primary current injection testing is to make a programmed sequence of overload and fault-magnitude currents flow in a circuit breaker and measure the periods of time that are required for the trip device to activate. When these tests are performed at a factory or repair facility, current is injected into all three poles of a circuit breaker at the same time. Startup and maintenance tests are performed using a primary current injection test set that is specifically designed to be lighter in weight and more portable than factory test equipment. Consequently, this portable test set has insufficient capacity, in most cases, to inject current into all three interrupters of a circuit breaker simultaneously. Because of this shortcoming and other factors that make field testing generally less accurate than factory testing, single-pole testing of low-voltage circuit breakers is almost universally accepted as a reasonable compromise. A complete description of the methods and interpretation of field testing of molded-case circuit breakers can be found in NEMA standard AB-4. [3]

Fig. 4 is a photograph of a low-voltage power circuit breaker connected to a primary-current injection test set. The test set has a built-in high-current transformer that supplies the simulated overload or fault current. Test sets are built with seven-second current ratings ranging from 500 to 100,000 amperes.
Fig. 4: Primary Current Injection Test Set and Circuit Breaker

K. Secondary Current Injection Tests of Solid-State Trip Devices

Secondary current injection tests are performed for the same reason as primary current injection tests -- to verify the correct functioning of automatic trip devices during startup inspections or maintenance inspections. Secondary current tests can be performed on the solid-state trip devices of low-voltage power circuit breakers or molded-case circuit breakers. Fig. 5 shows an example of a secondary current injection test set.

Fig. 5: Secondary-Current Injection Test Set

L. Using the Self-Test Facilities of Solid-State Trip Devices

Solid-state trip devices and protective relays of recent manufacture contain built-in self-test facilities. Typically, a self-test can be conducted in two different modes:

1. No-trip mode -- The trip functions of the solid-state electronic circuit can be tested, but the trip device will not send a trip signal to the circuit breaker's trip actuator. Because a no-trip test will not cause the circuit breaker interrupters to open, it can be performed while the circuit breaker is carrying load current.

2. Trip mode -- The functions of the solid-state electronic circuit are tested in the same way as in the no-trip mode, but the trip device will send a trip signal to the circuit breaker's trip actuator. Because a trip test will open a circuit breaker, it is typically performed only when a circuit breaker is withdrawn from its compartment and therefore disconnected from the switchgear bus. For a circuit breaker that cannot be withdrawn from its compartment, an interruption of power must be expected.

Self tests are easier to perform and can be performed more frequently. For example, no-trip tests can be performed monthly. A trip test is very useful for troubleshooting a suspected circuit breaker malfunction. Like secondary current injection tests, self-tests do not verify the correct functioning of the trip system's current sensors. Additionally, some of the internal components of the trip device that carry secondary current cannot be functionally tested. For these reasons, self-testing is occasionally supplemented with secondary current injection testing or primary current injection testing.

Many modern solid-state trip devices continually execute a programmed sequence of self-diagnostic checks. Any potential problems that are detected result in a distinguishable change on the display panel of the trip device such as the cessation of the flashing of a status lamp or the appearance of an alpha-numeric fault message. Additionally, the trip device is able to communicate its alarm or fault condition via a built-in relay contact or digital communication system.

M. Functional Tests of the Electric Control

Before installing a new circuit breaker or returning it to service after a maintenance inspection, it should be installed in its test position in its compartment and operated closed and open electrically from as many control devices as practical. Checking the correct functioning of a circuit breaker's electric control verifies the integrity of control wiring, control components, and the source of control power. When a circuit breaker is in its test position in its compartment, closing its interrupters will not connect the associated load circuit with the switchgear's power source circuit. Note: The degree of electrical isolation that is provided by a circuit breaker in its test position does not meet the requirements of 29 CFR 1910 Subpart S that defines a safely de-energized power circuit. For this reason, the functional testing described in this paragraph cannot be performed while people are performing work on electrical equipment that is connected to the breaker's load circuit.

IV. MOLDED-CASE CIRCUIT BREAKER MAINTENANCE

A. Repair or Replacement of Underwriters Laboratory Listed Components

The majority of molded case circuit breakers have labels (paper sticker or silver-white stencil) that identify them as being listed or approved for use in a listed assembly by the Underwriters Laboratory (UL). For listed or approved breakers, the kinds of repairs or component replacements that can be made by the user are limited. The presence of
a paper label that would have to be broken to remove a cover or mounting screw of a breaker is an indication that no components under that label can be replaced or repaired without making the breaker's UL listing or approval void. This UL label is not the same as the factory warranty label that might also be present. A hard putty sealant over any screw head has the same function. The basic set of components that can be replaced by the user typically includes replaceable types of terminals (including lugs), replaceable types of trip devices, and rating plugs. Some manufacturers and independent service organizations offer repair services that include a revalidation of the UL labeling. Molded-case circuit breakers that are not labeled include replaceable types of trip devices, and rating plugs. Some includes replaceable types of terminals (including lugs), components that can be replaced by the user typically any screw head has the same function. The basic set of components that can be replaced by the user typically includes replaceable types of terminals (including lugs), replaceable types of trip devices, and rating plugs. Some manufacturers and independent service organizations offer repair services that include a revalidation of the UL labeling. Molded-case circuit breakers that are not labeled have a greater variety of internal components that can be replaced.

Any component of a UL-listed panelboard or motor starter must be replaced with a component of the same manufacturer and same type.

B. Replacement Circuit Breakers

A replacement circuit breaker is a molded-case circuit breaker that is manufactured specifically to fit into an obsolete style electrical assembly without the need to physically or electrically modify the assembly. It is not permissible to install a replacement circuit breaker into a newly constructed assembly.

C. Replacement of an Automatic Trip Device or Rating Plug

Some molded-case circuit breakers have a replaceable automatic trip device (thermal-magnetic types) or a replaceable rating plug (solid-state types). The ability to replace trip devices provides a flexible system for the application of circuit breakers according to the rules of the National Electrical Code. An additional benefit is the ability to replace an automatic trip device that has become defective. All modern type of molded-case circuit breakers have a system that prevents the installation of a trip device whose continuous-current rating is greater than the continuous-current rating of the breaker's frame.

D. Tightening of Connectors

The compression screws of the terminals (lugs) or bus connectors of a molded-case circuit breaker should be tightened periodically. Any terminal kit of recent manufacture is supplied with a paper label that lists the appropriate lb.-ft. or newton-meter values of torque for each compression screw. This label has an adhesive back and is intended to be affixed onto the inside of the sheet metal cover of the compartment in which the circuit breaker is installed. Note: Compression screws and mounting bolts are not intended to be tightened while a circuit breaker is connected to any source of electrical power.

E. Periodic Exercising

A molded case circuit breaker must be operated open and closed with sufficient frequency to ensure that its main contacts are cleaned by wiping action and that the lubrication materials within its mechanism remain evenly spread. For any circuit breaker that is not operated in its normal service, a periodic open-close exercise should be planned.

F. Primary Current Injection Tests of Automatic Trip Devices

Like low-voltage power circuit breakers, molded-case circuit breakers can be tested using primary current injection. Unlike other circuit breakers, the tolerances for minimum trip current values and trip times that are displayed on the time-current plots provided by the breaker's manufacturer cannot be accurately replicated using field test methods and field text equipment. For this reason, NEMA standards publication number AB-4 can be used as a guide for field testing. The trip times and tolerances that are listed in table IV are from this standard and represent reasonable expectations for field testing.

<table>
<thead>
<tr>
<th>Range of Rated Continuous Current Amperes</th>
<th>Maximum Trip Time in Seconds For Each Maximum Frame Rating*</th>
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<tbody>
<tr>
<td></td>
<td>250V</td>
</tr>
<tr>
<td>0-30</td>
<td>50</td>
</tr>
<tr>
<td>31-50</td>
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<td>140</td>
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<td>101-150</td>
<td>200</td>
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<tr>
<td>2501-5000</td>
<td>--</td>
</tr>
<tr>
<td>6000</td>
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</tbody>
</table>

*For integrally-fused circuit breakers, trip times may be substantially longer if tested with the fuses replaced by solid links (shorting bars).

G. Secondary Current Injection Tests of Solid-State Trip Devices

Molded-case circuit breakers that have solid-state trip devices can be tested by secondary current injection using a test set made specifically for this purpose by the breaker's manufacturer.

V. Conclusions

A history of significant in-service events such as interruptions of fault currents or frequent switching operations, analyzing maintenance inspections to discover deterioration, and a knowledge of the durability requirements set up in manufacturing standards enable a user to evaluate the service life of a circuit breaker. Performing current injection tests of a trip devices and visual inspections of a mechanism enable a user to find
failures before a circuit breaker needs to perform a critical protection action.

VI. REFERENCES

