



SURFACE VEHICLE STANDARD

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Circuit Breakers

RATIONALE

This document has been revised to add 48 V requirements.

1. SCOPE

This SAE Standard defines the test conditions, procedures, and performance requirements for circuit breakers in ratings up to and including 200 A. The document includes automatic reset, modified reset, and manually reset types of circuit breakers for 12 VDC, 24 VDC, and 48 VDC electrical systems. Some circuit breakers may have dual voltage ratings (AC and DC); however, this document evaluates DC performance only.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J1127	Low Voltage Battery Cable
SAE J1128	Low Voltage Primary Cable
SAE J1171	External Ignition Protection of Marine Electrical Devices
SAE J1211	Handbook for Robustness Validation of Automotive Electrical/Electronic Modules
SAE J1428	Marine Circuit Breakers
SAE J1455	Recommended Environmental Practices for Electronic Equipment Design in Heavy-Duty Vehicle Applications

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2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE J554	Electric Fuses (Cartridge Type)
SAE J537	Storage Batteries
SAE J1284	Blade Type Electric Fuses
SAE J1888	High Current Time Lag Electric Fuses
SAE TSB002	Preparation of SAE Technical Reports
TMC RP156A	Electrical Circuit Protection Components

2.2.2 CSA Publications

Available from CSA International, 178 Rexdale Boulevard, Toronto, Ontario, Canada M9W 1R3, Tel: 416-747-4000, www.csa-international.org.

CSA C22.2 No. 14-M1987	Industrial Control Equipment
CSA C22.2 No. 235-M89	Supplementary Protectors

2.2.3 U.S. Government Publications

Copies of these documents are available online at <https://quicksearch.dla.mil>.

MIL-STD-202G	Test Method Standard - Electronic and Electrical Component Parts
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2.2.4 UL Publications

Available from UL, 333 Pfingsten Road, Northbrook, IL 60062-2096, Tel: 847-272-8800, www.ul.com.

U.L. 1077	Standard for Supplementary Protectors for use in Electrical Equipment
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3. DEFINITIONS

3.1 CIRCUIT BREAKERS

Overcurrent protection devices, responsive to electric current and to temperature.

NOTE: There are no implied restrictions on circuit breaker design as to component form or ornamental housing designs provided the circuit breaker exhibits performance characteristics within the scope of this standard. This standard has been developed for use by the ground transportation industry; however, other users of DC circuit protection may find the test and performance requirements of benefit.

3.2 EXTERNALLY MOUNTED CIRCUIT BREAKERS

Self-contained circuit breakers, which are mounted individually or in assemblies via brackets, bus bars, electrical centers, compatible fuse holders, or mechanically in or through panels. Designed for easy replacement.

3.3 INTERNALLY MOUNTED CIRCUIT BREAKERS

Protection sub-assemblies that are integrated with other electrical devices, such as part of a switch with circuit breaker function or in a motor housing to provide overload protection to the motor windings. Replacement will require disassembly of a parent device.

3.4 There are three general classes of circuit breaker, defined as follows:

3.4.1 TYPE 1 - AUTOMATIC RESET

Defined as cycling or continuously self-resetting unit, which is opened by overcurrent. The terms "cycling" and "continuously self-resetting" refer to the functional characteristic in which the reset feature is not dependent upon any deliberate action or intervention by the user or user's application system to initiate the reset of the tripped circuit breaker. These terms do not imply that the trip and reset function can continue unabated without consequence to either the life of the circuit breaker or potentially adverse effects to an electrical system wiring and/or components, if a fault condition persists undetected and uncorrected.

NOTE: Type 1 automatic reset circuit breakers are best utilized in applications that provide for other self-limiting or non-resettable means (such as after a main fuse, main manual reset circuit breaker, or momentary switch). Intermittent electrical short circuit operation, which may be observed during a cycling event on a Type 1 automatic reset circuit breaker after overload or short, could be misinterpreted as loose connections by operators if self-limiting means are not in place, which in turn may lead to delayed service of a fault.

3.4.2 TYPE 2 - MODIFIED RESET

Defined as a device that is opened by overcurrent and remains open as long as a minimum voltage and current is available to the affected circuit (as established in this standard). A sequence of trip and reset cycles may occur prior to achieving the steady-state open condition as defined in the test and performance requirements.

3.4.3 TYPE 3 - MANUAL RESET

Defined as a non-cycling unit that is opened by overcurrent. A manual reset circuit breaker, once opened by overcurrent requires manual actuation of a reset mechanism in order to re-establish continuity.

NOTE: Trip free designation on manual reset circuit breakers as it applies to this standard; it indicates a manual reset circuit breaker in which any forced restriction of the reset mechanism in the operating mode does not prevent cycling under fault current, or causes the circuit breaker to keep passing electrical current in lieu of any form of trip function.

3.4.3.1 TYPE 3 - MANUAL RESET WITH SWITCHABLE FEATURE

Functions as a conventional manual reset circuit breaker as defined in 3.4.3, but also has a mechanism, which when exercised at the discretion of the user, permits opening of the breaker's internal circuit to stop current flow. The breaker is reset to its normal operating condition by the manual reset function, whether tripped unattended by a real fault condition or by the user.

3.4.3.2 TYPE 3 - MANUAL RESET/SWITCH

An integrated switch design that provides both switching function for on-off activations and includes a circuit breaker feature to "toggle" the switch to an off position in the event of overcurrent or short circuit. Reset function is likely to be incorporated into the on/off activating mechanism, permitting reset of the circuit breaker portion of the device.

4. TEST REQUIREMENTS

4.1 Test Equipment, Instrumentation, and Conditions

4.1.1 Power Supplies

4.1.1.1 A current and voltage regulated DC power supply shall be used for all tests, except 4.2.6.

The power supply shall be capable of delivering 14.0 VDC, 28.0 VDC, and 48 VDC during open circuit portion of tests and have sufficient current output capacity to meet highest load requirements. Voltage and current settings shall be accurate to within $\pm 1\%$ of set point. Power transient response shall be such that when a 30% step increase in power is demanded by the load, the transient in the regulation output shall typically recover to within 3% of the final value within 100 ms or better. The power supply shall be operated with controlling circuitry to achieve all necessary test conditions.

NOTE: DC power supplies used for testing could have large storage capacitors in the DC output section. Load switching may induce current spikes, which while brief in duration, may be significant enough to bias test results or affect reset and re-trip activity of circuit breakers (especially more vulnerable lower amperage rated devices). For this reason, it is necessary to buffer the output by placing low resistance power resistors (generally 1 Ω or less) in series with the DC power supply output as part of the overall circuit breaker test circuit. See Figure 1.

4.1.1.2 Storage batteries specified in Table 1 shall be used as the power supply for 4.2.6. Open circuit voltage as specified shall be maintained by a battery charger or power supply with voltage regulated per Table 1 and charging current output restricted per Table 1.

Table 1 - Storage batteries

Current Rating	Voltage Rating	Cold Cranking Amperage (CCA)	Open Circuit Voltage	Maximum Charging Current
0- 50 A	12 V	575 min/ 750 max	14.0 VDC ± 0.5 VDC	30 A
0- 50 A	24 V ⁽¹⁾		28.0 VDC ± 1.0 VDC	30 A
0- 50 A	48 V ⁽²⁾		56.0 VDC ± 2.0 VDC	30 A
\geq 50-200 A	12 V	1100 min/1200 max	14.0 VDC ± 0.5 VDC	100 A
\geq 50-200 A	24 V ⁽¹⁾		28.0 VDC ± 1.0 VDC	100 A
\geq 50-200 A	48 V ⁽²⁾		56.0 VDC ± 2.0 VDC	100 A

⁽¹⁾ Two 12 V batteries connected in series. Single or series battery configuration is discretionary.

⁽²⁾ Four 12V Batteries connected in series. Single or series battery configuration is discretionary.

NOTE: For all tests, it shall be alternatively acceptable for users to utilize storage batteries per 4.1.1.2, battery charger to maintain open circuit voltage requirements per Table 1, and test circuit with resistor load as is shown in Figure 1, except that the power supply is replaced with a storage battery and suitable battery charger. It shall be necessary, however, to ensure that essential control mechanisms and test current adjustability is achieved to attain accuracy and repeatability of testing.

4.1.2 Voltmeter

0 to 58 VDC maximum range, capable of displaying full open circuit voltage with accuracy of $\pm 1\%$.

NOTE: A digital meter having at least 3-1/2 digits readout with an accuracy of $\pm 1\%$ plus 1 digit is recommended for millivolt readings.

4.1.3 Ammeter

Capable of displaying full load current with an accuracy of $\pm 1\%$. A calibrated shunt shall be used in series with the test circuit to minimize circuit resistance (use of an inductive ammeter is permissible in lieu of an ammeter/shunt set-up, provided accuracy and stability of load current reading is demonstrated).

NOTE: A digital voltmeter having at least a 3-1/2 digit readout with an accuracy of $\pm 1\%$ plus 1 digit is recommended for amperage readings when used in conjunction with a millivolt output calibrated shunt.

4.1.4 Digital Oscilloscope

Capable of triggering on and displaying voltage waveforms is recommended to verify instantaneous applied currents during interrupt, endurance, and transient current cycling tests. Used with the millivolt calibrated current shunt.

4.1.5 Current Shunt

Should be rated at approximately twice the applied current, to assure accuracy, and prevent thermal damage to the shunt. The current shunt is used in conjunction with the voltmeter and/or oscilloscope to observe current through the circuit.

4.1.6 High-Voltage Breakdown Tester

Capable of providing 500 VAC rms to 60 Hz, accuracy $\pm 5\%$.

4.1.7 Thermocouple and Meter

0 to 150 °C minimum range, accuracy $\pm 2\%$, maximum thermocouple wire size 0.22 mm² (24 AWG).

NOTE: A digital thermometer with thermocouple input is recommended, with an accuracy of ± 1 °C.

4.1.7.1 Two ambient observations are necessary during test cycles: ambient of test room and ambient of test chamber containing breakers under test.

4.1.7.2 Delta heat rise of terminations shall be calculated during 4.2.1.1 testing (at the tester's discretion).

4.1.8 Oven

Variable controlled temperature oven able to vary temperature at a rate of 1 °C/min and control temperature ± 1 °C of set point accurate to ± 2 °C.

4.1.9 Test Load

Any combination of fixed and/or variable resistor(s) capable of varying circuit load to specified test requirements in conjunction with a power supply. A test circuit by-pass may be employed during circuit set-up. Current through the unit under test shall be monitored and controlled during the test.

4.1.9.1 When performing transient current cycling tests, 12 VDC or 24 VDC automotive lamps (original equipment or aftermarket, sealed beams or halogen bulbs) shall be used in sufficient total wattage and quantity to meet test load requirements of 4.2.5.4. Note: For 48 V systems, this test protocol does not apply.

4.1.9.2 Unless otherwise specified, the test loads required in rating tests shall have a tolerance of $\pm 1.5\%$.

4.1.10 Test Leads

Circuit breakers shall be tested using copper stranded wire sizes listed in Table 2 that conform to wire specifications as found in SAE J1128 or SAE J1127. The wire length shall be 1.22 m (48.0 inches) for all voltages tested and insulation shall be rated 105 °C or above.

Table 2 - Test lead sizes

Rated Current	SAE Wire Size No.	ISO Cable Size
5 to 10 A	#18	0.8 mm ²
>10 to 15 A	#16	1 mm ²
>15 to 20 A	#14	2 mm ²
>20 to 30 A	#12	3 mm ²
>30 to 40 A	#10	5 mm ²
>40 to 50 A	#8	8 mm ²
>50 to 60 A	#6	13 mm ²
>60 to 90 A	#4	19 mm ²
>90 to 120 A	#2	32 mm ²
>120 to 150 A	#0	50 mm ²
>150 to 200 A	#00	62 mm ²

NOTE: ISO metric cable sizes are not exact equivalents to the SAE wire sizes. Tests and requirements in this standard are based on SAE wire. Use of ISO metric cable may require shortening of the test leads from 1.22 m in length for SAE wire to between 500 mm and 1.0 m in length for resistive and thermal compensation.

4.1.10.1 Termination of Test Leads

All test leads shall use standard commercially available terminals; ring terminals for threaded studs or screw type terminals, quick connect terminals for blade type terminations. To avoid secondary heat generation and/or adverse millivolt drop, it is recommended that test lead terminals be crimped and soldered; also, connections to breakers must be repeatable and uniform. Terminals shall be attached to breakers with screw threads to a specified torque value that is generally recommended for the particular thread size. Terminals applied to quick connect blades shall have an established minimum insertion and withdrawal force for test purposes to reduce the chance of marginal connections from fatigued test lead terminal materials (recommended values shall be obtained from the terminal manufacturer). For custom terminations, consult the circuit breaker manufacturer.

4.1.10.2 Transient Cycle and Interrupt Test Cables

Current requirements of 4.2.5 and/or 4.2.6 may not be obtainable using the test leads specified in Table 2 due to cable or test system resistance. In these cases, use a shorter length of cable or next larger gauge cable. Record test configuration in applicable test records. These tests simulate low resistance events, such as damaged conductors near the circuit breaker. They are of sufficiently fast duration that heat sinking effects of the large cable will not adversely affect the test.

4.1.11 Test Enclosure

Provide for a test chamber free of draft and convection air current with a volume of approximately $5.66 \times 10^4 \text{ cm}^3$ (2.0 ft³). Chamber must allow for test lead access, internal chamber temperature monitoring, and indirect venting if needed to assure requirements of 4.1.12 are met.

4.1.12 Ambient Conditions

Environmental conditions have been selected for this document to help assure satisfactory operation under general customer use conditions. Circuit breakers shall be tested in still air at the temperatures indicated and allowed a 30 minute soak without electrical load before testing (and repeated 30 minute soaks for individual breakers that are involved in more than one test condition). Equipment listed in 4.1.11 fulfills the still air requirement. If not otherwise specified, all tests shall be performed at room temperature $23^\circ\text{C} \pm 3^\circ\text{C}$ (68 °F to 79 °F) at a relative humidity (RH) of 45 to 75% (standard condition). If room ambient is unstable or unregulated and an environmental chamber is employed, breakers under test must be isolated from chamber forced air currents. 4.1.11 shall be used within the chamber compartment and temperatures monitored per 4.1.7.1.

NOTE: Breakers stored in environments below 15°C (59 °F) or above 35°C (95 °F) shall be allowed a minimum of 1 hour soak at the specified test temperature prior to initiation of any testing.

4.1.12.1 Test leads and terminations subject to thermal rise from test operations shall be allowed to re-stabilize to ambient conditions before starting a new test. Alternating between multiple sets of leads is suggested.

4.1.13 Mutual Heating of Multiple Samples

Many of the specified tests are typically conducted with multiple samples running simultaneously. Circuit breakers shall be spaced adequately apart in free air to prevent mutual heating. Suggested spacing is 6 inches, minimum.

4.1.14 Heatsinking

Circuit breakers, test blocks, and lead cables shall be isolated from heatsinks, such as metal tables, bracketing, etc., that could remove heat from the test leads or the circuit breaker under test.

4.1.15 Circuit Breaker Polarity

Direct current tends to degrade material from one side of a contact pair. Therefore, circuit breakers that can be installed in either voltage polarity shall be tested in both polarities, equally proportioned during each test. Polarity of each sample shall be recorded in applicable test records and that same polarity shall be applied to an individual circuit breaker throughout its full test sequence.

4.1.15.1 If the circuit breaker is designed for use in only one voltage polarity, that polarity shall be clearly marked on the part, and all tests shall be conducted in that polarity.

4.2 Test Procedures

4.2.1 Current Rating Test Procedures

The circuit breaker shall be electrically connected with a pair of test leads described in 4.1.10 in series with the power supply as described in 4.1.1.1, a voltmeter as described in 4.1.2, a shunt with ammeter as described in 4.1.5, and an appropriate test load as described in 4.1.9 to provide the required current pass through the circuit breaker.

4.2.1.1 Maximum Voltage Drop Test Procedure

With the circuit breaker connected as described in 4.2.1, the circuit breaker shall carry 100% of rated current for 30 minutes, minimum. Voltage drop across the circuit breaker terminals shall be measured while the breaker is passing full rated current and has achieved equilibrium (exhibited by no appreciable increase in voltage drop). For threaded terminals, voltage drop is measured on the terminals at or immediately adjacent to the threaded surface. For blade terminals, voltage drop is measured on the blade, adjacent to the housing. See 4.1.10.3. If equilibrium has not been attained after 30 minutes of continuous operation at 100% of rated current, continue testing until equilibrium has been attained and voltage drop is within acceptable limits, or unit exceeds voltage drop limits and/or trips out.

NOTE: For applications sensitive to heat-rise at the circuit breaker terminations, thermocouple leads may be affixed to the terminations. General practice is to place the thermocouple lead on that portion of the terminal that comes in contact with the wire lead insulation. Benchmark values for delta heat rise (observed thermocouple temperature minus ambient temperature) are 65 °C delta for factory wired terminations and 50 °C delta for field wired terminations, which is based on 90 degree rated wire insulation. Test temperature readings should be compared with the rating of application wire. Results of this testing will assist the user with circuit design and proximity considerations for breaker installation.

4.2.1.2 Overload Trip Rating Test

After a 30 minute ambient temperature soak, reconnect the breaker as described in 4.2.1. Operate at 135% of rated current and record the elapsed time in seconds for the breaker to trip. If breaker has not opened after 30 minutes, discontinue the test. Repeat 30 minute ambient temperature soak, operate at 200% of rated current, and record elapsed time for the breaker to trip. If breaker has not opened after 60 seconds, discontinue the test.

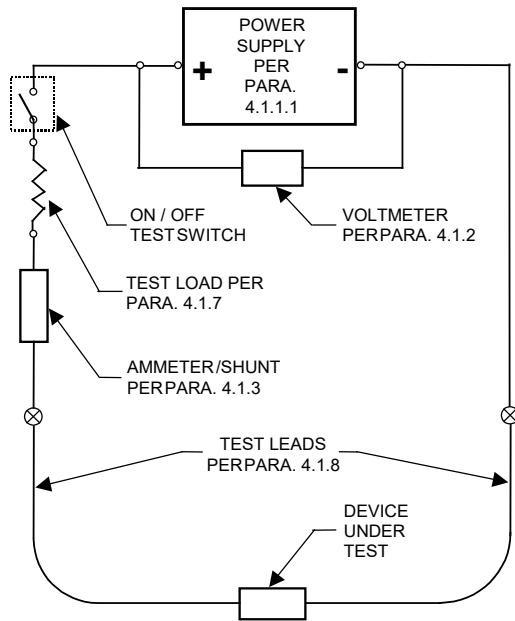


Figure 1 - Current rating test circuit

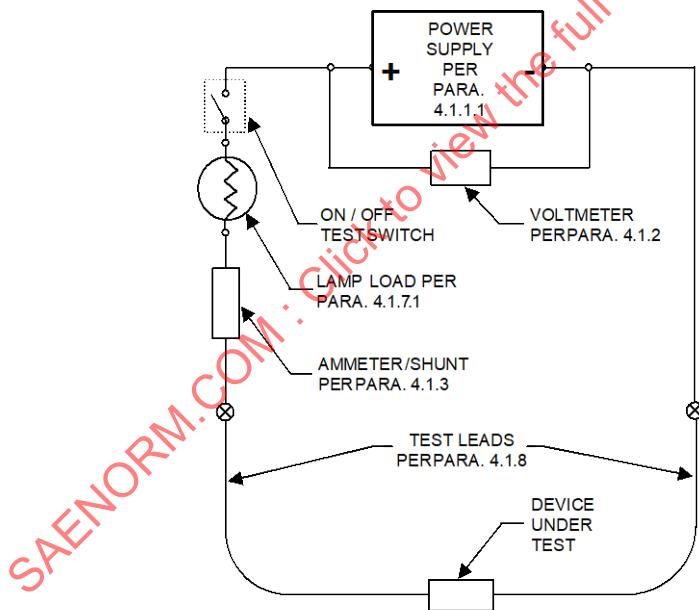


Figure 2 - Transient cycling test circuit

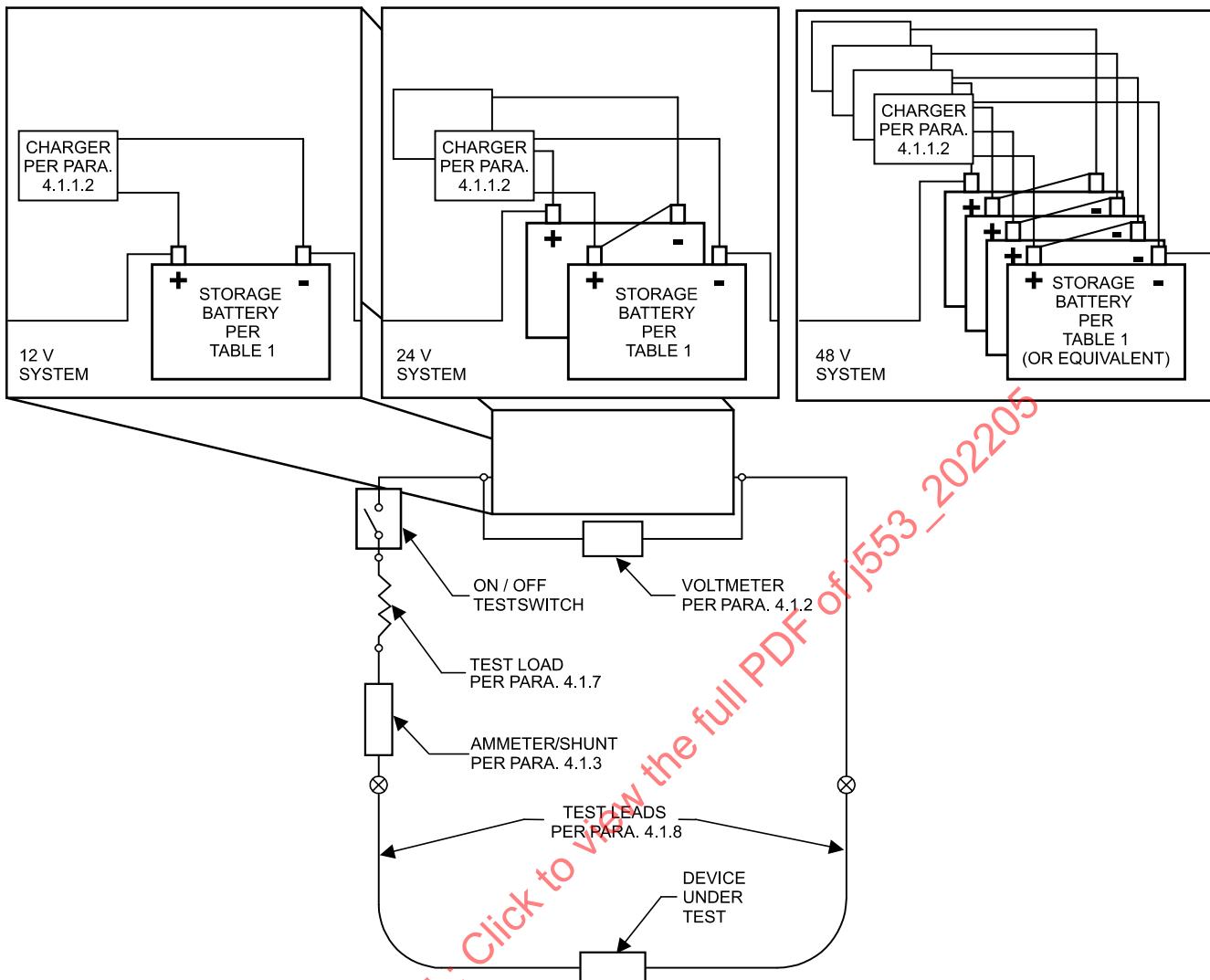


Figure 3 - Interrupt cycling test circuit

NOTE: For a 48 VDC system, the storage battery used for the interrupt cycling test circuit can use either four 12 VDC batteries (described in Table 1) wired in series or a battery pack with equivalent characteristics.

4.2.2 Effective Current Limitation Test Procedure

4.2.2.1 Type 1 Only

With the circuit breaker connected as described in 4.2.1 and test current set at 200% of rated current, allow the breaker to cycle. At the end of 10 minutes (600 seconds), record the total elapsed time (in seconds) during which the breaker passed current. Effective current value is calculated by taking the square root of total time the circuit breaker conducted current during the 600 seconds divided by 600 seconds and then multiplying this square root value times the 200% rating of the circuit breaker tested (e.g., a 10 A circuit breaker conducts current for 210 seconds during the 600 second test interval: $\sqrt{(210 \text{ s}/600)} = \sqrt{0.35} = 0.5916$, $(10 \text{ A} \times 200\%) = 20 \text{ A}$ $(20 \text{ A} \times 0.5916) = 11.83 \text{ A}$ effective current value).

4.2.2.2 Type 2 Only

With the circuit breaker connected as described in 4.2.1 and test current set at 200% of rated current, allow the breaker to cycle. Begin timing the test from when the breaker initially trips and continue application of test current for 1 minute (60 seconds). Count the number of cycles (one trip and one reset equals one cycle) that the breaker passed 200% of rated current. At the end of the 1 minute (60 second) time period, observe if the breaker has stopped cycling and if it is passing a reduced current value. If so, record the reduced current value, expressed either in milliamps or tenths of an amp. If not, continue the cycling at 200% until cycling stops and a reduced current value is displayed for recording, or terminate the test if 5 minutes elapse and the breaker is still cycling. For this particular test, the open circuit voltage must rise to 14.0 VDC \pm 1% VDC for 12 VDC breakers, 28.0 VDC \pm 1% VDC for 24 VDC breakers and 56.0 VDC \pm for 48 VDC breakers and remain stable during reset portions of the cycling, and at the end of the 1 minute (60 second) test duration when the reduced current value is measured (or until 5 minute test termination limit, if necessary).

4.2.2.3 Type 3 Only

Disable the trip indicator/reset mechanism in such a fashion as to allow the breaker to perform as a Type 1 style. Perform the same test instructions as in 4.2.2.1.

NOTE: If the Type 3 breaker is constructed in such a way that depression of the reset button does not allow the thermal element to cycle as if a Type 1 design, but rather trips and resets by definite mechanical action only, then this test is not required.

4.2.3 Voltage Breakdown Test Procedure (Externally Mounted Type 1 and Type 2 Circuit Breakers Only)

4.2.3.1 Connect and cycle the circuit breaker as described in 4.2.5 for 10 minutes. At the end of 10 minutes, check the continuity at 440 VAC between each terminal of the circuit breaker individually and the cover of the breaker with the breaker in both an open and closed circuit condition.

NOTE: This test is not required on devices utilizing nonmetallic, nonconductive covers.

4.2.4 No Current Trip and Reset Temperature Test Procedure

4.2.4.1 Place the circuit breaker(s) in a variable temperature controlled environmental chamber heated to 10 °C below the minimum opening temperature (use 72 °C starting point for 10 A and below rated breakers, and 102 °C starting point for above 10 A rated breakers), and soak at the starting temperature for 30 minutes. Utilize the test enclosure as described in 4.1.11 to shield the breaker(s) under test from environmental chamber convection currents (forced air models). After soak, raise temperature at a rate not exceeding 1 °C/min. When the temperature has exceeded the minimum temperature the breaker(s) must endure without opening, continue elevating the temperature at the same rate of increase and record the temperature at which the breaker(s) opens. A test termination point at 200 °C is suggested. If a breaker under test fails to open by 200 °C, reevaluate performance per 4.2.4.2. Once the breaker has opened (or all breakers have opened if testing in multiples) decrease the temperature at a rate not exceeding 1 °C/min and record the temperature at which the breaker(s) closes.

NOTE: If electrically operated indicators are employed to signal opened and closed states, voltage and current shall be at trace levels, 6 V/100 mA maximum to prevent heating of breaker thermal elements if they are part of the indicator circuit loop, and to prevent operation of Type 2 heating circuits during ambient induced open cycles.

4.2.5 Endurance (Overload) Test Procedure

NOTE: If a power supply (per 4.1.1.1) is used, verify that full voltage is instantaneously applied as the circuit breaker transitions from carry to open mode (contacts are opening). Verification is not required if the storage battery and power resistors configuration (per 4.1.1.2) is used, as the battery cannot supply reduced voltage.

4.2.5.1 Type 1 Circuit Breakers

4.2.5.1.1 Connect the circuit breaker as described in 4.2.1. Type 1 externally mounted circuit breakers shall be cycled for 30 minutes at 400% of rated current. Following the 30 minutes of cycling at 400% of rated current, perform a millivolt drop test in accordance with 4.2.1.1, at 80% of rated current.

4.2.5.1.2 Using the circuit breaker from 4.2.5.1.1 (unless 4.2.5.1.1 requirements were not met), reconnect as described in 4.2.1 and cycle Type 1 circuit breaker at 400% of rated current for an additional 4 hours, after which terminate the test.

4.2.5.2 Type 2 Circuit Breakers

4.2.5.2.1 Connect the circuit breaker as described in 4.2.1. Type 2 circuit breakers shall first be subjected to 30 on-off cycles at 400% of rated current. The "on" time of each cycle shall be 60 seconds, during which time the circuit breaker must open at least once, with repeated cycling possible and open circuit voltage rising to 14.0 VDC for 12 V breakers, 28.0 VDC for 24 V breakers, and 56.0 VDC for 48 V breakers. The "off" time of each cycle shall be long enough to allow the circuit breaker to close by de-energizing the test circuit prior to initiating a subsequent "on" cycle, and no greater than the reset time plus 15 seconds. The "on" time of the 30th cycle shall be 12 hours with voltage reduced to 10.5 V for 12 V breakers, 22.6 V for 24 V breakers, and 36.0 V for 48 V breakers once breakers are in a steady-state open circuit as induced by the heating circuit. During this time, the circuit breaker contacts must remain open. The circuit breaker shall then be allowed to re-close and again be subjected to the 30 cycles test, excluding the 12 hours "on" time of the last cycle. Following the second 30 cycles test at 400% of rated current, perform a millivolt drop test in accordance with 4.2.1.1, at 80% of rated current.

4.2.5.3 Type 3 Circuit Breakers

4.2.5.3.1 Connect the circuit breaker as described in 4.2.1. Type 3 circuit breakers shall be cycled for 100 on-off cycles at 400% of rated current utilizing the trip indicating/reset mechanism of the breaker. Cycle time shall be adjusted to accommodate the reset characteristics of the circuit breaker and to facilitate actuation of the reset mechanism for initiation of repetitive cycles within 15 seconds of becoming ready to reset. Following the 100 on-off cycles, perform a millivolt drop test in accordance with 4.2.1.1, at 80% of rated current.

4.2.5.4 Transient Current Cycling Endurance Test (Optional)

4.2.5.4.1 With the circuit breaker connected as described in 4.2.1 and Figure 2, apply a transient current cycling waveform as shown in Figure 4 through the breaker for 25000 cycles. The lamps employed for the test load as described in 4.1.7.1 shall be sufficient to create a current level of 95 to 100% of the circuit breaker rating. Lamp aging that diminishes load over time is acceptable; however, lamps that fail must be replaced immediately. This test procedure is applicable to all breaker types. Monitor the test circuit for uninterrupted continuity through the circuit breaker.

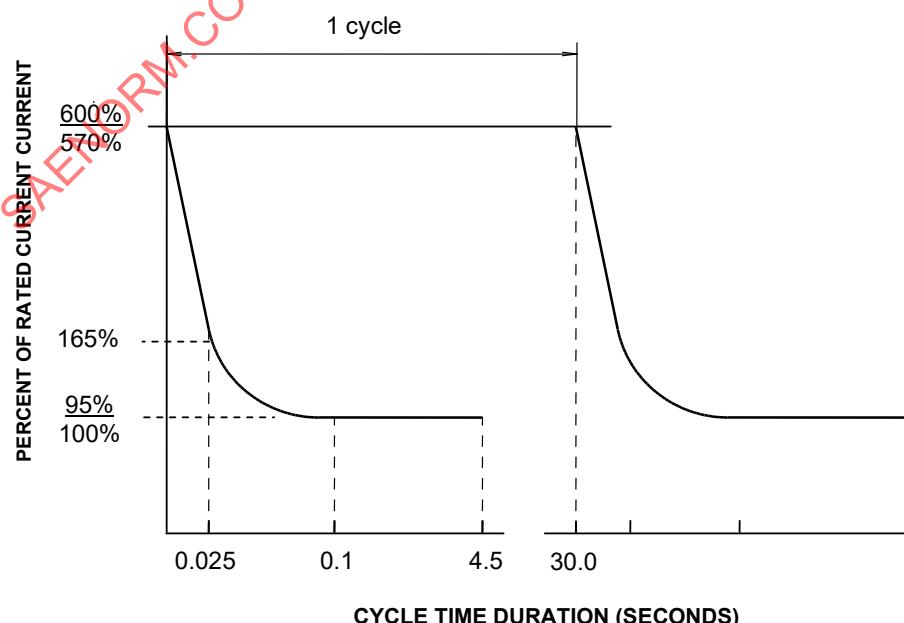


Figure 4 - Transient current cycling waveform

4.2.6 Interrupt Test Procedure

4.2.6.1 Type 1 Circuit Breakers

4.2.6.1.1 With the circuit breaker connected as described in 4.2.1 and Figure 3 (utilizing 4.1.1.2 power source), Type 1 circuit breakers shall be subjected to 1-1/2 cycles of interrupt current at the level specified by Table 3 and in the pattern shown by Figure 5. Following the interrupt cycles, perform a millivolt drop test in accordance with paragraph 4.2.1.1, at 80% of rated current.

4.2.6.1.2 Using the circuit breaker from 4.2.6.1.1 (assuming 4.2.6.1.1 requirements were met), reconnect as described in 4.2.1 and cycle Type 1 breaker until failure as described in 5.7.1.2.1. Monitor current using the oscilloscope and current shunt. As the circuit breaker approaches failure, very short duration, sporadic current events may occur, which indicate that the circuit breaker has not reached its final failure mode. Set the oscilloscope trigger threshold and time span as low as possible. Maintain voltage on the circuit until at least 15 minutes elapse after last transient event.

4.2.6.2 Type 2 Circuit Breakers

4.2.6.2.1 With the circuit breaker connected as described in 4.2.1 and Figure 3 (utilizing 4.1.1.2 power source), Type 2 circuit breakers shall be subjected to 1-1/2 cycles of interrupt current at the level specified by Table 3 and in the pattern shown by Figure 5. If the breaker does not reset after 1/2 cycle due to its normal Type 2 function, terminate the test at that point and proceed with the post-test evaluation. Following interrupt test, perform a millivolt drop test in accordance with 4.2.1.1, at 80% of rated current. Following the millivolt drop test, perform a 200% test in accordance with 4.2.2.2 to evaluate the Type 2 function.

NOTE: There are two possible conditions indicated after the first 1/2 cycle of interrupt current. Type 2 circuit breakers, as part of their operational characteristics, typically employ a heating resistor to bias the thermal element into a tripped condition, which will remain that way until power is removed and the element cools to reset. It is also allowed for some cycling to occur until this condition is achieved (see 4.2.2.2). Depending on how quickly this function enables itself, it is possible that after the first 1/2 cycle of interrupt current, the Type 2 function takes over and the breaker does not permit closure and re-trip to complete 1-1/2 cycles. The post-test evaluation shall be performed after either completion of 1/2 cycle if Type 2 function occurs, or after 1-1/2 cycles, whichever may be the case.

4.2.6.2.2 Using the circuit breaker from 4.2.6.2.1 (assuming 4.2.6.2.1 requirements were met), reconnect as described above and cycle circuit breaker until failure as described in 5.7.1.2.1. Monitor current using the oscilloscope and current shunt. As the circuit breaker approaches failure, very short duration, sporadic current events may occur, which indicate that the circuit breaker has not reached its final failure mode. Set the oscilloscope trigger threshold and time span as low as possible. Maintain voltage on the circuit until at least 15 minutes elapse after last transient event.

4.2.6.3 Type 3 Circuit Breakers

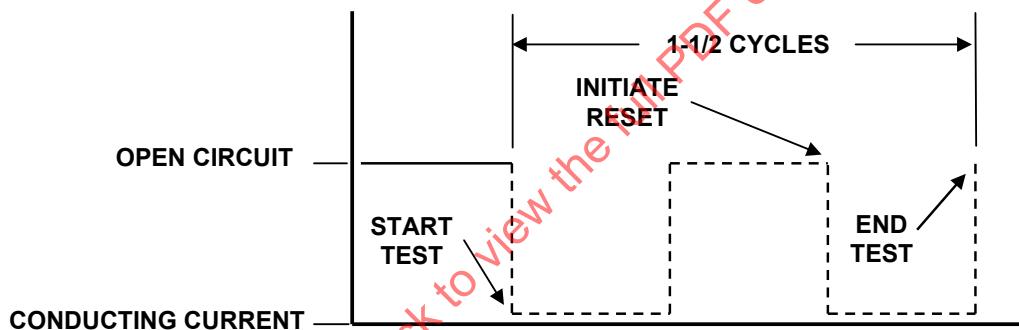
4.2.6.3.1 With the circuit breaker connected as described in 4.2.1 and Figure 3 (utilizing 4.1.1.2 power source), Type 3 circuit breakers shall be subjected to 1-1/2 cycles of interrupt current. Procedure shall be to apply fault current for first 1/2 cycle. The next 1/2 cycle shall consist of allowing the unit to come into the "ready to reset" mode. As soon as reset capability is enabled, the reset mechanism shall be activated to restore the circuit, at which time the last 1/2 cycle of interrupt current will be present. Following interrupt test, perform a millivolt drop test in accordance with 4.2.1.1, at 80% of rated current.

Table 3 - Interrupt test current requirements

Rated Current	12 VDC	24 VDC	48 VDC
5 to 10 A	150 A	100 A	75 A
<10 to 15 A	225 A	150 A	100 A
<15 to 20 A	300 A	200 A	135 A
<20 to 30 A	450 A	300 A	200 A
<30 to 40 A	600 A	400 A	See Note 2
<40 to 50 A	750 A	500 A	See Note 2
>50 to 70 A	900 A	600 A	See Note 2
>70 to 90 A	1200 A	800 A	See Note 2
>90 to 110 A	1500 A	1000 A	See Note 2
>110 to 130 A	1800 A	1200 A	See Note 2
>130 to 150 A	2100 A	1400 A	See Note 2
>150 to 175 A	2500 A	1667 A	See Note 2
>175 to 200 A	3000 A	2000 A	See Note 2

NOTE 1: The instantaneous fault current required and delivered from the storage battery is not the same value represented by cold cranking amps (CCA) as indicated in Table 1. It is the result of the overall test circuit impedance and general condition of the battery being used.

NOTE 2: As agreed between customer and supplier.

**Figure 5 - Interrupt cycle definition**

4.2.7 Insulation Test (Dielectric Strength)

The CB shall be measured in OFF position. Apply a voltage of 100 VDC \pm 5 VDC for 1 minute between the terminals of the circuit breaker in both the off and tripped positions.

NOTE: This test is not applicable to Type 2 circuit breakers.

4.2.8 Environmental Tests

Since end use applications may differ, the following tests are recommended, but not mandatory, to determine general suitability of components. All tests shall follow the guidelines as set forth in SAE J1211 or SAE J1455, unless otherwise specified.

4.2.8.1 Temperature Test

- Motor vehicles: Perform per SAE J1211. Minimum temperature shall be -40°C , maximum temperature shall be 85°C . Cycle per SAE J1211 Figure 2B for a total elapsed time of 96 hours. Following temperature test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.
- Heavy-duty trucks: Perform per SAE J1455. Test as described for temperature cycling, thermal shock, and thermal stress at the specified test temperatures and in accordance with the temperature transition charts. Following temperature test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.

4.2.8.2 Humidity Test

- a. Motor vehicles: Perform per SAE J1211, using the 10 day soak method at 95% relative humidity, temperature at 38 °C. Following humidity test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.
- b. Heavy-duty trucks: Perform per SAE J1455, in accordance with recommended test procedures and environmental conditions. Following humidity test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.

4.2.8.3 Salt Fog Test

- a. Motor vehicles: Perform per SAE J1211. Alternate standard would be MIL-STD-202F, Method 101E, with a 5% salt concentration at 35 °C for an elapsed time of 48 hours minimum. Following salt fog test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.
- b. Heavy-duty trucks: Perform per SAE J1455. Time duration may vary, depending on anticipated location of breaker and potential for exposure to saline solutions. Following salt fog test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.

4.2.8.4 Immersion and Splash Test

For general guidelines, refer to SAE J1211 (motor vehicles) or SAE J1455 (heavy-duty trucks).

NOTE 1: Immersion testing shall apply only to devices that are stated as being "waterproof," "sealed," "watertight," etc. Test procedures per SAE J1171 may be followed for basic test requirements.

NOTE 2: Splash testing shall apply only to devices which are stated as being "splash-proof," "water resistant," "weatherproof," etc. Test procedure in SAE J1428 may be used. Devices passing immersion testing do not require splash testing.

NOTE 3: Chemicals used for testing shall be restricted to water for immersion and splash. Evaluation of external identification marking shall be conducted by splash testing utilizing commonly encountered chemicals which shall include: engine oil, power steering fluid, windshield washer solvent, gasoline, diesel fuel, diesel exhaust fluid, antifreeze, steam, and salt water. Splash testing of additional chemicals may be required by specific customers/contracts. Refer to SAE J1455, 4.4, for additional candidate chemicals.

4.2.8.5 Mechanical Vibration Test

- a. Motor vehicles: Perform per SAE J1211 (random vibration test). Test shall be for 1 hour in each of three mutually perpendicular primary axes using the suggested current practice per SAE J1211. During the last 30 minutes of the test, apply a test load to the circuit breaker under test at 80% of rated current. Continuously monitor the circuit breaker function and observe for any loss of continuity while the 80% load is applied.
- b. Heavy-duty trucks: Perform per SAE J1455 (random vibration test). Test shall be for 1 hour in each of three mutually perpendicular primary axes using the suggested current practice per SAE J1455. During the last 30 minutes of the test, apply a test load to the circuit breaker under test at 80% of rated current. Continuously monitor the circuit breaker function and observe for any loss of continuity while the 80% load is applied.

4.2.8.6 Drop Test

- a. Motor vehicles: Test breakers shall be dropped onto a steel plate 6.35 mm (1/4 inch) thick in one of six different directions along three mutually perpendicular primary axes from a height of $1.0\text{ m} \pm 0.01\text{ m}$. Following drop test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.
- b. Heavy-duty trucks: Perform per SAE J1455. Following drop test, perform a millivolt drop test in accordance with 4.2.1.1, except that test current shall be at 80% of rating.

4.2.8.7 Environmental Extremes Test

- a. Motor vehicles: For reference, refer to SAE J1211. Actual test shall be to soak test breakers at $150^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for 240 hours and at $-40^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for 240 hours without any electrical load.
- b. Heavy-duty trucks: Generally handled in 4.2.7.1.1, but the motor vehicle test as described may be performed if deemed appropriate.

5. PERFORMANCE REQUIREMENTS

5.1 Current Rating

With the circuit breaker connected as described in 4.2.1, all circuit breakers shall pass $100\% \pm 1.5\%$ of rated current continuously for a minimum of 30 minutes, shall open at $135\% \pm 1.5\%$ of rated current within 30 minutes, and shall open at $200\% \pm 1.5\%$ of rated current within 1 minute. Internally mounted circuit breakers (as defined in 3.3) shall pass $80\% \pm 1.5\%$ of rated current at $52^{\circ}\text{C} \pm 2^{\circ}\text{C}$ for 30 minutes without opening.

5.2 Maximum Voltage Drop

Using the procedure described in 4.2.1.1, the maximum voltage drop across the circuit breaker shall be within the limits shown in Figure 6.

NOTE: When performing post-tests at 80% of rating, the maximum millivolt requirement shall be derived from Figure 6 at the 80% adjusted value (e.g., $15 \times 0.80\text{ A} = 12\text{ A}$). For circuit breakers rated greater than 50 A, the maximum voltage shall be within limits provided by the manufacturer.

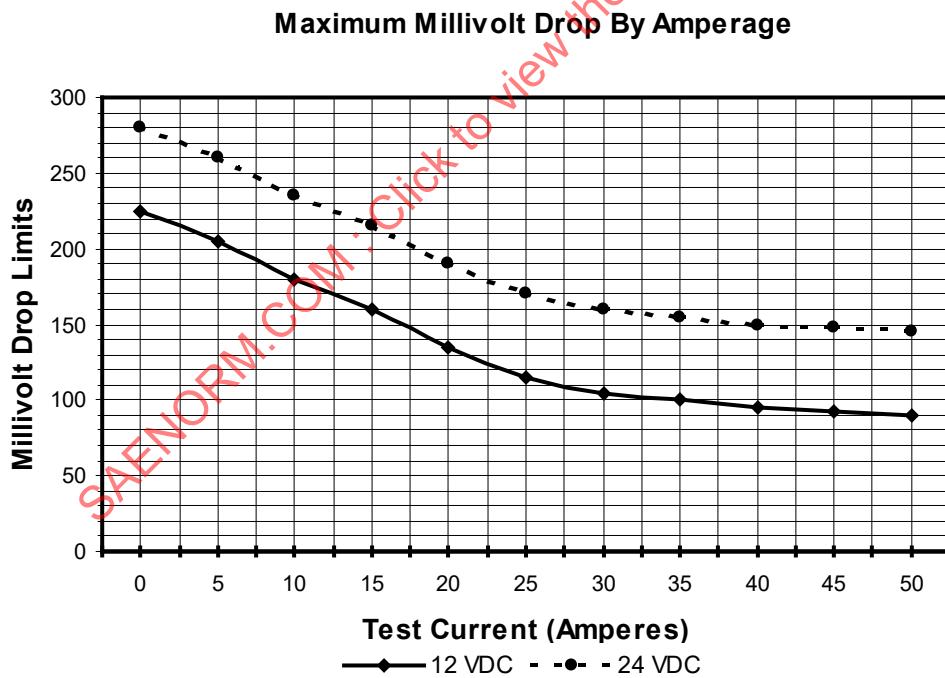


Figure 6 - Voltage drop curves

NOTE: A calculation of 48 V curve is required. A possible solution is using the 24 V for the 48 V and 24 V levels.

5.3 Effective Current Limitation

5.3.1 Type 1

Using the test procedure described in 4.2.2.1, the maximum value of effective current passed through the automatic reset circuit breaker shall not be greater than 135% of its rated current for an externally mounted breaker or greater than 150% of its rated current for an internally mounted breaker.

5.3.2 Type 2

Using the test procedure described in 4.2.2.2, the current passing through the modified reset circuit breaker shall not exceed 0.5 A (500 mA) after reaching a maintained open condition. The maintained open condition shall be reached within 60 seconds after the breaker initially opens. Breakers that exceed 60 seconds, but maintain open condition prior to 5 minute test termination, shall be reported as variant. Suitability should be evaluated with regard to intended application.

NOTE: 1 A (1000 mA) will be too large because of potential CB temperature and the discharge of the battery.

5.3.3 Type 3

Using the test procedure described in 4.2.2.3, the maximum value to effective current passed through the manual reset breaker (with disabled reset mechanism) shall not be greater than 135% of its rated current for an externally mounted breaker or greater than 150% of its rated current for an internally mounted breaker.

5.4 Voltage Breakdown

Using the test procedure described in 4.2.3, there shall be no continuity between either terminal of the circuit breaker and the cover.

5.5 No Current Trip and Reset Temperature

Using the procedure described in 4.2.4, all circuit breakers shall open and re-close in accordance with the following requirements:

NOTE: Recognizing device design variations as well as the possibility of ambient compensating mechanisms, it is recommended that manufacturers' temperature de-rating curves be consulted for application considerations. Consequently, the test procedure of 4.2.4 and performance requirements of 5.5 may, at the tester's discretion, be omitted from the test program.

5.5.1 Circuit breakers rated 10 A or less shall not open at less than 82 °C and shall re-close before the temperature is below 65 °C. A minimum 50% rated current is to be maintained at 65 °C.

5.5.2 Circuit breakers rated above 10 A shall not open at less than 112 °C and shall re-close before the temperature is below 85 °C. A minimum 50% rated current is to be maintained at 85 °C.

5.6 Endurance Test

5.6.1 Type 1 externally mounted circuit breakers shall be tested as described in 4.2.5.1.1 and then shall continuously pass $80\% \pm 1.5\%$ of rated current for 30 minutes, and the millivolt drop at 80% of rated current shall be within the limits specified in Figure 4 at the 80% rating value. After re-connecting and cycling the circuit breakers for 4 hours, as described in 4.2.5.1.2, the preferred condition is continued cycling function; however, an open circuit condition may occur dependent upon design characteristics, which is acceptable as well.

5.6.2 Type 2 externally mounted circuit breakers shall be tested as described in 4.2.5.2.1 and then shall continuously pass $80\% \pm 1.5\%$ of rated current for 30 minutes, and the millivolt drop at 80% of rated current shall be within the limits specified in Figure 4 at the 80% rating value.

5.6.3 Type 3 externally mounted circuit breakers shall be tested as described in 4.2.5.3.1. The breaker shall trip and reset without failure. There shall be no measurable current passing through the breaker while in the tripped position for the 100 cycles. It shall then continuously pass $80\% \pm 1.5\%$ of rated current for 30 minutes, and the millivolt drop at 80% of rated current shall be within the limits specified in Figure 4 at the 80% rating value.

5.6.4 All breakers, when tested as described in 4.2.5.4.1, shall maintain continuity for the 25000 cycles.

5.7 Interrupt Test

5.7.1 Type 1 Circuit Breakers

5.7.1.1 When tested as described in 4.2.6.1.1, the preferred performance is for the circuit breaker to demonstrate continuity and functionality by passing $80\% \pm 1.5\%$ of rated current for 30 minutes. Circuit breakers that clear the circuit but cease to function shall be examined according to the guidelines of 5.7.1.2.1.

5.7.1.2 When tested as described in 4.2.6.1.2, the circuit breaker shall cease functioning and exhibit characteristics as described in 5.7.1.2.1.

5.7.1.2.1 If failure occurs with the circuit breaker tested, the ultimate failure of all circuit breakers shall result in an open circuit in the circuit breaker, and there shall be no damage to the associated wiring. Failure falls into three general categories: (1) sacrificial failure—part of the electrical contacts and/or thermostatic material is destroyed and the circuit path is broken (contained with breaker housing/no external manifestations); (2) operational fatigue—thermostatic material loses original form, no longer cycles or chatters (trip/reset excursions less than 1 second in duration), or loses contact pressure resulting in circuit discontinuity; and (3) contact failure—electrical contact material erodes or carbons to a level of non-conductance or high resistance, causing inability to pass current (which is exhibited by measured current less than 5 mA).

NOTE: In some circuit breaker applications instances, a high circuit resistance, and/or low current power source, may not provide enough fault current to assure that ultimate failure will always result in an open circuit breaker.

5.7.2 Type 2 Circuit Breakers

5.7.2.1 When tested as described in 4.2.6.2.1, the preferred performance is for the circuit breaker to demonstrate continuity and functionality by passing $80\% \pm 1.5\%$ of rated current for 30 minutes. Circuit breakers that clear the circuit but cease to function shall be examined according to the guidelines of 5.7.1.2.1.

5.7.3 Type 3 Circuit Breakers

5.7.3.1 When tested as described in 4.2.6.3.1, the preferred performance is for the circuit breaker to demonstrate continuity and functionality by passing $80\% \pm 1.5\%$ of rated current for 30 minutes. Circuit breakers that interrupt the fault current but are non-functional afterwards shall be examined according to the guidelines of 5.7.1.2.1.

5.8 Environmental Tests

5.8.1 Temperature Test (Thermal Shock)

5.8.1.1 After completion of test as described in 4.2.7.1.1, the circuit breaker shall exhibit no signs of physical damage and be capable of passing $80\% \pm 1.5\%$ of rated current for 30 minutes.

5.8.2 Humidity Test

5.8.2.1 After completion of test as described in 4.2.7.1.2, the circuit breaker shall perform in accordance with 5.1 and 5.2 at $80\% \pm 1.5\%$ of rated current.

5.8.3 Salt Fog Test

5.8.3.1 After completion of test as described in 4.2.7.1.3, the circuit breaker shall perform in accordance with 5.1 and 5.2 at $80\% \pm 1.5\%$ of rated current. Physical corrosion shall not prevent proper fit and function of the breaker.

5.8.4 Immersion and Splash Test

5.8.4.1 Immersion Test

After completion of test as described in 4.2.7.1.4, pass/fail criteria of SAE J1171 shall apply.

5.8.4.2 Splash Test

After completion of test as described in 4.2.7.1.4, pass/fail criteria of SAE J1428 shall apply.

5.8.5 Mechanical Vibration Test

5.8.5.1 While testing as described in 4.2.7.1.5, the circuit breaker shall continuously pass $80\% \pm 1.5\%$ of rated current during the last 30 minutes with no loss in continuity. Loss of continuity is defined as a resistance across the circuit breaker terminals in excess of 100 W, or a voltage rise across the terminals exceeding 50% of test circuit unloaded voltage for longer than 5 ms.

5.8.6 Drop Test

5.8.6.1 After completion of test as described in 4.2.7.1.6, the circuit breaker shall not exhibit any physical damage. It shall be capable of passing $80\% \pm 1.5\%$ of rated current for 30 minutes minimum and comply with 5.2.

5.8.7 Environmental Extremes Test

5.8.7.1 After completion of testing described in 4.2.7.1.7, there shall be no significant degradation of product materials, such as softening of plastics, creep, or other deformations that could alter product performance or reliability. If test unit is suspect, perform tests per 4.2.1, 4.2.1.1, 5.1, and 5.2.

5.9 General Requirements

5.9.1 Marking

Externally mounted circuit breakers shall be permanently and legibly marked with the current rating and maximum system voltage as well as any other identifying part numbers. Circuit breaker exterior package designs, which may appear identical in Type 1 or Type 2 versions, shall be marked in a consistent fashion to provide distinction between Type 1 or Type 2. Date coding is strongly recommended. Marking shall be generally resistant to common contaminants and chemicals. Evaluate suitability during 4.2.7.1.4 testing.

NOTE: Specifying of marking information, use of color codes, or custom information shall be the responsibility of the circuit breaker manufacturer. Specialized marking requirements may be developed as needed jointly between manufacturer and user.

5.9.2 Application

The specific current capacity of the circuit breaker is a function of the particular electrical system being utilized. It is recommended that actual performance be verified through testing experimentally in the proposed application. To aid in determining the actual capacity change caused by variations in circuit parameters, several factors should be considered by the application engineer.

5.9.2.1 Voltage Rating

The voltage rating marked on the externally mounted circuit breaker (14 V, 28 V, and 56 V) is the maximum value recommended (system, not charging voltage). Use at higher voltages may significantly shorten the ultimate life under overload conditions and/or destroy Type 2 components.

5.9.2.2 Current Rating

The current rating marked on externally mounted circuit breakers is the maximum value/ultimate rating but is subject to redefinition based on the application analysis. It is generally not desirable to specify circuit protection where the breaker will pass 100% of rated current during normal continuous circuit load. Electrical system engineers generally specify circuit protection such that normal continuous circuit loads are approximately 75 to 80% of the circuit breaker current rating. 5.9.2.3 and 5.9.2.4 explain why.

5.9.2.3 Ambient Temperature

The circuit breakers covered by this document are thermal devices. Changes in the ambient temperature will have an effect on the current carrying capacity and on the effective limitation of current during overload cycling. Therefore, the application engineer needs to consider environmental conditions to which the breaker will be subject during operation and make use of circuit breaker manufacturer's de-rating/re-rating curve information if available.

5.9.2.4 Wire and Terminations

The connecting wires and their terminations will affect the heat dissipation characteristics of the circuit breaker. Deviations from the circuit breaker application specifications may affect the current carrying capacity or the effective limitation of current during overload cycling. Heat sources associated with poor interfacing terminations that connect with the circuit breaker may be a cause of abnormal circuit resistance, excessive millivolt drop, damage to associated wiring, and ultimately, significant de-rating/re-rating.

6. QUALIFICATION TEST SEQUENCE

6.1 Test Programs

Test sequences are listed in Table 4; the basic test sequence that covers all core requirements, and the expanded test sequence, which in addition to the basic test includes additional optional tests that may be selected for further evaluations as deemed appropriate for application conditions. Sample size and sample group distributions for tests are indicated accordingly.

Table 4 - Test sequence chart

Step No.	Test Description	Test Para	Sample Group Distribution	
			Basic Test Routine	Expanded Test Routine
Electrical Tests				
1	100% carry/maximum voltage drop	4.2.1.1	X (15)	X (15)
2	Overload trip rating - 135%	4.2.1.2	X (15)	X (15)
3	Overload trip rating - 200%	4.2.1.2	X (15)	X (15)
4	Effective current limitation	4.2.2	Use Step 3 samples, numbers 1-5	Use Step 3 samples, numbers 1-5
5	Voltage breakdown	4.2.3	Use Step 4 samples	Use Step 4 samples
6	No current trip and reset	4.2.4	Optional (see expanded tests)	Use Step 3 samples, numbers 6-10
7	Endurance test	4.2.5	Use Step 3 samples, numbers 6-10	Use Step 3 samples, numbers 11-15
8	Transient current cycling	4.2.5.4	Optional (see expanded tests)	Use Step 5 samples
9	Interrupt test	4.2.6	Use Step 3 samples, numbers 11-15	Use Step 6 samples
Environmental Tests				
10	Temperature test	4.2.7.1.1	Optional (see expanded tests)	Separate group X (5)
11	Humidity test	4.2.7.1.2	Optional (see expanded tests)	Separate group X (5)
12	Salt Fog test	4.2.7.1.3	Optional (see expanded tests)	Separate group X (5)
13	Immersion and splash test	4.2.7.1.4	Optional (see expanded tests)	Separate group X (5)
14	Mechanical vibration test	4.2.7.1.5	Optional (see expanded tests)	Separate group X (5)
15	Drop test	4.2.7.1.6	Optional (see expanded tests)	Separate group X (5)
16	Environmental extremes test	4.2.7.1.7	Optional (see expanded tests)	Use Step 7 samples

7. NOTES

7.1 Revision Indicator

A change bar (I) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

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APPENDIX A - CIRCUIT PROTECTION APPLICATION GUIDELINES FOR THERMAL CLASS CIRCUIT BREAKERS

A.1 SCOPE

Appendix A provides technical commentary regarding the use of thermal design circuit breakers in vehicular and/or motor vehicle accessory (service equipment or components) applications and certain limitations to consider. Appendix A does not set forth any tests or performance criteria. Test and evaluation specifications are found in the preceding sections of this document.

A.2 DEFINITIONS

A.2.1 Circuit breakers for purposes discussed here are overcurrent protective devices that are responsive to electric current and to temperature. As thermally classified circuit breakers, their protective action is based largely on an ability to respond predictably to temperature change induced by elevated current pass through the circuit breaker's thermally active element. The activity of the thermal circuit breaker (making or breaking continuity) is primarily a function of varying rates of heating or cooling. The source of the heating or cooling should ideally be limited to changes in electrical current passing through the thermally active element. However, other sources of heating or cooling may impact the operation of the thermal circuit breaker in conjunction with varying rates of current pass.

A.2.2 There are three general classes of thermal circuit breakers, defined as follows:

A.2.2.1 Type 1 - Automatic Reset

Automatic reset circuit breakers are defined as cycling or continuously self-resetting units, which are opened by overcurrent. The terms "cycling" and "continuously self-resetting" refer to the functional characteristics in which the reset feature is not dependent upon any deliberate action or intervention by the user or user's application system to initiate the reset of the tripped circuit breaker. These terms do not imply that the trip and reset function can continue unabated without consequence to either the life of the circuit breaker or potentially adverse effects to an electrical system wiring and/or components, if a fault condition is not reasonably and prudently detected and corrected.

A.2.2.2 Type 2 - Modified Reset

Modified reset circuit breakers are devices that are opened by overcurrent and remain open as long as the power is on to the affected circuit or until the load is removed. A number of cycles may occur before achieving a steady-state open circuit condition.

A.2.2.3 Type 3 - Manual Reset

Manual reset circuit breakers are non-cycling devices that open by overcurrent and elevated temperatures, but remain open until manually reset into a conducting state. A trip-free designated manual reset circuit breaker indicates that any forced restriction of the reset mechanism in the operating mode does not prevent cycling of the thermally active element under fault current. This means that an operator or technician cannot create a condition where the circuit breaker must pass current continuously in the presence of fault current on the protected circuit.

A.2.2.4 Type 3 - Switchable Manual Reset

Functions as a conventional manual reset circuit breaker as defined in A.2.2.3, but also has a mechanism, which when exercised at the discretion of the user, permits opening of the breaker internal circuit to stop current flow. The breaker is reset to its normal operating condition by the manual reset function, whether tripped unattended by a real fault condition or by the user. A trip-free designated switchable manual reset circuit breaker indicates that any forced restriction of the reset mechanism in the operating mode does not prevent cycling of the thermally active element under fault current. This means that an operator or technician cannot create a condition where the circuit breaker must pass current continuously in the presence of fault current on the protected circuit. These types of circuit breakers have a switching capability that is incorporated for convenience, so that users may disable an electrical circuit for maintenance or tests without removing or disconnecting the circuit breaker. It is likely that they do not have switch ratings, such as high cycle life as true switches normally would. Their primary function is as a protective device with function as a switch being the secondary function.

A.2.2.5 Type 3 - Manual Reset/Switch

An integrated switch design that provides both switching function for on-off activations and includes a circuit breaker feature to "toggle" the switch to an off position in the event of overcurrent or short circuit. Reset function is likely to be incorporated into the on/off activating mechanism, permitting reset of the circuit breaker portion of the device. These types of devices are preferred in applications requiring active on-off switching function in the installed electrical circuit. Their primary function is as a switching device with protection as a circuit breaker being the secondary function.

A.3 APPLICATION CONSIDERATIONS

A.3.1 General Considerations

A.3.1.1 Electrical

A.3.1.1.1 Voltage

Thermal circuit breakers are typically rated for a standard voltage. For vehicular use, the three most frequently used ratings are 12 VDC, 24 VDC, and 48 VDC. These ratings refer to the standard system nominal voltage specification. In actual conditions, system voltages may range from 9 to 16 VDC, 18 to 32 VDC, and 38 to 56 VDC, respectively. Just as voltage fluctuations may adversely affect electronic components, abnormally low or high system voltages may adversely affect thermal circuit breakers. Examples: a Type 2 circuit breaker that uses a resistive element to create the maintained open state upon overload may not generate adequate heat due to low source voltage; a Type 1 breaker may fail prematurely under cycling conditions due to abnormally high source voltage that induces excessive arcing between the electrical contacts; and a Type 2 heater element may be destroyed by excessively high voltage (or if a Type 2 12 VDC rated unit is installed in a 24 VDC system).

A.3.1.1.2 Current

The current rating on a thermal circuit breaker is the maximum value (sometimes referred to as the ultimate rating) the breaker is capable of passing without tripping, for an indefinite time. The current rating assigned is based upon performance under standardized conditions in a nominal ambient environment of 23 °C. The current rating, while a specification of its maximum continuous current-pass amount is not generally considered to be the sole basis for application specification. Circuit designers must consider other thermal factors that directly or indirectly impact upon the circuit breaker's environment. The sum of these factors will determine the breaker's true rating as it applies to a specific application or installation.

A.3.1.1.3 Wiring and Terminations

The connecting wires and their terminations will affect the heat dissipation characteristics of the thermal circuit breaker. Terminals, whether screwed on, plugged on, welded on, soldered on, or integral to a mating interface terminal block or harness, act in some fashion as heat sinks to a thermal circuit breaker. Poor connections, whether the result of inadequate design, looseness, corrosion, or other induced elevated resistance, cause elevated voltage drop and hot spots in the presence of high current conditions. If poor connections are sufficiently adverse, de-rating/re-rating and premature tripping of the thermal circuit breaker will occur.

A.3.1.2 Environmental

A.3.1.2.1 Ambient Temperature Conditions

The environmental temperature conditions prevalent both where circuit breakers are used (as in geographical climatic conditions) and relative to their installation (as in proximity to other sources of heat and cold), have considerable bearing on the selection of the appropriate amperage rating. In some instances, circuit design changes, relocation of circuit breaker mounting, or ventilation or insulation from other sources of ambient altering environments must occur.

A.3.1.2.1.1 Examples of potentially detrimental environmental conditions relative to temperature: mounting a breaker or multiple breaker harness near heat sources such as exhaust manifolds, coolant hoses, heater cores, or external oil reservoirs and or filtering systems; mounting a breaker or multiple breaker harness in a restricted space without even convection ventilation possible; mounting a breaker or multiple breaker harness exposed externally to wind chill effects.

A.3.1.2.2 Other Environmental Factors

While temperature conditions are the most significant factor affecting breaker performance, other conditions may with sufficient severity and duration of exposure negatively impact circuit performance, reliability, and longevity. Typical environmental conditions of this sort may include: thermal shock, high humidity, salt fog or spray, immersion or splash of liquids (water-based compounds and petroleum-based compounds), mechanical vibration, and sudden impact. Positioning of circuit breakers so that environmental factors are managed is crucial to ensuring dependable service.

A.3.1.2.2.1 Examples of other environmental factor negative effects: chemically induced corrosion deteriorates terminal connections causing elevated resistance, intermittent continuity, or total loss of continuity; unusually persistent or severe cyclic harmonic vibration induces momentary loss of continuity between the circuit breaker electrical contacts.

A.3.1.3 Interfacing Component Materials

A.3.1.3.1 When circuit breakers are interfaced with wiring harnesses via terminated plastic distribution modules, heat generation factors resulting from normal as well as potential abnormal circuit breaker operation must be considered when specifying the plastic materials to be used in such proximity. Low temperature index plastics that lend themselves to certain design flexibilities and reduced costs can pose performance problems if heat wicking from circuit breakers causes softening or more severe degradation from long-term exposure to elevated temperatures.

A.3.1.3.1.1 Higher performance plastics with respect to heat indices should be used for test purposes during circuit breaker performance evaluations. Radiant heat characteristics developed by circuit breakers should be thoroughly considered in the design phase of plastic-based terminal blocks intended for interface with circuit breakers.

A.3.2 Circuit Breaker Type Considerations

A.3.2.1 Type 1 Circuit Breakers

A.3.2.1.1 Type 1 circuit breakers are the most basic design of the thermal circuit breaker family. As cycling or continuously resetting devices, their use is best applied protecting loads controlled by momentary switches or other self-limiting means. In select situations, they protect circuits where cycling of an overloaded circuit is preferred over complete disruption of service until the fault condition is corrected for reasons of operator safety or other compelling interest.

A.3.2.1.2 Favorable aspects of Type 1 circuit breakers are: simplicity of design; lower cost as a component; automatic resetting after a trip event; and are available for applications requiring complete waterproofing.

A.3.2.1.3 Unfavorable aspect of Type 1 circuit breakers are: cycling may not be conducive for adequate protection of sensitive equipment for repetitive fault current exposure; the cycling condition may encourage operators or technicians to unwisely delay correction of a fault; cycling may continue for extended periods and drain storage batteries below minimum cranking capacity; and extended cycling without proper attention may create conditions that lead to damage of peripheral components or wiring harnesses. It is important to note that cycle life of a thermal circuit breaker is impacted both by the operational characteristic of the circuit breaker as well as the relative magnitude and duration of overcurrents or short-circuits that the device experiences. For this reason, it is impractical to establish cycle life predictions for a Type 1 circuit breaker, as the impact of overcurrents or short-circuits upon the circuit breaker are infinitely variable within the confines of a specific electrical system. Type 1 circuit breakers will encounter the most electro-mechanical degradation under extended cycling, which in turn diminishes function and response over time.

A.3.2.2 Type 2 Circuit Breakers

A.3.2.2.1 Type 2 circuit breakers initially function with great similarity to Type 1 breakers. Upon presentation of fault current the breaker will react under the same time constraints as a Type 1 and after an initial trip may cycle (trip and reset) several times, appearing to perform as if a Type 1 design. During this initial period of reaction to the fault current, a secondary circuit within the breaker construction is creating a heat source each time the breaker has tripped. Within a relatively short time span (typically 60 seconds and up to 300 seconds) this secondary heating circuit will have developed sufficient heat radiation to maintain the breaker's thermal element in a tripped state. After the circuit breaker achieves a maintained, tripped condition, there is a reduced current value (typically 1 A or less) drawn by the heating circuit. Virtually no current is passed on through to the fault site. Type 2 circuit breakers are reset by disconnecting or switching off the power source to the protected circuit for a time period long enough to allow the breaker components to cool off and the thermal element to revert to its conducting state. This cooling off may require several minutes until a stable conducting state is achieved.

A.3.2.2.2 Type 2 circuit breakers may be used instead of Type 1 circuit breakers where the possibility of long-term cycling during faults is not desirable or the location of the breaker prevents easy access for resetting if a Type 3 circuit breaker had been preferred over Type 1.

A.3.2.2.3 Favorable aspects of Type 2 circuit breakers are: simpler design alternative to Type 3 breakers when Type 1 usage is undesirable; can be reset from any point in the same circuit where power switching is possible; less likely to drain storage batteries before fault is detected and corrected; and encourages timely maintenance since components affected are not functional even intermittently as with Type 1.

A.3.2.2.4 Unfavorable aspects of the Type 2 circuit breaker are: cannot be reset without shutting circuits down; extreme low source voltage may prevent successful Type 2 function rendering the breaker into a Type 1 operation; extreme high voltage may radically shorten Type 2 function; tripped Type 2 breaker may radiate excess heat and de-rate other breakers in a confined close proximity installation; and time between initial trip and maintained open state may still be too long for the level of protection necessary to prevent further equipment damage where the fault has occurred.

A.3.2.3 Type 3 Circuit Breakers

A.3.2.3.1 Type 3 circuit breakers differ significantly from both Type 1 and Type 2 breakers in that they provide a complete interruption of circuit continuity once tripped. Continuity restoration will not occur until a conscious decision is made by a responsible party to initiate circuit breaker resetting. This is typically accomplished by inspecting the breaker for visual indication of a tripped state (a button or lever extended or moved from a normal operating location) and manually with physical force replacing the indicator to its original state.

A.3.2.3.1.1 In the case of switchable Type 3 or manual reset/switch circuit breakers, circuit continuity can be broken by the breaker on a manual basis without the presence of fault current by the definite choice of an operator or technician.

A.3.2.3.1.2 Type 3 circuit breakers are used where no cycling after a fault is desired or deemed safe and where an immediate investigation of fault causes is the most appropriate course of action.

A.3.2.3.1.3 Favorable aspects of Type 3 circuit breakers are: highly unlikely to permit damage to wiring or interfaces from long-term fault exposure; brings human element of analysis into the decision to reset or not; can provide circuit interruption for maintenance or investigation (if with switchable or switching feature); and provides operators with a sense of control and awareness over electrical systems.

A.3.2.3.1.4 Unfavorable aspects of Type 3 circuit breakers are: cannot be reset unattended; mounting requirements (reset mechanism access) may restrict location options; higher initial cost to install likely; and may not be practical for some circuits with shared components having requirements for quick or unattended re-initiation of electrical power.