ELECTRIC POWER
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Plant Engineering: Relay Procurement and Acceptance

Checklist and Considerations

2015 TECHNICAL REPORT

Plant Engineering: Relay Procurement and Acceptance

Checklist and Considerations

All or a portion of the requirements of the EPRI Nuclear Quality Assurance Program apply to this product.

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Abstract

This report provides guidance for the procurement and acceptance of general-purpose, electromechanical control relays. The report is presented in the form of a checklist and includes considerations for information to include in procurement documents and acceptance tests.

Keywords
Acceptance testing
Relay
Procurement

Executive Summary

Purpose

The purpose of this report is to provide a checklist of considerations to be made when procuring and accepting relays for use in nuclear power plants.

Introduction

Operating experience in commercial plants reflects failure of relays during acceptance testing at receipt and while operating. This report is intended for use by individuals responsible for the procurement and acceptance of relays in an effort to reduce failures in-service.

Scope

This report is intended to provide guidance for use in procurement and acceptance of relays that can be followed to improve the reliability of installed relays.

This report focuses on electromechanical, general-purpose auxiliary and control relays. Protective, hybrid, and digital relays are not included in the scope of this report.

Key Conclusions

The main conclusion that emerged from the development of the guidance in this report is that the reliability of relays can be improved through the following:

- Procurement specifications that effectively communicate pertinent information to the relay supplier
- Acceptance testing that is based on the application and function of the relays prior to acceptance for use
- An effective in-storage maintenance program

Table of Contents

List of Figures

List of Tables

Section 1: Introduction

1.1 Objectives

The objective of this guidance is to provide a checklist that can be used to ensure that appropriate considerations are made during the procurement and acceptance of electromechanical control and auxiliary relays. The report and checklists can be revised as necessary in the future to correct, adjust, and capture activities and methodologies that yield successful results.

Operating experience in commercial plants reflects failures of relays during acceptance testing at receipt and while operating. Although this served as the genesis to this report, troubleshooting and investigating failures are outside the scope of this report. Additional guidance on relay troubleshooting and failure modes can be found in the Electric Power Research Institute (EPRI) reports *Maintenance and Application Guide for Control Relays and Timers* (TR-102067) [1] and *Protective Relay Maintenance and Application Guide* (NP-7216) [2].

1.2 Approach

The checklist items included in this report were developed by subject matter experts (SMEs) actively involved in procurement and testing of relays. The technical advisory committee that developed this guidance included both power plant and supplier personnel.

1.3 Applicability

The tests and inspections included in this report are intended to be conducted prior to accepting relays for use and should not replace bench testing conducted immediately prior to installation or post-maintenance testing.

Relays perform a vital role in the control of both safety- and non-safety-related equipment in nuclear power plants. Relays are used in a variety of applications, including motor control centers, switchgear panels, and control panels.

Control relays and auxiliary relays share the same construction. The difference in nomenclature describes the relay's application or function. This report uses the term *relay* to describe both control and auxiliary relays.

In general, relays are electrically operated switches used to control downstream devices, such as motor starters and pilot devices. They are used in applications that typically involve control circuit voltages, such as 120 Vac, 125 Vdc, or less. They are available in a wide variety of coil ratings, configurations, and contact ratings.

In most applications, relays are used in low-voltage and current-switching applications, as opposed to contactors whose primary application is to reliably supply and interrupt the main branch power. Although this restriction is placed on relays, they still may be used to control equipment that might have a high current demand.

One of the most common relay types is electromechanical. The design of electromechanical relays is based on the use of an electromagnet (either electromagnetic attraction or electromagnetic induction). Figures 1-1 and 1-2 show the electromagnetic attraction mechanism, which is the more common of the two mechanisms. As shown in Figures 1-1 and 1-2, the state of a relay coil governs the relay output contact states. When the relay coil is energized, the electromagnetic force generated by the electromagnet (iron core + coil) induces a physical deformation of the ferrous-based armature arm. The deformation induces the closing of the relay's normally open contact, allowing current flow through the relay common and normally open terminal. In much the same way, the deformation induces the opening of the relay's normally closed contact, preventing current flow through the relay common and normally closed terminal. Because the relay contains electrical and mechanical mechanisms, both should be taken into account.

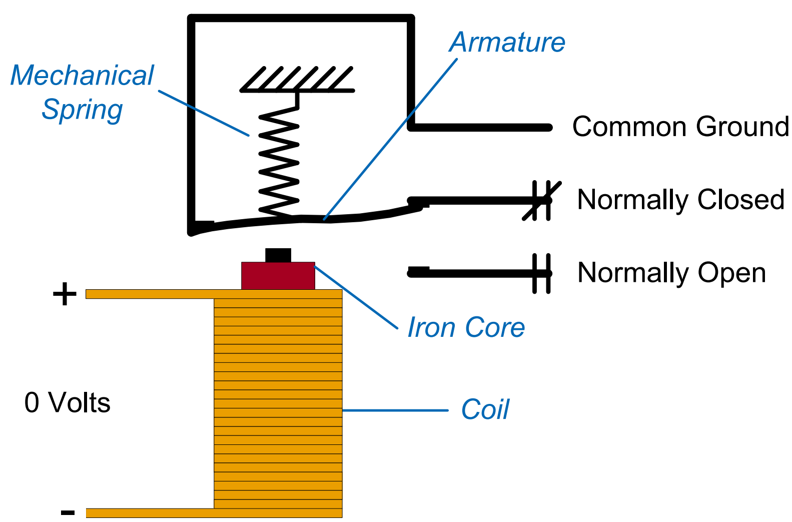

Figure 1-1
Electromechanical relay internal configuration (no load)

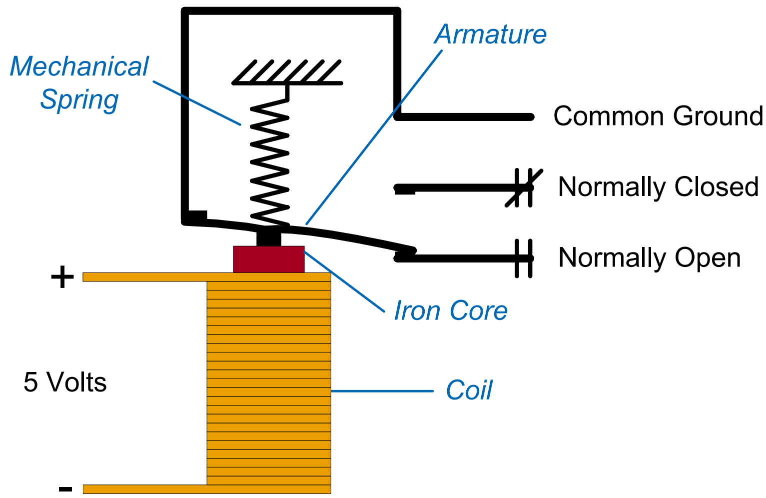

Figure 1-2
Electromechanical relay internal configuration (with load)

The EPRI reports *Maintenance and Application Guide for Control Relays and Timers* (TR-102067) [1] and *Protective Relay Maintenance and Application Guide* (NP-7216) [2] include comprehensive information on relay topics and can be consulted for in-depth discussions on the use and importance of relays.

The tests and inspections included in this report may be used to identify typical failures experienced by general-purpose, electromechanical control and auxiliary relays.

1.4 Conclusions

The reliability of relays can be improved through procurement specifications that effectively communicate pertinent information to the supplier. Reliability can also be improved by performing testing that is based upon the relays' intended applications and functions prior to acceptance for use.

1.5 Basic Stages of Relay Procurement and Acceptance

A section is included in this report for each basic phase in relay procurement and acceptance. These stages and the associated report section are shown in Table 1-1.

Table 1-1
Basic stages of relay procurement and acceptance

Key Phases	Report Section
Procurement Document Information	3
Acceptance Testing	4
Long-Term Storage Considerations	5

Section 2: Terms and Definitions

2.1 Lexicon

Table 2-1 presents the lexicon used in discussions about procurement and inspection of relays. The source document for each definition is noted.

Table 2-1
Lexicon

Acceptance testing	Tests and inspections performed after relays are received to gain additional confidence that they will function correctly and reliably. Acceptance tests are conducted prior to the relay's acceptance for use.
Auxiliary contact	Contacts in addition to the main circuit contacts that function with the movement of the main circuit contacts. Source: ANSI/IEEE Standard 100-1984, IEEE [3].
Auxiliary relay	A relay whose function is to assist another relay or control device in performing a general function by supplying supplementary actions (also called a *control relay*). Source: ANSI/IEEE Standard 100-1984, IEEE [3].
Basic component	(1) When applied to nuclear power reactors, any plant structure, system, component, or part thereof necessary to assure (i) The integrity of the reactor coolant pressure boundary, (ii) The capability to shut down the reactor and maintain it in a safe shutdown condition, or (iii) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to those referred to in § 50.34(a)(1), § 50.67(b)(2), or § 100.11 of this chapter, as applicable.

Table 2-1 (continued)
Lexicon

Basic component (Continued)	(2) When applied to other types of facilities or portions of such facilities for which construction permits are issued under § 50.23, a component, structure, system or part thereof that is directly procured by the construction permit holder for the facility subject to the regulations of this part and in which a defect or failure to comply with any applicable regulation in this chapter, order, or license issued by the Commission could create a substantial safety hazard. (3) In all cases, *basic component* includes safety related design, analysis, inspection, testing, fabrication, replacement parts, or consulting services that are associated with the component hardware, whether these services are performed by the component supplier or other supplier. Source: 10CFR50.2 [4].
Break contact	A contact which is open when the relay is in its operate condition and which is closed when the relay is in its release condition. Source: International Electrotech-nical Commission (IEC) 60050, Area 444-04-18, January 2002 [5].
Class 1E	The safety classification of the electric equipment and systems that are essential to emergency reactor shutdown, containment isolation, reactor core cooling, and containment and reactor heat removal, or otherwise are essential in preventing significant release of radioactive material to the environment. Source: IEEE 323-1974 [6].
Contact	(1) A conducting part that acts with another conducting part to make or break a circuit. (2) The portion of current-carrying members at which electrical circuits are opened or closed. Sources: ANSI/IEEE Standard 100-1984, IEEE [3], EPRI 102067 [1].
Dropout	Dropout contact operation (opening or closing) as a relay just departs from pickup. The value at which dropout occurs is usually stated as a percentage of pickup. For example, dropout ratio of a typical instantaneous overvoltage relay is 90 percent. Source: ANSI/IEEE Standard 100-1984, IEEE [3].

Table 2-1 (continued)
Lexicon

Dropout voltage	The voltage at which the device will release to its de-energized position. Source: ANSI/IEEE Standard 100-1984, IEEE [3].
Environmental qualification	The generation and maintenance of evidence to assure that equipment will operate on demand, to meet system performance requirements within specified environmental conditions—a more limited term than *equipment qualification*. Source: *Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1* [7].
Hold-in voltage	As the current or voltage on an operated relay is increased, the value at or below which all relay contacts must restore to their operated positions. Also referred to as *hold in value*.
Hold point	A specified place in work processes, procedures, or instructions that requires a witness or verification action beyond which work is not to continue without approval indicating that the specified criteria for the hold were satisfactorily fulfilled. Source: *Plant Engineering: Guideline for the Acceptance of Commercial-Grade Items in Nuclear Safety-Related Applications: Revision 1 to EPRI NP-5652 and TR-102260* [8].
Inductive kick	Describes the large reverse voltage transient that occurs when the current through an inductor is suddenly interrupted [9].
Like-for-like replacement	The replacement of an item with an item that is identical. Source: *Plant Engineering: Guideline for the Acceptance of Commercial-Grade Items in Nuclear Safety-Related Applications: Revision 1 to EPRI NP-5652 and TR-102260* [8].
Make contact	A contact that is closed when the relay is in its operate condition and which is open when the relay is in its release condition. Source: ANSI/IEEE C37.98-1987 [10].
Normally open contact	A contact combination that is open when the armature is in its unoperated position [1].
Normally closed contact	A contact combination that is closed when the armature is in its unoperated position [1].
Pickup	A term used to describe the condition that occurs when a relay changes from an un-energized to an energized condition and actuates contact(s). Source: ANSI/IEEE Standard 100-1984 [3].

Table 2-1 (continued)
Lexicon

Pickup voltage	The minimum voltage at which the device moves from its de-energized into it fully energized position. Source: ANSI/IEEE Standard 100-1984 [3].
Safety-related	Safety-related structures, systems, and components means those structures, systems, and components that are relied upon to remain functional during and following design basis events to assure: (1) The integrity of the reactor coolant pressure boundary (2) The capability to shut down the reactor and maintain it in a safe shutdown condition; or (3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the applicable guideline exposures set forth in § 50.34(a)(1) or § 100.11 of this chapter, as applicable. Source: 10CFR50.2 [4].
Seismic qualification	The generation and maintenance of evidence to assure equipment's ability to perform its safety function during and/or after the time it is subjected to the forces resulting from one safe shutdown earthquake. Source: IEEE 344-2004 [11].

2.2 Acronyms and Abbreviations

Table 2-2 sets forth the acronyms and abbreviations used in this report.

Table 2-2
Acronyms and abbreviations

ANSI	American National Standards Institute
ac	alternating current
°C	degree(s) Celsius
CFR	Code of Federal Regulations (U.S.)
dc	direct current
EMI	electromagnetic interference
EPRI	Electric Power Research Institute
Hz	hertz
IAEA	International Atomic Energy Agency
IEC	International Electrotechnical Commission
IEEE	IEEE-SA (formerly, Institute of Electrical and Electronics Engineers)
INPO	Institute of Nuclear Power Operations
ISO	International Standards Association
M&TE	measurement and test equipment
NC	normally closed (contact)
NEMA	National Electrical Manufacturers Association
NO	normally open (contact)
OEM	original equipment manufacturer
OES	original equipment supplier
QA	quality assurance
RFI	radio frequency interference
rms	root-mean-square
R_P	potentiometer resistance
RRS	required response spectra
SME	subject matter expert
T_{TE}	thermal equilibrium
V	volt(s)
Vac	alternating current voltage
Vdc	direct current voltage
WANO	World Association of Nuclear Operators

Section 3: Procurement Document Information

Procurement documents are the primary means of communicating important information to the supplier and play an important role in design control. Pertinent design information and technical requirements are included in procurement documents to ensure that the relay provided is the correct relay and meets all applicable requirements. In addition, the information helps to ensure that the supplier provides the correct item and gives notification when the information in the procurement document is not consistent with the item that the supplier plans to provide.

The following types of information should be considered for inclusion in relay procurement documents. The type and detail of information included vary.

3.1 Operating Experience Review

A review of operating experience is recommended prior to establishing procurement requirements. The sources of operating experience on relays include the following:

3.1.1 ☐ Operating experience internal to the organization procuring the relays

3.1.2 ☐ Regulatory documents (such as those issued by the U.S. Nuclear Regulatory Commission and other regulatory agencies)

3.1.3 ☐ Other sources of operating experience, such as the World Association of Nuclear Operators (WANO), Institute of Nuclear Power Operations (INPO), and International Atomic Energy Agency (IAEA)

3.1.4 ☐ Manufacturer's bulletins and information letters

3.2 General Information

The following types of information provide the supplier with the information necessary to identify and supply a relay that meets all applicable requirements:

3.2.1 ☐ Original equipment manufacturer (OEM)

3.2.2 ☐ Model number

3.2.3 ☐ Original equipment supplier (OES) name and part number or other identifying information (particularly in cases where the original relay was not provided by the OEM)

3.2.4 ☐ Identification of the original shop order

3.2.5 ☐ Precautions related to outdated specifications or other information that is not current or no longer applies to the relay(s) being procured

3.2.6 ☐ Operating experience/failure information that may assist the supplier in reducing the likelihood of similar failures

3.3 Qualification Requirements

Additional information should be included in procurement documents when the relays being procured are required to be seismically and/or environmentally qualified. In the case of like-for-like replacements, information relative to the original qualification must be provided. In the case of relays that have not been previously qualified, the information necessary to perform qualification testing must be provided.

3.3.1 Relays for Which Seismic Qualification Has Not Been Previously Established

The information presented in the checklist items in this section only applies to relays that are subject to seismic qualification requirements.

The information presented in 3.3.1.1–3.3.1.7 should be included in procurement documents for relays that are subject to seismic qualification requirements but for which seismic qualification has not yet been established. As a minimum, the information presented in 3.3.2.1 and 3.3.2.2 should be included in procurement documents for relays that are subject to seismic qualification requirements and for which seismic qualification was previously established.

3.3.1.1 ☐ **Contact configuration and type** (such as normally open, normally closed, make before break, break before make, number of poles, throws, and default position [form]).

3.3.1.2 ☐ **Nominal coil voltage**. **Note**: For alternating current (ac) relays, the coil voltage frequency needs to be specified. Most North American plants operate using 60-Hz power, whereas most Asian and European plants operate using 50-Hz power.

3.3.1.3 ☐ **Degraded voltage requirement** (such as pickup/ dropout).

3.3.1.4 ☐ **Required response spectra (RRS)**. In the event that the RRS are not provided, IEEE C37.98-1987, *IEEE Standard Seismic Testing of Relays* [10], recommends standard multifrequency broadband RRS whose shape is dependent on the zero period acceleration. Use of the standard should be agreed upon in cases where RRS are not provided.

3.3.1.5 ☐ **Accessories** (surge suppressors, auxiliary contacts). Qualification testing used to establish the suitability of a relay with one set of auxiliary contacts may not extend to establish the suitability of a relay with more than one set of auxiliary contacts. Pickup voltage typically increases proportionally with the number of auxiliary contacts. Because seismic qualification testing should be performed at the degraded voltage condition, the number of contacts can impact qualification.

3.3.1.6 ☐ **Mounting hardware and torque specifications**.

3.3.2 Relays for Which Seismic Qualification Was Previously Established (and Documented in a Seismic Qualification Report)

3.3.2.1	☐	The original seismic qualification report and applicable revision are included in the procurement documents.
3.3.2.2	☐	The procurement document includes a requirement for the supplier to provide certification to the original seismic qualification report.

3.3.3 Environmental Qualification

This section applies only to relays that are subject to environmental qualification requirements.

The information presented in 3.3.3.1–3.3.3.10 should be included in procurement documents for relays that are subject to new environmental qualification requirements but for which environmental qualification has not yet been established. In addition to accident profiles, the minimum and maximum service conditions should be included in procurement documents that require environmental qualification testing.

3.3.3.1	☐	Operating time (such as continuous or according to a client-specified duty cycle)
3.3.3.2	☐	Thermal conditions (temperature)
3.3.3.3	☐	Pressure conditions
3.3.3.4	☐	Relative humidity (condensing/noncondensing) conditions
3.3.3.5	☐	Radiation conditions (that is, gamma/beta)
3.3.3.6	☐	Steam conditions
3.3.3.7	☐	Chemical spray conditions
3.3.3.8	☐	Special seismic tests
3.3.3.9	☐	Accident and post-accident profiles
3.3.3.10	☐	Identification of nonmetallic materials used in construction of the relay

As a minimum, the information in 3.3.3.11 and 3.3.3.12 should be included in procurement documents for relays that are subject to environmental qualification requirements and for which environmental qualification was previously established:

3.3.3.11	☐	The original environmental qualification report and applicable revision is included in the procurement documents.
3.3.3.12	☐	Certification to the original environmental qualification report is a purchase order requirement.

3.3.4 Electromagnetic/Radio Frequency Interference Requirements

Typically, electromagnetic interference (EMI) and radio frequency interference (RFI) do not have an adverse effect on electromechanical relays that do not include digital or solid-state components. However, in some cases, such as for relays used in dc applications, EMI/RFI testing of the relays might be required.

Surge and transient suppression devices can be added to relay circuitry to mitigate the impact of inductive kick and other electrical transients. These devices include resistor/capacitor networks, varistors, and diodes. The inclusion of these items into testing is outside the scope of this report. Perform surge suppression selection in accordance with plant procedures.

Additional information on electromagnetic testing is included in the EPRI report *Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment: Revision 4 to TR-102323* (3002000528) [12].

3.3.4.1 ☐ Surge and transient suppression devices are specified in the procurement documents when applicable.

3.3.5 Cyber Security/Computer Program Verification and Validation

Verification, validation, and cyber security considerations are not addressed in this report because the scope of the report is limited to analog relays.

3.3.5.1 ☐ Verify that the relay does not contain any digital devices.

3.4 Applicable Standards and Specifications

3.4.1 ☐ Applicable National Electrical Manufacturers Association (NEMA) specifications are identified in the procurement documents.

3.4.2 ☐ Applicable IEC specifications are identified in the procurement documents.

3.5 Quality Assurance and Technical Requirements

3.5.1 ☐ Quality assurance (QA) program requirements applicable to the seller should be included in the procurement document. The following quality and technical requirements are compulsory (in the United States) for relays being procured as basic components (safety-related):

- ☐ The seller's QA program must comply with the requirements of 10CFR50, Appendix B [13].
- ☐ Report defects and noncompliance in accordance with the requirements of 10CFR, Part 21 [14].

3.5.2 ☐ QA hold points (as applicable).

3.5.3 ☐ QA source surveillance requirements (as applicable).

3.5.4 ☐ Rights to access the seller's facilities.

3.5.5 ☐ Documentation requirements:

3.5.5.1 ☐ Certification to procurement document requirements

3.5.5.2 ☐ Certification to seismic and environmental qualification reports

3.5.5.3 ☐ Examination and testing records

3.5.5.4 ☐ Drawings

3.5.5.5 ☐ Maintenance manuals

3.5.5.6 ☐ Packaging and shipping requirements

3.5.5.7 ☐ Storage and shelf-life recommendations, including in-storage preventive maintenance recommendations

3.5.5.8 ☐ Registration requirements, such as registration with Underwriters Laboratory and Canadian Standards Association

3.6 Information Required to Evaluate Relays Proposed as Equivalent Replacements

3.6.1 ☐ Dimensional and configuration information

3.6.2 ☐ Mounting and footprint information

3.6.3 ☐ Engineering change notifications/reports

3.6.4 ☐ Information on features

3.7 Supplemental Information That May Be Useful When Using a Supplier Other Than the OEM

3.7.1	☐	Photographs of the original relay to help better identify the relay desired
3.7.2	☐	Original specification

3.8 Information Related to Material Requirements and Accessories for Relays Used in Special Applications

3.8.1	☐	Surge and transient suppression devices.
3.8.2	☐	Contact material type and rating (very low resistance, gold, and so on). **Note**: A wide variety of contact materials can be specified. For example, gold contacts are used in low-voltage/low-current applications due to their resistance to tarnish or oxidation. Section 2.1.2.3 of *Maintenance and Application Guide for Control Relays and Timers* (EPRI TR-102067) [1] covers a variety of relay contact materials.

3.9 Request for Shelf-Life and In-Storage Preventive Maintenance Information

3.9.1	☐	A request that the manufacturer's recommended shelf life information be provided with the relay
3.9.2	☐	A request that the manufacturer's recommended in-storage preventive maintenance information be provided with the relay

Section 4: Acceptance Testing

Tests and inspections can be performed after relays are received to provide additional confidence that they will function correctly and reliably. Acceptance tests and inspections are typically performed by receipt inspectors, instrumentation and control technicians, or other qualified individuals. Tests and inspections included in this section were identified by the technical advisory committee involved in developing this report and may not include all tests and inspections available. Acceptance testing should be based upon factors such as the relay's application, operating conditions, and operating experience.

Tests and inspections included in this section may also find application in commercial-grade item dedication. Additional insight relative to procurement of relays may be gleaned through tracking and trending the results of acceptance testing.

It may be appropriate to test relays that have been in storage for extended periods prior to installing them.

The following tests and inspections shall be performed in sequence, unless otherwise noted. The testing methodology and acceptance criteria are presented below. Measurement and test equipment (M&TE) should be calibrated in accordance with the applicable QA program requirements. When available, facility-specific acceptance criteria and test procedures or manufacturer's ratings should be used in lieu of those included in this section.

Whenever sampling is used, the basis for selection and use of a particular sample plan should be documented. The EPRI report *Guideline for Sampling in the Commercial-Grade Item Acceptance Process* (TR-017218-R1) [15] provides guidance that may be applied to establish sample sizes for tests and inspections.

This section uses the terms *OPEN* and *CLOSED*. For the purposes of this report, contact resistance greater than 40 megaohms (or to the limitation of the M&TE multimeter) is considered open, and contact resistance less than 1 ohm is considered closed. However, because the criteria for OPEN and CLOSED may vary, the resistance values for open and closed defined in applicable testing procedures should be used when conducting tests and inspections.

Information in facility-specific testing and inspection procedures relative to cleaning contacts prior to testing by burnishing, energizing, or cycling should be followed.

4.1 Test Setup

4.1.1 ☐ Test fixtures for relays should be designed so that relays are mounted in their installed configuration prior to testing.

4.1.2 ☐ Review the relay manufacturer's published literature to determine if the relay requires adjustment prior to testing. For example, certain relays have long contact fingers that may result in movement during shipping. Following the manufacturer's recommendations and making necessary adjustments prior to testing may help avoid unnecessary testing failures.

4.2 Coil Resistance

A coil resistance test helps to establish that the coil winding is correct. Incorrect coil winding can prevent pickup at degraded voltage or produce overheating at elevated voltage.

4.2.1 ☐ Measure the coil resistance of each relay. As a general rule, coil resistance values in a single lot of relays should not vary more than 10% from the average value of all relays measured. Coil resistance in excess of 10% of the average may indicate a defect. Therefore, coils with resistance in excess of 10% of the average should be further evaluated prior to accepting the coil for use.

4.2.2 ☐ The coil resistance value for each coil should be within the manufacturer's published tolerances. In cases where the manufacturer's coil resistance tolerance criteria are not available, it may be useful to maintain a documented record of test results for each make and model number. Such a record can be used to establish acceptance criteria and trend performance of specific relay models.

4.3 Contact Configuration Under No Load

This test should be performed prior to any subsequent test to ensure that the received relay's contact configuration is correct without it being energized.

4.3.1 ☐ Measure normally open contact resistance to verify that it meets established acceptance criteria.

4.3.2 ☐ Measure normally closed contact resistance to verify that it meets established acceptance criteria.

4.4 Undervoltage Testing

The purpose of undervoltage testing is to test to the application-specific degraded voltage and/or minimum pickup requirements. These requirements are dependent on the application and the facility in which the relay is installed. Testing at degraded voltage conditions validates that the relays will pick up when operating in degraded voltage conditions.

Undervoltage testing may be performed at the minimum pickup voltage specified by the manufacturer or at the minimum pickup voltage specified in applicable procedures.

Undervoltage testing is typically performed as follows:

4.4.1 ☐ The relay is tested at the specified undervoltage condition to verify that the relay successfully picks up.

a. Typically, ac coils will operate at voltages 15–20% below rated voltage.
b. Typically, dc coils will operate at voltages 20–25% below rated voltage.

Acceptance is as follows:

- Normally open contact resistance = CLOSED
- Normally closed contact resistance = OPEN

4.5 Overvoltage Testing

WARNING
Overvoltage testing is potentially destructive. Exercise extreme caution and do not exceed test levels.

The purpose of overvoltage testing is to verify that the relay will not malfunction (for example, overheat) during short- or long-duration elevated voltage conditions, such as those present when a battery is being charged.

Direct current relays can experience long-duration elevated voltage conditions in the range of 132 Vdc in applications such as where a battery float voltage is placed on a 125-Vdc (nominal) system. In addition, dc relays can experience elevated voltage conditions in the range of 142 Vdc in 125-Vdc (nominal) applications, such as a system with a battery equalizing charge voltage.

Normal operating voltage for ac relays is typically close to the system's nominal voltage.

Overvoltage testing is appropriate for normally energized relays installed in applications that experience overvoltage conditions.

Test voltages are based on the system operating voltage (not relay coil voltage). The test voltage is typically 110% of nominal voltage, and it should be based upon the intended application.

Successful completion of overvoltage testing does not indicate that a relay will not experience damage when exposed to high-voltage spikes. If high- voltage input spikes are a known concern for the system in which the relays are installed, surge suppression equipment should be considered as a means to protect relays and associated electrical equipment.

Overvoltage testing is typically performed as follows:

4.5.1 ☐ Apply the specified overvoltage value to the relay coil for the specified duration noted in the following. Measure contact resistances. Perform the test two times. Visually inspect the relay for damage. Acceptance is as follows:

- Normally open contacts resistance = CLOSED.
- Normally closed contacts resistance = OPEN.
- Duration: The duration is the amount of time until the relay has reached thermal equilibrium (T_{TE}) plus 10% of this duration.

  Duration is equal to 1.1 times T_{TE}, where T_{TE} is the time it takes the relay to reach thermal equilibrium.

  Note: In this context, thermal equilibrium is the steady-state temperature of a measured device. *Steady state* is typically defined as a temperature fluctuation of equal to or less than 1°C in a 1-minute duration.
- No visible sign of damage to the relay should be evident.

4.6 Contact Rating

Relay contact ratings are typically verified by performing a continuous contact rating test. However, in certain high-voltage dc applications (such as 250-Vdc nominal systems) that are susceptible to contact arcing, a continuous contact rating test and a make/break rating test can be conducted. Arcing is significantly less destructive in ac circuits at the same root-mean-square (rms) voltage/current because the arc is extinguished at the zero potential of each wave cycle. Testing should be conducted in accordance with the applicable specifications and procedures.

Make/break rating testing is appropriate for relays used in applications such as high-voltage dc systems where electrical arcs can occur between the two relay electrodes during opening and closing of the switch, with the opening arc typically being more destructive. The heat developed by the resulting arc can cause the switch contact metal to migrate between electrodes, resulting in permanent electrical conduction between electrodes.

4.6.1 Continuous Current Rating

Manufacturer specifications typically include a continuous contact current rating, which is the maximum continuous-use current that can be injected through a closed relay contact for a certain duration. Testing may be conducted using the duration specified by the manufacturer or the duration required for the relay to function in its intended end-use application.

4.6.1.1 ☐ With the relay de-energized and all normally closed contacts wired in series, the manufacturer's rated continuous current is injected through the closed contacts for the applicable duration. Figure 4-1 depicts a typical contact current rating test setup for this step.

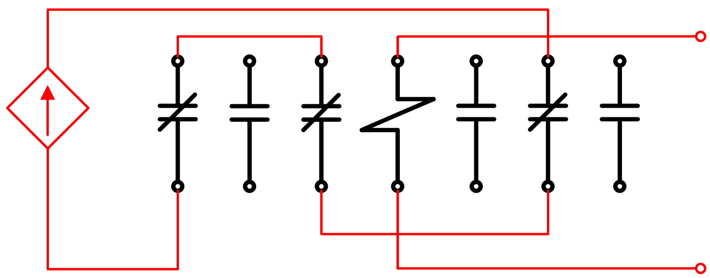

Figure 4-1
Example of a contact rating test setup for a relay with three normally open and three normally closed contacts—relay de-energized

4.6.1.2 ☐ With all normally open contacts wired in series, the manufacturer's rated current is injected through the contacts while rated voltage is applied to the relay coil for the applicable test duration. Afterward, the power to the relay coil is removed. Figure 4-2 depicts a typical contact current rating test setup for this step.

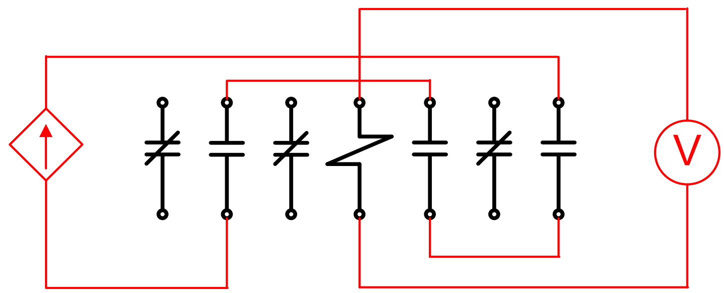

Figure 4-2
Example of a contact rating test setup for a relay with three normally open and three normally closed contacts—relay energized

4.6.1.3 ☐ Remove all jumpers and visually inspect each of the contacts to verify that no damage is evident.

4.6.1.4 ☐ Verify that OPEN and CLOSED contact resistances are acceptable through direct measurement. Cycle the contacts by applying nominal voltage to the relay coil to inspect contact resistance in the opposite state.

4.6.2 Contact Make/Break Rating Test

Electrical arcing may occur when a relay transitions from a closed to open state (breaks) or from an open to a closed state (makes). Arc energy is higher in applications that experience inductive load. Arc energy slowly degrades the contact due to migration of the surface material between contacts. Contact degradation can eventually result in failure of the relay.

Break Testing

4.6.2.1 ☐ Figure 4-3 illustrates a configuration for break testing at the manufacturer-specified voltage, V. An ammeter placed in series measures current. The potentiometer resistance, R_P, is adjusted so that current through the initially closed contact is equal to the manufacturer's rated break current at voltage V.

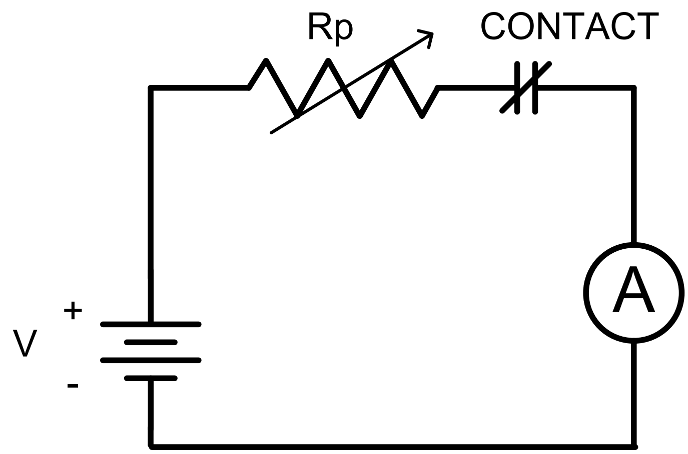

Figure 4-3
Example break test setup

4.6.2.2 ☐ Rated voltage is applied to the relay coil, and the contacts are visually observed as they open. Afterward, contacts are visually inspected to confirm that no damage is evident. Verify that OPEN contact resistance is acceptable through direct measurement. **Note**: Arcing is present during switching on any electrical power device, although this is typically very minor and unnoticeable over the entire lifetime of the relay.

4.6.2.3 ☐ Remove power to the relay coil. Verify that the CLOSED contact resistance is acceptable through direct measurement.

Make Testing

4.6.2.4 ☐ Figure 4-4 illustrates a typical setup for make testing. The voltage, V, is provided by the manufacturer. The potentiometer resistance, R_P, is adjusted based on Ohm's Law to meet the required current. Place an ammeter in series to measure the current.

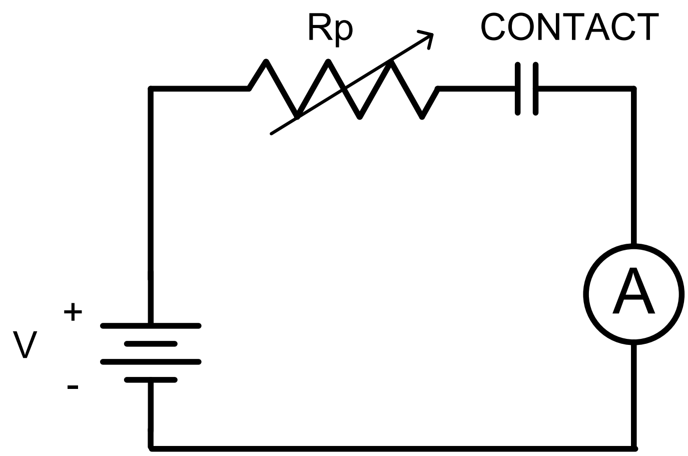

Figure 4-4
Example make test setup

4.6.2.5 ☐ Apply rated voltage to the relay coil, and observe the contact under test as it closes. Verify that there is no visible damage to the contact after the test. Verify that the CLOSED contact resistance is acceptable through direct measurement.

4.6.2.6 ☐ Remove power to the relay coil. Verify that the OPEN contact resistance is acceptable through direct measurement.

4.7 Insulation Resistance Testing Considerations

WARNING
Never conduct insulation resistance testing across normally open contacts.

The purpose of an insulation resistance test is to ensure that the relay does not contain any breakdown of electrical insulation and/or unwanted conduction paths. The typical test is a high-voltage dc test; however, this can be substituted by power frequency dielectric tests as prescribed in Section 4.8.

If a power frequency dielectric test (using a hi-pot tester) is to be performed instead of a typical high-voltage dc test, perform the steps in Section 4.8 instead of the steps noted in this section.

Table 4-1 contains the typical minimum insulation resistance test parameters included in NEMA ICS 1-109, *Tests and Test Procedures* [16].

Table 4-1
Minimum test voltage for insulation resistance testing

Relay Voltage Rating	Minimum Test Voltage (dc)
0–50	500 V
51–600	1000 V + 2 X nominal voltage rating
601–5000	2000V + 2 ¼ X nominal voltage rating

4.7.1 ☐ Perform insulation resistance testing using the minimum required voltages included in Table 4-1.

4.7.2 ☐ Minimum insulation is 10 megaohms + 10^{-2} x nominal rated voltage.

4.7.3 ☐ The test duration shall be 1 minute or as specified in applicable procedures.

4.8 Additional Testing Considerations

(**Note**: The test sequence should be determined by experienced technicians.)

The following optional tests may be performed on relays as appropriate to validate the relay's capability to perform its intended function. For example, a minimum pickup time test could be specified to verify that a relay will not inadvertently energize downstream equipment.

4.8.1 ☐ **Power frequency (hi-pot) testing**. The purpose of power-frequency dielectric tests is to check for electrical isolation between electrical circuits that are designed to be electrically isolated from each other. This is a post-assembly test, instead of a typical component high-voltage dc test. In certain applications, equivalent dc rms values may be used (post-assembly high-voltage dc test).

NEMA ICS 1-109, *Tests and Test Procedures* [16], includes criteria for power frequency testing.

4.8.2 ☐ **Coil inrush characteristics**. The purpose of a coil inrush characteristic test is to verify the manufacturer's rated inrush (transient) volt-ampere rating. This value is important in preventing excessive voltage drop and malfunctions during transient conditions. Test and acceptance criteria for performing coil inrush characteristic testing is typically obtained from the relay manufacturer.

4.8.3 ☐ **Coil seal-in characteristics**. The purpose of a coil seal-in characteristic test is to verify the manufacturer's rated seal-in (steady-state) volt-ampere rating. This value is important when determining steady-state circuit parameters and thermal load behavior. The test and acceptance criteria for performing coil seal-in characteristic testing are typically obtained from the relay manufacturer.

4.8.4 ☐ **Coil maximum drop-out voltage**. **Note**: This value is sometimes significantly lower than the minimum pickup voltage, especially for dc applications.

4.8.5 ☐ **Dropout time at loss of nominal voltage**.

4.8.6 ☐ **Pickup time**.

Other special tests based upon specific applications and operating experience concerns may also be appropriate, such as the following:

- Contact over-travel test
- Contact air gap test
- Wear allowance test

Section 5: Long-Term Storage Considerations

Although relays are generally not considered to be sensitive to degradation while in storage, it is possible for relays that are subjected to long-term storage to experience degradation. Over time, contacts may develop oxidation. In addition, suboptimal storage conditions may result in degradation of insulation. Some relays are provided with lubricant applied to moving parts. Lubricants, such as grease, may dry out and harden during long-term storage. Therefore, the manufacturer's shelf-life recommendations should be considered for relays supplied with lubricant.

Some or all of the following may be appropriate for relays that have been in storage for extended periods.

5.1 Shelf Life and In-Storage Maintenance

5.1.1	☐	Follow the manufacturer's shelf-life recommendation.
5.1.2	☐	Follow the manufacturer's in-storage preventive maintenance recommendations.

5.2 Operation and Testing After Long-Term Storage

5.2.1	☐	Operate the coil (prior to testing). Operating the coil may serve to condition oxidized contacts.
5.2.2	☐	Inspect the condition of contacts.
5.2.3	☐	Perform a coil resistance test.
5.2.4	☐	Perform a contact rating test.

Section 6: References

6.1 In-Text References

1. *Maintenance and Application Guide for Control Relays and Timers*. EPRI, Palo Alto, CA: 1993. TR-102067.
2. *Protective Relay Maintenance and Application Guide*. EPRI, Palo Alto, CA: 1993. NP-7216.
3. *IEEE Standard Dictionary of Electrical and Electronics Terms*. ANSI/IEEE Standard 100-1984 Institute of Electrical and Electronics Engineers, Inc., New York, NY: 1984.
4. U.S. Code of Federal Regulations, Title 10, Chapter 1, Part 50, Domestic Licensing of Production and Utilization Facilities. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, D.C.
5. *International Electrotechnical Vocabulary.* IEC 60060. International Electrotechnical Commission, Geneva, Switzerland: January 2002.
6. *IEEE Standard-for Qualifying Class IE Equipment for Nuclear Power Generating Stations*. IEEE 323-1974, Institute of Electrical and Electronics Engineers, Inc., New York, NY: 1974.
7. *Plant Support Engineering: Nuclear Power Plant Equipment Qualification Reference Manual, Revision 1*. EPRI, Palo Alto, CA: 2010. 1021067.
8. *Plant Engineering: Guideline for the Acceptance of Commercial-Grade Items in Nuclear Safety-Related Applications: Revision 1 to EPRI NP-5652 and TR-102260*. EPRI, Palo Alto, CA: 2014. 3002002982.
9. H. Ott, *Electromagnetic Compatibility Engineering*. John Wiley & Sons, Hoboken, NJ: 2009.
10. *IEEE Standard Seismic Testing of Relays.* ANSI/IEEE C37.98-1987. IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 1987.
11. *IEEE Recommended Practice for Seismic Qualification of Class 1E Equipment for Nuclear Power Generating Stations*. IEEE 344-2004, Institute of Electrical and Electronics Engineers, New York, NY: June 2005.
12. *Guidelines for Electromagnetic Compatibility Testing of Power Plant Equipment: Revision 4 to TR-102323*. EPRI, Palo Alto, CA: 2013. 3002000528.

13. U.S. Code of Federal Regulations, Title 10, Chapter 1, Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, D.C.
14. U.S. Code of Federal Regulations, Title 10, Chapter 1, Part 21, Reporting of Defects and Noncompliance. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, D.C.
15. *Guideline for Sampling in the Commercial-Grade Item Acceptance Process*. EPRI, Palo Alto, CA: 1999. TR-017218-R1.
16. *Tests and Test Procedures*. NEMA ICS 1-109. National Electrical Manufacturers Association, Rosslyn, VA: 1978.

6.2 General References

6.2.1 Relay References

IEEE Standard for Relays and Relay Systems Associated with Electric Power Apparatus. ANSI/IEEE C37.90-2005, IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 2005.

IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus. ANSI/IEEE C37.90.1-2012. IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 2012.

IEEE Standard for Qualifying Class 1E Protective Relays and Auxiliaries for Nuclear Power Generating Stations. ANSI/IEEE C37.105-2010. IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 2010.

IEEE Standard for Surge Withstand Capability (SWC) Tests for Relays and Relay Systems Associated with Electric Power Apparatus. IEEE C37.90.1 2002. IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 2002.

6.2.2 Quality Assurance References

Quality Assurance Program Requirements for Nuclear Power Plants. ANSI N45.2. American National Standards Institute, Washington, D.C: 1978.

Quality Assurance Requirements for Nuclear Facility Applications (QA). ASME NQA-1-2008 (edition). American Society of Mechanical Engineers, New York, NY: 2008.

6.2.3 Qualification Testing References

IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations. IEEE 323. IEEE Standards Association, Institute of Electrical and Electronics Engineers, Incorporated, New York, NY: 2003.

U.S. Code of Federal Regulations, Title 10, Chapter 50.49, Environmental Qualification of Electric Equipment Important to Safety for Nuclear Power Plants. Office of the Federal Register, National Archives and Records Administration, U.S. Government Printing Office, Washington, D.C.

IEEE Standard for Seismic Testing of Relays. IEEE 501-1978. Institute of Electrical and Electronics Engineers, New York, NY: 1978.

6.2.4 Other References

IEEE Standard Electrical Power System Device Function Numbers, Acronyms, and Contact Designations. ANSI/IEEE C37.2-2008. IEEE Standards Association, Institute of Electrical and Electronics Engineers, New York, NY: 2008.

Industrial Control and Systems: General Requirements. NEMA ICS 1-2000 (R2005-R2008). National Electrical Manufacturers Association, Rosslyn, VA: 2010.

AC General-Purpose Motor Control Centers. NEMA ICS 2-322. National Electrical Manufacturers Association, Rosslyn, VA: 1978.

Standard for Acceptance Testing Specifications for Electrical Power Equipment and Systems. NETA ATS-2013. International Electrical Testing Association, Portage, MI: 2013.

Standard for Maintenance Testing Specifications for Electrical Power Distribution Equipment and Systems. NETA MTS-2011. International Electrical Testing Association, Portage, MI: 2011.

Standard for Certification of Electrical Testing Technicians. NETA ETT 2010. International Electrical Testing Association, Portage, MI: 2010.

General Requirements for the Competence of Testing and Calibration Laboratories. ISO/IEC Guide 17025:2005. International Organization for Standardization, Geneva, Switzerland: 2005.

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