ELECTRIC POWER
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Plant Engineering: Control Relay Aging Management Guideline

Auxiliary, Control, and Timing Relays

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ABSTRACT

The concept for this report came from the concern that many control relays have been in service for an extended period of time and an effective aging management program may not be in place for these relays. In addition, recent Institute of Nuclear Power Operations (INPO) data indicate that relays are one of the leading component types causing scrams. With control relay age increasing and relays being a significant contributor to scrams, an evaluation of control relay maintenance and replacement strategies was needed with the objective of providing better guidance for addressing relay aging.

In some cases, there has been little preventive maintenance performed on control relays. However, in many cases, control relays are not designed to accommodate much preventive maintenance. Recognizing that control relay preventive maintenance practices vary across the industry, a collaborative approach was used to develop this guide, based on utility input on issues and analysis of industry relay data. The intent was to obtain a large data sample to support conclusions, based on statistical analyses of empirical data, related to relay aging decision making.

To accomplish this control relay aging maintenance strategy evaluation, a technical advisory group (TAG) was formed with representatives from several sites participating. The initial steps taken were to define what control relay data were needed, determine the relays that would be included in the scope of the control relay evaluation, gather current industry guidance and data for control relays (including maintenance strategies), and have TAG members obtain their site-specific data. Auxiliary, control, and timing relays were selected as being within the scope of this project. The data for the control relay population were fairly easily obtained; however, obtaining the failure data required a significant amount of time. In some cases, manufacturer and model information was also difficult to obtain. In addition to the above data, TAG members were requested to obtain their current control relay maintenance strategies and identify any that could be considered industry best practices.

All of the data obtained were reviewed, consolidated, and analyzed to draw initial conclusions that were reviewed by the TAG. From this evaluation, recommendations were developed for addressing control relay aging. The results include guidance on maintenance strategies and frequencies, a decision-making flowchart, programmatic recommendations, and best practices. In addition, several issues were identified from this evaluation that will require further follow-up.

Keywords

Aging management
Auxiliary relay
Control relay
Preventive maintenance
Timing relay

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1
PURPOSE

Auxiliary, control, and timing relays (collectively referred to as *control relays* in this document) at most nuclear power plants have accumulated many years of service life and will be supporting operation for life extension. The concept for the project to develop this report started with the realizations that control relays have been in service for an extended period of time, in many cases they are not designed to accommodate much preventive maintenance, and there may not be an effective aging management program in place. Reliability of these aging relays may be in question for the following reasons:

- Continuously energized relays age at an accelerated rate.
- Normally deenergized relays may have latent failures associated with moisture, corrosion, loose connections, and so on.

Periodic testing may be effective in identifying some failures; however, this operating experience may not be reported and shared across the industry since these failures did not occur during normal in-service operations or meet the reporting threshold. A variety of devices are used at each plant and across the industry, making it even more difficult to recognize adverse trends. In addition, obsolescence of control relays is quite common.

A collaborative approach was used in developing this guide, based on utility input on issues and relay data. The intent was to obtain a large data sample to support conclusions, based on statistical analyses of empirical data, related to relay aging decision making.

Recommendations and maintenance practices contained in this guide will address the reliability challenges for circuits that use control relays, many of which are latent and may not be identified until critical functions are not performed as intended. Ensuring equipment reliability for control relaying circuits helps ensure reliability of the critical systems they support.

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BACKGROUND

In recent U.S. Nuclear Regulatory Commission (NRC) and Institute of Nuclear Power Operations (INPO) site evaluations, issues related to relay preventive maintenance programs have been identified, including adherence to relay replacement intervals, vendor replacement recommendations not being followed, and inadequate justifications for deviations from vendor recommendations. Relay issues continue to surface, and the interest by INPO and NRC in relay failures is increasing. Relays have been identified as an industry issue that warrants increased attention.

In a recent Instrumentation and Control (I&C) meeting held at the Electric Power Research Institute (EPRI), a presentation of INPO failure data for scrams mentioned that relays and air-operated valves (AOVs) were now tied as the third largest contributor to scrams. In the discussions during this meeting, it was pointed out that the actual normalized rate for relay failures is lower than other component types as there is a much larger relative population of relays than for other components. It was also mentioned that the failures of components other than relays has decreased due to industry improvements that have caused relays to move up the list. Industry organizations are working on various relay issues as follows:

- **EPRI**: In prior discussions between EPRI and INPO, it was acknowledged that Equipment Performance and Information Exchange (EPIX) data include only a portion of the data that exist in the industry since many of the failures do not meet the threshold requirements for reporting. EPRI would like to obtain empirical data on service life achieved commensurate with relay environment and service conditions and to compare them with vendor-recommended service life as well as results of engineering evaluations of service life performed by utilities. Replacing relays too late will obviously impact reliability; however, replacing prematurely can adversely impact reliability (infantile failures and errors introduced through replacement activities) while consuming resources better used in other areas to improve equipment reliability. The goal is to determine the best strategy for maintenance and replacement to ensure high reliability.
- **INPO**: In a presentation by INPO at the EPRI Relay Aging Technical Advisory Group (TAG) Meeting held in St. Charles, Missouri, it was pointed out that from January 2006 through June 2010, relays have been involved in 24 scrams, 15 outage impacts, and 11 power reductions as well as the loss of over 3 million MWh of electrical generation. In addition, important systems such as the emergency diesel generator (EDG) system are being affected by relays. It was mentioned that mitigation system performance indicators (MSPI) reportable failures for EDGs are increasing and that relays are a significant contributor.

  As a result of these equipment trends, INPO is now focusing on relays, electronics including capacitors, and circuit cards as part of its evaluations.

- **NRC**: The following excerpts related to electronic components, including relays, are from NRC Operating Experience Smart Sample (OPESS) FY 2010-01, "Recent Inspection Experience for Components Installed beyond Vendor Recommended Service Life." This is a public document.

  This OPESS provides additional guidance and examples of inspection findings of components that: 1) failed as a result of exceeding vendor-recommended service life, or 2) failed prior to reaching their recommended service life. Inspection experience over the past five years (2005-2010) has revealed approximately 30 inspection findings and non-cited NRC violations to utility licensees (including 2 greater than green inspection findings) where the root or contributing causes of the failure(s) involved exceeding the vendor recommended service life of components. For some of these failures, the root causes were also attributed to accelerated aging due to environmental conditions or unforeseen causes. The frequency for these types of events that resulted in documented inspection findings doubled over the past 12-month period ending in June 2010.

  Relays have often been in service beyond vendor-recommended life times, where either: 1) no additional evaluation has been completed to justify continued in-service performance, or 2) the component has not been included in the licensee's PM (preventive maintenance) program.

  Examples of component types that inspectors have found to exceed vendor recommended life times, or were degraded due to accelerated aging beyond reasonable expectations are listed below.

  Electrical:

  - Capacitive coupled potential device (CCPD) used in high current, low frequency electrical circuits, such as power supply filters and controller circuits.
  - Surge arresters (associated with station transformers)
  - Molded case circuit breakers (MCCBs) and 480 V motor control unit MCCBs (Westinghouse Tech Bulletin TB-04-13)
  - Electrolytic capacitors installed in battery chargers
  - Electrolytic capacitors in safety related SCI-model inverters
  - Relays and Tyco/Agastat E7000 time delay relays used in Engineered Safety Features Actuation System (ESFAS) circuits and in other safety-related electrical circuits (e.g., EDG output breaker closing circuit for EDGs)
  - Electrolytic capacitors installed in 120 VAC instrument inverters
  - Submerged safety related cables not evaluated for extended submergence

  In addition, this report provides guidance to NRC inspectors, some of which is shown below:

  Review past equipment failures of the audited components (from the Q-list) for root causes attributable to components or sub-components being left in a system beyond their intended service life.

  For those components that are beyond vendor-recommended life, use licensee procedures governing PM practices for safety-related components to verify that the licensee has a

PM program that includes these components, the PM program is adequate and robust and incorporates accepted industry practices (e.g., R.G. 1.33), and the licensee has conducted an appropriate assessment for age-related issues for components installed beyond vendor-recommended life through periodic testing or an engineering evaluation that has accounted for environmental effects (elevated temperatures, humidity, harsh environments).

For components that do not have vendor-recommended life times, ensure that the licensee has addressed possible issues with aging of these components through engineering evaluations and has incorporated any concerns into periodic surveillance and maintenance programs.

It should be noted that the NRC’s Component Design Basis Inspection will now include an evaluation of component service life, drawing from the guidance in this recently released OPESS.

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RELAY SCOPE

The type of relay (protective or control) makes a difference in terms of what types of preventive maintenance (PM) is usually performed. Included in this evaluation were auxiliary, control, and timing relays. The TAG requested that the scope be defined based on the Institute of Electrical and Electronics Engineers (IEEE) designations and that the auxiliary, control, and timing relays be identified in addition to the relays to be included in the protective relay group (to be evaluated later). From this discussion, the relays were separated based on IEEE designations into the *control and timing relay* group and the *protective relay* group according to the lists in Appendix A.

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RELAY DATA COLLECTION

The TAG discussed the types of data needed for the relay evaluation. This discussion included items that could have an effect on the relay's service life such as contact voltage, temperature in the relay's environment, and voltage fluctuations. From this discussion, a list of the important data needed for collection by TAG members was created. A standard format was developed for ease of consolidating the data received. The data collection was to include data both available and reasonable to obtain by the TAG members. Following is the list that was developed for data collection:

- Service life: how long the relay has been installed (operating). Some sites may not have this information readily available.
- Population of relays by manufacturer and model: number of relays installed by manufacturer and model (including spares if data are available).
- Criticality: relay importance (for example, critical, noncritical, run-to-failure [RTF]).
- Duty cycle: how often the relay is operated, if available.
- Service condition: environment in which the relay resides (ambient temperature if available); if the relay is inside a panel, it is the panel's internal temperature. It was recommended that if this information is not available, it could be obtained by performing thermography for these panels; however, several readings would be needed (possibly different seasons) to determine a reasonable average.
- Energization state: normally energized (NE) or normally deenergized (NDE).
- Current methodology for maintenance: testing, calibration, replacement, thermography, and so on; types of activity employed for maintaining the relays and how often (frequency) they are performed. This should include any differences based on the criticality of the relays.
- Relay aging decision-making charts and process procedures/guidance: copies of flowcharts used for decision making were requested for this evaluation. Any process procedures or guidelines for the relay maintenance strategy were also requested.
- Failure analysis information: it was noted that several of the sites send relays offsite for analysis, and the failure analysis information may be readily available. Failure data should include (if available) the following:
  - Manufacturer and model
  - Energized/deenergized
  - Applied voltage
  - Contact loading

  - Service life
  - Failure resulted in end of life (EOL)
  - Cause of failure, description of failure mechanism (for example, shorted, burnt open, or caused an upstream fuse to blow)

- Surge suppression information: information on surge suppression components such as thermistors, ferrite beads, and varistors. It was determined that although information on surge suppression components was not a specific requirement for the project, it would be good to gather any available information on this subject.
- Electrolytic capacitors: capacitors were discussed and it was agreed that as relay manufacturer and model information was collected, it would be good to identify which relays have capacitors and which do not.
- Best practices information: any practices thought to be industry best were requested.
- Obsolescence issues: obsolete relay information was requested, if known by relay model and manufacturer.

  This list was the original data set that was attempted. As the project progressed, TAG members found that much of this data was not easily obtainable. The failure data were taking an extensive amount of time to collect as it required review of individual work orders to determine the failure mechanisms or a review of the corrective action program (CAP) database. Energization state NE or NDE, if not already determined, would require an extensive review of the prints to determine. The TAG also had difficulty in obtaining data for control relays in the following areas:

  - Service life of installed relays
  - Energization state
  - Electrolytic capacitors
  - Obsolescence

- Due to the difficulty in obtaining these data, it was determined that the manufacturer and model data would be obtained for all the control relays, but the rest of the data, including failure data, would be obtained only for the Tyco/Agastat/Amerace 7000 and E7000 series relays.

5
RELAY DATA

Control relay data (population by manufacturer and model number) provided by the industry TAG members were consolidated and reviewed, relay failure information from the EPIX database was reviewed, and a comparison was made between relay failures and relay population in the industry. It should be noted that the relay population data is a subset of the industry and may not be adequate in normalizing relay failure data. In addition, data were reviewed for specific relay models or series variants based on plant type or design.

EPIX Data

A report was run from the beginning of the EPIX database in 1997 through June 2010 for relays. Note that there is not an easy way to separate out relay types using the EPIX reporting criteria. Based on this, the report contained all relays including control and protective types. The EPIX data were analyzed several ways to identify potential trends and to determine which relays had the highest number of reported failures.

From the EPIX data set, 1,988 specific relay failures were identified in the report. For each of these failures, the relay manufacturer and model information was reviewed and a relay series designator assigned (for example, Agastat/Amerace E7022 was assigned a series designator of E7000 series).

It should be noted that out of 1,988 failures, there were 175 entries where a manufacturer and/or model was not entered. This equates to 8.8% of the relay entries in EPIX. From this EPIX review, the completeness and accuracy of the data entry into EPIX was recognized as needing improvement. The TAG discussion of EPIX data resulted in the following observations:

- EPIX data reflects only the relay failures/issues that meet EPIX reporting requirements.
- Most relay failure information is not reported via EPIX since the majority of the relay failures do not meet the EPIX reporting threshold requirements (noncritical and RTF components are not reported).
- EPIX data in many cases are incomplete (for example, fields are blank or data entered are generic in nature).
- The EPIX database could be enhanced and used to better assist the industry in capturing more detailed failure as well as reliability information, which could provide better indications of the real service life for relays and other components. EPRI and INPO are discussing ways to help improve data collection.
- The EPIX data are limited and only as good as the data that get entered.

Overall the EPIX data show a declining trend in relay failures in recent years. However, this trend may be due to changes in reporting/screening used by the plants. Most relay failures that were entered into EPIX did not have a plant-level impact. The EPIX data indicate that relay contact issues are one of the largest contributors to relay failures.

Table 5-1 shows relay manufacturers listed in EPIX with 10 or more relay failures. This table does not contain relays where a manufacturer was not identified or where the manufacturer was listed as N/A for subcomponent. General Electric, Westinghouse, and Agastat/Amerace had the largest numbers of failures listed in EPIX by a significant amount.

Table 5-1
EPIX data: manufacturers with ≥10 relay failures

Manufacturer	Count of Relays/Failures
General Electric Company	495
Westinghouse	320
Agastat/Amerace	319
Potter & Brumfield	63
Cutler-Hammer	49
Gould	48
Asea Brown Boveri (ABB)	45
Combustion Engineering, Inc.	42
Clark Control Co./A. O. Smith, Inc.	38
Siemens Electromech. Comp.	34
Midtex Mfg. Co.	33
Allen-Bradley Co.	26
Nuclear Research Corp.	26
SQUARE D CO.	21
Bailey Instrument Co., Inc.	21
Thomas & Betts Corp.	19
Struthers Dunn, Inc.	18
Eagle Signal Div/Gulf & Western	18
Electro Switch Corp.	17
Tyco Electronics Corp.	16
Electro-Mechanics, Inc.	11
Atlas Copco Compressors. Inc.	10

Table 5-2 shows the relay model numbers entered in EPIX for relays where there were 10 or more failure entries. This table does not include relays that did not have a model number specified or where the model number was listed as N/A for subcomponent. Note that relay model numbers in the HFA, EGP, and CR120 series relays are listed, but the E7000 and 7000 series relay specific model numbers did not show up in this list.

Table 5-2
EPIX data: relay model numbers with $\geq$10 failures

Relay Model Number	Count of Relays/Failures
12HFA151A9F	31
EGPI004	25
EGPD004	24
BF66F	18
12HFA51A49F	17
ADM-600AV11	16
J13PA3012	15
12HGA11A52F	13
AR440AR	13
CR120K	13
ETR14D3D004	12
BF-66F	12
2837A91G01	11
CR120K42002AB	11
CR120A	11
12HFA151A2F	10
CAT J16S10012	10

Since specific model numbers did not indicate a significant trend or variance, a column was added and a relay series was entered for each model number to provide grouping.

When looking at the totals using the relay series identifier, the relay series listed in Table 5-3 had 10 or more EPIX entries. It should be noted that when looking at the relay series grouping results, the E7000 series, EGP series, and HFA series relays show a significantly larger amount of failures than other relay series.

Table 5-3
EPIX data: failures by relay series

Relay Series	Count of Relays
HFA Series	128
EGP Series	100
E7000 Series	100
CR120 Series	66
2837 Series	59
MDR Series	50
HEA Series	45
7000 Series	44
ETR Series	41
BF Series	36
AR Series	35
156 Series	33
HGA Series	28
ADM Series	26
D26 Series	26
BFD Series	23
700 Series	22
ARD Series	21
J13 Series	20
NGV Series	18
GP Series	18
DSC Series	17
CV Series	14
IAC Series	14
5U14 Series	13
PM Series	13
NBFD Series	12
HMA Series	11
CO Series	11
J16 Series	11
KHS Series	10

The ranking by relay series was checked for variations between BWR and PWR plant types as shown in Table 5-4. For BWRs, the most significant relay series for EPIX failures are HFA, EGP, and CR120 series. For PWRs, the most significant series for EPIX failures are E7000, 2837, and BF series with the 156 and MDR series relays not far behind the BF series.

Table 5-4
EPIX data: relay series failures by plant type (BWR and PWR)

BWR Relay Series	Count EPIX Failures
HFA Series	106
EGP Series	94
CR120 Series	51
E7000 Series	37
7000 Series	30
HGA Series	26
MDR Series	18
HEA Series	14
ETR Series	14
GP Series	13

PWR Relay Series	Count EPIX Failures
E7000 Series	63
2837 Series	59
BF Series	36
156 Series	33
MDR Series	32
HEA Series	31
AR Series	28
ETR Series	27
ADM Series	26
D26 Series	24

The average age of relays failing was looked at by individual model numbers, but these data did not provide very meaningful results as there were very few relays (30 or less) for most specific model numbers. The relay series developed earlier was then used to determine average age at failure.

Table 5-5 shows the average age at failure for each relay series where there were 10 or more relays in the series. Relays that could not be grouped into a series are not included in the table. In addition, this table shows the minimum age and the maximum age in the group of relays. The age in EPIX is listed in days and was converted into years.

Table 5-5
EPIX data: average relay age at failure by relay series

Relay Series	Count of Entries	Min Years	Max Years	Average Age Years
HFA Series	128	0.0	39.4	21.6
EGP Series	100	0.1	35.4	13.1
E7000 Series	100	0.0	36.2	14.1
CR120 Series	66	0.0	40.0	18.1
2837 Series	59	7.7	28.9	19.0
MDR Series	50	0.0	31.3	14.8
HEA Series	45	0.7	37.7	17.9
7000 Series	44	0.0	33.6	13.6
ETR Series	41	0.1	29.1	12.1
BF Series	36	1.4	38.1	26.0
AR Series	35	1.0	40.1	16.8
156 Series	33	1.7	21.7	11.5
HGA Series	28	4.0	37.2	25.2
ADM Series	26	0.0	15.6	9.4
D26 Series	26	0.0	37.3	15.9
BFD Series	23	2.4	34.8	22.2
700 Series	22	0.0	33.6	11.1
ARD Series	21	0.0	28.3	11.5
J13 Series	20	1.0	34.5	11.9
NGV Series	18	0.4	34.7	20.9
GP Series	18	0.0	33.9	13.3
DSC Series	17	1.4	24.7	6.9
CV Series	14	0.6	34.9	25.5
IAC Series	14	2.6	35.9	19.1
5U14 Series	13	23.7	34.9	26.8
PM Series	13	9.5	29.5	22.9
NBFD Series	12	1.5	25.5	12.5
HMA Series	11	0.3	25.3	14.7
CO Series	11	1.1	35.3	17.4
J16 Series	11	5.3	22.3	18.2
KHS Series	10	0.1	36.3	14.5

The average age at failure for all relay entries in EPIX (including relays without manufacturer or model information) where age was entered in EPIX is shown in Table 5-6.

Table 5-6
EPIX data: average age at failure for all relays combined

Relay Series	Count of Entries	Min Years	Max Years	Average Age Years
All Relays	1988	0	40.2	16.5

The minimum age for failure being very short (in some cases, less than 1/10 of a year before failure) represents the infant mortality side of the bathtub failure curve. The very long age of service before failure, many greater than 30 years, is indicative of the wear-out (EOL) side of the bathtub curve. Therefore, the average age at failure where there is a large population of relays can be considered to be in the normal useful life period for these relays. However, we are looking only at a portion of the failures in the industry (the ones that meet EPIX reporting criteria). More importantly, these data do not include information on the entire population of relays used in the industry; that is, reliability information includes service life data on healthy relays as well as the ones that fail or are removed from service due to degradation or reliability concerns. Drawing conclusions based on failure data alone will likely bias replacement decisions toward worst-case results.

Site Manufacturer and Model Data

The TAG members were requested to provide control relay population data by manufacturer and model numbers for their plants. These data were compiled into one file for all the plants that submitted data.

There was a large variance in the population of relays for these plants. The control relay data sets submitted had as little as 30 component IDs up to a maximum of over 7100 component IDs. Plants listing smaller numbers of relays indicated that unique component ID numbers were not typically assigned to relays, thus those were not included in their data. The relay data sets included protective relays as well as control relays, so the protective relays had to be filtered out and removed from the data set.

The graph in Figure 5-1 shows the total number of control relay IDs that came in from the various plants. Note that several of the plants have multiple units, so the total relay control relay count is much higher. The plant names have been removed and replaced with generic designations using the alphabet. A total of 24 plant sites submitted control relay data, representing a total of 38 operating units (18 BWR, 16 PWR, and 4 CANDU).

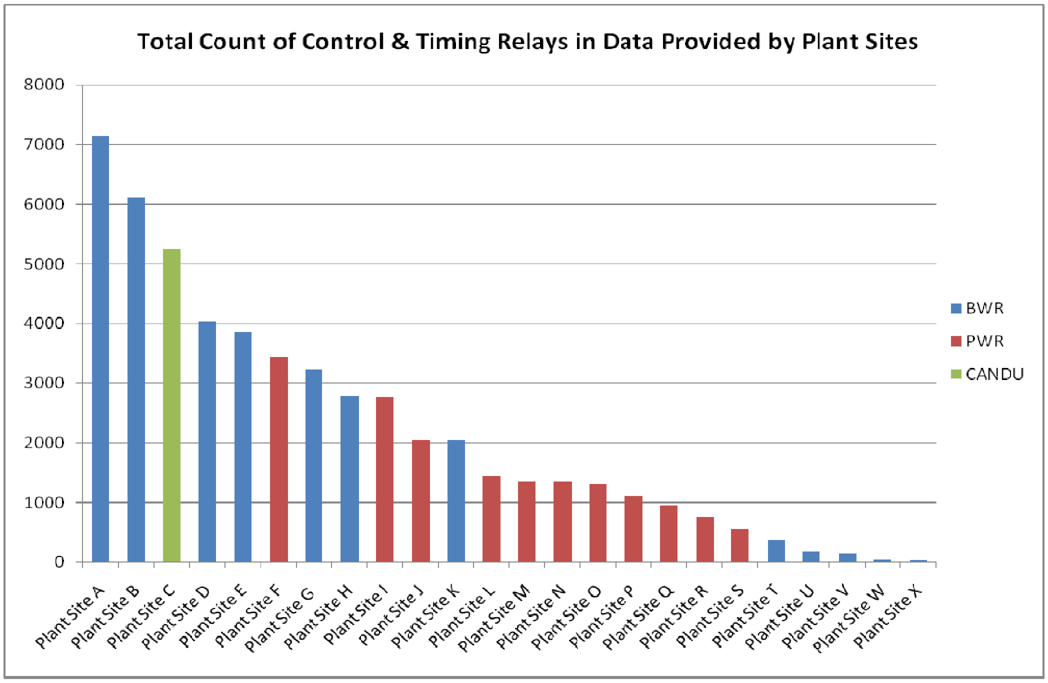

Figure 5-1
Total count of control and timing relays in data provided

Overall the total number of control relays in the data set was 52,250. When reviewing the data, it was noted that for PWRs there is generally fewer total control relays than for BWRs. The approximate average number of relay IDs per unit for PWRs was 1000, for CANDU 1300, and for BWRs 1600. Within the PWR and BWR plant types, the total number of relays identified for each site varied by a large amount.

The data were analyzed, and for each relay a relay series designation was assigned. In some cases, a relay series could not be assigned as the relay model number was not identified. In the combined data set, 20% of the control relays did not have a manufacturer listed and 21% did not have a model number listed. The relays without manufacturer or model number information were taken out of the results used for comparing data sets.

Comparison

A comparison was made between the EPIX data, which provide relay failure information, and the population data provided by the TAG members. Tables 5-7 through 5-11 provide this comparison. Note that the EPIX data include all relay types (control and protective) while the industry data contain only control relays.

Table 5-7 provides a comparison of the relay manufacturers. From this comparison, 14 of the top 20 manufacturers for relays that were associated with EPIX failure data are also in the top 20 for the industry population. Agastat/Amerace, General Electric, and Westinghouse represent a substantial portion of the failure information in EPIX as well as the population of relays in the industry control relay data.

Table 5-7
Normalized ranking of relays by manufacturer: industry population compared to associated failures in EPIX

24 Plant Sites That Submitted Control Relay Data

Manufacturer	Norm %
Agastat/Amerace	22.7
General Electric	22.5
Westinghouse	13.7
Potter & Brumfield	8.2
Tyco Electronics	5.5
Kinectrics	4.5
Cutler-Hammer	3.6
Struthers Dunn	2.4
Midtex	2.0
Allen Bradley	1.3
Square D CO	1.2
Asea Brown Boveri (ABB)	1.0
Sylvania Clark Controls	0.9
Thomas & Betts Corporation	0.7
Klockner-Moeller	0.7
Couch/Deutsch Relays, Inc.	0.7
Moeller Electric	0.6
Gould	0.5
Asea Electric Incorporated	0.4
Telemecanique Incorporated	0.4

Industry EPIX Failure Data: All Relay Types

Manufacturer	Norm %
General Electric Company	26.3
Westinghouse	17.0
Agastat/Amerace	17.0
Potter & Brumfield	3.4
Cutler-Hammer	2.6
Gould	2.6
Asea Brown Boveri (ABB)	2.4
Combustion Engineering, Inc.	2.2
Clark Control Co./A. O. Smith, Inc.	2.0
Siemens Electromech. Comp.	1.8
Midtex Mfg Co.	1.8
Allen-Bradley Co.	1.4
Nuclear Research Corp	1.4
SQUARE D CO	1.1
Bailey Instrument Co., Inc.	1.1
Thomas & Betts Corp.	1.0
Struthers Dunn, Inc.	1.0
Eagle Signal Div/Gulf & Western	1.0
Electro Switch Corp	0.9
Tyco Electronics Corp	0.9

When looking at model numbers as shown in Table 5-8, only four control relay model numbers were in the top 20 for EPIX failures as well as the industry relative population. Note that Agastat/Amerace 7000 and E7000 series relay numbers did not show up. This seems to indicate that these models relative to others are having fewer failures and are not high in the relative population.

Table 5-8
Ranking of relays by model number: industry population compared to associated failures in EPIX

24 Plant Sites That Submitted Control Relay Data

Model	Norm %
CR120HF13W10D	2.3
156-14T300	2.1
CR120A	2.0
EGPI	1.8
EGPI004	1.7
AR440AR	1.4
EGPD004	1.3
2384A28H02	1.2
EGPD002	1.1
EGPI002	1.0
EGPD	1.0
71C620005411401	0.9
EGPB	0.9
DILR40/04 C/W CSDIL00	0.9
EGPB004	0.9
219XDXPLV	0.9
2384A28H01	0.8
KUR11D11	0.8
C50CN3	0.8
CR120KX3A	0.8

Industry EPIX Failure Data: All Relay Types

Model	Norm %
12HFA151A9F	1.7
EGPI004	1.4
EGPD004	1.3
BF66F	1.0
12HFA51A49F	0.9
ADM-600AV11	0.9
J13PA3012	0.8
12HGA11A52F	0.7
AR440AR	0.7
CR120K	0.7
ETR14D3D004	0.7
BF-66F	0.7
2837A91G01	0.6
CR120K42002AB	0.6
CR120A	0.6
12HFA151A2F	0.6
CAT J16S10012	0.6
HFA	0.5
CV-7	0.5
156-14C-300	0.5

When the various individual relay model numbers are grouped by relay series designations, the Agastat/Amerace 7000 and E7000 series relays show up in both categories as shown in Table 5-9. These relay series are in the top 8 out of 20 for both relative populations in the industry and the number of failures reported in EPIX. Overall 12 of the top 20 relay series matched for high relative population in the industry and high relative failures in EPIX.

Table 5-9
Ranking of relays by relay series: industry population compared to associated failures in EPIX

24 Plant Sites That Submitted Control Relay Data		Industry EPIX Failure Data: All Relay Types	
Relay Series	**Norm %**	**Relay Series**	**Norm %**
EGP Series	14.23	HFA Series	7.1
CR120 Series	13.97	EGP Series	5.5
HFA Series	4.81	E7000 Series	5.5
7000 Series	4.40	CR120 Series	3.6
AR Series	3.60	2837 Series	3.3
156 Series	3.59	MDR Series	2.8
MDR Series	3.44	HEA Series	2.5
E7000 Series	3.35	7000 Series	2.4
2384 Series	2.94	ETR Series	2.3
ETR Series	1.97	BF Series	2.0
HGA Series	1.96	AR Series	1.9
219 Series	1.95	156 Series	1.8
IC Series	1.75	HGA Series	1.5
BF Series	1.68	ADM Series	1.4
GP Series	1.47	D26 Series	1.4
DIL Series	1.47	BFD Series	1.3
2383 Series	1.19	700 Series	1.2
700 Series	1.11	ARD Series	1.2
KRP Series	1.09	J13 Series	1.1
71C620005411401 Series	0.90	NGV Series	1.0

A comparison was made for relay series based on plant type (BWR, PWR, and CANDU) as shown in Table 5-10. It is interesting to note that for each plant type there is a specific relay series (or two) that has a significantly higher overall population compared to all the other series of relays. This list of Industry Top 20 relay series excludes entries that were blank or undetermined.

For BWRs, the EGP relay series is by far the highest relative population; for PWRs the 156 series, 2387 series, and AR series relays make up the largest populations; and for CANDU plants the CR120 series accounts for almost 70% of the control relay population in the data supplied. As shown in Table 5-11, when looking at specific model numbers for the control relays for each plant type, a large population gap appears again for specific models for PWRs and especially for CANDU plant types.

Table 5-10
Ranking of relays series by plant type

BWRs Relay Series	Norm %
EGP Series	23.7
CR120 Series	8.7
HFA Series	6.6
7000 Series	5.4
MDR Series	3.2
HGA Series	3.1
IC Series	3.0
219 Series	2.9
ETR Series	2.8
GP Series	2.5
E7000 Series	2.0
AR Series	1.6
700 Series	1.4
C50DN3 Series	1.4
DA Series	1.4
KRP Series	1.3
7305 Series	1.1
DIL Series	1.1
M-D26 Series	1.0
A210 Series	0.9

PWRs Relay Series	Norm %
156 Series	12.3
2384 Series	10.0
AR Series	9.2
E7000 Series	7.6
BF Series	5.4
MDR Series	5.4
7000 Series	4.3
2383 Series	4.1
HFA Series	3.3
71C620005411401 Series	3.1
NBFD Series	2.6
CP Series	2.3
ARD Series	2.3
KGU Series	1.7
EGP Series	1.7
KHU Series	1.5
J13 Series	1.4
ETR Series	1.1
KRP Series	1.1
700 Series	0.9

CANDU Relay Series	Norm %
CR120 Series	69.33
DIL Series	6.66
686 Series	6.07
KUR Series	5.78
906523C1 Series	4.45
GB Series	2.42
PRS Series	1.83
CDB Series	1.71
1338 Series	0.68
1025930 Series	0.38
1013634 Series	0.27
CB Series	0.11
CGD Series	0.11
1038032 Series	0.08
49955-1 Series	0.04
701724C1 Series	0.04
1031741-1 Series	0.04

Table 5-11
Ranking of relay model numbers by plant type

BWRs

Model Number	Norm %
CR120A	3.4
EGPI	3.4
EGPI004	3.1
EGPD004	2.5
EGPD002	2.0
EGPI002	1.8
EGPD	1.7
EGPB	1.5
EGPB004	1.4
219XDXPLV	1.4
C50CN3	1.3
CR120KX3A	1.3
HFA	1.2
EGPD003	1.2
DA317A6541P2	1.1
EGP	1.1
IC2820A200B2E	1.1
M-D26MR02A	1.0
7305	1.0
HGA	0.9

PWRs

Model Number	Norm %
156-14T300	8.9
AR440AR	5.9
2384A28H02	4.2
71C620005411401	3.1
2384A28H01	2.5
BF66F	2.4
4CP36AF	2.3
2384A28H01	1.9
HFA151A2H	1.8
ARD440SR	1.8
KGU431C	1.7
MDR131-1	1.5
BF22F	1.5
2383A35	1.5
2383A37	1.4
156-14C300	1.4
KHU17	1.3
EGPDR	1.2
NBFD22S	1.1
2384A28H03	1.0

CANDU

Model Number	Norm %
CR120HF13W10D	69.1
DILR40/04 C/W CSDIL00	6.7
KUR11D11	5.8
906523C1	4.5
686E9996-D	4.2
77 GB4N-4-A-1.8K	2.4
PRS 12 VDC LD 2 CO	1.8
CDB38-70004 , 686N3073-D	1.7
686C1141-D	0.7
1338D10A01	0.7
686E0700-D	0.4
686C0966-D	0.4
1025930	0.3
686N2583-D	0.3
1013634	0.3
CR120HH13W10D	0.2
CB-1036D-39 , 686J5614-D	0.2
CGD38-30010M (686H8183)	0.1
686B9695-D	0.1
1038032	0.1

Failure Data

Several discussions were held on relay failure data and the difficulty in obtaining the data for all the control relays in the list for each site. It would take a significant amount of time to obtain detailed failure data on the more than 52,000 control relays in the data set. Comments received from TAG members indicated that the difficulties involved determining the failure mechanisms, which in many cases would require individual work order review or research in their CR database. Based on these discussions and limited time available, detailed failure information collection was reduced to only the Agastat/Amerace 7000 and E7000 series relays. This failure information will be discussed later in this report.

General control relay failure issues mentioned by the TAG members during discussions are listed below:

- Some relays were categorized as noncritical, but their failures resulted in upstream fuses operating, placing the plant in an LCO or affecting operation of additional relays.
- 40-year-old noncritical NE relays randomly failed.
- NE relays became magnetized so they would not deenergize.
- Some new replacement relays are having infant mortality issues.

Service Life

Initially service life data were requested for the control relay population. The same type of difficulties occurred in obtaining these data as was mentioned for obtaining detailed relay failure data. Again, based on the time requirements to collect this type of data, service life information was reduced to being collected only for the Agastat/Amerace 7000 and E7000 series, which will be discussed later in this report.

It seemed that a lot of the difficulty in determining the service life came from trying to determine the date of installation, which required a lot of research time at some sites, and review of replacement history to determine the age of currently installed relays.

6
RELAY MAINTENANCE STRATEGIES

Control relay maintenance strategies vary significantly across the industry. In this section, industry preventive maintenance strategy recommendations from EPRI and Nuclear Electric Insurance Limited (NEIL) are reviewed as well as the current preventive maintenance strategies from several sites provided by the TAG members.

Industry Maintenance Strategies

Table 6-1 provides a high-level view of typical industry recommendations for preventive maintenance strategies for control relays.

Table 6-1
Industry preventive maintenance recommendations for control relays

Task Description	EPRI TR-102067	EPRI PM Basis Database	Nuclear Electric Insurance Limited Loss Control Standards
Operations and Engineering	NA	NA	NA
Operator Rounds and Readings	Periodic	Not addressed	Not addressed
Regulatory	NA	NA	NA
Perform Technical Specification or Other Regulatory Required Testing	Periodic	Not addressed	Not addressed
Perform EQ Required Maintenance	Not addressed	Not addressed	Not addressed
Condition Monitoring	NA	NA	NA
Perform Thermography	Not addressed	As Required	Not addressed
Relay Population Sampling Replace Relay and Inspect	Not addressed	Not addressed	Not addressed
Time-Based PM	NA	NA	NA
Functional Testing Clean and Inspection	Periodic	2Y	Not addressed
Relay Calibration, Clean and Inspection (Includes As-Found Testing)	1Y–3Y	As Required	Not addressed
Perform Replacement of Relay or Electrolytic Capacitor	6–17Y	10Y	Not addressed

Table 6-1 (continued)
Industry preventive maintenance recommendations for control relays

Task Description	EPRI TR-102067	EPRI PM Basis Database	Nuclear Electric Insurance Limited Loss Control Standards
Condition-Based PM	NA	NA	NA
Perform Replacement of Relay or Electrolytic Capacitor	NA	NA	NA
PM That Will Not Be Performed	NA	NA	NA
System Performance Walkdowns	Not addressed	Not addressed	Not addressed

Maintenance Strategy Considerations

Developing a control relay maintenance strategy requires a thorough understanding of several types of information for the relays, such as:

- Duty cycle
- Service conditions
- The failure mechanisms that can occur (see EPRI PM Database [1018758] for FMEA information)
- Vendor recommendations for maintenance
- Historical performance of the relays
- Relay time in service (age)
- As-found conditions of the relays during maintenance

For control relays, electrical status, thermal degradation, and high cycling are the primary drivers for degradation. These considerations are described as follows:

- Electrical status: normally energized relays tend to have higher rates of degradation due to heating of the coils. Voltage transients and voltage fluctuations can also contribute to degradation rates.
- Thermal degradation: relays installed in high-temperature areas can degrade at a faster rate due to overheating. Relays may be installed in close proximity to each other, which can reduce cooling air flow, causing overheating of the relays. This can lead to thermal degradation and cracking of relay cases.

- High cycling: relays experiencing a large number of operations may experience degradation. Operating experience indicates that high cycling duty contributes to early failure or high rate of drift, requiring frequent calibration. By design, timing relays are not affected by high cycling.
- Low cycling: relays that are not cycled very often may not function properly if the diaphragm is left in one position for a long time (it may become stiff in that configuration and not function properly); contact corrosion or oxidation may cause contacts to stick.

Relays installed in applications with normally severe service conditions will likely degrade and have a shorter service life. Severe conditions can be described as follows:

- High or excessive humidity
- Excessive temperatures (high: >104°F/low: <32°F)
- Excessive environmental conditions (for example, dust, dirt, high radiation, salt, corrosion, spray, or steam)
- High vibration
- Voltage above rated, that is, elevated DC bus voltage
- Close proximity to heat sources with inadequate ventilation

Control relays can be of a sealed or open contact design. Open contacts can be contaminated with dust, dirt, and so on and may require cleaning.

Certain control relay types contain electrolytic capacitors. These capacitors can be monitored and replaced based on condition or age/time in service. Replacement of electrolytic capacitors can be performed in both electromechanical and solid-state relays. The entire relay does not have to be replaced unless it is more cost effective to do so or required for other reasons.

Leakage or failure of electrolytic capacitors is not typically expected for at least 10 years (aluminum). Tantalum capacitors can be expected to last about twice as long as the aluminum types. For relays with electrolytic capacitors, a time-based replacement should be considered based on historical performance and/or condition monitoring activities. Condition monitoring can be performed using a population sampling replacement strategy to address age-related failure mechanisms for most types of control relays in noncritical applications. This sampling program involves inspections and testing of relays removed to determine the extent of degradation. Periodic calibration can be used to monitor the condition of timing relays. Relays that are routinely drifting out of calibration may provide indications of capacitor degradation. Population sampling relay programs are discussed in the potential best practices section of this report.

If no condition monitoring is taking place, a 9-year replacement interval for relays with aluminum capacitor types and an 18-year replacement interval for relays with tantalum capacitor types can be considered. However, historical performance should be reviewed to see if these intervals for replacement are supported by any degradation indications.

For relays with installed capacitors that are in storage, shelf life should be considered. Programs have been suggested to reform capacitors that are in storage; however, the specific recommendations for reforming capacitors vary. Military specification MIL-HDBK-1131B for Storage, Shelf Life, and Reforming Aluminum Electrolytic Capacitors recommends reforming capacitors after as little as 4 years in storage and disposal after as little as 12 years. However, EPRI report TR-1001257, *Capacitor Performance Monitoring*, does not indicate this to be necessary. This report makes no specific recommendation to reform capacitors but demonstrates capacitor insensitivity to aging and reduction in capacitance. The Capacitor Performance Monitoring Project concluded that aluminum electrolytic capacitors as old as 30 years had not appreciably lost capacitance (the key parameter for power supply filtration) and had no significant increase in leakage current. Therefore, a rigorous program of electrolytic capacitor replacement or reforming is not indicated by the results of the Capacitor Performance Monitoring Project. If it is desired to perform re-forming of capacitors, a more advisable action is to perform this re-forming before or during the installation process and prior to releasing the equipment for service.

Site-Specific Maintenance Strategies

The TAG members were requested to provide their site-specific maintenance strategy information for control relays, including PM program tasks and frequencies along with any program instructions or guidance documentation. In addition, any site-specific decision-making flowchart or logic diagrams for control relays were also requested.

The information received was compiled into a table for each PM task description and the industry recommendations added at the top of the table. Eleven control relay PM program files were provided, each representing either a plant or fleet PM strategy. These plant or fleet names have been replaced and labeled with generic plant IDs using the alphabet in no particular order. These PM task compilations show the wide variety of PM task scope and frequency currently in use for control relays.

Tables 6-2 through 6-5 have been built for thermography, functional testing, calibration, and replacement of control relays. These are the main tasks found throughout the industry data for control relay preventive maintenance.

From this review, the frequencies for these tasks have a wide range. Below are the tasks and ranges based on the site-specific programs:

- Thermography: range from as required, frequencies 1M to 2Y
- Functional testing, clean, and inspect: as required, frequencies 2Y to 12Y
- Calibration, clean, and inspect: as required, frequencies 18M to 15Y
- Replacement relay or electrolytic capacitor: frequencies 5Y to 40Y

Table 6-2
Thermography recommendations and practices

Task Description	
Condition Monitoring	
Perform Thermography	
Industry/Plant Site	**PM Strategy**
EPRI TR-102067	Not addressed
EPRI PM Basis Database	As Required
Nuclear Electric Insurance Limited Loss Control Standards	Not addressed
Plant A	Based on the Panel/Cabinet Task, or 1M to 6M 1Y - Struthers Dunn HFA - 3 months
Plant B	No Input
Plant C	AR - High/Low Critical and High Duty Cycle Timing Relays - AR for High Duty, NA for Low Duty
Plant D	Electromechanical AR - Critical only (starting 2Y freq rec) NR - Others Solid State AR - Critical only NR - Others Timing Relays AR - All (starting 2Y freq rec). Note duty cycle not factor rated 140K cycles no Low cycle values.
Plant E	NR - All High and Low Criticalities
Plant F	Timing Relays ITE NR - All High and Low Criticalities
Plant G	Gould Relays (J series) 3Y - High Critical 9Y - Low Critical
Plant H	Timing relays NR - All Criticalities Agastat Relays NR - All Criticalities Couch Ordinance NR - All Criticalities Control Relays (all types excluding Agastat, Deutsch, Westinghouse) NR - All Criticalities Westinghouse Relays NR - All Criticalities

Table 6-2 (continued)
Thermography recommendations and practices

Task Description	
Condition Monitoring	
Perform Thermography	
Industry/Plant Site	**PM Strategy**
Plant I	GE Relays HGA AR - High or Low Critical High Duty NA - all Others GE Relays HFA AR - High or Low Critical High Duty NA - all Others
Plant J	General Electric Model 12HFA151 and 12 HFA153 No PM required
Plant K	Solid State 2Y - Critical High Duty AR - Critical Low Duty NR - all others Control Relays 2Y - Critical High Duty AR - Critical Low Duty NR all others

Table 6-3
Functional testing, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Functional Testing Clean and Inspection	
Industry/Plant Site	**PM Strategy**
EPRI TR-102067	Periodic
EPRI PM Basis Database	2Y
Nuclear Electric Insurance Limited Loss Control Standards	Not addressed
Plant A	As Required Based on Site-Specific Experience or as part of normal system operations Critical (High - CC1 or Low CC2) relays or Noncritical (Criticality 2) relays that do not have calibration tasks or that are utilized for asset protection.

Table 6-3 (continued)
Functional testing, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Functional Testing Clean and Inspection	
Industry/Plant Site	**PM Strategy**
Plant B	No Input
Plant C	3Y - High Critical all duty cycle and service conditions 9Y - Low Critical Severe 12Y - Low Critical Mild Timing Relays 3Y - High or Low Critical Mild NA or NR for rest
Plant D	Electromechanical 2Y- Critical Severe and Critical High Duty Mild AR Critical Low Mild NR - Important Solid State 2Y - Critical only NR - Others Timing Relays 2Y - Critical High Duty NR - Important
Plant E	2Y - Critical NR - Important
Plant F	Timing Relays ITE 3Y - High Critical NR - Low Critical Agastat ETR 3Y - High Critical Severe 6Y - High Critical Mild NR - Low Critical Potter & Brumfield MDR 3Y - High Critical 9Y - Low Critical Severe NR - Low Critical High Duty Mild 12Y - Low Critical Low Duty Mild Agastat GP/EGP 3Y - High or Low Critical Severe 6Y - High or Low Critical Mild NR - Low Critical

Table 6-3 6-3 (continued)
Functional testing, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Functional Testing Clean and Inspection	
Industry/Plant Site	**PM Strategy**
Plant G	GE Relays HFA/HMA/HGA 3Y - High Critical 9Y - Low Critical Severe 12Y - Low Critical Mild GE Relays CR120 3Y - High Critical 9Y - Low Critical
Plant H	Timing relays AR - All Criticalities Agastat Relays AR - All Criticalities Couch Ordinance AR - All Criticalities Control Relays (all types excluding Agastat, Deutsch, Westinghouse) AR - All Criticalities Westinghouse Relays AR - All Criticalities
Plant I	GE Relays HGA 3Y - High Critical 9Y - Low Critical Severe 12Y - Low Critical Mild GE Relays HFA 3Y - High Critical 9Y - Low Critical Severe 12Y - Low Critical Mild
Plant J	General Electric Model 12HFA151 and 12 HFA153 No PM required Agastat E7000s Test and Inspect 18M, 3Y, 48M, 54M - Critical 1 5Y, 6Y, Critical 1 and Critical 2 Agastat ETRs-Inspect/Test 54M GE NAM11Bs -Test and Inspect 54M, 5Y Westinghouse -Test and Inspect 5Y Others 3Y - Eagle CG 5Y - Agastat, GE

Table 6-3 (continued)
Functional testing, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Functional Testing Clean and Inspection	
Industry/Plant Site	**PM Strategy**
Plant K	Solid-State 2Y - Critical Severe, High Duty 4Y - Critical Low Duty, Mild AR - Significant High Duty NR - all others Control Relays 2Y - Critical AR - Significant High Duty NR all others

Table 6-4
Relay calibration, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Relay Calibration, Clean, and Inspection (Includes as-found testing)	
Industry/Plant Site	**PM Strategy**
EPRI TR-102067	1Y – 3Y
EPRI PM Basis Database	As Required
Nuclear Electric Insurance Limited Loss Control Standards	Not addressed
Plant A	18M to (2Y to 4Y) All but RTF Timing Control Relays
Plant B	10Y burnish CAC relay contacts LER 98-005 10Y-12Y HFA maintenance
Plant C	6Y - High Critical Severe and Low Critical High Duty Severe 9Y - High Critical Mild and Low Critical Severe Low Duty 12Y - Low Critical Mild Timing Relays 6Y - High or Low Critical Severe High Duty 9Y - For all other High or Low Critical

Table 6-4 (continued)
Relay calibration, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Relay Calibration, Clean, and Inspection (Includes as-found testing)	
Industry/Plant Site	**PM Strategy**
Plant D	Electromechanical AR - Critical only NR - Others Solid-State AR - Critical only NR - Others Timing Relays 4Y - Critical High Severe 6Y - Critical High Mild AR - for all Important (note 4Y to 10Y rec for Important)
Plant E	AR - Critical NR - Important
Plant F	Timing Relays ITE 6Y - High Critical Severe and Low Critical Low Duty Severe 9Y - High Critical Mild and all Important Agastat ETR 6Y - High Critical Mild and Low Critical High Duty Mild 9Y - High Critical Low Duty Severe and Low Critical Low Duty
Plant G	Gould Relays (J series) 6Y - High or Low Critical Severe 9Y - High or Low Critical Mild GE Relays HFA/HMA/HGA 9Y - High Critical Severe 12Y - High Critical Low Mild 15Y - all Low Critical NR - High Critical High Duty Mild GE Relays CR120 6Y - High or Low Critical Severe 9Y - High or Low Critical Mild

Table 6-4 (continued)
Relay calibration, clean, and inspection recommendations and practices

Task Description	
Time-Based PM	
Relay Calibration, Clean, and Inspection (Includes as-found testing)	
Industry/Plant Site	**PM Strategy**
Plant H	Timing relays AR - All Critical NR - Noncritical Agastat relays AR - All Critical NR - Noncritical Couch Ordinance AR - Critical NR - Noncritical Control Relays (all types excluding Agastat, Deutsch, Westinghouse) AR - Critical NR - Noncritical Westinghouse Relays AR - Critical NR - Noncritical
Plant I	GE Relays HGA AR - All High or Low Critical GE Relays HFA 6Y - High Critical Severe 9Y - High Critical Mild or Low Critical Severe 12Y - Low Critical Mild
Plant J	General Electric Model 12HFA151 and 12 HFA153 No PM required
Plant K	Control Relays 4Y - CHS 6Y - CLS, CHM 8Y - CLM, SHS, SHM 12Y - SLS NR all others

Table 6-5
Perform replacement of relay or electrolytic capacitor

Task Description	
Time-Based PM	
Perform Replacement of Relay or Electrolytic Capacitor	
Industry/Plant Site	**PM Strategy**
EPRI TR-102067	6 – 17Y
EPRI PM Basis Database	10Y
Nuclear Electric Insurance Limited Loss Control Standards	Not addressed
Plant A	10Y to 20Y Critical (High - CC1 or Low CC2) relays or Noncritical (Criticality 2) relays with known industry issues or poor performance history.
Plant B	6Y Agastats NE 10Y-13Y Agastats NDE 12Y EGP NE or NDE 2Y Plug In Agastat EDG relays 12Y Chiller relays 20Y Scram Relays 20Y CR120A
Plant C	18Y - High Critical High Duty all other AR Agastat Relays 10Y - High Critical High Duty AR for others
Plant D	Electromechanical 10Y- Critical Severe and Critical High Duty Mild NR - All others with note on ease of replacement staying away from time based. Solid-State 10Y - Critical only NR - Others Timing Relays 10Y - Critical High Duty NR - Important
Plant E	10Y - Critical High Duty AR - Critical Low Duty NR - Noncritical

Table 6-5 (continued)
Perform replacement of relay or electrolytic capacitor

Task Description	
Time-Based PM	
Perform Replacement of Relay or Electrolytic Capacitor	
Industry/Plant Site	**PM Strategy**
Plant F	Timing Relays ITE AR - All High and Low Criticalities Agastat ETR 7Y - High or Low Critical Severe High Duty 12Y – High Critical High Duty Mild AR - Low Critical Potter & Brumfield MDR 9Y - High Critical High Duty Severe 12Y - High Critical High Duty Mild, Low Critical High Duty AR - All others Agastat GP/EGP 7Y - High or Low Critical High Duty Severe 9Y - High or Low Critical Low Duty Severe 12Y - Low Critical
Plant G	Gould Relays (J series) 18Y - High Critical High Duty 21Y - High Critical Low Duty Severe 24Y - High Critical Low Duty Mild AR - Low Critical GE Relays HFA/HMA/HGA 18Y - High Critical High Duty AR - all Others GE Relays CR120 18Y - High Critical Severe and High Critical High Duty Mild 21Y - High Critical Low Duty Mild and Low Critical High Duty Severe AR - All Others

Table 6-5 (continued)
(continued)
Perform replacement of relay or electrolytic capacitor

Task Description	
Time-Based PM	
Perform Replacement of Relay or Electrolytic Capacitor	
Industry/Plant Site	**PM Strategy**
Plant H	Timing relays 20Y- All Critical NR - Noncritical Agastat Relays EGPI/D and ETRI/D (NE) 5Y - Critical NR - Noncritical Agastat Relays EGPB and ETRB (NE) 8Y - Critical NR - Noncritical Agastat Relays EGP and ETR (NDE) 20Y - Critical NR - Noncritical Agastat Relays 7000 series 20Y - Critical NR - Noncritical Agastat Relays all Other Types AR - Critical NR - Noncritical Couch Ordinance 10Y - Critical NR - Noncritical Control Relays (all types excluding Agastat, Deutsch, Westinghouse) 15Y - Critical NR - Noncritical Westinghouse Relays (NE) 19Y - Critical NR - Noncritical Westinghouse Relays (NDE) 40Y - Critical NR - Noncritical
Plant I	GE Relays HGA 18Y - High Critical High Duty Severe 27Y - High Critical High Duty Mild AR - all Others GE Relays HFA 18Y - High Critical High Duty Severe 27Y - High Critical High Duty Mild AR - all Others
Plant J	General Electric Model 12HFA151 and 12 HFA153 No PM required Agastat E7000s - Replace 9Y - All Critical relays Agastat ETRs - Replace 9Y
Plant K	No Input

Replacement Intervals

The NRC's OPESS document discussed earlier in this report refers to conducting an appropriate assessment for age-related issues for components installed beyond vendor-recommended life through periodic testing or an engineering evaluation that has accounted for environmental effects (elevated temperatures, humidity, harsh environments). At some plant sites, an analysis or engineering evaluation is being performed for equipment that is in service longer than vendor-recommended service life. In this section, a few example conclusions of these engineering evaluations are presented. At some sites, a service life analysis (SLA) or engineering evaluation (EE) is being performed for control relays to determine an appropriate timeframe for when replacement tasks should be completed.

At one of the TAG member's plant sites, an EE was performed for Agastat/Amerace EGP relays. This plant site will be referred to as *Plant A*. The Plant A representatives indicated that the EE was performed based on the relay temperature and materials. The calculations resulted in a service life for EGP relays located in a non-harsh environment and NE of 12 years and 20 years for NDE. The validity of this calculation was called into question by the NRC. The calculations were based on the critical subcomponents. The relay bobbin was specifically excluded in this calculation as it was considered a noncritical subcomponent. The bobbin had the lowest activation energy, which correlated to a 7.5 year service life. When the bobbin was determined not to be a critical subcomponent and taken out, the service life went to 12 years. The site was questioned about not taking the worst-case component into account. The NRC initially disagreed with the site taking the bobbin out of the calculation (see additional discussion below).

The calculation considered 75% of the time at 90°F and 25% of the time at 104°F with a 9° heat rise. Actual calculations came out to greater than 13 years, and 5% was taken off for shelf life, which brought the service life down to 12.6 years. This was then lowered to 12 years to provide additional conservatism. At one point, the calculation was discussed as being potentially flawed, prompting a site violation from the NRC. It should be noted that the manufacturer uses the date of manufacture to begin the service life. The manufacturer recommends a 4.5-year service life for EGP NE relays.

In a later discussion, issues with the EE at Plant A that resulted in a 12-year service life have been resolved, and 12 years remains the service life to be used at that plant. As part of the resolution, the bobbin was found not to perform a safety function in an NE EGP relay. Additionally, the site conducted further review of the bobbin material, Zytel 101, and found that with 7.1-year activation energy, only a 50% reduction in tensile strength force occurs.

Plant B performed a service life calculation and determined the service life of continuously energized Agastat ETR relays to be 13.92 years thermal life – 0.86 year required DBE/post-DBE operation = 13.06 years.The calculated service life of the NE relays (that is, 13.06 years or 114,481 hours at a relay temperature of 81.6°C) can be used to determine the equivalent service life of NDE relays. The service life of the NDE Agastat ETR relays is 41.10 years, including the required DBE/post-DBE operation.

Plant C performed a shelf and service life calculation for non-EQ relays in mild service environments for EGP, ETR, and E7000 series relays. This calculation was performed to address the current assumed service life, which was 5 years for NE and 10 years for NDE relays. Based on this calculation, the shelf life for EGP and ETR relays was calculated to be over 40 years, and the site recommended a shelf life of 20 years. For E7000 series relays, the calculated shelf life was over 30 years, and the site recommended a shelf life of 20 years.

The Plant C service life for normally energized EGP and ETR relays was calculated to be between 8.7 and 12.6 years, depending on the location of the relays. For normally deenergized EGP and ETR relays, the calculated service life was between 81 and 151 years, depending on location. The recommended service life determined from the calculation for use for normally energized EGP and ETR relays is 8.5 to 12 years, depending on location. For deenergized EGP and ETR relays, the recommended service life is 20 years.

The Plant C service life for normally energized E7000 series relays was calculated to be between 20.2 and 56.1 years, depending on voltage (ac or dc) and location. The service life for normally deenergized E7000 series relays was calculated to be between 73.2 and 152 years, depending on voltage (ac or dc) and location. The site recommended a service life of 20 years for normally energized and 40 years for normally deenergized.

From the above examples of engineering evaluations, the service life may be determined to be much longer than the service life recommendations from vendors. These types of calculations take into account degradation mechanisms such as aging from thermal degradation, radiation, and other environmental conditions and the effects on the material properties of the relay subcomponents. During TAG discussions, it was noted that the NRC had recently issued findings to utilities for some calculations of service life extensions. It appears that the NRC questioned those calculations as they did not account for considerations of cycling or percent energization for the given applications. These findings were mostly related to items covered under the EQ program and were recently discussed at the Nuclear Utility Group on Environmental Qualification (NUGEQ) meeting held in Washington, D.C. Based on these comments, duty cycle of the relays and percent energization should be taken into account in SLA or EE evaluations.

During TAG discussions, the EPRI template recommendations and vendor recommendations were discussed. A TAG member mentioned a discussion with a relay vendor and was told that the 10-year replacement frequency recommendation was arbitrary and that it was recognized that the relays may last 20 or 30 years. The vendor stated that it can complete calculations that can extend the timeframe. However, the TAG member stated that these calculations are performed for a fee.

Industry Surveys Related to Control Relays

Two surveys were conducted related to control relays during the project timeframe. The following are short summaries of these surveys.

Surge Suppression Survey

This survey asked about maintenance strategies for diodes that are installed across the coil of some control relays. These diodes may be called *surge suppression*, *back EMF*, or *fly back diodes*. In general, most sites do not have any maintenance strategy for these components and address them under corrective maintenance. Out of 11 responses, one site had performed a one-time replacement on these components in EDG circuits, and one site performs forward and reverse checks of these components where they are installed.

Contact Burnishing

A survey was conducted on contact burnishing for relays. Six responses were received. All six indicated that contact burnishing is performed at their sites. Contact burnishing is performed as part of inspections, PM, or according to site procedures. Burnishing is performed more often on protective relays where the contacts are accessible. Many control relays are sealed or enclosed and do not allow easy access to contacts for burnishing. One site stated that contacts are burnished when resistance is greater than 1 ohm. All six respondents indicated that they were not experiencing a high rate of contact resistance issues. If high resistance is found in most responses, the contacts are burnished and the relay replaced only when burnishing is ineffective.

Vendor recommendations for contact cleaning and burnishing generally apply to protective relays with little mention of performing it on control relays. A TAG member stated they had contacted TYCO and that this manufacturer did not take a stance on burnishing although it was acceptable to do so. In a similar discussion, a GE representative said that they were pretty adamant about not performing burnishing of the contacts; however, it should be noted that several of the GE relay vendor documents refer to performing contact cleaning. Contact cleaning practices varied among the TAG team members participating: some performed cleaning of contacts on a routine basis, some performed contact cleaning on an as-needed basis (usually contact resistance), and others did not routinely perform contact cleaning.

7
INDUSTRY RELAY STANDARD AND BEST PRACTICES

Standard Practices

From TAG discussion, the following practices were considered to be standard in the industry.

- Perform burn-in testing of critical relays prior to installation.
- Perform periodic calibration of timing relays.
  - Calibration environment should match installation environment.
  - Calibration data trending is useful in recognition of relay degradation and can help in determining if replacement is warranted.

Best Practices

The following list contains both practices and recommendations that were considered to be among the best practices in the industry for relay maintenance. These practices and recommendations were categorized by organizational groups.

- Supply Chain
  1. Take actions to address potential vendor quality and FME issues
     - Provide input to NUPIC for focus during audits.
     - Strengthen vendor oversight of manufacturing.
     - Performance testing; ensure that acceptance testing is performed.
  2. Standardize testing and acceptance criteria for critical spares.
  3. Verify that shelf life limits and maintenance during storage are effectively managed. Ensure that relay storage requirements and handling requirements address tracking the shelf life of relays. The list of nonmetallic parts should be used for calculating shelf life.
- Engineering
  1. Designate a relay component engineer for each station.
  2. Assign component IDs for all control relays. Address unidentified components in panels, cabinets, skid-mounted equipment, and so on. (IDs should be created for critical or high critical applications at a minimum.)
     - Perform component categorization and identify critical components.
     - Identify single point vulnerabilities (SPVs).

    - For SPVs, consider possible redesign to eliminate where practical or identify actions to enhance reliability.
    - Ensure that the PM program addresses identified components.
3. Develop a program (governance) document for relays.
    - Provide considerations for deviating from vendor recommendations. Address SLA or EE where needed for critical relays.
    - Define data needs and reporting requirements. See the data collection list in Section 4.
    - Collect service life data. Ensure that program documentation addresses collection of required data to support determination and tracking of service life for installed relays.
    - Reliability issues: reevaluate relay applications with chronic reliability issues. Determine if the relays are well suited for the application. In some cases, relays installed may not be robust enough for the given application.
    - Automate trending of relay data if possible: automate the data collection and tracking for relays so that trends in performance can easily be determined. See the KHNP relay testing information later in this section.
4. Engage vendors: contact vendors as needed to assist with relay program issues such as the following:
    - Relay application: ensuring that the right relays are used for a given application.
    - Relay testing: verifying that relays are being tested properly and gathering insights on any testing that can improve reliability assessment.
    - Relay failure rates: if failures are occurring and trends indicate degradation, consulting the vendor can help provide input on assessing program changes.
    - Service life: vendor recommendations for service life are generally considered conservative. Deviations from vendor recommendations, however, should be based on solid performance history data or SLA or EE evaluation when the relays are in critical applications.

- Maintenance
    1. Perform thermography where relays are accessible and scans can be effectively performed. HFA and CR120 series relays can be monitored effectively for coil temperatures to identify relay degradation. HFA relay coils are monitored from the back side of the relay, and CR120 relays are monitored from the front for coil temperatures. GE Supplement SIL 219 provides information on relay coil temperatures; they can also be obtained from vendors.
    2. Contact resistance testing can be used for critical applications to monitor for contact degradation, including oxidation or corrosion. Resistance indication limits such as greater than 1 ohm can be used to determine when contact burnishing is required.

3. Evaluate condition/degradation of relays removed from service:
    - Relays with no plans for reuse should be evaluated for extent of degradation and remaining service life (forensics).
    - Relays that will be reused should be inspected (visual and electrical testing).
4. When testing relays that are known to cause entry into a short LCO action statement, it is a good practice to have a relay tested and ready to install in case the one currently installed fails testing.

- All organizations:
    1. Share training relative to relays via NANTeL.
    2. Initiate CRs for pre-installation test failures as well as in-service failures for tracking purposes.
    3. Ensure that failures reported are accurately described/categorized. Ensure that there is enough detail to understand the failure mechanism (such as service life before failure, service environment, duty cycle, ambient temperature, and humidity).

International Best Practices

KHNP (Korea Hydro & Nuclear Power Co., Ltd.) uses an automatic testing system to test relays during outages. The contact providing the information for KHNP indicated that the company does not have many relay failures. When asked about details of its relay maintenance program, the following were mentioned:

- Actions have been taken to remove SPVs.
- Automatic testing is performed during outages.
- Vendor recommendations on replacement intervals are followed.

Additional questions were asked to obtain more specifics on the program. From these questions, the following were noted:

- Only plug-in type relays are removed to test with the automatic relay tester.
- The criteria for relay testing results (references) are determined by engineering judgment with vendor data (for example, technical specifications or data sheets).
- Data trending is possible with the automatic tester, and each plant has a trend (data gathered) from periodic maintenance of relays.
- Relay test frequency is determined by its functional importance, so some minor relays are not tested/replaced under schedule.
- Replacement frequency of a relay is determined by its functional importance in the PM template as shown in Table 7-1, considering vendor recommendations, operating experiences, installation condition, and so on.

Table 7-1
KHNP relay replacement frequency table

	Critical				**Minor**			
Duty cycle	High	Low	High	Low	High	Low	High	Low
Service condition	Severe		Mild		Severe		Mild	
Replacement	10Y	15Y	10Y	15Y	AR	AR	AR	AR

When asked about observations from the test program (for example, problems identified, trends, and observations on relay condition when replaced), the following items were mentioned as sample cases:

- ESFAS relays were replaced in advance due to an increase in contact resistance.
- Relays in the plant computer system are tested every refueling outage, and about 10 relays that can not meet the preset references are replaced.
- Relays installed in the reactor protection system and ESFAS are tested every refueling outage, and about 10 relays that can not meet the preset references are replaced.

8

POTENTIAL BEST PRACTICES

Population Sampling Control Relay Replacement Program

Population sampling is a new approach to addressing failure mechanisms related to age. Relays are grouped usually by manufacture and type; that population is then trended by the relay component engineer. Of the total population of relays in a group, some are replaced, and these relays become the testing population upon which true end-of-life durations can be determined and applied to the rest of the group.

All relays removed from the plant—whether a time-based replacement, replaced under population sampling, or replaced based on conditions found—must be inspected. This inspection is performed to assess the true as-found conditions and the life remaining for the relay. This information is then used to ensure that reliability is maintained for the relay group. Actions must be taken if excessive degradation is found. Actions needed may include making changes to the frequency or scope of the sampling population for the group, performing more sampling (that is, expanding the population), or possibly a change to time-based replacement. This approach can maintain reliability of the control relays while reducing the overall costs of the program. A cost comparison example is shown in Table 8-1.

Table 8-1
A sample comparison of time-based to population sampling (This represents a best-case situation without a noticeable increase in degradation.)

Relay Strategy Employed	Strategy	Frequency	Population of Relay Replacements Over 30 Years 10<n<40?	Estimated Cost to Perform Per Relay Replacement	Total Estimated Cost of Program
Initial Path	Follow Industry Standard Guidance	Replacement of Relays at 10 Yr Time-Based Frequency	**409x3 = 1227**	**$1000**	**$1,227,000**
New Path	Use Population Condition Sampling	Relay Groups Replacements ~5% Per 2 Yr Cycle	**21x15 = 315**	**$1000**	**$315,000**
Differences	NA	NA	**920**	NA	**$912,000**

Reuse Relays: Critical to Noncritical or Run-to-Failure Applications

When critical control relays have reached their replacement age according to the preventive maintenance program, they may still be functioning normally and still have a long period of useful service life left. Consider moving the critical control relays removed to an application where the control relay is in a noncritical or run-to-failure circuit application (identical environment/service duty). This will allow the relay to continue to be used and real service life data collected without a significant impact on plant reliability.

Tracking of the relays will be more complex; however, cost savings can be realized by reusing the relays in the noncritical or run-to-failure applications. A storage and tracking management system may be needed to keep track of the relays that have been removed from critical applications to ensure that they are reused only in noncritical or run-to-failure applications. This requires the ability to track each relay and keep data associated with that device, including return to warehouse and reissue. The same approach applies to utilities that use new components for contingency spares or swap out devices to minimize outage time. This may require a unique tracking code (UTC) type of coding or labeling for the relays.

9 AGASTAT/AMERACE 7000 AND E7000 SERIES RELAYS

Background

Based on the availability of data and the difficulties in getting the right information needed during the initial data collection phase of this project, the scope of the data collection was revised to focus on the Agastat/Amerace 7000 and E7000 series relays. Even though the scope was reduced, the amount and detail level of the data needed for statistical analysis was not obtained. Enough data were obtained to support the development of some observations and drawing some conclusions. This section will discuss the Agastat/Amerace 7000 and E7000 data obtained.

Population

From the industry data collected, 17 plants reported E7000 series relays totaling 1,381 relays, and 18 plants reported 7000 series relays totaling 1,815 relays. These two series represent more than 3,000 total relays when added together out of a total industry control relay population data set developed from TAG members' data of 52,250 relays. This means that the Agastat/Amerace 7000 and E7000 relay series accounts for about 6% of the total control relay population.

Failure Data

Detailed Agastat/Amerace 7000 and E7000 data were received from only a few sites and two fleets. The total failures in the data set amounted to 115 failures; 29 were 7000 series and 86 were E7000 series relays. Table 9-1 shows the failure information received.

Table 9-1
Agastat/Amerace failure data by plant site

Relay Failure Series	Plant A	Plant B	Plant C	Plant D	Plant E
7000	0	0	0	3	26
E7000	19	1	1	9	56

This seemed to be a small number of failures. Failure data were requested for at least a 5-year period. These data are from three individual sites and two fleets. This represents 115 failures from a population of about 3000 relays in the industry data set or about 5%.

The age of the relays at failure was checked and the minimum, maximum, and average age at failure determined. Table 9-2 shows these results.

Table 9-2
Age of Agastat/Amerace relay at time of failure

Relay Failure Series	Count Failures	Average Age Years	Minimum Age Years	Maximum Age Years	EPIX Average Age Years Failure
7000	29	11.2	0.2	30.9	13.6
E7000	86	12.1	0.0	34.9	14.1

From this review, the average age at failure for the 7000 compared to the E7000 relays is a difference of less than 1 year. The maximum age at failure, however, varies by a larger delta of 4 years, with the E7000 being longer. It was interesting to note that the average age per the site failure data for both series was over 2 years less than the EPIX average age. To see the distribution of the failures, graphs were developed to show the failures for each series. Figure 9-1 shows a graph of the age at failure of the E7000 series relays; the number for each relay is along the bottom axis.

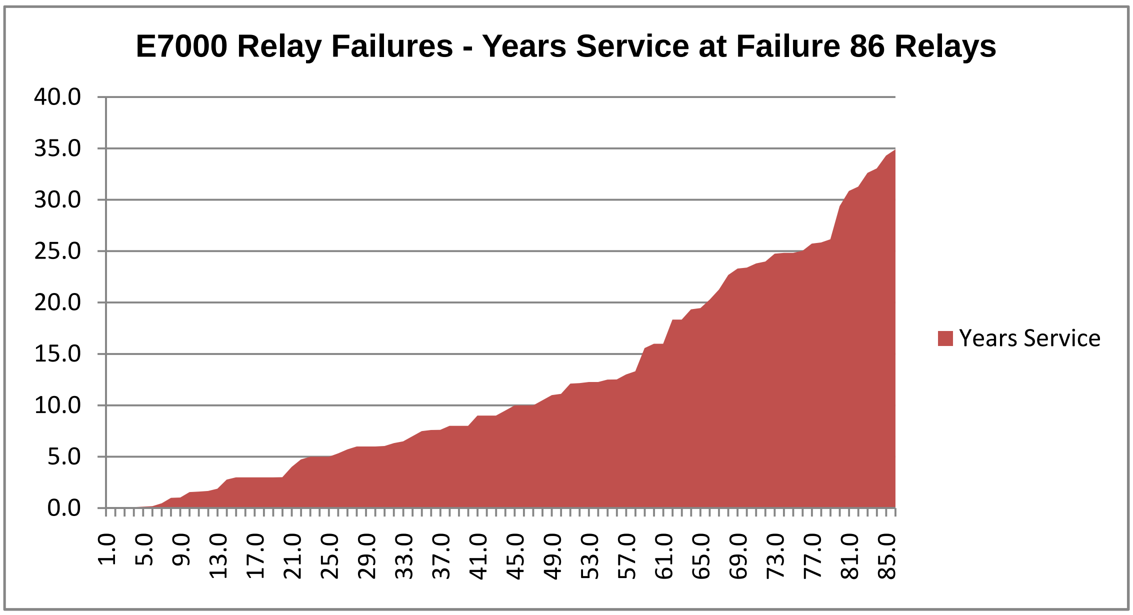

Figure 9-1
E7000 series relay failures

From this graph of 86 relay failures, one might suggest that the roughly 25% of relay failures that occurred in less than 3 years possibly represents infant mortality issues. About 50% of the failures occurred in less than 10 years. Approximately 30% of all the failures occurred in greater than 15 years, with about 10% occurring at over 30 years of service. Overall this graph does not provide a good indication of relay life expectancy since there are no sharp changes that would indicate a wear-out plateau. More importantly, we were not able to determine the percentage of the population that failed as a function of age. One could determine from this plot that the failure rate was about constant until the relays reached about 13 years in service, and the failure rate then increased. Unfortunately, it is difficult to draw conclusions about reliability of components without having data on the healthy population as well as the failures. Furthermore, if the infant mortality issues did represent 25%, we would want to avoid replacing relays more frequently than warranted to avoid an inordinate amount of risk as well as adversely consuming resources.

Figure 9-2 is a similar graph for the 7000 series relays that failed; the bottom axis reflects the number for each relay.

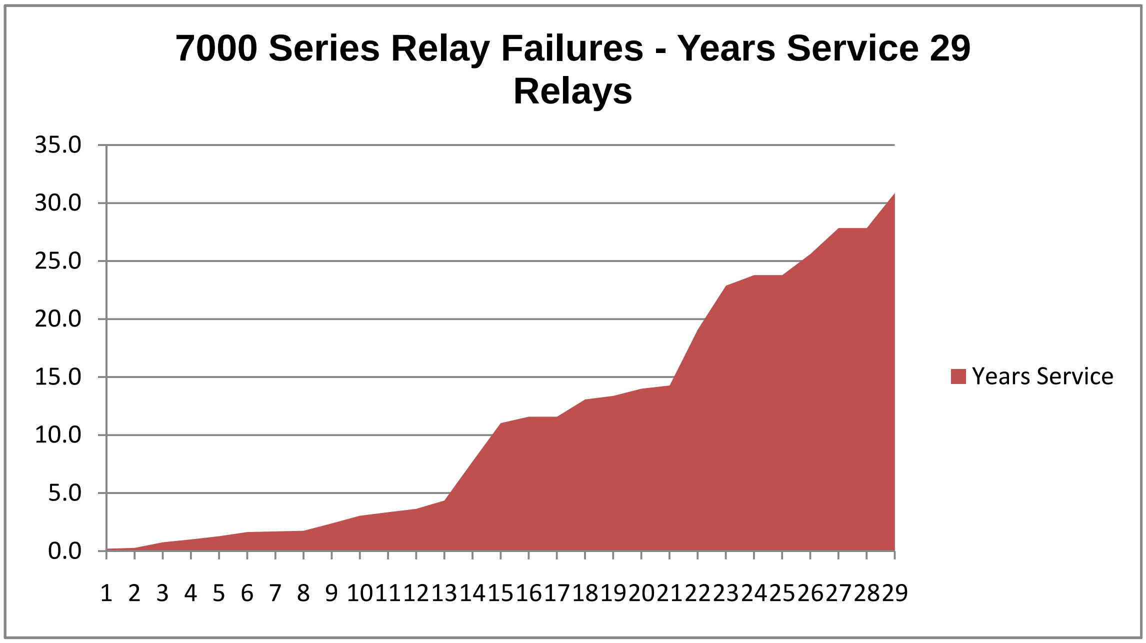

Figure 9-2
7000 series relay failures

Out of the 29 relay failures, half of the failures occurred within less than 10 years of service. About 30% of the failures occurred at over 20 years of service. From this graph, it appears that if a 7000 relay makes it past 4 years without failure, it has a fairly high chance of making it beyond 10 or more years of service. Could one determine from this plot that close to half of these relays had infant mortality issues? The slope of the failure plot seems to be constant for relays 15 through 21 and 23 through 29. As noted in the discussion above relative to the E7000 plot, it is difficult to draw valid conclusions about reliability of these components without having service life data on the healthy population as well as data on the relays that failed.

Service Life Information

For service life information, only two individual plants provided data on the current life of E7000 and 7000 series relays installed that have not failed. From these two sites, there are a total of 69 relays in the 7000 series and 207 in the E7000 series. Table 9-3 shows the minimum age in service, maximum age in service, and average age in service for the relays that are still installed and have not failed. Some of these relays have been in service over 50 years without failure.

Table 9-3
Agastat/Amerace service life data

Relay Series	Count of Relays	Average Age Years	Minimum Age Years	Maximum Age Years
7000	69	18.8	0.8	52.9
E7000	207	13.9	0.0	52.9

Next, let's look at the same type of distribution graph we looked at for the failures earlier. Figure 9-3 shows the E7000 relay distribution for 207 relays.

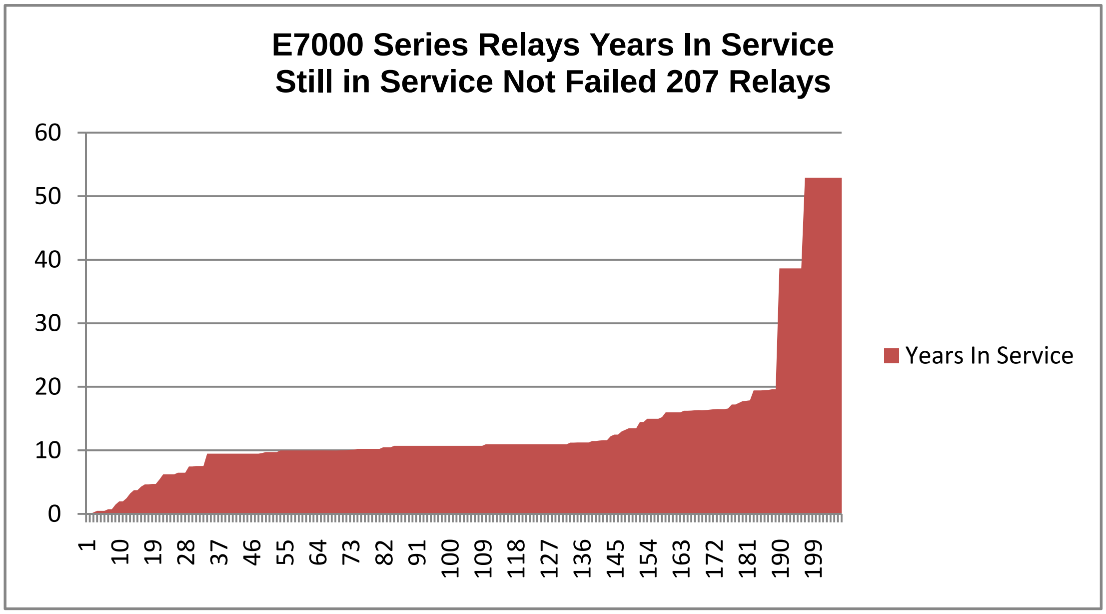

Figure 9-3
E7000 series relays still in service without failure

Out of the 207 relays, less than 25% are under 10 years old. This means that over 75% of the relays are 10 years or older. About 25% of the relays are over 15 years old. About 10% are over 35 years old and still have not failed. Unfortunately we do not have information on how many healthy relays were removed from service due to time-based replacement schedules and what their age was when removed.

Figure 9-4 is a similar graph for the 7000 series showing the age distribution for the 69 relays in this data set.

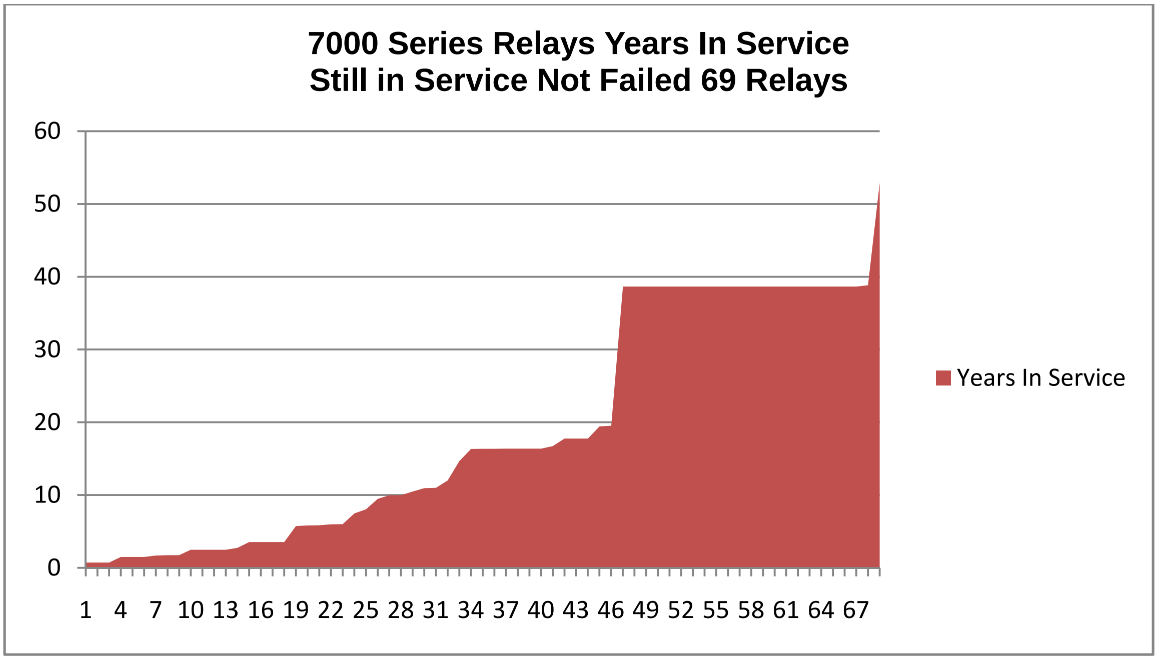

Figure 9-4
7000 series relays still in service without failure

In the 7000 series graph, the distribution is quite different. About half the relays are over 15 years old. About 30% of the relays are at 38 or more years old and still have not failed. A much larger percentage of the 7000 series relays is over 30 years old than for the E7000 series at these plant sites. As noted above, we were not able to obtain service life data for healthy relays that were removed via time-based replacements.

Purchasing Information

Since we had limited failure data to work with, we asked TAG members to provide supply chain data, for example, how many relays are being purchased each year other than for new projects. This would hopefully help us gain some insights into the number of relay replacements occurring for failures as well as time-based schedules. Purchasing information was supplied by a few plant sites and one fleet. Data were requested for at least 3 to 5 years of purchasing for 7000 and E7000 series relays, where the relays were purchased for performing work other than plant modifications. These data were compiled and put into Figures 9-5 through 9-8. Plant names have been replaced with generic designations using the alphabet. Below is the E7000 purchase count per year for three individual plants and two fleets. Data in some cases go back as far as 2003 and in others only as far back as 2007.

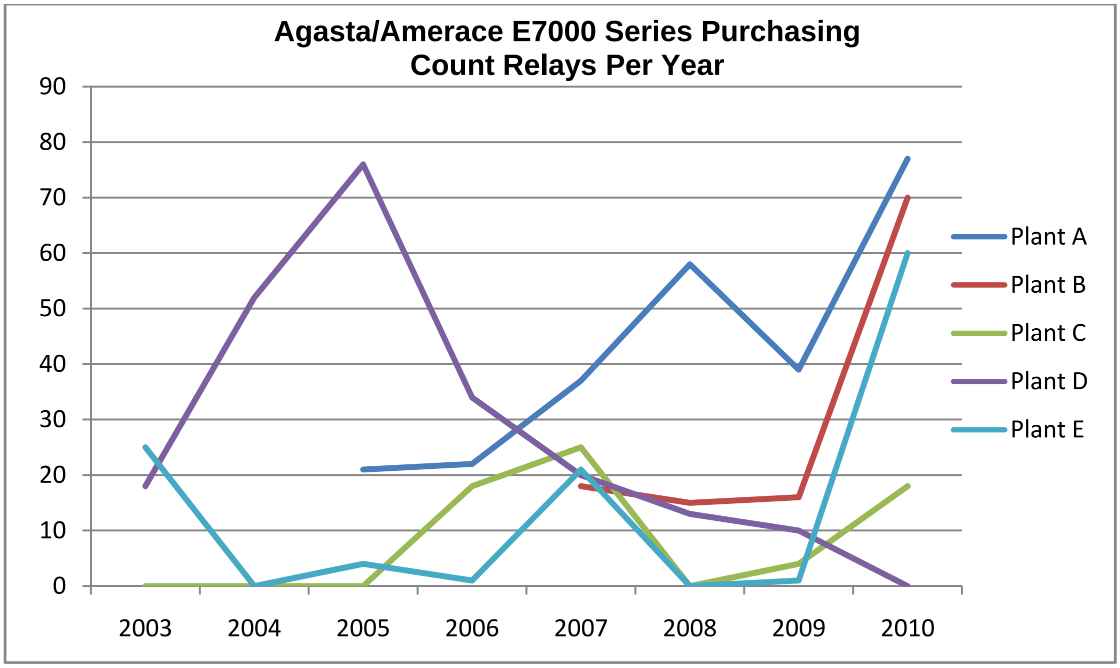

Figure 9-5
E7000 series relay purchasing data

Most of the sites (four out of five) show increased purchases for 2010 over the amount purchased in 2009. Overall the trend appears to be going up significantly for E7000 purchases. To check the trend, a combined bar graph was developed as shown in Figure 9-6.

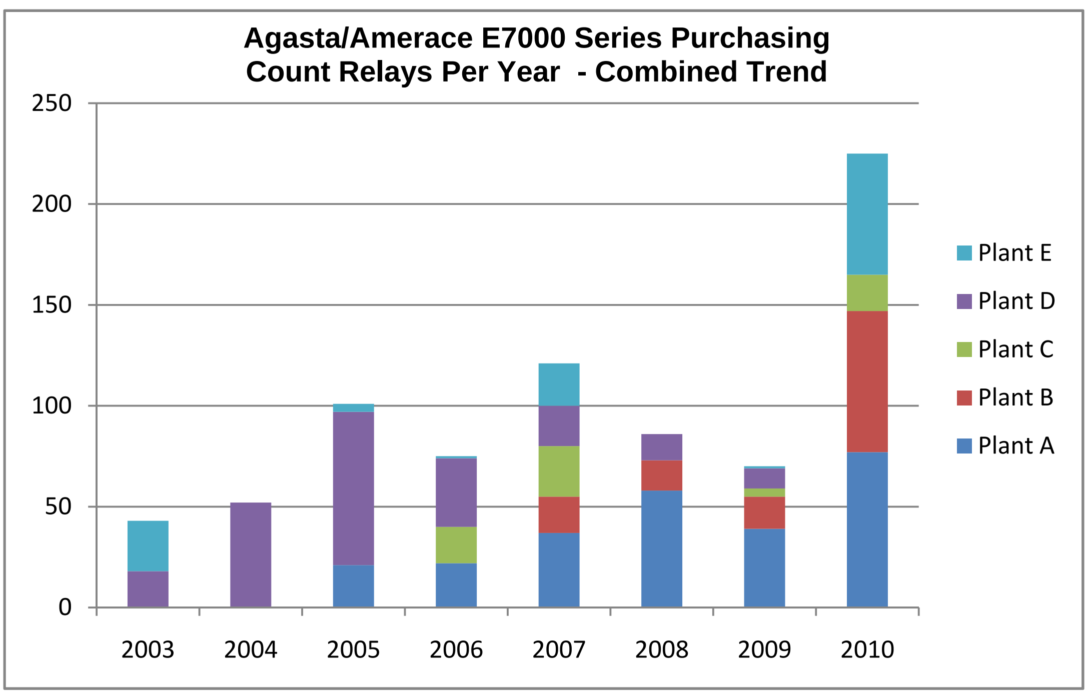

Figure 9-6
E7000 series relay purchasing data trends

The combined bar graph shows that E7000 purchases were cycling for the years 2003 to 2009 but show a significant increase in 2010. For 2010, E7000 purchases are more than twice the peaks of 2005 and 2007.

Figure 9-7 shows the graph for the 7000 series relay purchases data provided by three individual sites and one fleet. Again, plant names have been alphabetized.

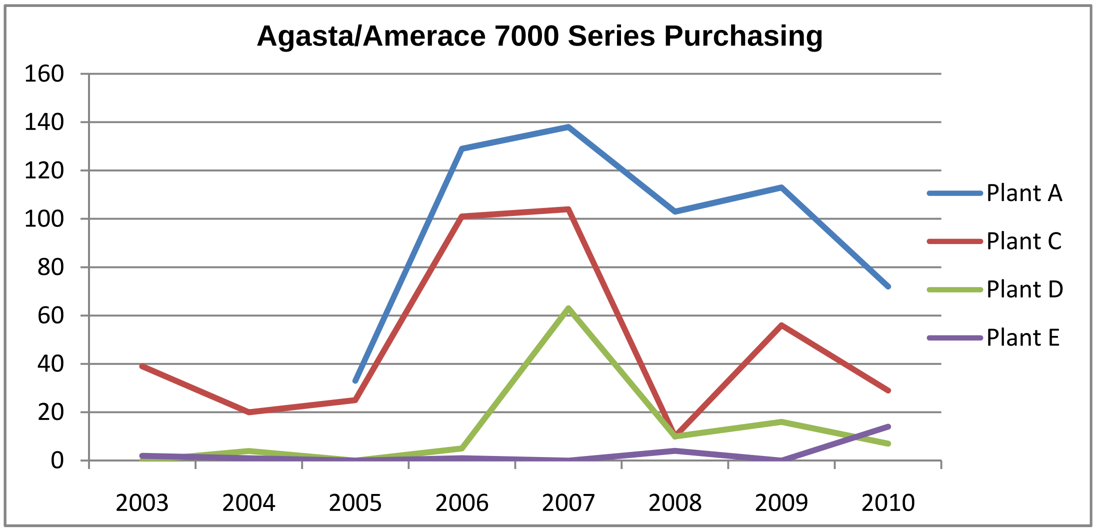

Figure 9-7
7000 series relay purchasing data

The 7000 series relay purchases show a significant increase for most of the sites that reported for 2006 and 2007. Overall the purchases for 7000 series relays appear to be on a decline. A combined bar graph follows in Figure 9-8.

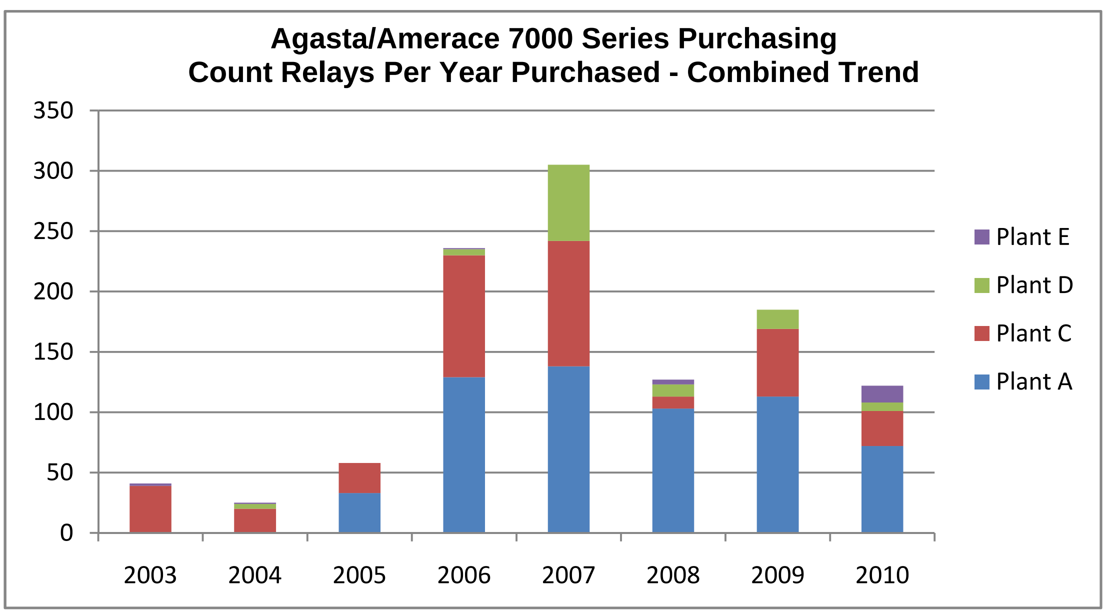

Figure 9-8
7000 series relay purchasing data trends

The combined bar graph shows the peaks of 2006 and 2007 followed by a decline in purchases. The trend is down from the peak of 2007. Although these data are interesting, it would be difficult to draw any conclusions given the limited sample and not knowing the basis for these purchases.

Potential Replacements for This Relay Series

Replacement relays for Agastat/Amerace E7000 and 7000 series relays were discussed by the TAG. Members were asked if their sites have been changing from electromechanical to digital relays and if the same types of problems are occurring with the digital relays. From this discussion, most sites are performing this transition during modifications due to licensing requirements for safety-related relays where it is more difficult to change to digital. We were not able to obtain good information on how many sites have transitioned to digital. One plant site mentioned that it changed most of its E7000 series to ETR when it completed a breaker replacement project, and all safety-related overcurrent protective relays have been replaced with Basler solid-state relays. These Basler solid-state relays had to be seismically qualified.

A survey was conducted on replacements for Agastat/Amerace 7000 series pneumatic timing relays. There were 14 site responses; all 14 indicated that they had 7000 series pneumatic timing relays installed. Eleven indicated that they have them installed in critical or safety-related applications. Of these, seven indicated that they are considering replacement with a different model. The models that are either being considered for replacement or have been installed as replacements are listed below with notes:

- NTS Model 812 solid-state: 5 sites considered this for a replacement, 4 sites indicated that they had replaced the relays with this type, 1 site indicated that it had replaced a qualified EQ relay with this model.
- Allen Bradley 700-RTC: 2 sites considered this for a replacement, 1 site performed a replacement with this model, and there were no EQ replacements. **Note**: the site that did perform a replacement commented that additional contacts were needed and that the 700DDCP400Z1 slave relay was used.
- ATC365A300: 1 site considered this for a replacement, 1 site performed replacement with this model, and there was 1 EQ replacement. This relay was manufactured by Automatic Timing & Control and is now obsolete. The replacement occurred a few years ago; Trentec performed the qualification.
- Agastat Solid-State ETR model: 2 sites indicated that they had performed replacements using this model. There were no EQ replacements.

10 INDUSTRY RELAY CHALLENGES

The following items were identified as industry issues during the development of this guidance document.

Unidentified Components

A recent failure at one of the sites was discussed by a TAG member. The relay involved did not have a unique component ID number, so it was not included in the site's CMMS database. This prompted a discussion of relays in the plant that do not have component identification numbers in CMMS systems. From this discussion, it was recognized that this is a fairly common industry issue. The relay that failed was an auxiliary relay for an undervoltage relay circuit. At many sites, there are panels and terminal boxes in the plants that have circuit cards, relays, small transformers, and other equipment located within them that are not identified in the CMMS database. Some of these components can be in critical circuits or even be a single point vulnerability concern. Each site should review its panels, cabinets, skid-mounted equipment, and so on to check for any unidentified relays or other components that are potential critical components and/or that need to be included in the PM program to monitor/manage aging. These components should be classified for criticality and reviewed for preventive maintenance strategy.

Users Groups

During the discussion of data gathering, it was mentioned by a TAG member who had recently attended an EPRI Circuit Breaker Users Group meeting that data gathering was difficult for their group to complete. The participant strongly recommended that the Relay Users Group be resurrected as the week-long Circuit Breaker Users Group meetings give the participants the time needed to gather data required and assist with formulating conclusions like the information contained in NMAC guides.

The Relay Users Group functioned for about three years when a decision was made to discontinue the group. This decision was based on there being few relay issues at that time and therefore no compelling reason to keep the users group going. The users group was funded by the participants; at the time it was stopped, there was not a lot of funding to support the group. The TAG members would like to see the Relay Users Group reformed. At this time, the TAG is planning to continue meetings using WebEx or something similar to continue to share information.

The Relay Users Group and periodic meetings would be beneficial for the following:

- To share lessons learned
- To share best practices
- Standardization

- To share/learn about new technology and equipment replacement
- Vendor interaction
- To address new requirements (for example, NRC, FERC, and NERC)

Equipment Data Capture

Improvement in data collection for industry reference is an open action item that came from this project. Collection of relay service life data and failure data needed for this project pointed out the need for a better means of collecting, tracking, and trending relay data. The INPO representative at the Relay Aging meeting held in St Charles mentioned that INPO's ICES project is planned to combine the EPIX and OE databases. From the meeting discussion, TAG members determined that this issue does not apply only to control relays but also to all component types. This data capture issue became an EPRI/INPO action item. Examples of these data and collection points include the following:

- Criticality information
- Manufacturer, model, and series (note that this information is not currently available)
- Installation date/service life information
- The reason equipment was taken out of service
- Failure information details
- Single-point entry and location for entry of these data
- Unique component ID is required for each component
- Data need to be available to plant sites and INPO
- Need for a simple interface similar to Turbo Tax drop-down format

11
RECOMMENDED CONTROL RELAY MAINTENANCE AND REPLACEMENT STRATEGIES

The following is the recommended strategy for performing maintenance on control relays. These recommendations align with and complement Figures 11-1 and 11-2, which provide a visual diagram showing control relay decision-making logic.

Frequency recommendations vary based on criteria and decisions made for each relay. For relays that have known industry failure/performance issues, are high critical, are high risk, or will cause regulatory exposure, a conservative frequency is recommended. A less conservative frequency is recommended for relays that do not meet these types of criteria.

Conservative frequency generally means to align with vendor or industry recommendations for replacement or preventive maintenance task intervals. Vendor recommendations are usually very conservative. If a vendor recommendation for replacement is not available, industry guidance, operating experience, and plant historical performance can be used to determine an initial frequency. However, a service life calculation may be warranted.

If the frequency for critical relays is going to be less conservative (longer intervals) than vendor recommendations, it is recommended that a service life analysis or engineering evaluation be performed to assist in determining the appropriate frequencies. These evaluations should include analysis based on thermal degradation, environment, location, radiation exposure, energization state of the relays, and cycling of the relays. See the section earlier in this report discussing NRC inspection guidance.

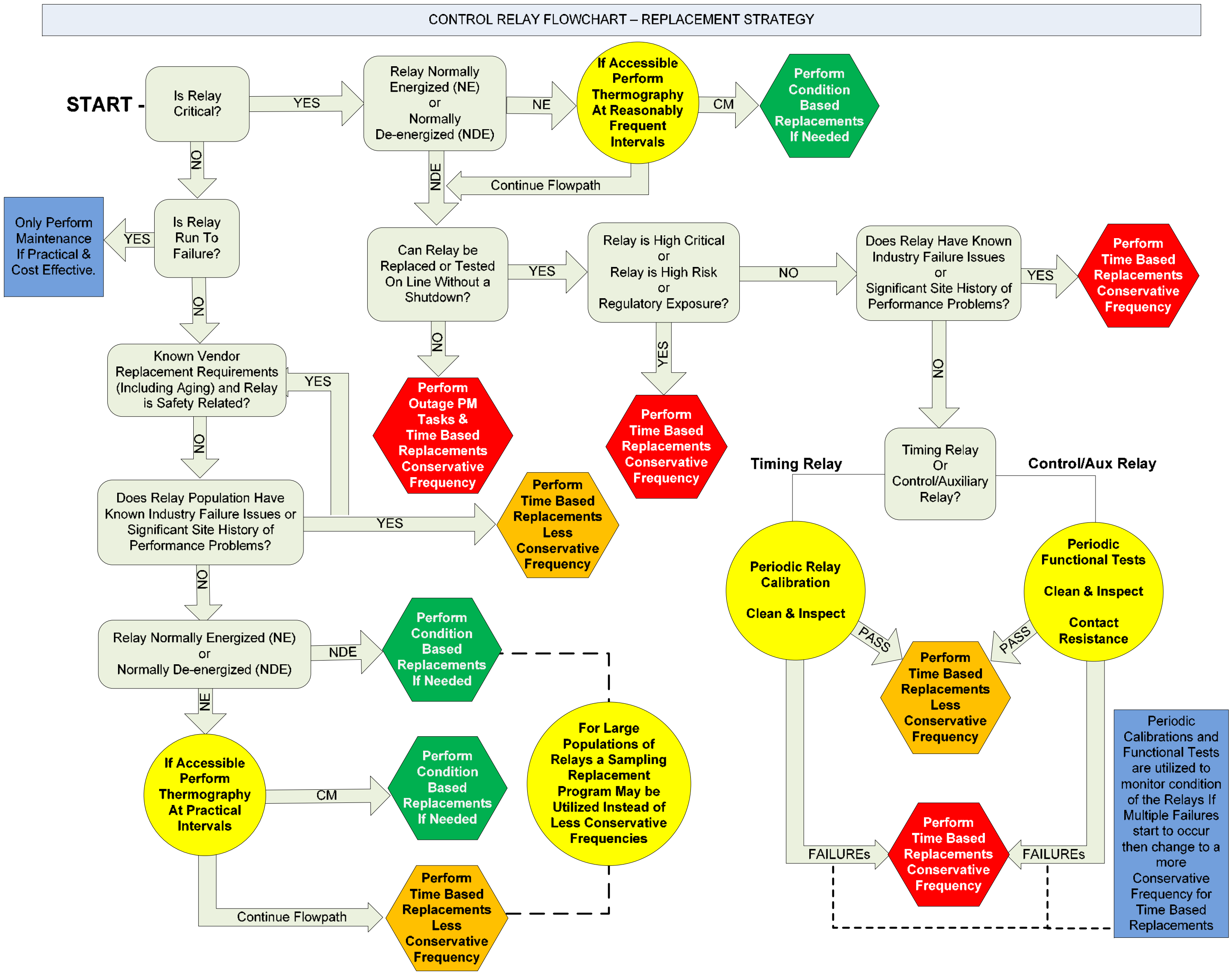

Figure 11-1
Relay replacement flowchart

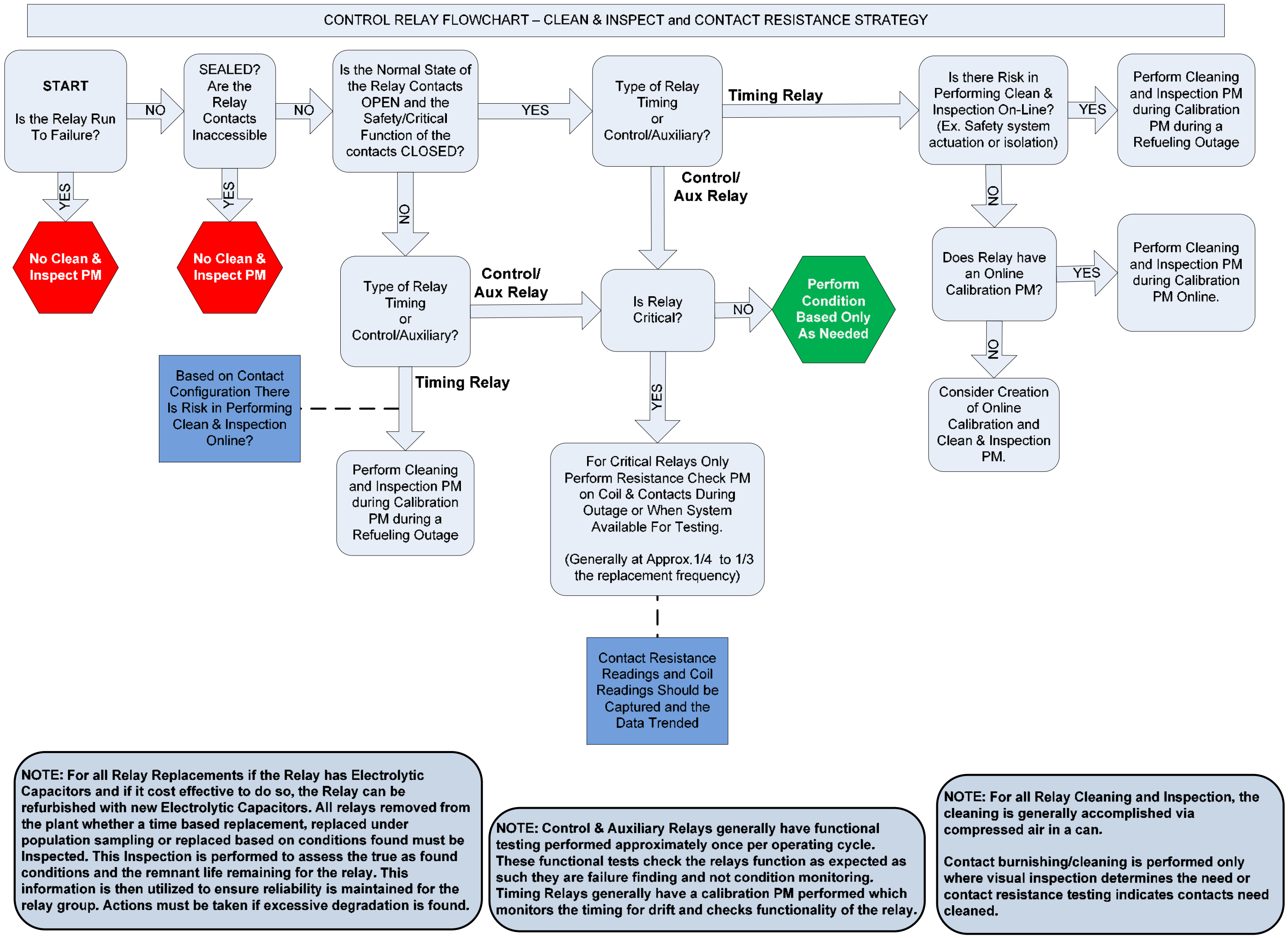

Figure 11-2
Relay clean, inspect, and contact resistance flowchart

Relay Maintenance and Replacement Strategies: Categories of Components Defined in AP-913

Critical Control Relays

1. Periodic maintenance
    a. Visual inspection: control, auxiliary, and timing relays
    b. Functional test (as-found condition): control and auxiliary relays
    c. Calibration check (as-found condition): timing relays
    d. Resistance tests (coil and contacts): control and auxiliary relays
    e. Others as applicable based on specific component involved and OE

Conservative frequency: based on vendor recommendations, service life analysis, engineering evaluation, service conditions, duty cycle, and decision-making logic (that is, for relays that are high criticality, high risk, subject to regulatory exposure, or have known industry failure issues or a significant site history of performance problems).

Less conservative frequency: a less conservative frequency can be used for critical relays that do not meet any of the above categories from the decision-making logic. Normally deenergized relay PM tasks are usually performed much less frequently than normally energized relays.

Note: If found out of calibration, recalibrate and see if results are satisfactory. If satisfactory results are obtained after recalibration, relay use will be continued.

If recalibration results are **not** satisfactory (will not calibrate), perform condition based replacement (see note that follows).

2. Replacement strategy

    Normally energized (NE) relay:

    a. If component installation is accessible and thermography would be effective, perform thermography at reasonably frequent intervals.
    b. Perform time-based replacements (see note that follows) based on vendor recommendations, OE, and/or service life or engineering evaluation and decision-making logic (refer to frequency criteria above).

    Normally deenergized (NDE) relay:

    a. Perform time-based replacements (see note that follows) based on temperature of installed location, service conditions, duty cycle, and/or OE and decision-making logic (this is much less frequently performed than the normally energized relays).

Note: Document service life obtained, condition, nature of failure, service duty, and environmental parameters (especially temperature, radiation, and humidity).

If an electrolytic capacitor or other subcomponent is known to significantly limit the life of the component, replacement of the subcomponent(s) may be an effective PM strategy. In addition, it may be cost effective and/or beneficial to move the relays that are removed on a time-based schedule and use them in run-to-failure applications. If installed in similar service duty and environments, service life data can be bridged and monitored.

Noncritical Control Relays

1. Periodic maintenance
   a. Visual inspection: control, auxiliary, and timing relays
   b. Functional test (as-found condition): control and auxiliary relays
   c. Calibration check (as-found condition): timing relays
   d. Resistance tests (coil and contacts): control and auxiliary relays
   e. Others as applicable based on specific component involved and OE

Conservative frequency: based on vendor-recommended replacement (including for known aging issues) if the relay is safety related or has a known industry issue with relay failures or a significant history of performance problems; also based on service conditions, duty cycle, and decision-making logic. This is a less conservative frequency (compared to critical relays).

Less conservative frequency: based on service conditions, duty cycle, and decision-making logic, this frequency is a less conservative (longer) frequency (compared to the critical relays' less conservative frequency). A less conservative frequency or population sampling may be used (for large populations of relays).

Note: If found out of calibration, recalibrate and see if results are satisfactory. If satisfactory results are obtained after recalibration, relay use will be continued.

Recalibration results are **not** satisfactory (will not calibrate), perform condition-based replacement (see note that follows).

2. Replacement strategy

   Normally energized (NE) relay:

   a. If component installation is accessible and thermography would be effective, perform thermography at practical intervals (for example, prior to seasonal hot temperatures, once per year, or once per fuel cycle).
   b. Perform time-based replacements (see note that follows) based on vendor recommendations, OE, and/or service life or engineering evaluation and decision-making logic. See frequency discussion earlier; population sampling may be used for large populations of noncritical NE relays:
      - Inspect/evaluate components removed from service to determine if aging/degradation concerns exist, and/or
      - Install in similar duty and service run-to-failure applications and continue to monitor service life

Normally deenergized (NDE) relay:

a. Perform condition-based replacement (see note that follows) **if** there are any concerns related to aging, material, or performance degradation. Population sampling may be used for large populations of NDE noncritical relays.

Note: Document service life obtained, condition, nature of failure, service duty, and environmental parameters (especially temperature, radiation, and humidity).

Run-to-Failure Control Relays

1. Perform maintenance only if practical and cost effective, for example:
   - It is convenient and effective to perform thermography while in a cabinet or in the area
   - There is an opportunity to use data to adjust PM frequencies (for example, checking calibration and performing recalculation functions)

2. Replace as needed (see note below)

Note: Document service life obtained, condition, nature of failure, service duty, and environmental parameters (especially temperature, radiation, and humidity).

12 SUMMARY AND CONCLUSIONS

Control relays have recently gotten considerable attention in the industry, and both the NRC and INPO have focused on relays and electronic components in recent evaluations. The NRC issued an OPESS report that discussed these inspections and provided guidance for future inspections. PM programs are being evaluated with a focus on how vendor recommendations are addressed and the technical justifications/basis for deviations from vendor recommendations. Service life analyses and engineering evaluations are being reviewed in detail. These evaluations need to address known stressors such as thermal degradation, radiation considerations, normally energized state, elevated voltage (dc), high cycling duty, extremely long intervals between contact operations with the contacts normally open, and so on.

Industry efforts related to aging effects currently focus on reporting failures and looking for early trends. Beneficial data on service lives achieved on healthy relays have not been captured, retrieved, or trended. From data collected via the TAG, there are indications that many relay types can perform reliably well beyond the vendor recommended service life; however, we were not able to obtain sufficient empirical data to substantiate this. To support determination of realistic service lives in the future, it is important that utilities document the following information when replacing relays:

- Service life obtained
- As-found condition of the relay
- Service conditions, including cycling and all stressors

Sufficient data could not be obtained during this project to support a statistically valid analysis for relay service life; however, enough data were obtained to support development of some observations and drawing some conclusions. The first conclusion is that better data are needed, which will require a better data collection tool, better data entry, and the ability for plants to access and trend the data easily. EPRI and INPO are working together on this issue as it applies to components other than relays.

Based on data reviewed and discussions with the TAG, the following items were identified as warranting more attention.

Identification of Critical Components

Utilities need to address subcomponents and electronic parts in panels, cabinets provided with major equipment, and skid-mounted equipment that are not identified in the site's CMMS system (that is, have no equipment ID). Some utility preventive maintenance programs have missed these relays and components since they did not have a unique equipment ID. Sites should reevaluate areas of the plant that have a potential for unidentified subcomponents, including control relays. When identified, these components should be classified for criticality and reviewed for PM requirements. In some cases, these subcomponents were determined to be SPVs.

Single-Point Vulnerabilities

Utilities should reevaluate relays in SPV applications and pursue design or other changes to eliminate the SPV risk if practical. The relays that are SPVs should be reviewed to ensure that PM is being appropriately performed; thermography should be routinely performed for normally energized relays if they are accessible; and time-based replacement tasks should be performed on a conservative replacement frequency.

Chronic Relay Problems

Relay problems that seem to occur more frequently than expected may indicate a relay misapplication. Trends should be reviewed for critical relays to identify potential misapplications. Replacement relays should be pursued if equipment reliability is being impacted.

Designated Relay Engineer

It is recommended that an appropriate individual be designated as the *relay engineer*. They should be engaged in the above activities and track data for calibrations, thermography, functional testing, replacements including installation dates, relay time in service, temperatures, humidity levels, environmental conditions, as-found relay conditions during maintenance, and so on. This type of condition monitoring data is useful in monitoring the relays for degradation. All relays removed from the plant—whether from PM, CM, or other maintenance activities—should be inspected for their condition and determination of remaining life. This information helps to gauge how to adjust the relay program for similar relays in similar conditions. A good relay data set and tracking and trending of the data can provide condition monitoring that can support extension of relay preventive maintenance tasks.

Relay Users Group

TAG members expressed a strong interest in having a Relay Users Group to share information on relay issues, best practices, vendor recommendations, operating experience, practices engaged to address SPVs, application of new technologies, and so on. Current TAG members are being invited to participate in a follow-on project to address protective relays. The TAG can serve this purpose in the interim, but this issue needs to be addressed for 2012 and beyond.

Generic Service Life Analyses

The TAG agreed that a follow-on project should be initiated to develop generic service life analyses. EPRI should coordinate a utility working group approach and engage vendors as needed to develop generic analyses and guidance that utilities can use to determine service life for individual relays based on their location and service conditions. The following discussion on Agastat/Amerace 7000 and E7000 series relay failures provides some insights on the benefits of this approach given the lack of empirical data to determine realistic service lives.

The Agastat/Amerace 7000 and E7000 relay series failure data indicate:

- The E7000 series failures are occurring at timeframes from a few months to greater than 30 years. There was no specific timeframe seen where there was a marked increase in failures that would indicate that an end-of-life or wear-out timeframe is being exceeded.
- The average age at failure for the 7000 series relays is relatively close to the EPIX average age of 13.6 years and the TAG data average age of 11.2 years. For the E7000 series, the EPIX average age at failure is 14.1 years, and the TAG data average age at failure is 12.1 years. At the same time, many E7000 series relays are still in service without failure, some for greater than 30 years. The story is very similar for the 7000 series relays with the difference being a larger percentage of 7000 series relays are higher in age in service without failure.

Based on these observations, the data collected and reviewed do not align with the vendor 10-year replacement as there are no indications that failures significantly increase after 10 or so years of service. Of the 207 E7000 series relays that continue in service without failure, 75% of them are 10 years of age or older. For the 7000 series, over 60% of the relays still in service without failure are 10 years of age or older. Current replacement intervals provided from the TAG member sites for Agastat/Amerace 7000/E7000 series replacement range from 6 years to 20 years.

A graded approach to replacement frequencies should be used based on the control relay criticality (critical, noncritical, and run to failure) (see Figure 11-1). Normally energized relays in critical applications should be monitored with thermography if accessible and effective on a monthly or fairly frequent interval. Time-based replacements tasks for critical relays should be scheduled.

From the limited purchasing data obtained and reviewed, it appears that either E7000 relay preventive maintenance replacements are increasing or that failures are increasing as the 2010 purchasing information indicates a significant increase in quantities ordered. This may also be due to the recent emphasis on these components. On the other hand, the number of 7000 relays being purchased was decreasing, possibly because they are being replaced with E7000 relays.

To ensure that the critical relays are replaced prior to failure and to have a better understanding of the expected service life of these relays, some sites are performing service life analyses or engineering evaluations. One such evaluation placed E7000 NE relay replacements at 20 years and NDE replacements at 40 years. These evaluations are very specific and take into account the service conditions for the relay at the installed location, thermal degradation, radiation, environment, and so on. In addition, evaluations should take into account cycling effects and any other stressors that might adversely affect aging. For critical relays, this provides some assurance that the relay replacement interval is adequate based on the predicted degradation of materials and subcomponents. These evaluations are a good way to justify extending PM replacements beyond vendor recommendations for critical applications.

In addition to the industry best practices included in Section 7 of this report, the following ideas could result in significant cost savings:

- Using population sampling in the relay replacement program for noncritical relay applications and making adjustments to PM frequencies based on data and as-found conditions
- Reusing relays removed from critical applications that are in good condition in run-to-failure or noncritical applications

Either of these practices can potentially save money with little risk to the plant. Utilities should review the best practices listed in Section 7 and determine if changes are needed in their relay programs.

EPRI and INPO are discussing issues related to data needs and collection that would provide a better understanding of equipment reliability and service life, especially for components that can not be refurbished and when condition monitoring does not necessarily provide an indication of imminent failure.

Anderson, Chavet, Anderson, Inc. (ACA) has developed a spreadsheet of information that contains Part 21, OE, and other information associated with relay model numbers for reference. This information is provided in Appendix B for quick reference; however, utilities should refer to the original documents for more information and perform searches as needed to identify more current data.

A
RELAY SCOPE BREAKDOWN IEEE DESIGNATIONS

Table A-1
Control and timing relay group

Device Codes	Control and Timing Relay	Protective
3.1.2 Device number 2—time-delay starting or closing relay	X	
3.1.3 Device number 3—checking or interlocking relay	X	
3.1.5 Device number 5—stopping device	X	
3.1.7 Device number 7—rate-of-change relay	X	
3.1.30 Device number 30—annunciator relay	X	
3.1.42 Device number 42—running circuit breaker	X	
3.1.44 Device number 44—unit sequence starting relay	X	
3.1.48 Device number 48—incomplete sequence relay	X	
3.1.49 Device number 49—machine or transformer thermal relay	X	
3.1.53 Device number 53—exciter or dc generator relay	X	
3.1.56 Device number 56—field application relay	X	
3.1.58 Device number 58—rectification failure relay	X	
3.1.62 Device number 62—time-delay stopping or opening relay	X	
3.1.69 Device number 69—permissive control device	X	
3.1.74 Device number 74—alarm relay	X	
3.1.77 Device number 77—telemetering device	X	
3.1.79 Device number 79—reclosing relay	X	
3.1.82 Device number 82—dc load-measuring reclosing relay	X	
3.1.83 Device number 83—automatic selective control or transfer relay	X	
3.1.85 Device number 85—carrier or pilot-wire relay	X	
3.1.93 Device number 93—field-changing contactor	X	
3.1.94 Device number 94—tripping or trip-free relay	X	

Table A-2
Protective relay group

Device Codes	Control and Timing Relay	Protective
3.1.21 Device number 21—distance relay		X
3.1.24 Device number 24—volts per hertz relay		X
3.1.25 Device number 25—synchronizing or synchronism-check relay		X
3.1.27 Device number 27—undervoltage relay		X
3.1.32 Device number 32—directional power relay		X
3.1.37 Device number 37—undercurrent or underpower relay		X
3.1.40 Device number 40—field relay		X
3.1.46 Device number 46—reverse-phase or phase-balance current relay		X
3.1.47 Device number 47—phase-sequence or phase-balance voltage relay		X
3.1.50 Device number 50—instantaneous overcurrent relay		X
3.1.51 Device number 51—ac time overcurrent relay		X
3.1.55 Device number 55—power factor relay		X
3.1.59 Device number 59—overvoltage relay		X
3.1.60 Device number 60—voltage or current balance relay		X
3.1.63 Device number 63—pressure switch		X
3.1.64 Device number 64—ground detector relay		X
3.1.67 Device number 67—ac directional overcurrent relay		X
3.1.68 Device number 68—blocking or “out-of-step” relay		X
3.1.76 Device number 76—dc overcurrent relay		X
3.1.78 Device number 78—phase-angle measuring relay		X
3.1.81 Device number 81—frequency relay		X
3.1.86 Device number 86—lockout relay		X
3.1.87 Device number 87—differential protective relay		X
3.1.91 Device number 91—voltage directional relay		X
3.1.92 Device number 92—voltage and power directional relay		X

B

ACA DATA: PART 21 NOTIFICATIONS, VENDOR BULLETINS, AND OPERATING EXPERIENCE

Notes: The Relay Manufacturer Model Table is provided as a link to the file. The data table is too large to reproduce in this report. This set of tables contains Part 21, OE, and other information associated with relay model numbers for reference. Refer to the original documents referenced for more information.

This relay data set was developed by ACA, Inc. and is provided as part of this report for industry use.

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