

IEEE Guide for Diagnostics and Failure Investigation of Power Circuit Breakers

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Abstract: Procedures to be used to perform failure investigations of power circuit breakers are recommended. Although the procedure may be used for any circuit breaker, it is mainly focused on high voltage ac power circuit breakers used on utility systems. Recommendations are also made for monitoring circuit breaker functions as a means of diagnosing their suitability for service condition.

Keywords: diagnostics, failure investigation, power circuit breaker

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Introduction

(This introduction is not part of IEEE Std C37.10-1995, IEEE Guide for Diagnostics and Failure Investigation of Power Circuit Breakers.)

This guide was prepared by the Quality and Reliability Working Group of the HVCB Subcommittee of the Switchgear Committee of the IEEE Power Engineering Society.

Work on this guide began in 1990 with the purpose of developing guidelines that could be used by utilities and industrial users alike in the process of investigating failures as well as in monitoring and diagnostics of the power circuit breakers.

Many papers have been written and numerous conferences have been held regarding reliability, maintenance, and diagnostics of power circuit breakers. The subject of monitoring and diagnostics is evolving rapidly. This guide attempts to bring together the current knowledge and techniques on these subjects into one comprehensive document.

This guide is in two parts. The first part describes a procedure to investigate and analyze circuit breaker failures. The second part describes diagnostics and monitoring of the circuit breaker functions as an aid to improve and extend circuit breaker service life. The annexes contain information on advanced diagnostics, diagnostic tests, and basic design and application of circuit breakers.

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IEEE Guide for Diagnostics and Failure Investigation of Power Circuit Breakers

1. Overview

1.1 Scope

This guide recommends procedures to be used to perform failure investigations of power circuit breakers. Although the procedure may be used for any circuit breaker, it is mainly focused on high-voltage ac power circuit breakers used on utility systems.

Recommendations are also made for monitoring circuit breaker functions as a means of diagnosing their suitability for service condition.

1.2 Purpose

The purpose of this guide is

- a) to provide a methodology by which the most probable cause of any particular circuit breaker failure may be determined;
- b) to provide sufficient guidelines and promote uniformity in the analysis of circuit breaker failures;
- c) to provide guidance for systematic and uniform data collection so that valuable facts are not lost or destroyed;
- d) to encourage cooperative efforts by users and manufacturers during failure analysis;
- e) to encourage consistency of nomenclature and compatibility with similar efforts by other organizations such as CIGRE (International Conference on Large Voltage Electric Systems), EEL (Edison Electric Institute), IEC (International Electrotechnical Commission), NEMA (National Electrical Manufacturers Association), and AEIC (Association of Edison Illuminating Companies).

1.3 Organization

This guide is divided into two main parts as follows:

Part I: Failure investigation

Part II: Diagnostics

Annexes provide information on advanced diagnostics, diagnostic tests, and circuit breaker basic design and application.

2. References

ANSI C37.06-1987, American National Standard for Switchgear—AC High-Voltage Circuit Breaker rated on a Symmetrical Current Basis—Preferred Ratings And Related Required Capabilities.¹

ANSI C37.11-1979, American National Standard Requirements for Electrical Control for AC High-Voltage Circuit Breakers rated on a Symmetrical Current Basis or a Total Current Basis.

IEEE Std 100-1992, The New IEEE Standard Dictionary of Electrical and Electronics Terms (ANSI).²

IEEE Std 1325-1996, IEEE Recommended Practice for Reporting of Power Circuit Breaker Field Failures.³

IEEE Std C37.04-1979 (R1988), IEEE Standard Rating Structure for AC High-Voltage Circuit Breakers rated on a Symmetrical Basis (ANSI).

IEEE Std C37.09-1979, IEEE Standard Test Procedure for AC High-Voltage Circuit Breakers rated on a Symmetrical Current Basis (ANSI/DoD).

IEEE Std C37.010-1979 (R1988), IEEE Application Guide for AC High-Voltage Circuit Breakers rated on a Symmetrical Current Basis (ANSI).

IEEE Std C37.011-1994, IEEE Application Guide for Transient Recovery Voltage for AC High-Voltage Circuit Breakers rated on a Symmetrical Current Basis (ANSI).

IEEE Std C37.012-1979 (R1988), IEEE Application Guide for Capacitance Current Switching for AC High-Voltage Circuit Breakers rated on a Symmetrical Current Basis (ANSI).

IEEE Std C37.100-1992, IEEE Standard Definitions for Power Switchgear (ANSI).

3. Definitions

3.1 ancillary equipment: Auxiliary or accessory equipment (e.g., thermometer, liquid level gauge, pressure gauge) (see also IEEE Std 100-1992).

3.2 circuit breaker downtime: Time from the discovery of the failure until the breaker is returned to service.

3.3 contributing cause: A cause that, of itself, may not result in failure.

3.4 control circuit failure: Failure attributed to the inability of the electrical control circuit to perform its function.

3.5 defect: Imperfection in the state of an item (or inherent weakness) which can result in one or more failures of the item itself or of another item under the specific service or environmental or maintenance conditions for a stated period of time.

3.6 diagnostic tests: Comparative tests or measurements of one or more of the characteristic parameters of a circuit breaker to verify that it performs its functions.

NOTE — The result from diagnostic tests can lead to the decision of carrying out overhaul.

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

²IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

³As this standard goes to press, IEEE Std 1325-1996 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is December 1996. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.

3.7 electrical failure (of a circuit breaker): Failure attributable to the application of electrical stresses to the main circuit of the circuit-breaker.

3.8 examination: An inspection with the addition of partial dismantling, as required, supplemented by diagnostic tests in order to reliably evaluate the condition of the circuit breaker.

3.9 failure: Termination of the ability of an item to perform its required functions.

NOTE — The occurrence of a failure does not necessarily imply the presence of a defect if the stress is beyond that originally specified.

3.10 failure analysis: The logical, systematic examination of an item or its diagram(s) to identify and analyze the probability, causes, and consequences of potential and real failure. (see IEEE Std 100-1992)

3.11 failure cause: The circumstances during design, manufacture, or use which have led to failure; *syn:* root cause. (see IEEE Std 100-1992)

3.12 failure detection: Examination to determine the position, evidence, and type of failure.

3.13 failure mode: The manner in which failure occurs; generally categorized as electrical, mechanical, thermal, and contamination.

3.14 focused tests: Tests performed to identify a particular area of failure.

3.15 forensic engineering: The application of engineering knowledge to questions of law affecting life and property.

3.16 initiating cause: A cause that directly leads to the failure.

3.17 in-service inspection: Visual periodic investigation of the principal features of the circuit breaker in service, without dismantling. This investigation is generally directed toward pressures and/or levels of fluids, tightness, position of relays, pollution of insulating parts; but actions such as lubricating, cleaning, washing, etc., that can be carried out with the circuit breaker in service, are included.

NOTE — The observations resulting from inspection can lead to the decision of carrying out overhaul.

3.18 major failure (of a circuit breaker): Failure of a circuit breaker that causes the termination of one or more of its fundamental functions, which necessitates immediate action.

NOTE — A major failure will result in an immediate change in system operating condition; e.g., the backup protective equipment being required to remove the fault, or will result in mandatory removal from service for non-scheduled maintenance (intervention required within 30 min).

3.19 mechanical failure: (of a circuit breaker): Failure other than an electrical failure.

3.20 minor failure: (of a circuit breaker): Any failure of a part or a sub-assembly that does not cause a major failure of a circuit breaker.

3.21 monitor: Continual or periodic testing with comparison to observe or determine trends.

3.22 overhaul: Work done with the objective of repairing or replacing parts that are found to be out of tolerance by inspection, or test, or examination, or as required by equipment maintenance manual, in order to restore the component and/or the circuit breaker to an acceptable condition.

3.23 repair: Work done to restore the component or the circuit breaker to condition for operation.

3.24 servicing: Planned servicing of the circuit breaker including lubricating and replacing minor parts.

Part I Failure investigation

4. Procedure for the investigation of circuit breaker failures

A failure investigation shall begin by determining if the failure was catastrophic, operational, or minor in order to decide what course of action to follow.

- a) *Catastrophic failures.* A failure of the circuit breaker in which physical damage has occurred to power current carrying or high-voltage isolating elements. Catastrophic failures require
 - Exercise of extreme caution to minimize risk to personnel and other system equipment
 - Collection of physical data and photos to aid in analyzing the failure
 - Clean-up, and repair or removal and replacement of the failed circuit breaker to restore service
- b) *Operational failures.* A failure of the circuit breaker in which a lack of basic function occurs such as, a change of state occurs when not commanded, a change of state does not occur when commanded, the circuit breaker is locked in position due to a lack of some critical parameter or an alarm is activated to warn of impending lack of basic function. An operational failure requires
 - Caution to determine if it is safe to approach the circuit breaker
 - Checking of troubleshooting features to diagnose the source of the failure
 - Repair of the circuit breaker to restore service
- c) *Minor failures.* A minor failure requires
 - Checking of troubleshooting features to diagnose the source of the failure
 - Repair or scheduling of repairs of the circuit breaker to prevent future lack of function

4.1 Immediate action

- a) If there has been any personnel injury and/or continuing fire, call for medical emergency help.
- b) Provide first aid as needed.
- c) Evacuate the immediate area.
- d) Electrically, pneumatically, etc. Isolate failed equipment as dictated by equipment condition.
- e) Do not try to operate failed equipment. Isolate from HV source. Before removing auxiliary power, verify status of all relay targets.
- f) Extinguish fire with caution or let it burn out. Cold water on hot porcelain can cause it to fracture. Prevent fire from spreading.
- g) Be aware of hazards of arced SF₆ gas and by-products, PCBs, asbestos, and other toxic materials that could be present.
- h) Secure the area. Wait a few minutes. Do not immediately approach failed equipment because there may be high pressures, voltage, charged springs, excessive thermal, or mechanical stresses in the equipment.
- i) Visually inspect failed equipment from a safe location to assess the situation.
- j) Follow established safe working procedures for isolation, grounding, etc., and practices regarding environment protection and spill control, etc.

4.2 Investigation

- a) Take good quality photographs of everything before any disassembly or moving of parts. Photographs showing an overview from all angles as well as photographs showing close details will assist in documenting visual evidence. If disassembly is required, photograph each step, with an information card appearing in the photo. Consider backup recording by video camera. Tape record all observations.
- b) Determine the position of all relays, targets, and counter readings before removing control voltages, if possible. Record also by photography, if possible.
- c) Interview observers or tape record as soon as possible.

- d) Obtain station oscillograms, sequence of events, and logs and fault recordings.
- e) Take samples of oil, gas, air, etc.
- f) Call the manufacturer and determine if the manufacturer wishes to be represented during failure investigation. Determine if a consultant is required to assist in analysis of failure.
- g) Think through a failure sequence first and then look at the evidence.
- h) All parts should be saved until the investigation is complete. Avoid a hasty cleanup.
- i) Determine events immediately preceding, immediately succeeding, and simultaneous with failure.
- j) Acquire/review manufacturer's engineering information, drawings, and test reports on other "special releases/reports."
- k) Investigate each subsystem thoroughly (tripping subsystem including latch energy sources, linkages, etc.; main current contact path and movement, arcing contacts, nozzles, etc.; fluid subsystems (gas, air, and liquid); (i.e. investigation on a system and subsystem basis).
- l) Review maintenance records to see if there has been any recent or repeating type activity. Often failures result from parts disturbed during maintenance procedure.
- m) Open breaker access, inspect internals, and disassemble as necessary. Try to avoid disassembly until experts arrive.
- n) Inspect circuit breaker (external). Look for sticking parts, arc marks, burning, eroded metal, molten metal, signs of excessive pressure, etc., leakage of fluids [smoke (gas) or oil (liquid)].
- o) Determine the position of all operating mechanism parts including auxiliary switch contacts, props, latches, linkage, pressure switches, valves, and control power breakers. Disconnect supply source switches before releasing mechanism stored energy.
- p) If a failure was explosive, determine distances parts travelled, sizes of parts, which parts, etc. Map location of exploded/propelled items. Inspect parts for arc marks etc. before beginning clean up, etc. Make pictures, movies, videotapes, drawings, etc. as appropriate.

4.3 Investigation flow chart

In many situations, it may be desirable to perform selected tests. Figure 1 has been developed as a guide to aid in the determination and investigation of a failure.

The two starting points for this flowchart are

- a) Circuit breaker failure.
- b) Routine tests that show deviation from past history. Routine tests cover such tests as those listed in table 3.

The paths in the flowchart lead to scrapping or returning to service. Prior to returning to service, it may be desirable to perform selected tests to verify suitability for service.

Based upon the external observations (see table 2) or the presence of obvious damage, selected tests may be performed as suggested in table 3. From their results, a hypothesis of failure can be developed. This may be confirmed through internal inspection and teardown as deemed appropriate.

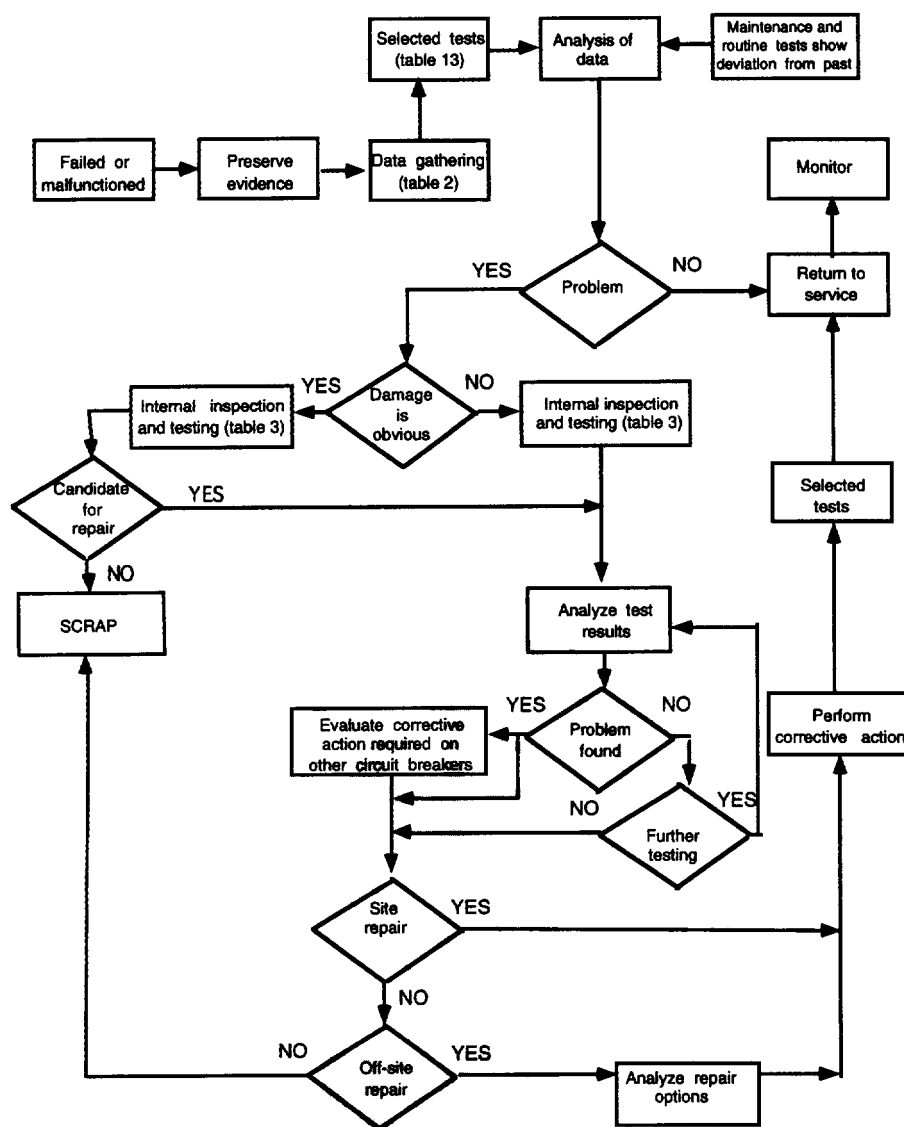


Figure 1— Suggested investigation flow chart that forms the basis for this guide

4.4 Recommended plan of action

4.4.1 Failure investigation

- a) Determine if the circuit breaker was in a long-term static position or if it had recently changed state when the failure occurred or was initiated.
- b) If the failure was during a static position
 - 1) Determine where the initial breakdown occurred.
 - 2) Determine whether the insulating fluid (gas or liquid) systems were fully charged and full.
 - 3) Determine whether the paths to ground were in specified condition, i.e., gas and air dry; minimum external contamination; no conducting paths to ground.
 - 4) Determine whether there were any voltage stresses that could have exceeded the nameplate levels, i.e., lightning; switching surges or other transients.

- 5) Look at maintenance records for clues.
- 6) If the breaker failed while open, check for condition of the grading capacitors that would cause unequal voltage distribution across the breaks.
- 7) Determine if other system events occurred recently or at the time of failure.
- c) If the failure appeared to be initiated during interruption
 - 1) Read oscillographs and digital fault recordings if available.
 - 2) Determine whether the operating voltage and system short-circuit level was within the nameplate rating of the switchgear.
 - 3) Determine whether the breaker has capability of switching capacitors if it was used for that purpose.
 - 4) Check the pressure interlocks for adjustment and proper functioning.
 - 5) Verify that all mechanisms are in the same position. Look for broken parts of mechanism or valve gear as well as for evidence of pumping if all mechanisms are not in the same position.
 - 6) If a circuit breaker opened and failed several seconds or minutes later, consider the possibility that it opened, dumped insulating fluid by a valve failure or other means and then failed dielectrically.
 - 7) Determine whether there was any lightning in the vicinity. If so, consider the possibility that the circuit breaker was opening due to a lightning stroke or shield failure and failed due to a subsequent lightning stroke.
 - 8) Look at maintenance records for clues
 - 9) Check condition of resistor switches, resistors, and grading capacitors for any malfunction that would cause unequal voltage distribution across the breaks.
- d) If the failure appeared to be initiated during closing
 - 1) Read oscillographs and digital fault recorders if available.
 - 2) Determine whether the system momentary current was within the nameplate rating of the circuit breaker.
 - 3) Determine whether the breaker was fully closed.
 - 4) Look at the maintenance records for clues.
- e) A review of the above results will probably give direction to the troubleshooting staff.

4.4.2 Summarizing failure analysis

- a) In summarizing the failure analysis, indicate the sequence of events that caused the failure. If possible, give the time the events occurred and backup data.
- b) State the most probable cause of failure.
- c) State any preventive measure that may prevent future failure occurrences.

4.4.3 Summary

- a) Gather data per 4.2.
- b) Review records of oscillographs and operations, including weather, and any voltage and current transient information on system and related circuit breaker operations.
- c) Review application vs. ratings.
- d) Review maintenance records.
- e) Prepare sequence of events from the time all systems were normal until failure.
- f) Propose all possible failure sequences.
- g) Determine most likely cause.
- h) Determine if other similar equipment has had similar experiences, or could have similar failures in the future.
- i) Determine corrective action plan.
- j) Determine which parts are damaged and what damaged them.
- k) Inspect similar type circuit breakers and determine if all parts are present and no foreign parts are present.

5. Data collection

5.1 General approach

Cooperation at all levels of the participating organizations should facilitate the investigation at the site and improve the accuracy of the diagnosis.

It is important that the manufacturer be informed of the equipment failure, especially when it is under warranty and always if there is injury or major equipment damage. The manufacturer will probably be expected to supply information such as the factory test data, inspection history, and internal construction drawings, and investigation support. If at all possible, do not remove or disassemble until the manufacturer has visited or concurred.

Any significant failure and all failures that involve personal injury will probably be involved in litigation. Well documented records of all observations including photographs are critical to a factual recording. Nothing should be trusted to memory.

Development of a team concept may be helpful for the final analysis of data. It is suggested that the team include representatives of the user and manufacturer/repair facility. This may facilitate the work and may also eliminate any considerations of bias in the final diagnosis.

5.2 Preparation

Some preparation prior to travelling to the site will aid site investigation. Failure investigations at the site are similar to detective work; a knowledge of the subject, a sense of curiosity, and objectivity is vital.

A quick review of information that might be available in a file regarding the subject circuit breaker may prove to be valuable before travelling to the site. Some items may also be taken to the site. Table 1 is a suggested checklist of various items.

5.3 Immediate investigation

Timeliness of an inspection of the failed circuit breaker is very important. Data could be destroyed because of movement of the circuit breaker or changes in the system configuration; therefore, data collection and tests should proceed as quickly as possible.

Work crews are almost always on-site before investigators. Their standing instructions should be to follow the outline discussed in clause 4, and to bypass failed equipment rather than to “clean it up.” Someone in the work crew should be appointed to preserve evidence and to follow 4.2. However, it is not always practical to cease restoration of service until the investigators arrive on-site. Thus, instructions should be given to operating personnel for restoration of service consistent with minimum negative impact on failure investigation work. If possible, all work should cease on the circuit breaker until the investigators have a chance to look at the circuit breaker, take photographs, notes, and perform tests that will assist future analysis.

Oscillograms, digital fault recorders, sequence of events recordings, and printouts should be reviewed.

Familiarity with the site, circuit breaker and general area is important. Personnel familiar with the operation and maintenance of the circuit breaker should be part of the investigation team.

A complete investigation of each circuit breaker subsystem ensures a thorough investigation.

Table 1— Suggested checklist of preparation items

_____	Circuit breaker instruction manuals—includes such items as outline and schematic drawings, descriptions of components, and factory photographs.
_____	Test reports (factory and field)
_____	Any prior written reports or notes about previous failures
_____	Routine inspection reports
_____	One line diagram of station
_____	Relaying scheme
_____	Records of maintenance work which may include reports on past problems
_____	Camera (video, 35 mm including close-up lens), film, flash, batteries
_____	Tape measure, calipers (Vernier)
_____	Protective clothing, safety glasses, safety shoes, hard hat, gloves
_____	Binoculars
_____	Magnifying glass
_____	Tape recorder, tape and batteries
_____	Flashlights
_____	Oil sample bottle and syringes
_____	Gas sample bottles
_____	Plastic bag(s) to protect evidence
_____	Plastic tag(s) to identify evidence
_____	Records of relay targets
_____	Oscillographic, digital fault recordings or sequence of events records
_____	Identification of personnel who may have been present
_____	Information of system operating conditions
_____	Trouble reporting form
_____	Work permit

It is better that at least two individuals initially inspect the circuit breaker. Two people can support one another and discuss the various findings and the immediate “next step” at the site.

Items that may be of importance include conditions and events at the time of the failure, physical inspections of the circuit breaker following failure, and electrical conditions of the circuit breaker following failure. Table 2 is a suggested checklist of observations.

5.3.1 Electrical tests

Safe work methods and practices should be observed. Before performing any tests, precautions should be taken to assure that the circuit breaker is isolated from the power system and has been properly grounded and any necessary safe work permits have been issued. Table 3 is a suggested checklist of electrical tests. It is recommended to consult the manufacturer's instruction manual.

5.3.2 Tests of insulating medium

These should include chemical analysis of gas, moisture content, and dielectric withstand test. Check the polychlorinated biphenyls (PCB) content.

Table 2— Suggested checklist of general observations

External conditions	Recorded data
___ time of day	
___ “no lights” call (power out)	
___ storms or lightning in area, general weather conditions	
___ temperature	
___ unusual sounds, odors, sights	
___ debris expelled from circuit breaker	
___ dead animals in area	
___ evidence of animal contact (animal may not be dead)	
___ foreign objects in area	
___ parts—visual	
___ evidence of vandalism	
___ interview of witnesses or station operators present when unit tripped or failed	
___ load interrupted	
___ system disturbances—both local and remote	
___ switching configuration in station at time of event	
___ previous, subsequent or concurrent switching operations	
___ location of surge arrestors	
___ signs of arcing or damage (metal erosion) to substation bus, insulators, steel structures	
___ movement of circuit breaker on its base	
Main tank	Recorded data
___ bulged	
___ cracked	
___ leaks	
___ evidence of overheating	
___ oil level	
___ gaskets or seals, leaks, expulsion, etc.	
___ gas temperature	
___ presence of arc marks, eroded metal, molten metal	
___ air or gas valves—open or closed	
___ air pressure	
___ gas pressure	
Bushings	Recorded data
___ signs of arcing—phase to phase or phase to ground	
___ leaks	
___ broken porcelain	
___ holes in cap	
___ pollution	
___ tracking	
___ oil level	
___ gas pressure	

Operating mechanism	Recorded data
___ linkages, loose, bent, corroded, broken	
___ spring condition	
___ pressure in air reservoir, normal—low	
___ hydraulic “pre-charge” pressure	
___ sludged hydraulic fluid	
___ control valves—open or closed	
___ corrosion in air or hydraulic system	
___ piping, leaks	
___ oil level in dashpots	
___ blown fuses	
___ breaker position, open or closed	
___ counter reading	
___ loose bolt/nuts securing the operating mechanism to the breaker	
___ control cabinet condition	
Protective relay targets	Recorded data
___ all targets that dropped/indicated	
___ all targets that should have dropped but did not drop	
Operation of	Recorded data
___ oscillograph	
___ sequence of events recorder	
___ digital fault recorder	
___ fault recorder	
___ annunciator	
___ blown fuses	
___ operation counter	
___ operation of other breakers on the system	
___ gas pressure	

5.4 Subsequent investigation

- Review the application of the circuit breaker. (See IEEE Std C37.010-1979 for guidance.)
- Review maintenance records.
- Determine available fault current. The oscillograms, digital fault recordings, and the sequence of events recordings printouts may assist in determining the actual fault current and fault duration.
- Check the system TRV at the expected short-circuit current level to be sure the TRV falls within the rating of the circuit breaker. Calculate the prospective transient recovery voltage and rate of rise of recovery voltage in accordance with methods documented in ANSI and IEEE standards, e.g., IEEE Std C37.011-1979.

Table 3— Electrical and other tests

Field tests
-Auxiliary power supply voltage
-Contact resistance
-Insulation resistance
-Power factor
-Starting & running currents of motors
-Opening & closing coil resistances
-Timing test with motion analyzer
-Value of closing resistors
-Value of opening resistors
-Value of grading resistors
-Value of grading capacitors (capacitance, power factor)
-Insulation & resistance of bushing current transformers
-Insulation power factor (all paths)
-Contact wear/erosion
-Oil or gas quality
Other tests
Operating mechanism
-Calibration and scaling of safety valves
-Calibration of pressure gauges
-Calibration of pressure switches
-Free movement of mechanism
-Fluid in dashpots
-Compressor interstage pressures, oil level
-Moisture levels in air, oil, and gas systems
-Lubrication

NOTE — These are tests that are common. (Review the manufacturers instruction book for values and testing intervals.)

6. Failure analysis

6.1 General

Prior to analyzing the failure, it is imperative that all the investigations, data collection, and tests are performed. See clauses 4 and 5. When analyzing a failure, it is important to determine the sequence of events. Fault recorders, oscillographs and/or sequence of events recorders, if available, can help determine if a fault occurred, the number of faults, breaker operation, and the time of events. Analyzing the protective relay targets, annunciators, SCADA logs, breaker operations and interviewing witnesses can provide information to determine the sequence of events.

Once sufficient data has been gathered from the on-site and off-site investigations, several hypotheses should be developed using the scientific method. A hasty analysis may lead to a bad diagnosis. It is recommended that data be thoroughly studied before interpretations are finalized. In-service failure sometimes results in mechanical damage and

electrical failure. The energy available from the power system can cause both to occur. One must use caution in reporting cause and effect.

These hypotheses should be tested against the data and the performance of other system components. This may be done through peer group discussions and data verification. Any information found incorrect should be replaced, if possible, with correct information. Studies, appropriate laboratory experiments and factory simulations could be initiated to test the accuracy of each hypothesis.

If the assembled data does not support a proposed hypothesis, a revised hypothesis should be developed and retested. Unsupported hypotheses should be discarded.

6.2 Operating mechanism failures

A majority of circuit breaker failures are due to a failure of the operating mechanism.

Failure of the operating mechanisms are usually of the following type:

- a) Failure in the closed position
- b) Failure to close
- c) Failure to close properly
- d) Failure to stay closed, i.e., unintended trip
- e) Failure in the open position
- f) Failure to open
- g) Failure to open properly
- h) Failure to stay open, i.e., unintended close

Failure of the mechanism in the closed position could involve a failure to prepare for the next opening operation, such as failure of the motor to charge the closing springs. Inadequately charged closing springs would be indicated by the failure of the spring charged flag going from “discharged” to “charged,” but may not be noticed until an opening operation is attempted.

Failure to close or failure to stay closed, i.e., unintended trip, could be due to defects in the latches, the close coil, the anti-pump relay, the auxiliary switches, or other control scheme components.

A leak in the air storage tank of the pneumatic system or in the accumulator of the hydraulic system could cause excessive motor operation and circuit breaker lockout.

Failure to close properly, at the correct speed, or failure to stay closed, could be due to low pressure, weak springs, high friction in moving joints, improper latches operation, or higher than rated short-circuit current.

Failure to open or failure to stay open, i.e., unintended close, could be due to defects in the latches, shock absorbers, the trip coil, the auxiliary switches, or other control scheme component.

Failure to open is frequently from a slower than required opening speed usually caused by low operating pressure, weak or broken springs, or by excess friction in the moving joints.

The failure modes are as numerous as the types of designs. Obvious things would be broken mechanical parts, incorrectly manufactured parts, excessively worn parts, excessive corrosion, inadequate lubrication, gummy lubrication, incorrect adjustment, and things of this sort. The forensic analyzer should study carefully the manufacturer's schematics and drawings relating to the operation of the particular mechanism, considering the role of each part involved. After some study, a best fit scenario explaining the reason for failure shall be developed. Not all mechanical failures are attributed to the mechanism. There are a few that could be caused by jamming of the main contacts or contact rods, bell cranks, etc.