<Public>

WECC

# 2023 Protection Systems Performance Report

Protection and Control Subcommittee

November 5, 2024

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# Introduction

## Background

NERC has identified Protection System Misoperations as a significant concern to the reliability of the Bulk Electric System (BES), as they can increase the severity of an event. NERC tracks annual misoperation rates for each region to evaluate the performance of protection systems. The current metric is the ratio of Protection System Misoperations to the total number of Composite Protection System operations. Figure 1 shows a five-year history of these numbers for the Western Interconnection. The purpose of the Protection System Misoperations metric is to calculate a misoperations rate to determine the relative performance of protection system operations and allow WECC and NERC to identify concerning or improving trends. The misoperations rate provides a consistent way to trend misoperations and to normalize for weather and other factors that can influence the count.

The Protection and Control Subcommittee (PCS), part of the WECC committee structure (formerly the Relay Work Group (RWG)), created this report. The 2023 report provides a general review of misoperations in the Western Interconnection with an assessment of each of the cause categories included in the Misoperation Information Data Analysis System (MIDAS) program. The intent of the analysis is to identify key findings and important details related to protection systems that can improve the reliability of the BES of the Western Interconnection.

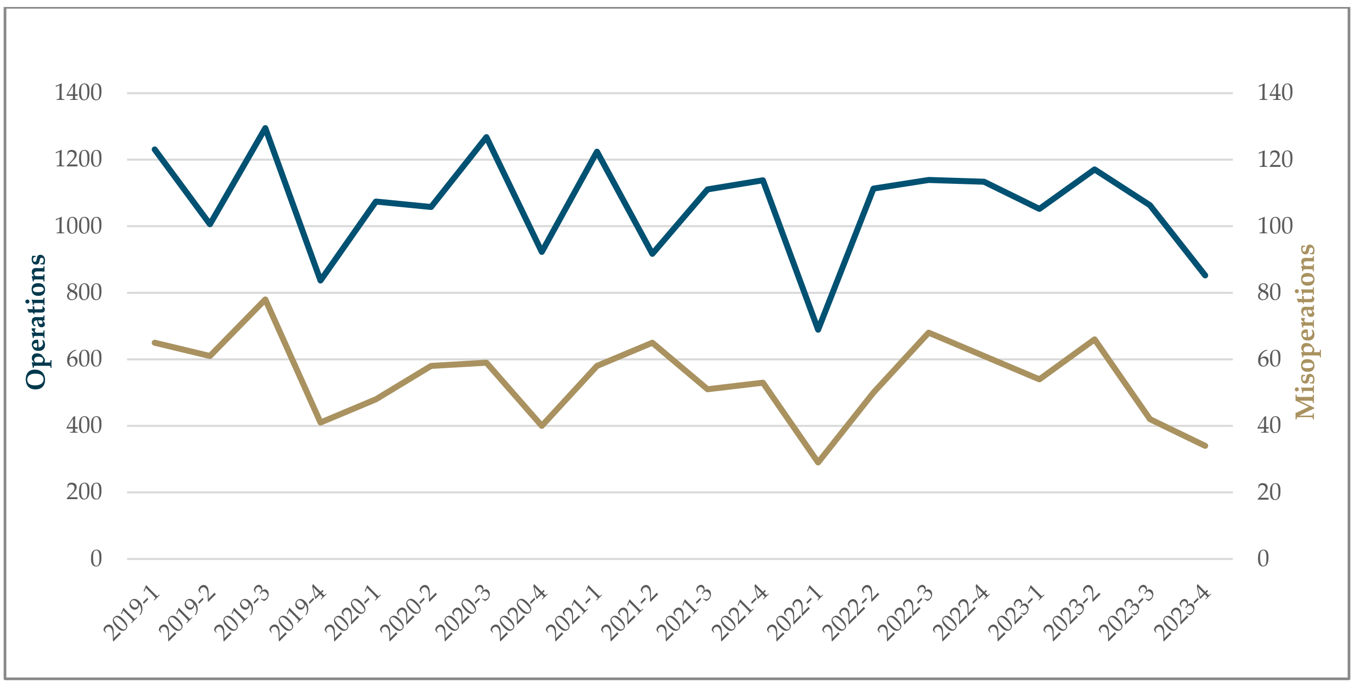


**Figure 1: Total Operations/Misoperations Trend, 2019–2023**

For the Western Interconnection, the annual misoperation rate has continued to trend downward as shown in Figure 2. The annual rate was 4.74% for 2023, a value not seen since 2020. The PCS recognizes this as a favorable trend and encourages entities within the interconnection to continue reviewing their internal protection system practices to further support this progress. As individual entities perform incremental process improvements, the performance of the protection systems within the Western Interconnection will be enhanced. Note that, while improvements in the misoperation rate are desirable, the misoperation rate does not capture the impact on the system or severity of misoperations. NERC introduced a metric in 2024 to quantify the severity of misoperations. The PCS plans to use this metric in future versions of this report.

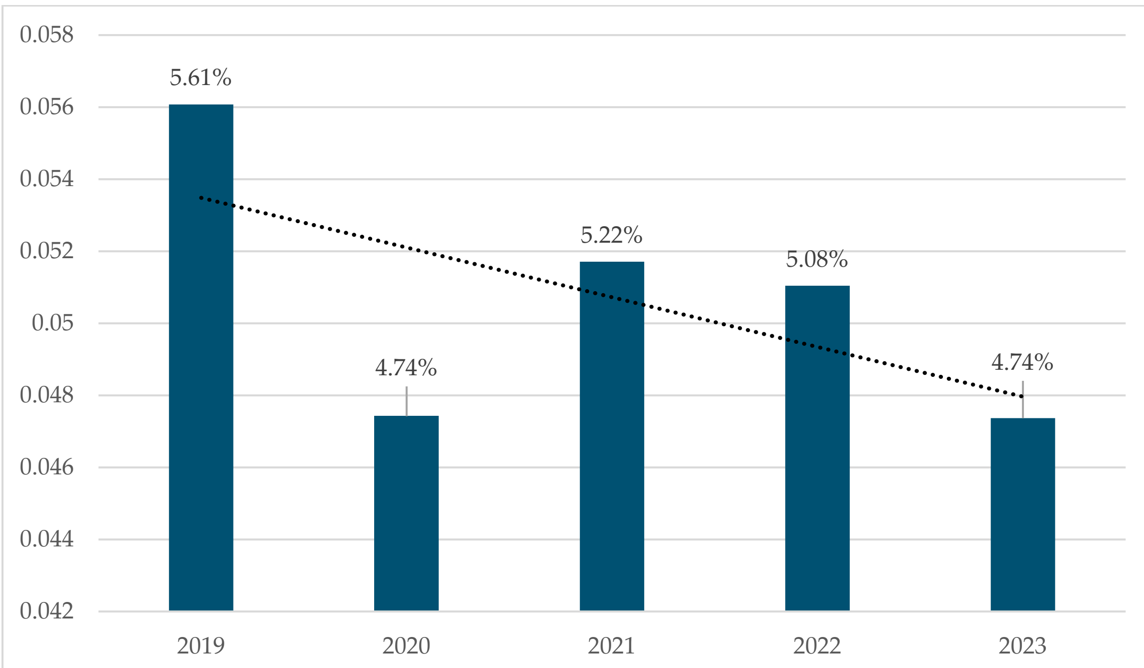


**Figure 2: Western Interconnection Misoperation Rate, 2019–2023**

## Purpose

The PCS reviews the quarterly misoperation data reported to NERC under Section 1600 for registered entities in the Western Interconnection. The PCS performs a yearly analysis and multi-year trending to:

- Provide trend analysis of Protection System Misoperation data and root cause identification.
- Form conclusions and recommendations to reduce the likelihood of future misoperations.
- Develop guidance and recommended practices for industry through technical documents and webinars pertaining to Protection System Misoperations.
- Publish the analysis results for WECC's Reliability Risk Committee (RRC) and the WECC membership.

The PCS focuses on misoperation causes to identify ways to reduce future misoperations.

## Data

The misoperation data used for the one-year analysis is from January 1 through December 31, 2023. The misoperation data used for the multi-year trend analysis is from January 1, 2019, to December 31, 2023.

- WECC obtained the dataset from the NERC MIDAS 1600 reporting template with defined categories and causes.
- Western Interconnection entities reported 196 misoperations during 2023.
- WECC used the reported corrective actions, event descriptions, and cause of the misoperations to assist in root cause identification.
- The PCS reviewed the 2023 misoperation data quarterly with resubmittals for clarification and correction.

## 2023 Misoperation Analysis

This report includes an analysis of the Western Interconnection 2023 data reported and the comparison of the 2019 through 2023 datasets for trending analysis. The analyses, conclusions, and recommendations for misoperations by cause are also included.

## Misoperation by Cause Category

The evaluation of misoperations by cause category shows misoperations attributed to human performance or a Protection System component. Figure 3 shows the distribution of misoperations as reported by cause category for 2023.

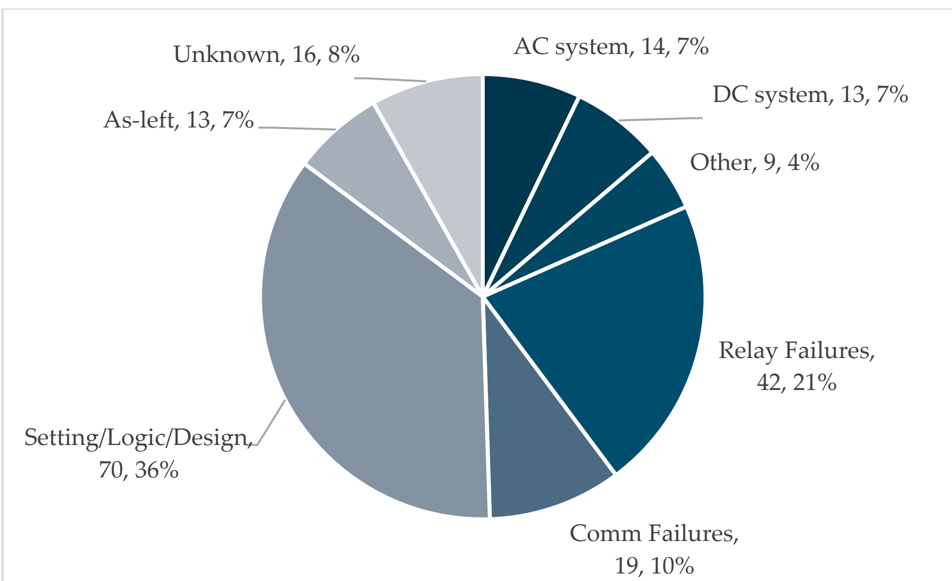


**Figure 3: 2023 Misoperations by Cause**

The largest contributor to misoperations in the Western Interconnection is Incorrect Settings, representing 28% of all misoperations in 2023, followed by Relay Failures/Malfunction with 21%, and Communications Failures with 10%. Nearly 60% of all misoperations for 2023 fall into these cause categories.

The PCS has separated the 2023 misoperations into two general categories: human influenced and equipment/material influenced. The Incorrect Setting, Logic Errors, and Design Errors, and As-left Personnel Error cause categories make up the human influenced group, while the Relay Failure/Malfunction, Communication Failures, AC Systems, and DC Systems cause categories make up the equipment influenced group. The Unknown/Unexplainable and Other/explainable cause categories were excluded from this analysis.

Evaluating the two groups shows—

1. 42% of all misoperations are related to human influences:
    a. Incorrect Setting
    b. Logic Errors
    c. Design Errors
    d. As-left Personnel Error
2. 45% of all misoperations are related to equipment influences:
    a. AC System
    b. Communication Failure
    c. DC System
    d. Relay Failures/Malfunctions

An observation from this breakdown is the significant contribution of human influenced misoperations. The PCS recognizes that not all misoperations in these subcategories are preventable; however, there are opportunities for improvement within these controllable categories.

Figure 4 shows that the Incorrect Settings and Relay Failure/Malfunctions categories have consistently been the highest contributors to misoperations over the past five years. While Incorrect Settings continues to be a prominent cause in 2023, it appears the overall trend is moving in a favorable direction. The opposite is true of the Relay Failure/Malfunctions category, which experienced a 35% increase from the previous year.

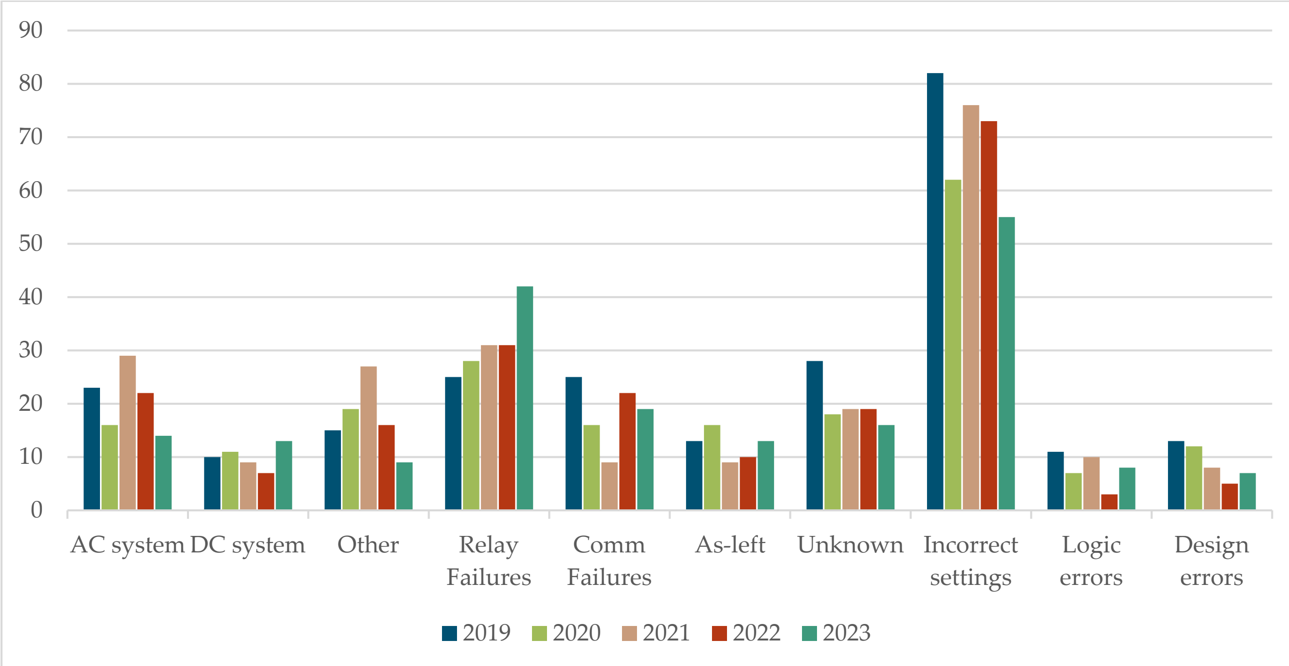


**Figure 4: Trending Misoperation by Cause, 2019–2023**

Another positive observation is the reduction in the number of Unknown/Unexplainable misoperations over this period. Unknown/Unexplainable misoperations are concerning because it is difficult to create an effective Corrective Action Plan when the root cause is unknown, and misoperations are prone to repeat when similar system conditions are present.

Figure 5 shows the distribution of misoperation causes by quarter for 2023, with a comparison to the quarterly average since 2019. Notice that Q2 of 2023 had the most misoperations for the year. The groups' analysis in 2022 showed Q3 had the most misoperations for that year, so no single quarter consistently experiences the highest number of misoperations for the interconnection.

Figure 6 is another view of the breakdown of misoperation causes. This chart shows the average number of misoperations per year over the last five years.

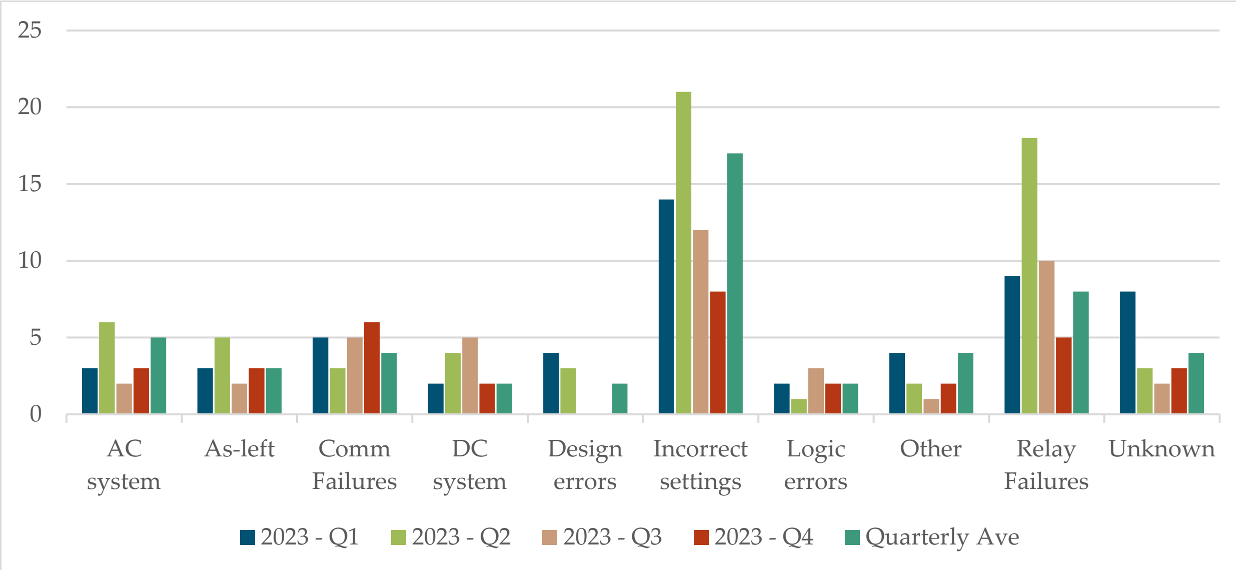


**Figure 5: 2023 Misoperation by Cause per Quarter**

Comparing these averages to the yearly totals in Figure 4 shows most categories have seen a reduction over this five-year period aligning with the downward trend of total misoperations for the interconnection.

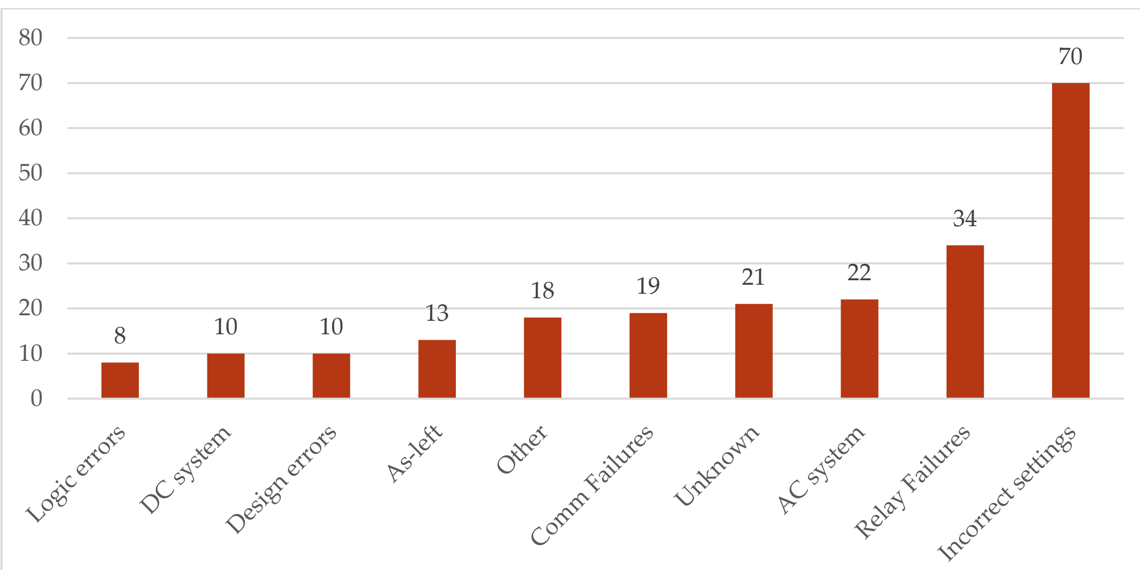


**Figure 6: Misoperation by Cause, Average Annual Count, 2019–2023**

Looking at the causes of misoperations through various methods reveals some helpful information. Knowing that 42% of misoperations in 2023 had some level of human influence allows entities to identify areas where improvements in practices can be made.

## Misoperation by Voltage Class

For MIDAS reporting purposes, voltage class is the operating voltage level of the equipment where the Protection System is applied. For misoperations involving equipment at multiple voltages (i.e., transformers) or misoperations affecting equipment at different voltage levels (e.g., breaker failure), the highest voltage class involved is reported. Figure 7 shows the breakdown of 2023 misoperations by voltage class, followed by the five-year trending graph in Figure 8.

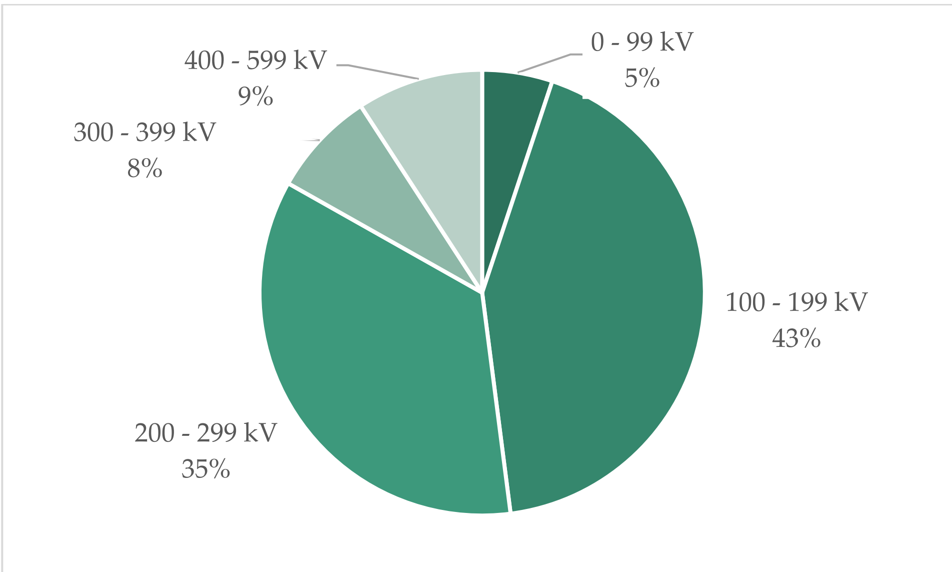


**Figure 7: 2023 Misoperation by Voltage Class**

In 2023, 83% of the misoperations for the year occurred on systems under 300 kV. A comparison to Figure 8 shows similar representation in previous years.

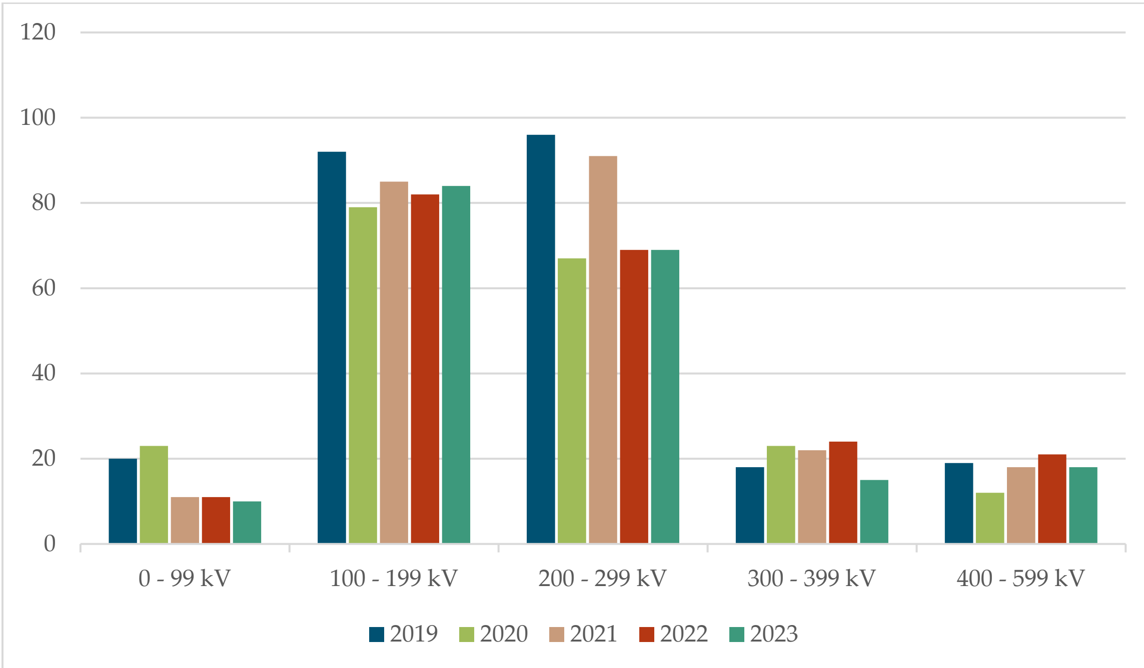


**Figure 8: Misoperation Count by Voltage Class, 2019–2023**

This is expected since these voltage classes represent the highest count of BES circuits in the Western Interconnection (see Table 1). While these voltage classes are generally have less influence on system stability, there are still reliability implications related to misoperations at these voltage levels, and all reasonable efforts should be taken to ensure protection operates as intended.

| Voltage Class | AC Circuit | Converter | DC Circuit | Transformer | Total Elements | # Misops | Fraction of Misops by Elements |
|---|---|---|---|---|---|---|---|
| 0-99 kV | 505 | 0 | 0 | 42 | 547 | 10 | 1.83% |
| 100-199 kV | 3472 | 0 | 0 | 196 | 3668 | 84 | 2.29% |
| 200-299 kV | 2015 | 5 | 3 | 746 | 2769 | 69 | 2.49% |
| 300-399 kV | 205 | 2 | 0 | 182 | 389 | 15 | 3.86% |
| 400-599 kV | 311 | 0 | 6 | 260 | 577 | 18 | 3.12% |

**Table 1: 2023 Fraction of Misoperations per TADS Element by Voltage Class**

A reliability indicator can be attained by knowing the number of elements in each voltage class. The number of misoperations per number of elements in a voltage class provides an additional view of where the misoperations are occurring in the Western Interconnection. The number of Elements per voltage class was taken from the Transmission Availability Data System (TADS) database. The results are the misoperation ratios in percentage, shown in Table 1. These values normalize the numbers as facilities are added or removed from the Western Interconnection.

The table shows the highest number of circuits within the Western Interconnection is in the 100–199 kV and 200–299 kV ranges. It also shows that the fraction of misoperations per TADS element by voltage class is highest for the 345 kV elements in the Western Interconnection, followed by the 500 kV elements. There are significantly fewer elements in these two voltage classes than the other classes indicating some protection engineers may have less experience working on settings for these elements. Some of these protections systems deal with less common and more complex protection applications (series compensation, single pole tripping, etc.), contributing to the likelihood of a misoperation.

The five-year trend in Figure 9 indicates misoperation rates by voltage class have stayed fairly constant, however, there is a noticeable decrease in the 0–99 kV voltage class during this five-year period. There is also a decrease in 2023 in the 300–399 kV voltage class, though, future performance will indicate whether this was a sustained change or just a one-year anomaly.

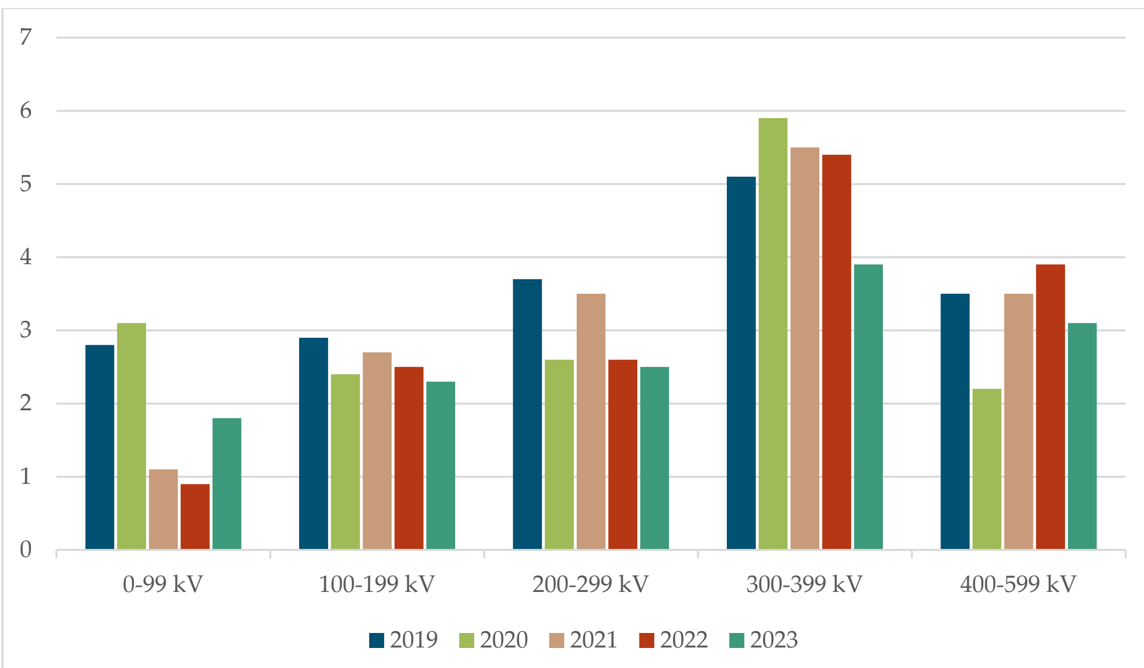


**Figure 9: Fraction of Misoperations per TADS Element by Voltage Class, 2019–2023**

While the number of misoperations shows a slight decrease, overall impact should be considered by the owner or operator of the equipment. Equipment considered critical by an entity should have more rigid in-service testing and commissioning performed when initially put into service, and possibly be maintained on a more stringent maintenance cycle. When a misoperation occurs on a more critical piece of equipment, a thorough investigation, Corrective Action Plan, and Extent of Condition should be completed.

## Analysis for Incorrect Settings, Logic Errors, and Design Errors

For analysis in this report, these three cause categories are combined. There were 70 misoperations attributed to Incorrect Settings, Logic Errors, and Design Errors, which is a decrease of 13.6% from the previous year. This continues to be the largest of all cause categories in 2023. Figure 10 shows that 96% of the misoperations caused by incorrect settings, logic errors, and design errors was on microprocessor relays.

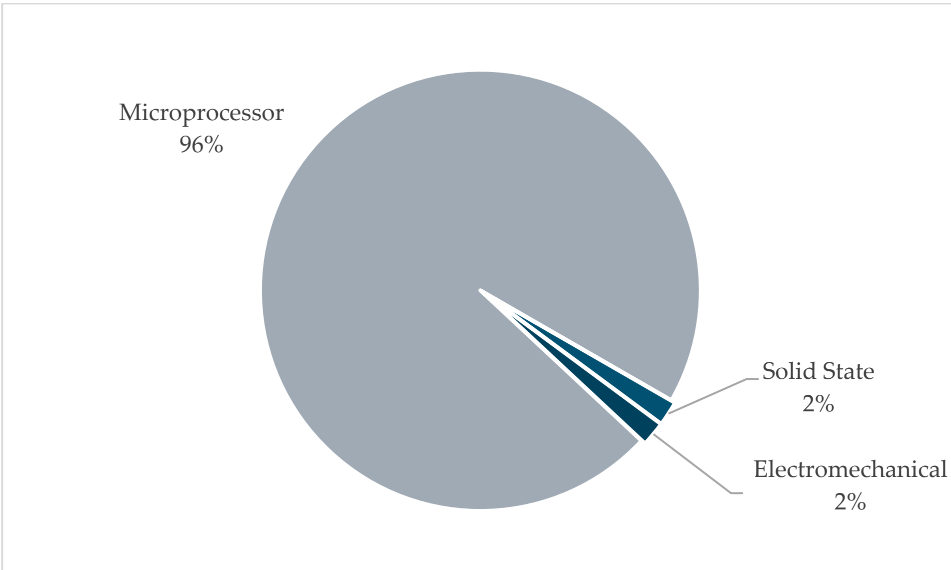


**Figure 10: 2023 Misoperations by Relay Technology**

While microprocessor relays was the technology associated with the majority of the misoperations for these causes, this is likely due to its wide-spread use. Additionally, misoperations related to incorrect settings, logic errors, etc. is more likely to occur in new schemes or relay upgrades, of which nearly all will involve microprocessor relays.

Figure 11 shows the distribution of the three cause categories. The chart shows incorrect settings make up 79% of the misoperations, with logic errors, and design errors contributing smaller numbers.

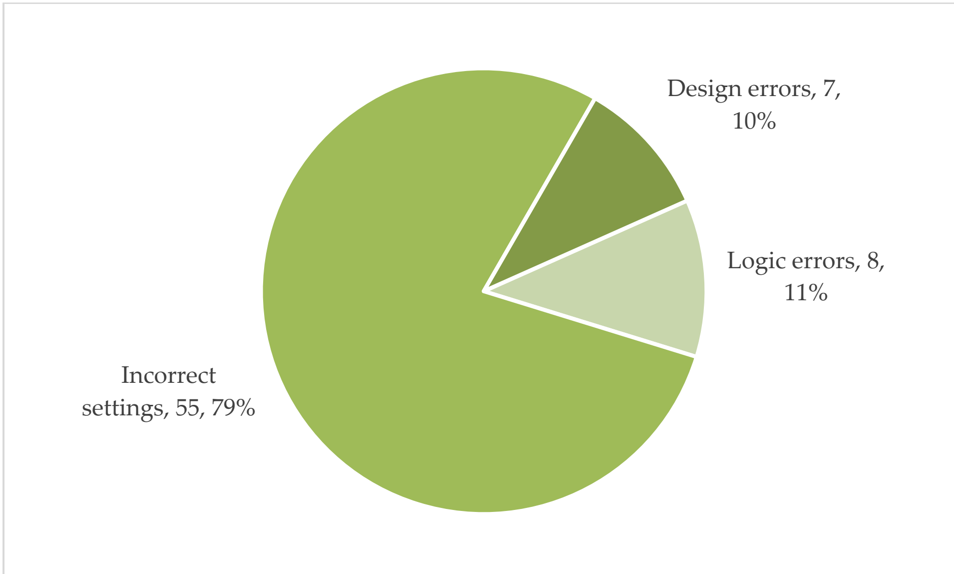


**Figure 11: 2023 Misoperations by Subgroup**

The five-year trend shown in Figure 12 indicates incorrect settings continue to be a significant cause of misoperations in the Western Interconnection.

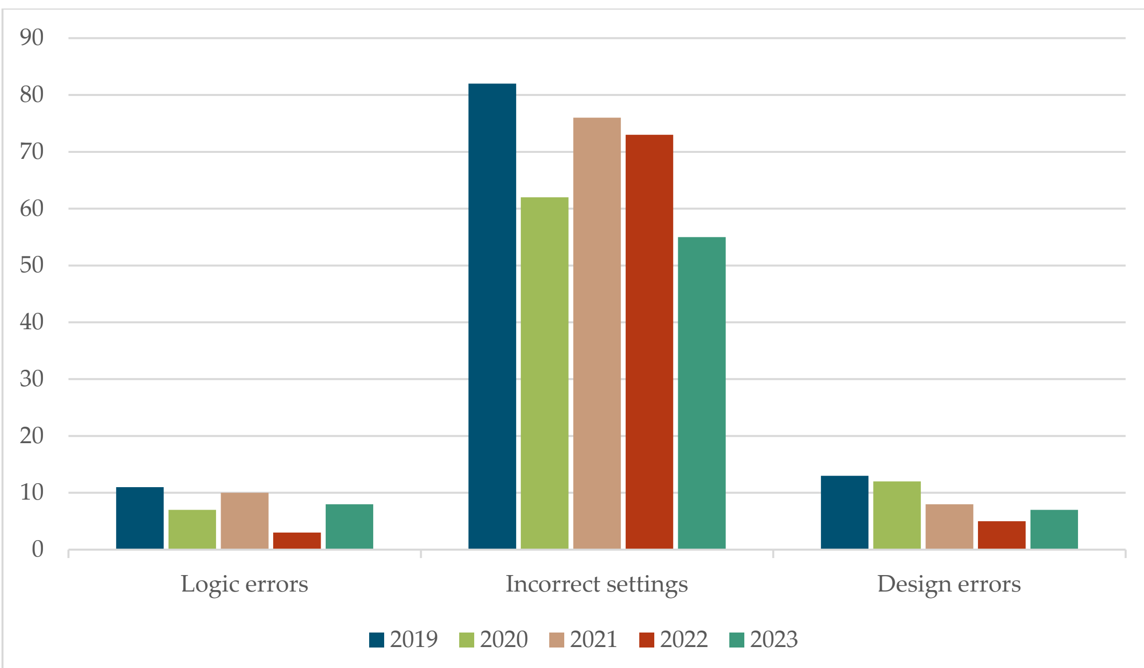


**Figure 12: Misoperations Subdivided into Setting and Logic/Design Errors, 2019–2023**

However, the trend shows a gradual decrease in the Incorrect Settings and Design Errors categories, with Logic Errors showing a static trend. Compared with 2022 data, design and logic errors increased slightly, but the largest category, Incorrect Settings, decreased by 24%.

Figure 13 analyzes the Incorrect Settings, Logic Errors, and Design Errors misoperation cause categories as they relate to whether a fault occurs at the same time.

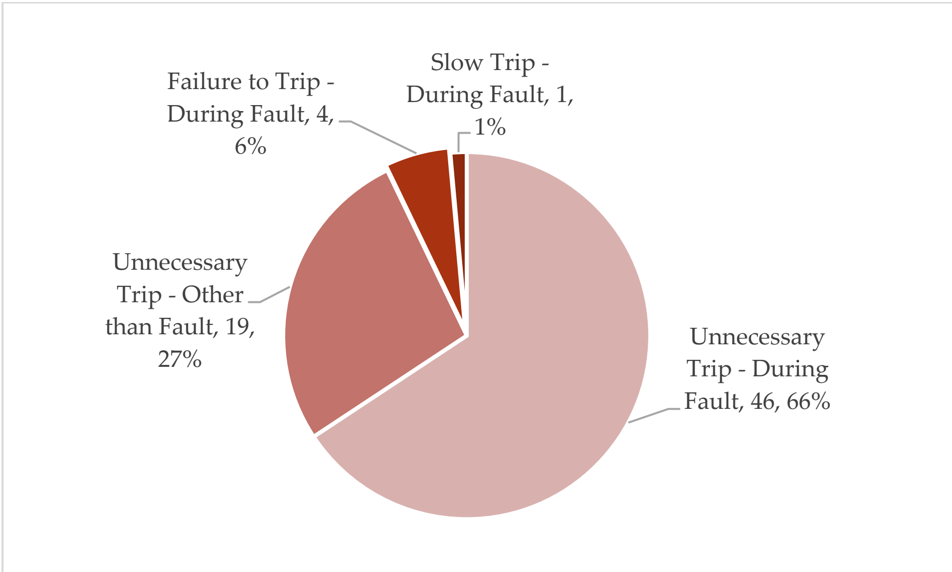


**Figure 13: 2023 Incorrect Settings, Logic Errors, and Design Errors by Misoperation Category**

Figure 13 shows 66% of incorrect settings, logic errors, and design errors resulted in an "unnecessary trip—during fault." This points to overtripping during fault conditions. While it is not ideal to have more elements removed during a fault, it is generally preferable to a failure to trip or slow trip during a fault. There is a balance between dependability and security when developing relay settings. Dependability is the certainty that the relays will operate correctly for all faults for which they are designed to operate. Security is the certainty that the relays will correctly not operate for all faults for which they are designed not to operate. The observation that relay settings lean more toward unnecessarily tripping than failing to trip points to the general practice to favor dependability when trying to achieve this balance.

Figure 14 shows a five-year trend of misoperations relating to system faults and demonstrates the continued trend that leaning toward dependability has been observed over the past five years.

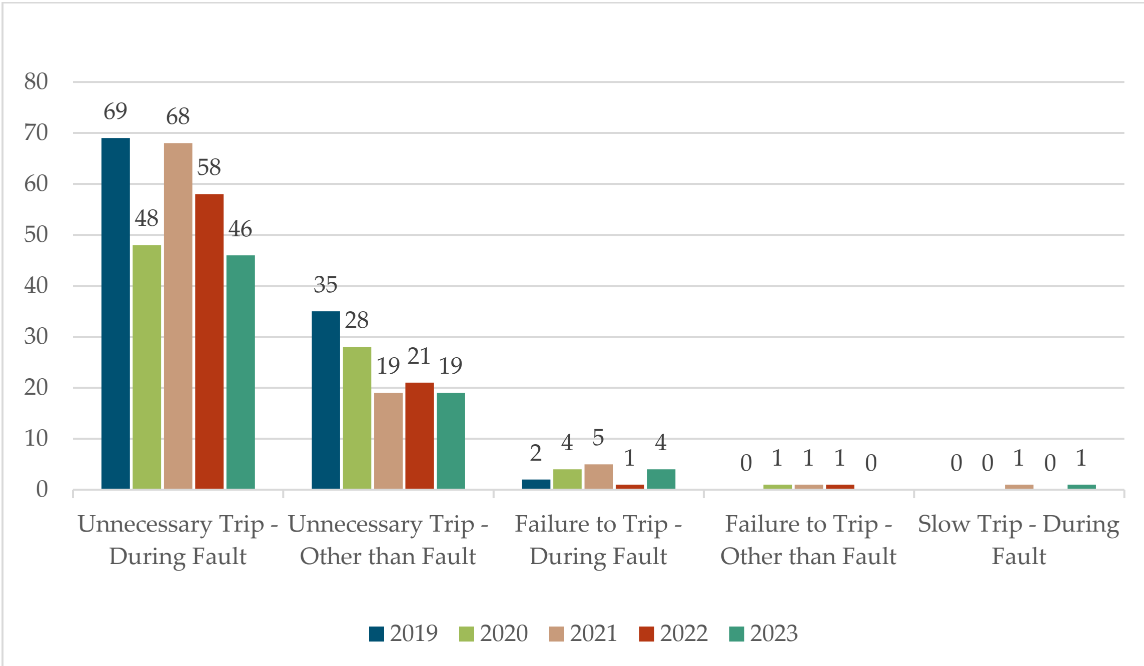


**Figure 14: Incorrect Settings, Logic Errors, and Design Errors by Misoperation Category, 2019–2023**

The Failure to Trip and Slow to Trip categories of misoperations generally represent more harmful misoperations. Fault conditions remain on the system for longer periods, exposing expensive, long-lead-time equipment to high current while also requiring remote equipment to operate to clear the fault. All efforts to prevent these misoperations should be taken.

In Figure 15, the PCS further investigated the 2023 misoperations in the category Incorrect Settings, Logic Errors, and Design Errors to identify the applications of these settings involved in misoperations.

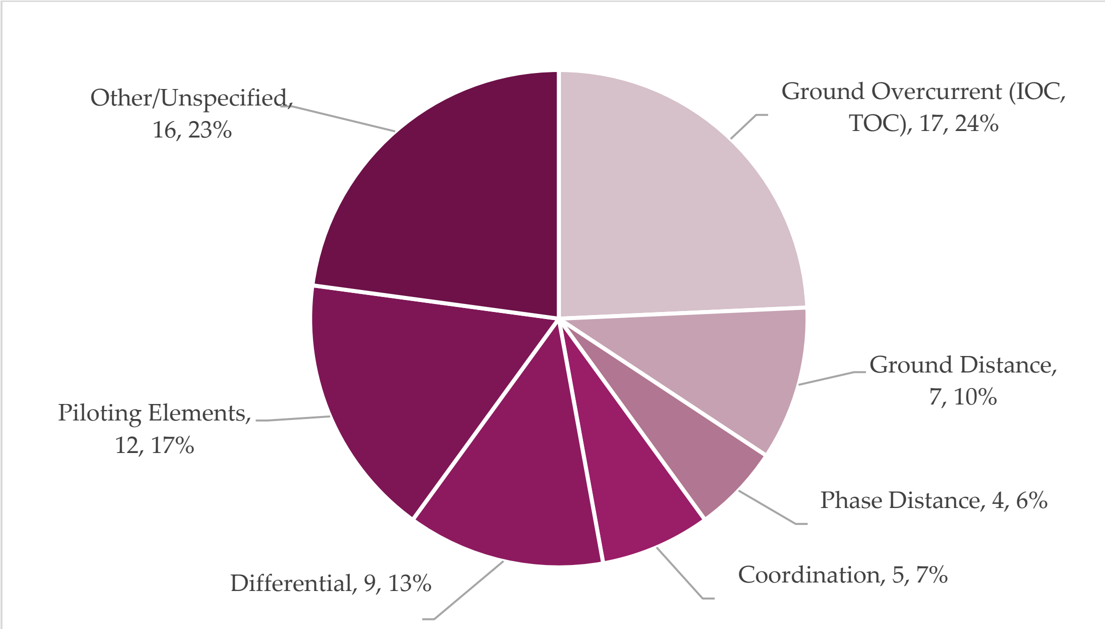


**Figure 15: 2023 Incorrect Settings, Logic Errors, and Design Errors by Root Cause**

The significant causes of misoperations identified were incorrect ground overcurrent settings, piloting errors and other/unspecified errors. The "other/unspecified errors" included anti-islanding, broken conductor logic, firmware conversion, frequency settings, incorrect group selection, PT error, and incorrect switch-on-to fault (SOTF) settings. We encourage entities to implement the recommendations below to help reduce the misoperations caused by incorrect settings, logic errors, and design errors.

## Incorrect Setting, Logic Errors, and Design Errors Misoperation Recommendations:

Entities should consider the following recommended practices:

- Develop written standards and guides explaining the expectations for their protection engineers about verifying that the fault system model is correct, the settings have been properly coordinated, the contingencies considered for coordination are consistently addressed, proper setting values of the elements are applied, and the elements for the application are enabled to ensure consistent performance.
- Develop a process for reviewing new and existing settings to ensure changes to the system do not result in misoperations. Have a formal training process for employees who are new to the Protection Department.
  - Use experienced personnel as mentors.
  - Establish a rough guideline on what and when skills should be introduced as experience is developed; for instance, non-directional overcurrent followed by transformer, differential followed by step distance, etc. during the first year to guide the mentor in developing the new engineer.
  - Establish familiarity with company standards and practices for protection systems.
  - Start with simple models and advance to more complex applications as skills develop.
  - Involve new employees in the setting testing process.
  - Review the process for developing and updating short-circuit models and testing programs.
- Use satellite-synchronized testing technologies when commissioning communications-assisted schemes to ensure all components of the protection system work as designed.
- Use standardized settings templates to reduce the opportunity for human errors when developing settings.
- Develop a process to regularly review existing ground overcurrent settings to ensure changing system conditions do not result in a misoperation.
- Review, from a process perspective, misoperations that occur. Determine changes that can be made in the process to prevent misoperations from recurring.
- Develop an applications-based testing method as a quality assurance measure to new and modified relay applications.
- Recommend hardware in the loop testing on EHV circuits and series compensated lines.

Additionally, entities can review the IEEE Power System Relaying Subcommittee report, "Processes, Issues, Trends and Quality Control of Relay Settings," for technical guidance for quality control of protective relay settings.

## Analysis of Relay Failures and Malfunctions

Figure 16 shows there were 43 misoperations attributed to Relay Failures/Malfunctions in 2023. The number of misoperations for this cause is notably higher than the previous four years, which averaged around 30 misoperations per year.

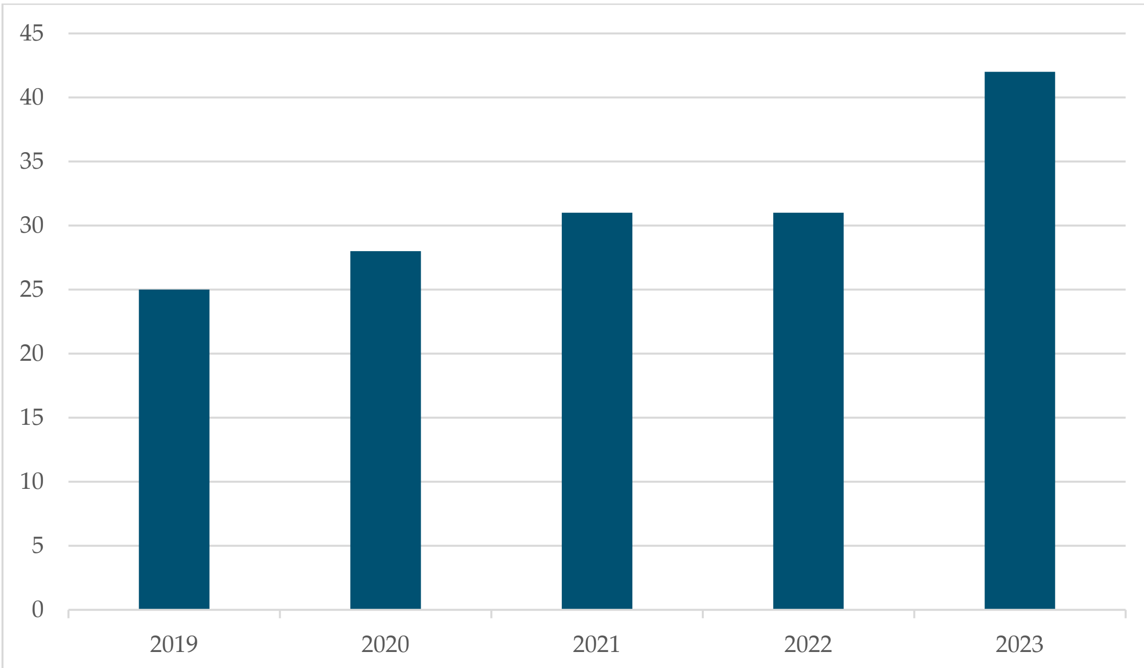


**Figure 16: Relay Failure/Malfunction, 2019–2023**

Microprocessor relays continue to be the most common relay type associated with Relay Failures/Malfunctions. Figure 17 shows the distribution of failures by relay technology for 2023, with over 75% of relay failures for the year occurring in microprocessor relays. Although failures of microprocessor relays had been above 85% of all failures during the previous four years, 2023 saw a slight increase in the failure of electromechanical and solid-state relays. Because almost all new installations use microprocessor relays, they will continue to be the largest percentage of the total Relay Failures/Malfunctions and of the relay inventory. However, since a complete inventory of relays is unavailable, we cannot say whether microprocessor relays have a higher failure rate than other relay technologies.

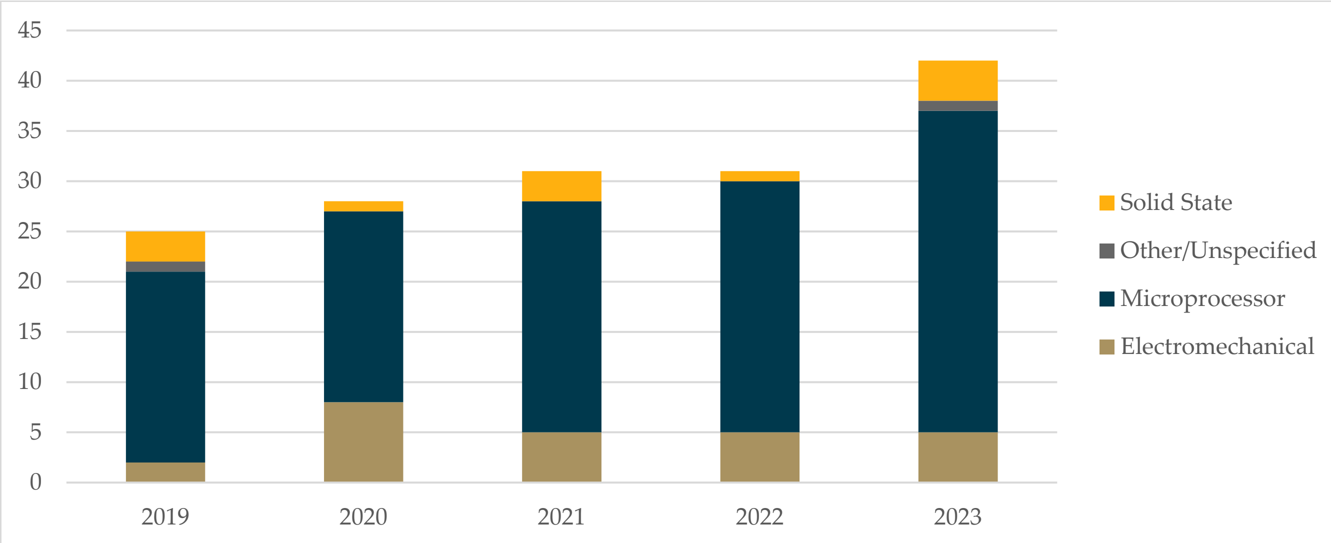


**Figure 17: Relay Failure/Malfunction by Relay Technology**

Over half of the 2023 Relay Failure/Malfunction submissions did not provide enough detail in the event description to identify the cause of failure. Many of the corrective actions for these submissions were to replace the relay without finding the cause of failure. We encourage entities to work with the relay manufacturer to identify the cause of failure. This can help identify whether there are other relays on their systems that are prone to the same type of failure. This can also help the manufacturer identify and correct issues with their products and prevent other utilities from experiencing similar misoperations.

The Relay Failure/Malfunction sub-cause column and information provided did give some insights into common types of relay failure in 2023. Failed components within the relay were the most common known cause. Some of the components leading to these misoperations were power supply failures, AC and DC I/O module failures, and CPU process failures. In 2023, I/O module failures resulted in the greatest number of misoperations at five; however, several AC I/O module failures combined with power supply failures were from the same type of relay.

In the past, there have been several failures and malfunctions of electromechanical relays due to calibration drift; however, in 2023 there were no misoperations reported due to this issue. Possible causes for this change could be improved PRC-005 maintenance programs, which address the calibration of electromechanical relays. It could also be due to the shrinking number of electromechanical relays in service, as most failed relays are replaced with microprocessor relays. If an entity has had an issue with relays drifting out of calibration, tracking the make and models with this problem is important. With this information, entities can decrease the time between maintenance cycles for relays to catch potential drift before a misoperation occurs. These units can also be put on a replacement list to eliminate the potential for a misoperation.

Figures 18 and 19 show the analysis of Reported Relay Failures/Malfunctions for 2023 as a function of the misoperation category. Most relay failures (29) caused an "Unnecessary trip—Other than Fault." This cause often has a lower impact than a failure of a relay to detect and clear a fault from the system. For misoperations during faults in 2023, there were seven unnecessary trips, one failure to trip, and three slow trips.

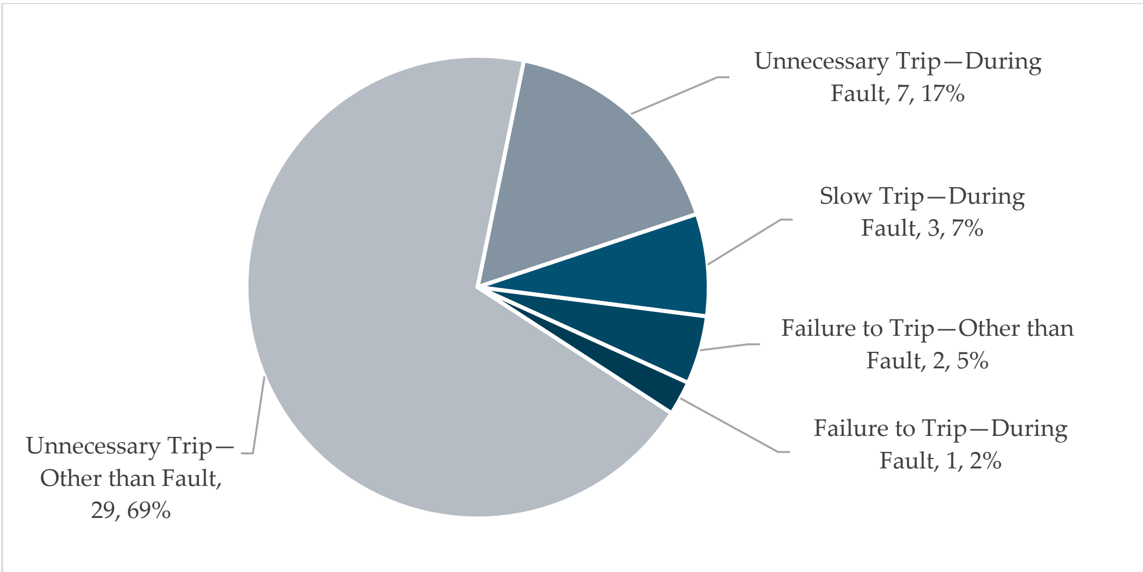


**Figure 18: 2023 Relay Failure/Malfunction Misoperations by Cause Category**

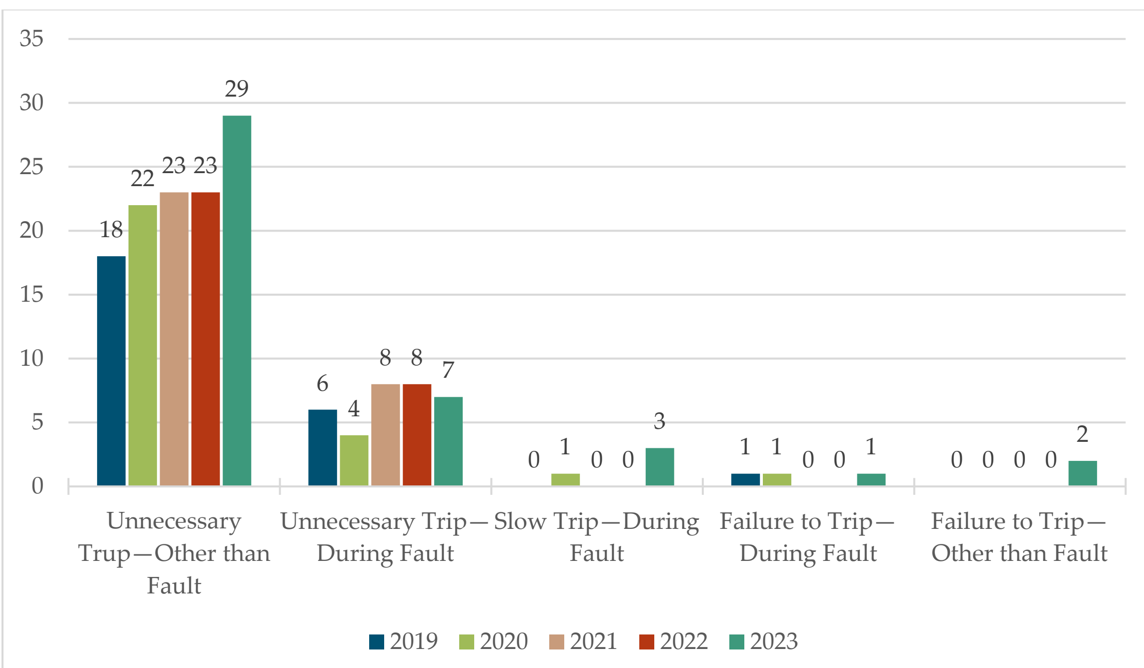


**Figure 19: Relay Failures/Malfunctions Misoperations by Category, 2019–2023**

**Relay Failures/Malfunctions Cause Category Recommendations:**

Entities should consider the following recommended practices:

- Determine the root causes of misoperations. This is critical to determining the proper corrective action to apply. It can show whether the event is a singular occurrence or whether corrective actions are needed for all similar installations in the system. Some helpful questions when investigating relay failures/malfunctions are:
  - Are there maintenance practices that could help in the reduction of relay failures/malfunctions?
  - Are there known makes and models of relays with a higher rate of failure?
- Establish a process to document and manage the firmware in place for each device to avoid incompatibility issues. For hardware in the loop testing, ensure the same firmware version originally installed is used so the testing results remain valid.
- Verify the operation of the entire composite protection system (e.g., both A and B schemes) following all relay operations. Even though the composite protection system may have operated successfully, components of the system may not have responded adequately due to a component failure or other cause. The component failure may cause a later misoperation under different conditions.

## Analysis of AC/DC System Misoperations

NERC defines AC System misoperations as "misoperations due to problems in the AC inputs to the Composite Protection System. Examples would include Misoperations associated with CT saturation, loss of potential, or damaged wiring in a voltage or current circuit." There were 14 misoperations attributed to AC systems for 2023. This is the lowest number of misoperations for this cause during the five-year period from 2019–2023. The overall 2019–2023 trend of AC failures has been relatively flat, with a reduced number in 2023, as seen in Figure 20.

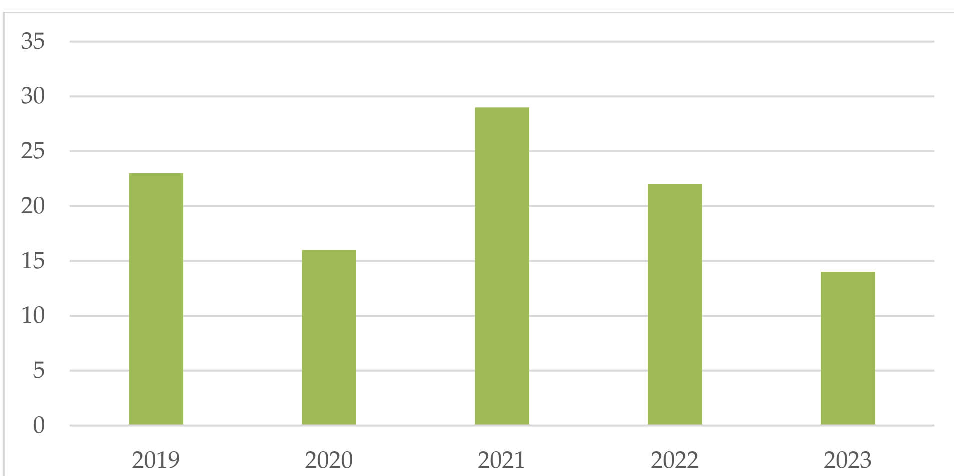


**Figure 4: AC Systems Misoperation Totals, 2019–2023**

NERC defines DC System misoperations as "misoperations due to problems in the DC control circuits. These include problems in the battery or charging systems, trip wiring to breakers, or loss of DC power to a relay or communication device." There were 13 misoperations attributed to DC systems for 2023. The overall 2019–2023 trend of DC failures has been relatively flat, with an increased number in 2023, as seen in Figure 21.

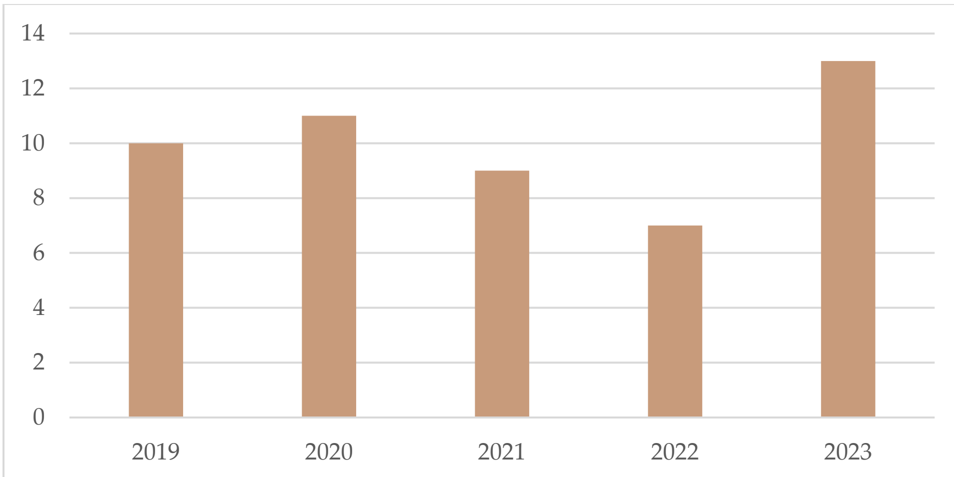


**Figure 21: DC Systems Misoperation Totals, 2019–2023**

Using the entity's reported descriptions of the misoperations and the Corrective Action Plans, the PCS broke AC/DC systems into various triggers. Like the previous years, the largest source of misoperations in 2023 was CT/PT wiring/connection issues at 48.1%, followed by equipment failure at 29.6%, as seen in Figure 22.

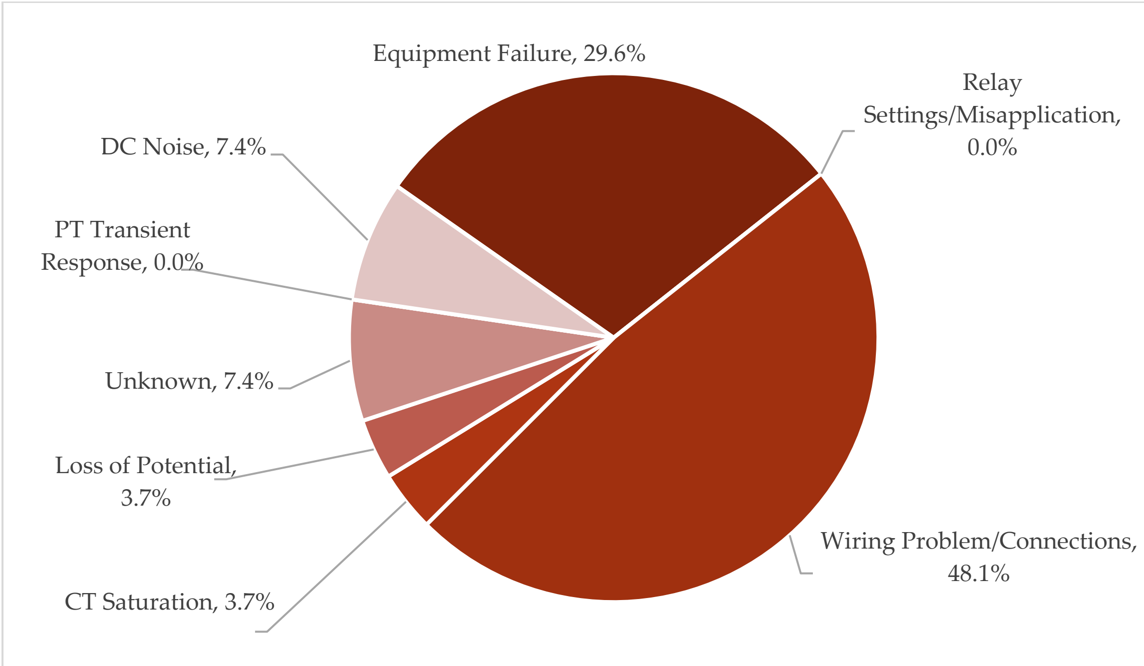


**Figure 22: 2023 AC/DC System Misoperations by Failure Mode**

Highlighting the top three triggers from the 2019–2023 indicates that Wiring Problem/Connections, by average, is the leading cause, shown in Figure 23.

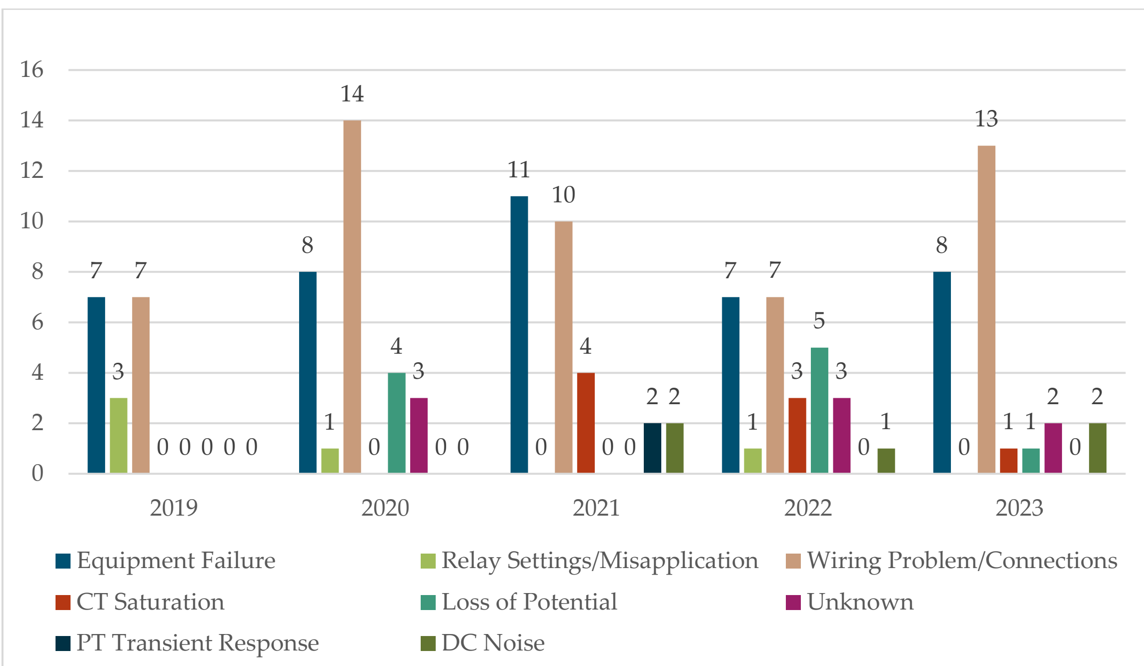


**Figure 23: AC/DC Misoperation by Cause, 2019–2023**

Many of the wiring problem/connections and CT/PT wiring/connection issues could have been identified either during commissioning or through maintenance practices.

### AC/DC System Misoperation Recommendations:

Entities should consider the following recommended practices:

- Update maintenance and commissioning practices to include burden and continuity checks of wiring plus visual inspection of equipment.
- Perform proper insulation test during the commissioning process. This often helps identify problems.
- Include redundancy in AC/DC system designs, which can help limit single points of failure and can help reduce the chances of failure to trip misoperations. The IEEE PSRC, Working Group I-25 document, [“Commissioning Testing of Protection Systems,”] is a helpful guide to incorporate into commissioning practices.

## Analysis for Communication Failures

Figure 24 shows there were 19 misoperations attributed to communication failures during 2023. This is three less than those reported in 2022, and one higher than the five-year average.

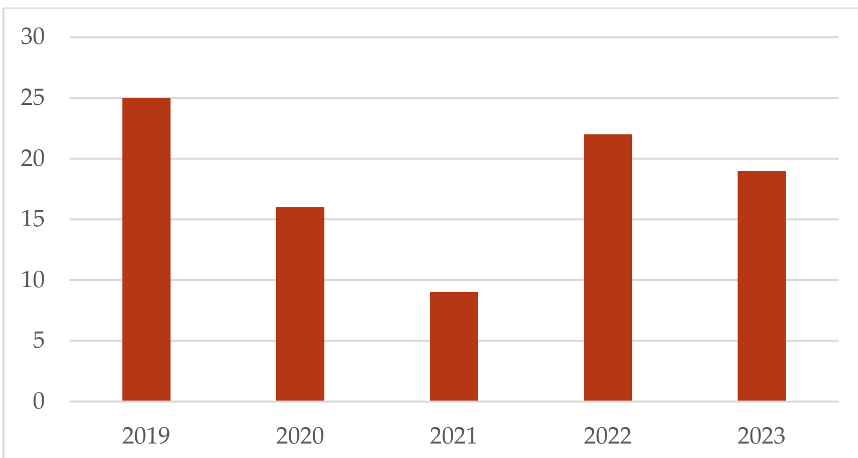


**Figure 24: Communication Failure Misoperations 2019–2023**

Figure 25 shows the 2023 Communication Failures misoperations by cause category. All but one of the misoperations were unnecessary trips, with over half of the misoperations due to unnecessary trips without a fault on the system.

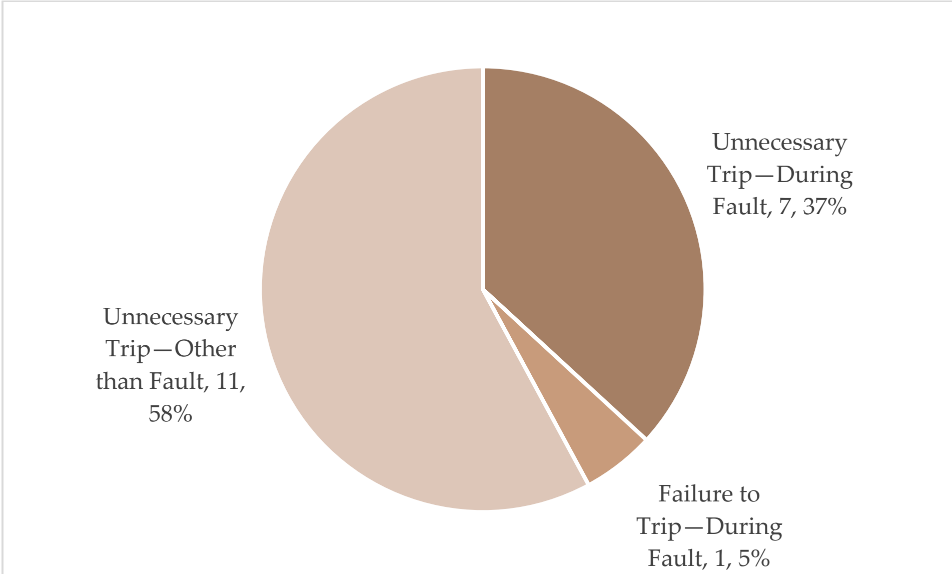


**Figure 25: 2023 Communication Failures Misoperations by Category**

Figure 26 shows the misoperation categories over the last five years. The year 2023 was comparable to 2022 in the number and type of misoperations. Most unnecessary trips (with or without a fault present) were due to channel asymmetry or noise on the communication system. The next largest category was Unknown/Unexplainable.

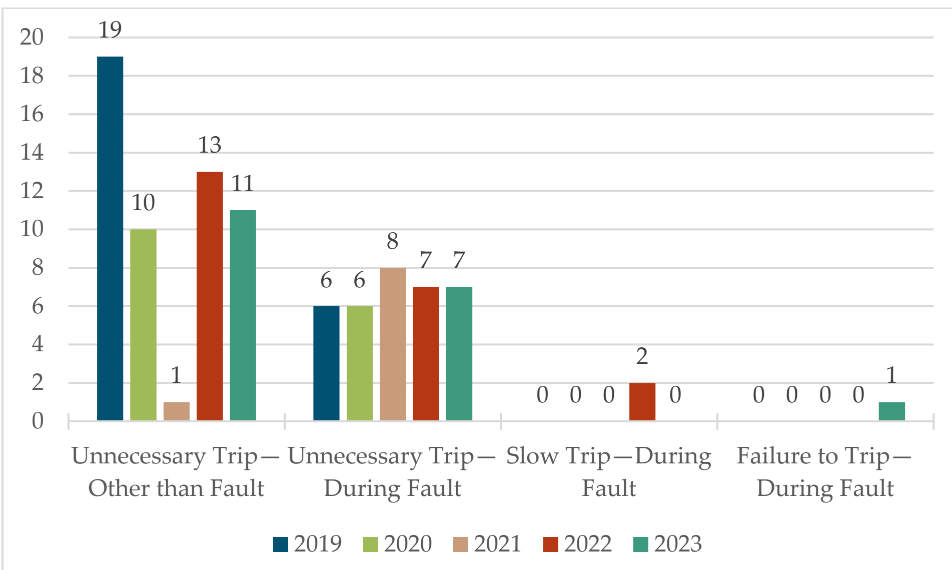


**Figure 26: Communication Failures Misoperations by Category 2019–2023**

Figure 27 shows the breakdown of communication-related misoperations by communication system type, though almost half of the submissions did not include this detail. The Communication System Type is an optional field in MIDAS, and this information was not provided in this field or in the event descriptions, limiting the PCS's ability to thoroughly analyze this cause category.

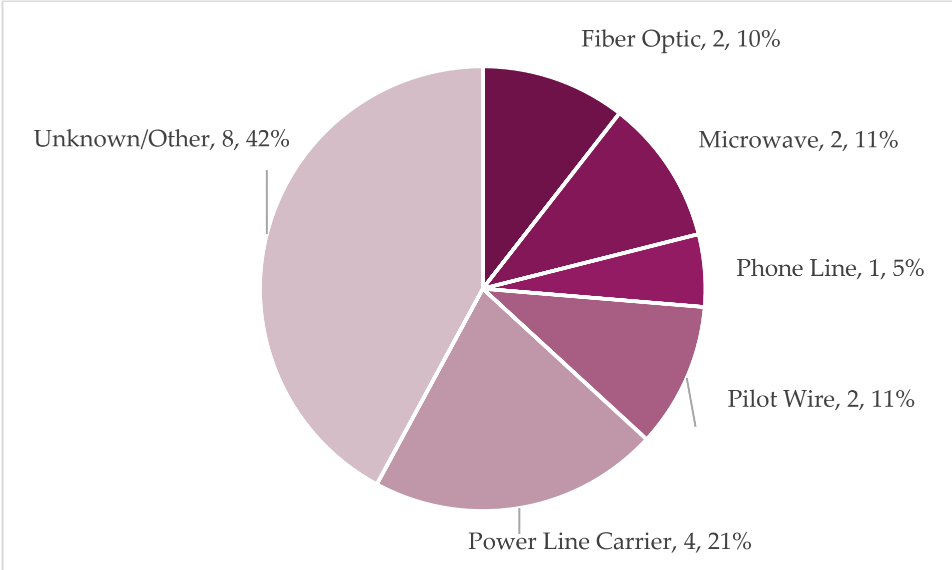


**Figure 27: 2023 Communication-related Protection Misoperations by Communication System Type**

2023 saw a high number of misoperations due to channel asymmetry. Manufacturers have recently added firmware features to monitor, alarm, and alter the functionality of the relay during these conditions. In addition to channel asymmetry issues, there was an increased number of misoperations due to noise on the communication channel. Of these misoperations there was no clear corrective action taken other than plans made to replace the pilot wire and power line carrier circuits with digital circuits.

### Communication Failures Misoperation Recommendations:

Entities should consider the following recommended practices:

- Protection engineers should understand the technology being employed in the protection scheme, including the risks of channel asymmetry, and the mitigation methods available to reduce the risk of misoperation.
- A possible solution for noise on a communication channel is to insert a small time delay to help ride-through noise. Entities must ensure that maximum clearing times allow for this delay.
- Entities should complete all fields in the MIDAS 1600 request, allowing the PCS to enhance its analysis. The PCS will encourage NERC to make the Communication System Type field be required, as well as adding fields to capture the protocols and technology used in the communications network (e.g., switched, MPLS, IP, Ethernet, TDM).

## Analysis for As-Left Personnel Errors

As-left personnel errors may occur after construction, operations, and maintenance activities once personnel have completed their work, returned equipment to service, and left the job site. Incorrect operations that occur with personnel on site during the work procedures are not counted as misoperations for reporting in the MIDAS system.

Figure 28 shows the five-year trend of misoperations for all as-left personnel errors. The overall numbers have been relatively flat, between 9 and 16, with an annual average of 12. These misoperations are a small fraction of the overall system misoperations.

As-left personnel errors do not include incorrect relay settings provided to field personnel, wiring design errors, and similar causes, which have their own separate cause codes within the MIDAS system.

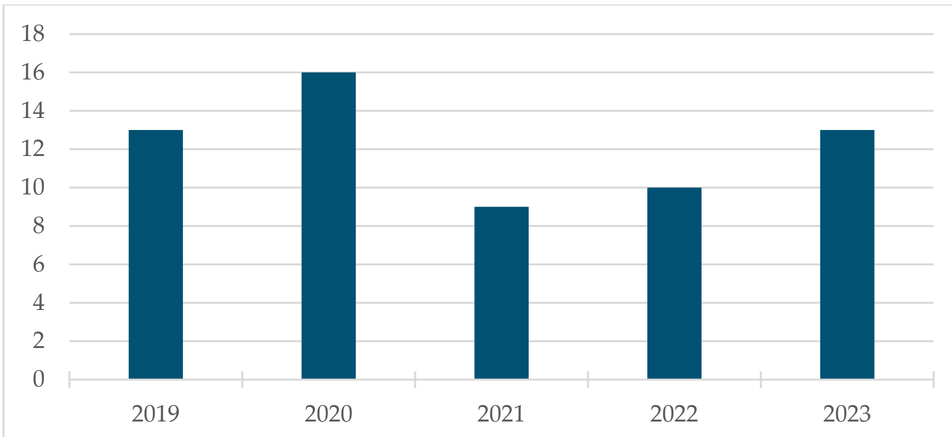


**Figure 28: Western Interconnection As-Left Personnel Error Misoperations, 2019–2023**

Figure 29 shows the trend for as-left personnel errors by voltage class. As with the overall misoperations, events for 100–299 kV facilities tend to dominate the numbers. Low voltage BES (<100 kV) and EHV (300+ kV) mostly include either a single Misoperation or none. This correlates with the lower number of these facilities on the system.

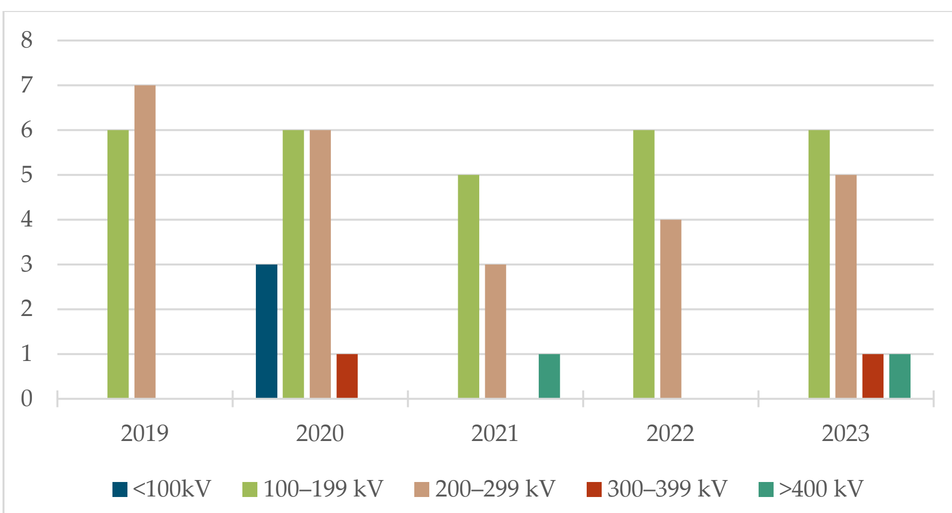


**Figure 29: As-Left Personnel Error Misoperations by Voltage Class, 2019–2023**

Figure 30 shows the trend for as-left personnel errors by tripping category. The 2019–2023 events did not include any Slow Trip during Fault misoperations, so that category does not appear in the figure. Nearly all these misoperations are unnecessary trips, either during or without a fault. Only one failure to trip during fault event occurred during this five-year period.

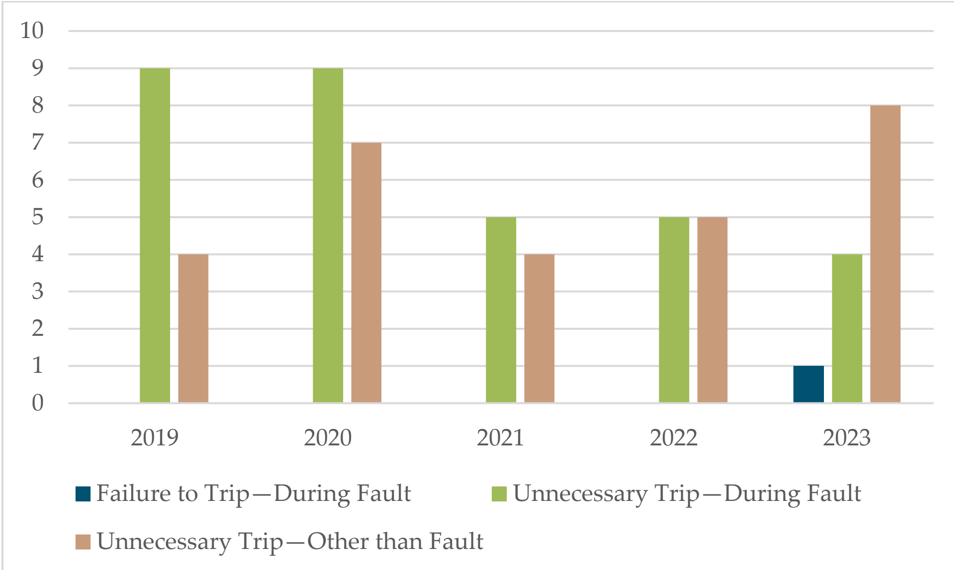


**Figure 30: As-Left Personnel Error Misoperations by Tripping Category, 2019–2023**

Figure 31 shows the trend for as-left personnel errors by cause. These categories, with some common examples, include:

- Left open switches or wiring—test switches incorrectly left open or loose wiring.
- Testing errors—"test" settings left on the relay after test rather than the correct "issued" settings, as-left relay testing calibration.
- Wiring errors—CT ratios, shorted CTs, rolled phases, inverted polarity.
- Switching errors—selector switch left in wrong position.
- Incorrect settings—error in installing intended "field" settings to the relay.

Wiring errors are the biggest root cause in the As-Left Personnel Errors category every year from 2019 through 2023, always substantially more than the next-largest cause and usually at least half of all events in this category. Several common wiring issues include wrong CT ratios wired, shorted CTs, and rolled phases among CTs. Inverted polarity has occurred with both CT and PT circuits. Testing errors are less common, consistently at two each year until three in 2023. Similar levels of leaving wrong settings on a relay occur.

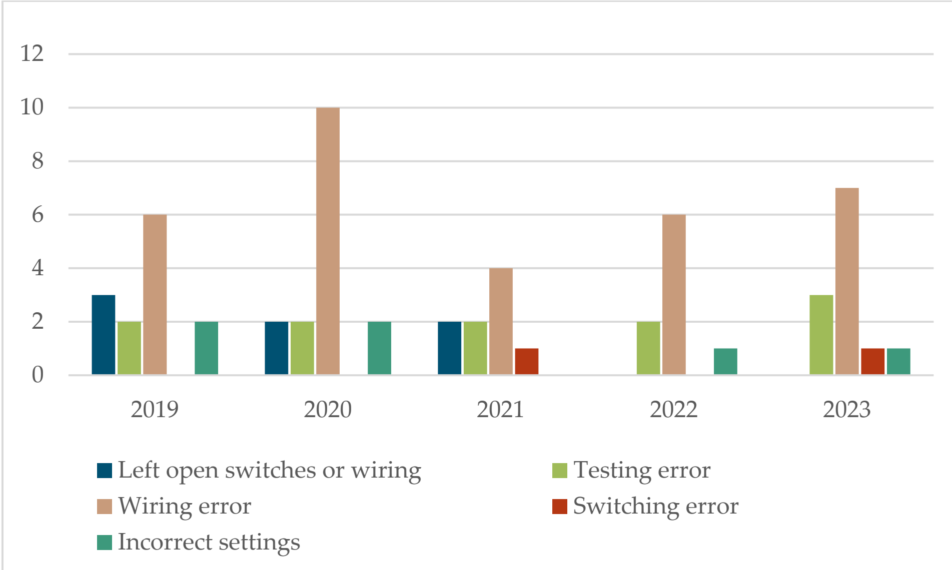


**Figure 31: As-Left Personnel Error Misoperations by Cause, 2019–2023**

As-left personnel errors represent a small fraction of overall misoperations, between 4% and 8% from 2019 to 2023, depending on the year, and about 6.5% in 2023. Nevertheless, wiring errors with CT circuits are the largest contributor to these misoperations, with other causes generally involving only two or fewer events per year.

### *As-Left Personnel Error Recommendations*

Entities should consider the following recommended practices:

- Perform peer reviews of the CT connections. Two common errors are: wrong CT ratios, and shorting screws improperly left in place. These should be easy to identify because the proper configuration can be confirmed visually even before in-service (load) checks are performed.
    - One form of peer review will use a different person to perform wiring checks than the person who did the original wiring.
- Perform in-service checks to confirm correct CT and PT phasing and polarity. If system conditions make in-service (load) checks difficult or inconclusive, primary injection tests can be helpful.
- Use commissioning checklists. Most of these issues can be successfully addressed using appropriate commissioning checklists, including in-service and primary injection checks, checking tight on connections, tugging on connections, and leaving quality assurance marking at the terminal block.
- Relay technicians should compare as-found and as-left settings after relay maintenance testing to reduce the chances of leaving wrong settings on a relay.
- Settings engineers should review as-left settings from the field and verify that any changes from the issued settings are acceptable.

- Perform test procedures designed to use settings-engineer-issued settings (not requiring temporary "test" settings) to reduce testing and incorrect settings errors. When this is not practical or possible, to minimize the chance that "test" settings could be left in place when "issued" settings should be restored, system design could include SCADA, annunciator, or HMI alarms when a "test" setting group is active or a selector switch is in the "test" position.
- Use design or operations practices that result in all test switches being closed during normal operation, making it easy to identify improperly open test switches.
- Point to point continuity checks can be documented to be completed with acknowledgement on the wiring diagram using a known marking color that represents completion of the task.

### Analysis of Unknown/Unexplainable Misoperations

In 2023 there were 16 events reported with the Unknown/Unexplainable cause category. The Unknown/Unexplainable cause category is used when no clear cause can be determined. After extensive investigation, the submitting entity may select this cause when no other option is suitable or the operation is still under investigation. If reporting Unknown/Unexplainable as the cause due to an ongoing investigation, the category should be updated in MIDAS at the conclusion of the investigation if a cause is found.

In 2023, unknown/unexplainable misoperations represented 8.16% (16/196) of all reported misoperations. In comparison, the 2019, 2020, 2021, and 2022 data represented 11.4% (28/245), 8.8% (18/205), 8.4% (19/227) and 9.1% (19/208), respectively, of all reported misoperations.

When the reason for a Misoperation is unknown, effective corrective actions cannot be taken to prevent another Misoperation from occurring at that terminal, nor can knowledge be gained that would allow the prevention of a similar Misoperation from occurring at other locations. Therefore, it is desirable to reduce the number of misoperations that cannot be explained and are categorized as unknown/unexplainable.

Figure 32 shows the total number of misoperations reported as unknown/unexplainable for each year from 2019 through 2023. The bar chart below shows that misoperations reported under this cause are trending downward overall.

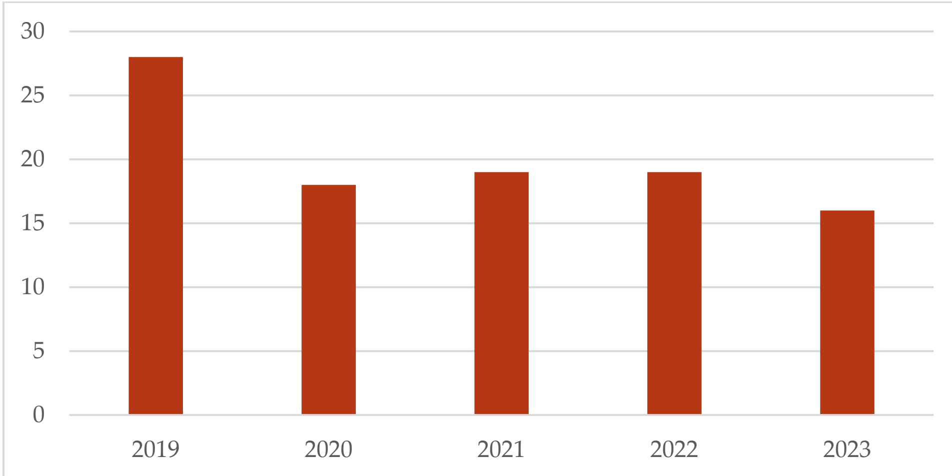


**Figure 32: Misoperations for Unknown/Unexplainable, 2019–2023**

Misoperations reported as unknown/unexplainable were further categorized by relay type, voltage class and Misoperation category to understand the effect on the Western Interconnection.

While the PCS does not have access to a complete inventory of BES relays in service in the Western Interconnection, it is expected that electromechanical and solid state relays represent a small fraction of the installed fleet. Due to the limited event recording capability of electromechanical and solid state relays, there is a higher probability of an unknown Misoperation occurring with these technologies. We recommend that entities install digital fault recorders (DFR) in locations with a high number of electromechanical relays to assist in event investigations.

In 2023, the percentage of unknown/unexplainable misoperations associated with each of the relay types continued toward a higher percentage of microprocessor technology, as shown in Figure 33. The higher percentage could suggest the larger installed fleet of microprocessor relays naturally results in a higher percentage of overall misoperations; or, as entities upgrade or replace older technologies, microprocessor relays may be sensitive to issues that older relays were not.

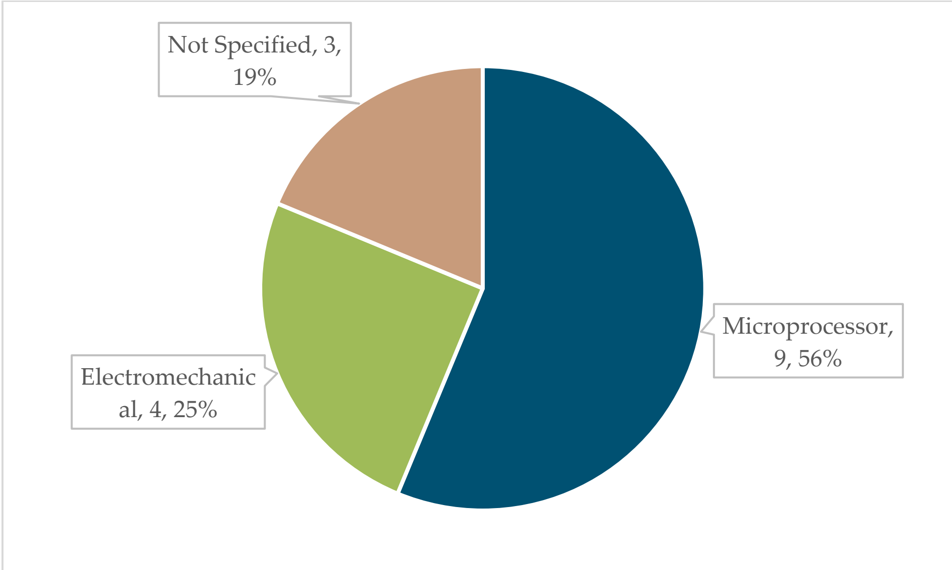


**Figure 5: 2023 Misoperations for Unknown/Unexplainable by Relay Type**

When voltage class is considered, there are fewer unknown/unexplainable misoperations on the 300 kV and higher voltage levels, as shown in Figure 34. This is most likely due to the higher number of microprocessor-based schemes that provide more diagnostic and event capture data.

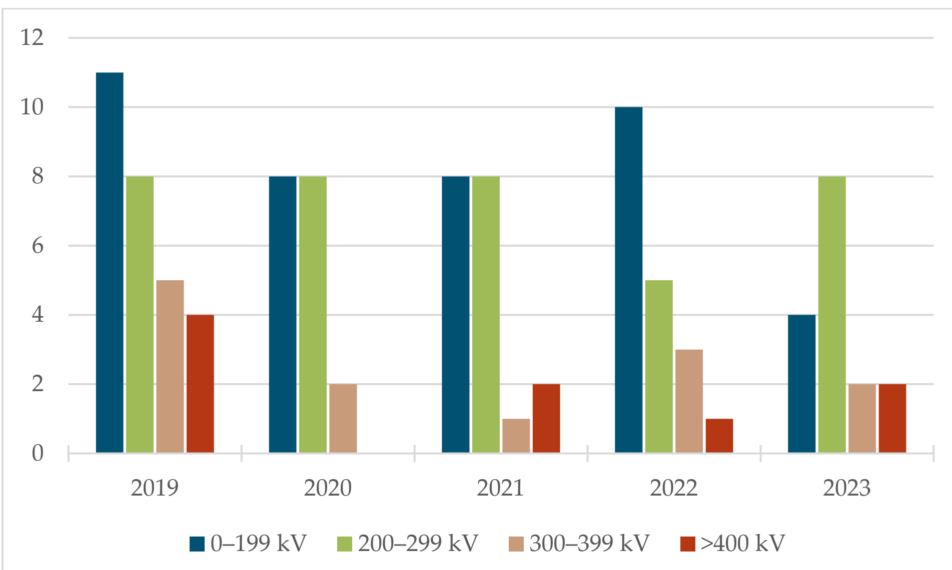


**Figure 64: Misoperations for Unknown/Unexplainable by Voltage Class, 2019–2023**

Most misoperations reported as unknown/unexplainable fell within the "Unnecessary trip—other than fault" category, as Figure 35 shows. An "Unnecessary trip—other than fault" can be more difficult to diagnose. The difficulty is such that during conditions of no fault, relay events may not be triggered and are not available to assist in the analysis. Adding DFRs, relay event, and SER triggering on breaker operations may help to better identify non-fault-based misoperations.

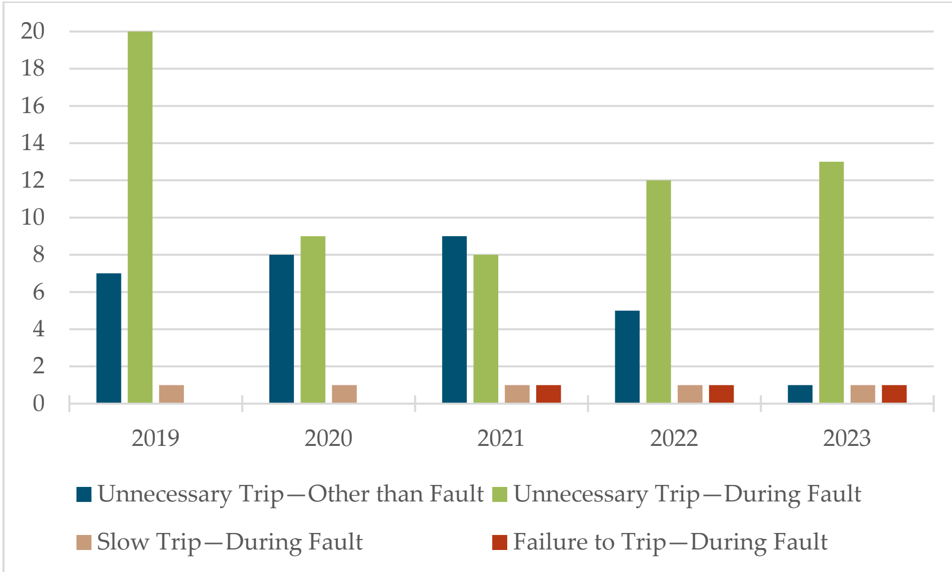


**Figure 35: 2023 Unknown/Unexplainable Misoperations by Category**

The number of misoperations reported as unknown/unexplainable remains relatively flat for the five-year trend and is now no longer one of the top three leading Misoperation causes in the Western Interconnection.

Many of the unknown causes continue to have Corrective Action Plans that involve testing the system, monitoring, working with the manufacturer, or replacing with microprocessor relays. The analysis in progress shows that entities are committed to finding root causes. Reporting to the NERC Section 1600 has improved, as entities now update the progress of investigations and include investigation actions being taken to determine misoperations.

### Misoperation Unknown/Unexplainable Recommendations

Entities should consider the following recommended practices:

- Install DFRs for unknown misoperations that occur on equipment protected by electromechanical relays. These recorders can provide valuable data for future operations for relays that do not give event records.
- Ensure MIDAS submissions that are reported as unknown/unexplainable are updated if the cause of the misoperation is identified after the original submission.
- Make all reasonable efforts to identify the cause of a misoperation. This allows for a Corrective Action Plan to be developed to prevent future occurrences.

As an unknown/unexplainable instance is resolved, and a cause is determined, the entity should resubmit to update the correct cause category of the Misoperation in MIDAS.

## Analysis for Other/Explainable Misoperations

Figure 36 demonstrates a decreasing trend in the number of other/explainable misoperations since 2021, from 27 events to 9, a 67% decrease. Year 2023 is the only instance of single-digit other/explainable misoperations in the five-year span, including 2019, with the five-year average at just over 17.

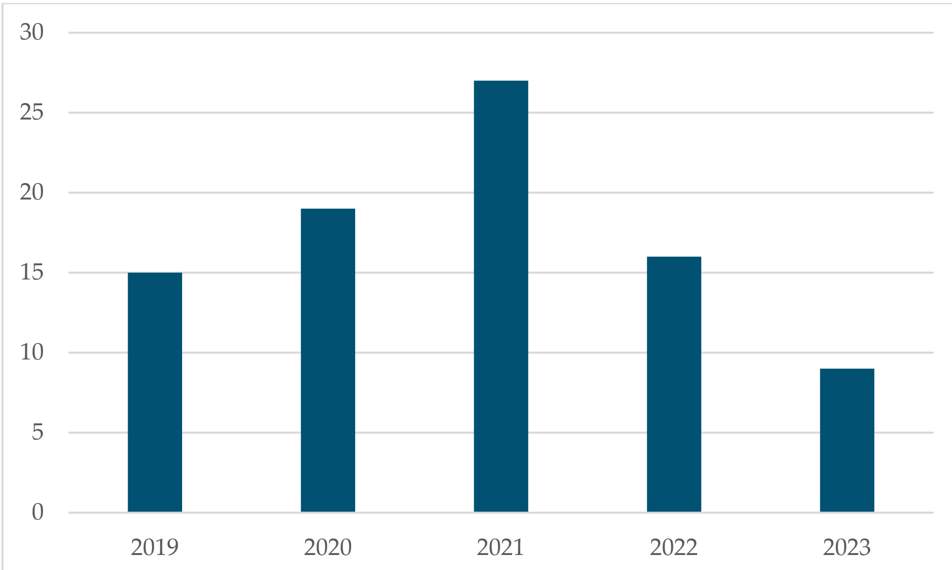


**Figure 36: Other/Explainable Misoperations, 2019–2023**

Figure 37 shows the breakdown of 2023 other/explainable misoperations by voltage class, as well as the five-year trending graph. Similar to all misoperations, most of other/explainable misoperations occurred on systems of 299 kV and below.

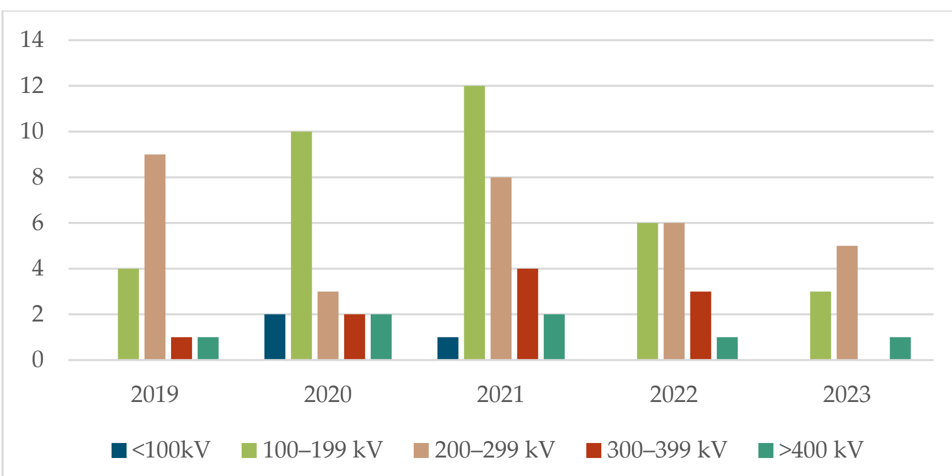


**Figure 37: Other/Explainable Misoperations by voltage class, 2019–2023**

This is a unique category, as the nine misoperations reported for this cause vary greatly. These are uncommon types of misoperations for which the cause has been identified, but the types do not fit the criteria of the other misoperation categories. Two of these events were on the same equipment for the same cause within a few days. Since the causes for these misoperations vary so much, there are no conclusions or recommendations made for this section.

## Conclusions

The trending of 2019 through 2023 indicates that the total misoperations have had a slight downward trend over the past five years. Incorrect Settings is still the leading cause of misoperations within the Western Interconnection. The PCS believes most misoperations due to settings errors are preventable. Best practices to avoid settings errors include using peer reviews, intentional training, performing more extensive fault studies, and standardizing protection scheme design/logic templates for microprocessor relays. A periodic review of the existing settings in the installed relay fleet can also reduce misoperations caused by a change in system topography as intended by NERC PRC-027.

The NERC 1600 reporting template added sub-cause categories in 2018 to the Incorrect Setting, Logic Errors, and Design Errors and Relay Failures/Malfunctions categories at the request of industry. Although the sub-cause entry is not required, entities who provide this data allow the industry to better perform trend analysis on misoperation causes and allow targeted use of resources to address potential misoperation causes.

We encourage entities to use the MIDAS Data Reporting Instructions manual to help determine whether a misoperation should be reported to MIDAS. The definitions, descriptions, and examples are valuable resources for compliance contacts and the engineering staff performing the analysis and reporting.

The PCS found that, while event descriptions continue to improve, they occasionally still fail to establish the root cause. A root cause is necessary to determine the proper corrective action to apply either to the Protection System, entity processes, or across all similar installations in the entity's system.

## Recommendations

1. Update maintenance and commissioning practices to include burden and continuity checks of wiring plus visual inspection of equipment. Better practices will find most problems before an AC misoperation can occur.
2. Perform peer review including verifying that the fault system model is correct, the coordination study is complete, the contingencies within the study are correct, proper setting values of the elements are applied, and the elements for the application are enabled.
3. Develop standards and guides for fault studies and a process for reviewing new and existing settings to ensure changes to the system do not result in misoperations. PRC-027 addresses

the periodic review of protection systems. This standard also establishes a peer review requirement, as well as performing evaluations on fault system models. Strong approaches to these topics can help prevent misoperations.

4. Establish a training program for personnel who work on protection schemes and applications.
5. Develop an applications-based testing method and apply as a quality assurance measure to new and modified relay applications.
6. Apply corrective action on similar protection systems throughout the system as root causes are found for Relay Failures/Malfunctions.
7. Have the technicians performing the work compare the “As-Left” settings on the relay to the desired settings given by the setting engineer, to avoid leaving incorrect settings on a relay.