WECC

2021 Misoperation Report

Relay Work Group

September 28, 2022

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Introduction

Background

NERC has identified Protection System Misoperations as a major area of concern to reliability of the Bulk Electric System as they can significantly increase the severity of an event. The NERC tracks annual misoperation rates for each region to evaluate the performance of Protection Systems. The metric is the ratio of Protection System Misoperations to the total number of Protection System operations. 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 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.

For the Western Interconnection, the total number of yearly misoperations has continued to trend downward. The trend of misoperations from 2017 to 2021 for the Western Interconnection is shown in Figure 1. The Western Interconnection misoperation rate has a slight downward trend, also shown in Figure 2.

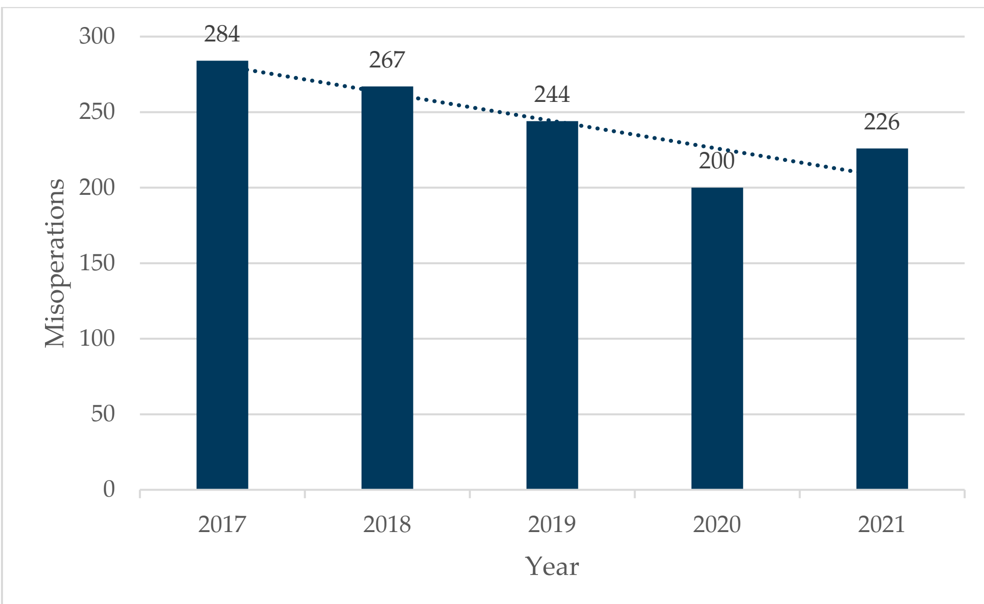

Figure 1: Western Interconnection Total Misoperations 2017 to 2021 trend

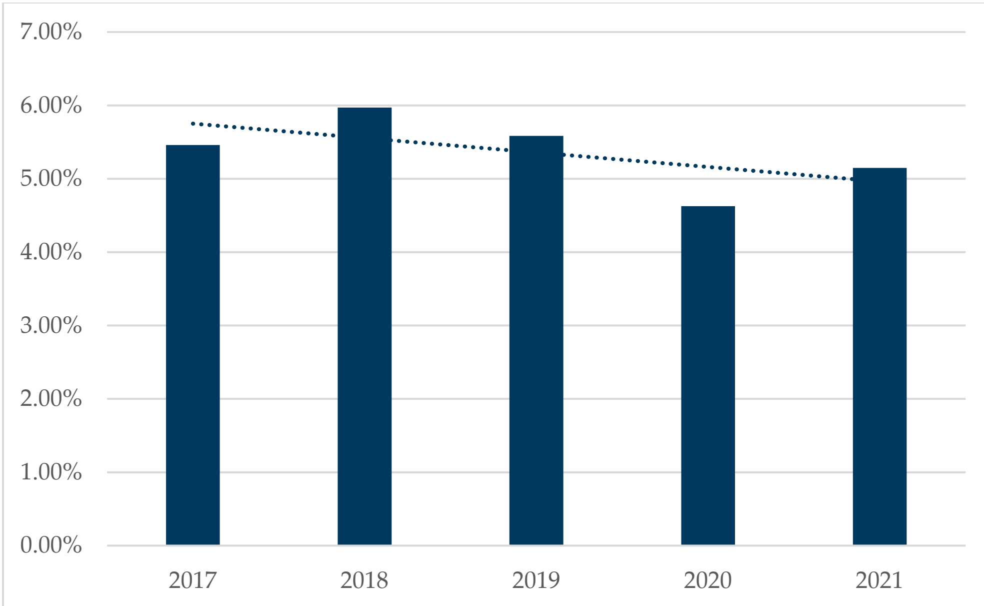

Figure 2: Western Interconnection Misoperation Rate 2017-2021

The Relay Work Group (RWG) 2021 report analysis focuses on a yearly review of misoperation cause categories along with an in-depth assessment of the top three cause categories within the Western Interconnection. The intent of the analysis is to develop key findings and actionable items within the Western Interconnection footprint to improve the reliability of the Bulk Electric System.

Purpose

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

- Provide trend analysis of Protection System Misoperation data and possible root cause identification.
- Form conclusions/recommendations from the analysis to reduce the likelihood of future misoperations.
- Develop guidance and best practices to industry through technical documents and webinars pertaining to Protection System Misoperation trends, conclusions, and recommendations.
- Publish the analysis results to WECC's Event and Performance Analysis Subcommittee (EPAS) and the WECC membership.

The RWG focus is on misoperations by cause to identify ways to reduce future misoperations. The impact of a misoperation on the BES was not considered in the evaluation. The impact of a misoperation on the BES is captured through the Event Analysis Process if the misoperation is involved in a reportable event.

Data

The misoperation data used for the one-year analysis is from the period January 1, 2021, through December 31, 2021. Trending data was from January 1, 2017, to December 31, 2021.

- The dataset was obtained by WECC from the NERC Misoperation Information Data Analysis System (MIDAS) 1600 reporting template with defined categories and causes.
- Western Interconnection entities reported 226 misoperations during 2021.
- The 2021 data was compared to data collected since 2017 for trending and analysis.
- The reported corrective actions, event description and cause of the misoperation were used to assist in root cause identification.
- The 2021 misoperation data was reviewed quarterly by the RWG with resubmittals of clarification and correction.

2021 Misoperation Analysis

An analysis of the Western Interconnection 2021 data reported and the comparison of the 2017 through 2021 datasets for trending analysis is provided. The analyses, conclusions, and recommendations for misoperations by the top cause are also included.

Misoperation by Cause Category

Evaluation of misoperations by cause category shows key indicators of misoperations attributed to human performance or a Protection System component. Figure 3 shows the distribution of misoperations as reported by cause category. The "Incorrect setting/logic/design errors" combined into one cause category was the largest, comprising 40% of all misoperations, followed by "Relay failures/malfunction" and "AC System" with 13% each of all reported misoperations. Over half of all misoperations falls into these three categories.

The "Incorrect setting/logic/design errors" cause category, along with the "As-left personnel error" primarily consist of human performance. The other four cause categories (excluding the "Unknown/unexplainable" and "Other/explainable" categories) consist of equipment or material problems and represent Protection System component type problems. Evaluating the two groupings shows—

1. 44% of all misoperations can be attributed to one of the cause categories related to human performance:
    a. Incorrect setting/logic/design errors,
    b. As-left personnel error.
2. 35% of all misoperations can be attributed to a Protection System component type category:
    a. AC system,
    b. Communication failure,

c. DC system,
d. Relay failures/malfunctions.

Of interest is that the "Other/Explainable" cause is one of the highest categories for 2021. A review of the causes indicates mis-categorizations for some of the misoperations. Some examples of explanations include incorrect settings, coordination studies, CT failures, DC transient to a relay input, and system VAR flows. The category is defined as "misoperations determined to have an identified cause but do not fit into any of the other categories." Some examples for the cause category are environmental issues, temporary changes to the system topology, or physical failure such as a trip coil. The RWG reviews the initial submittals quarterly and provides comments to the entity for correction. Often the entity chooses not to correct or, when root cause is found, does not update based on findings. The RWG encourages entities to incorporate misoperation updates into their reporting processes to ensure data integrity.

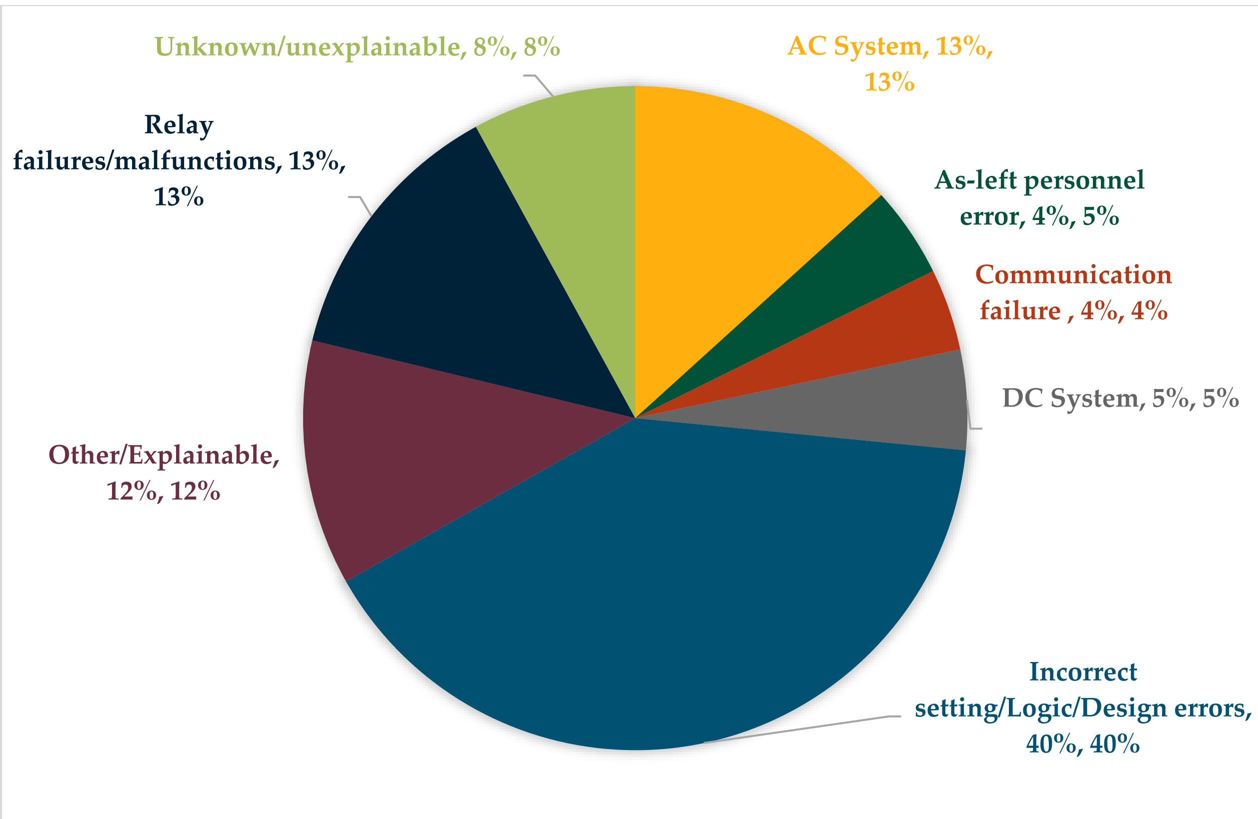

Figure 3: 2021 Misoperations by Cause

The trend in Figure 4 shows the top two cause categories for misoperations in the Western Interconnection: "Incorrect setting/logic/design errors," with a five-year running average of 99 misoperations per year, and "Relay failures/malfunctions," with an average of 33.6 misoperations a year. Both categories have seen a reduction from the previous years as the total of misoperations is on a downward trend as shown in Figure 1.

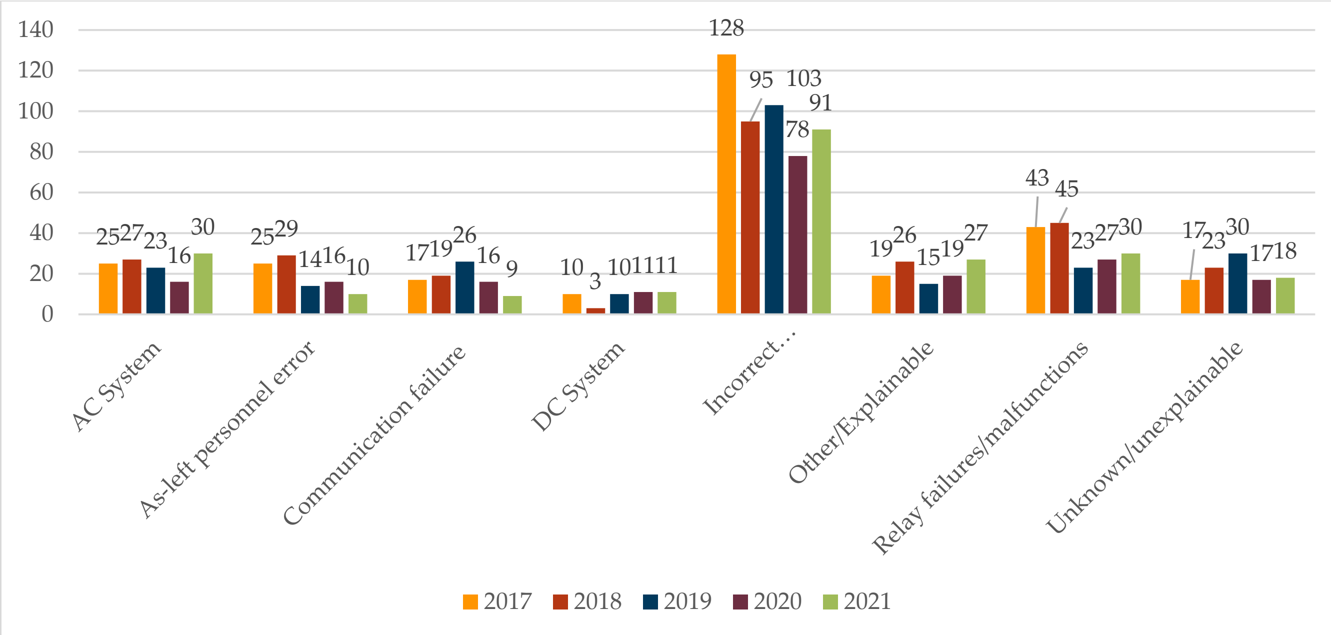

Figure 4: Misoperation by Cause, 2017 to 2021 Trending

Averaging the rest of the cause categories over the five-year period gives the following:

Table 1: Five-Year Average Misoperations by Cause

Cause Category	Number of Misoperations
AC system	23.8
As-left personnel error	18.8
Communication failure	17.4
DC system	9
Other/explainable	21.2
Unknown/unexplainable	21

Misoperation by Cause Category Conclusions and Recommendations:

- The "Incorrect setting/logic/design error" trend of percentage to the total number of misoperations per year remains flat although the number of overall misoperations has decreased. Human error continues to be the largest percentage of misoperations. Further analysis is provided in the focus section of "Incorrect setting/logic/design error."

Misoperation by Voltage Class

Generally, Voltage Class is considered to be 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. The number of misoperation by Voltage Class for 2021 is shown in Figure 5.

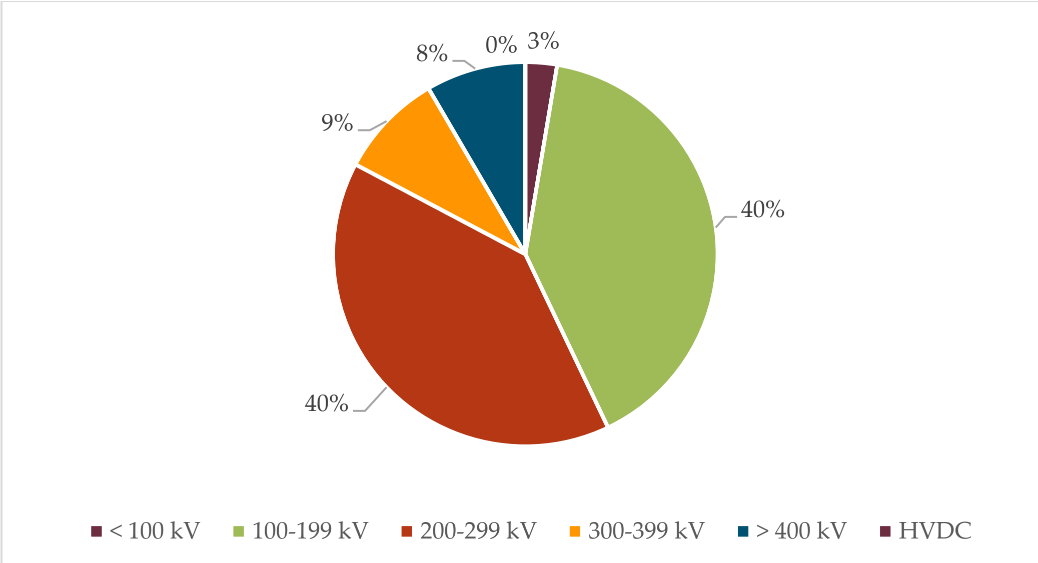

Figure 5: 2021 Misoperation by Voltage Class

An indicator of reliability 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 a better trend of what is happening in the Western Interconnection. The number of Transmission Availability Data System (TADS) Elements active in 2021 in the Western Interconnection was used to determine the number of Elements in a Voltage Class. The results are the misoperation ratios in percentage shown in Table 2. The ratio will normalize the numbers as facilities are added or removed from the Western Interconnection.

Table 2: 2021 Misoperation Ratio by TADS Voltage Class Element

Voltage Class	AC Circuit	Converter	DC Circuit	Transformer	# Misops	Misop Ratio
0-99 kV	504	0	0	42	6	1.1%
100-199 kV	3217	0	0	186	91	2.67%
200-299 kV	1880	5	3	710	90	3.46%
300-399 kV	185	2	0	178	20	5.48%
400-599 kV	297	0	5	241	19	3.5%

The trend for the misoperation ratios by voltage class Elements for 2019 to 2021 is shown in Figure 6. The chart indicates for most voltages the trend appears constant. Data is only available since 2019 when the RWG adopted the voltage class reporting levels used by NERC MIDAS criteria.

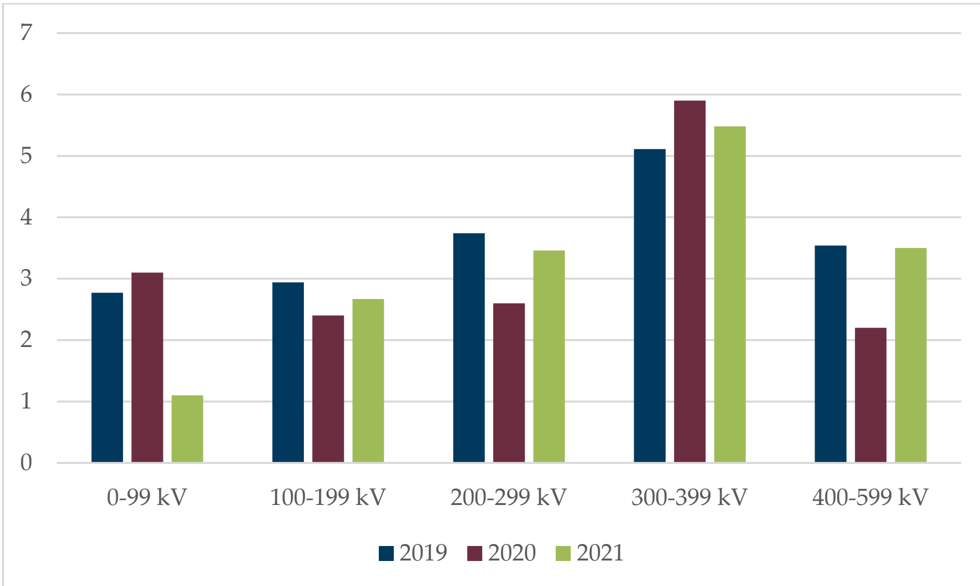

Figure 6: Misoperation Ratio by Voltage Class, 2019 to 2021 Trending

Misoperation Ratio by Voltage Class Elements Conclusions and Recommendations:

The separation by Voltage Class can give the Western Interconnection an indication of where to target improvements. The highest number of circuits within the Western Interconnection are in the 100-199 kV and 200-299 kV range. The three-year trend indicates misoperation ratios by voltage class Elements have stayed fairly constant.

Analysis for Incorrect Setting/Logic/Design Errors

There were 91 misoperations attributed to "Incorrect setting/logic/design errors," which is an increase from 2020, and still making it the largest of all cause categories in 2021. The following discusses the findings for the misoperations within this group.

Most misoperations involved microprocessor relay technology. The large number of misoperations suggests the widely adopted use of microprocessor technology. Enhanced event analysis is an effective tool in misoperation diagnosis; however, microprocessor relays' additional complexity is also a leading contributor to misoperations. Eventually 100% of the misoperations may become due to microprocessor-based relays when older technologies have been entirely replaced.

Figure 7 further subdivides the "Incorrect setting/logic/design errors" cause into setting, logic, and design errors. The chart shows setting errors make up 81% of the misoperations, while logic and design errors only account for 19%. This balance is similar to past years (see Figure 8). The percentages suggest most misoperations are attributed to setting errors, and when considered in conjunction with statistics on relay type, may be indicative of the complexity of microprocessor relays and their applications. The relatively small percentages of logic and design errors might suggest these subgroup have been more standardized for common applications.

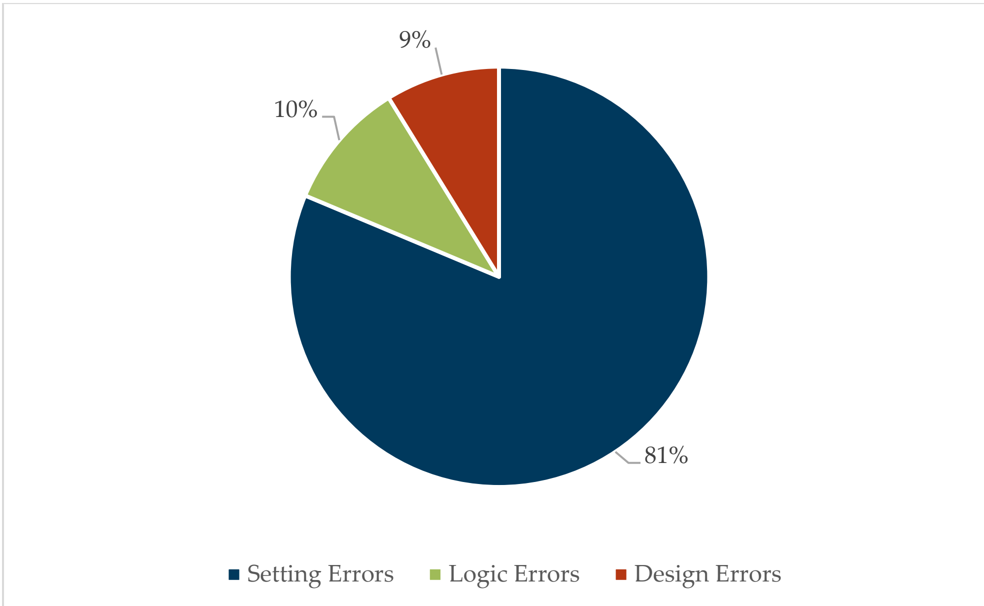

Figure 7: 2021 Misoperations by Subgroup

The trend shown in Figure 8 indicates setting errors continue to be the primary cause of misoperations. However, the trend shows a gradual decrease in the percentage attributed to settings errors, with a corresponding percentage attributed to logic and design errors remaining constant. While the rate of change is small, it may be attributable to factors such as optimizing core relay settings through analyzing operations and misoperations over time.

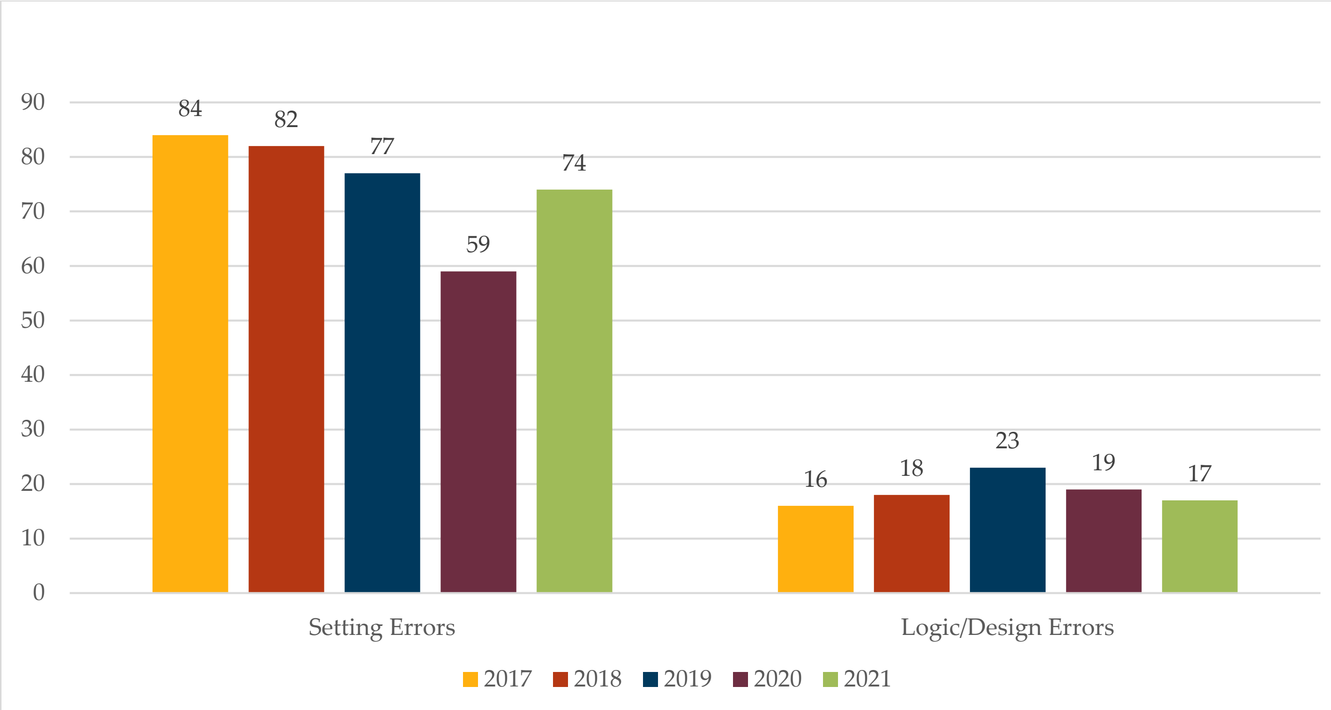

Figure 8: Misoperations subdivided into Setting and Logic/Design Errors, 2017–2021 Trending

When the errors were further investigated, as shown in Figure 9, three significant causes of misoperations are due to incorrect ground overcurrent/distance settings, logic settings and coordination. Logic settings were defined as directional elements misapplied, outputs not configured correctly, relay to relay communications inappropriately set and corrective action listed as reprogramming. The number of logic errors found in the descriptions does not match the number in the cause identified. Many entities' corrective action plans listed re-coordination of elements as the solution. As in 2020, the number of misoperations in which the cause remained undetermined was zero. A continued improvement of identification is a positive sign. Potential contributing factors include a higher installed percentage of microprocessor relays, in which event record data is easily available and supports misoperations analysis. Most settings and logic/design errors resulted in an "Unnecessary Trip—during fault" removing more elements from the system than necessary.

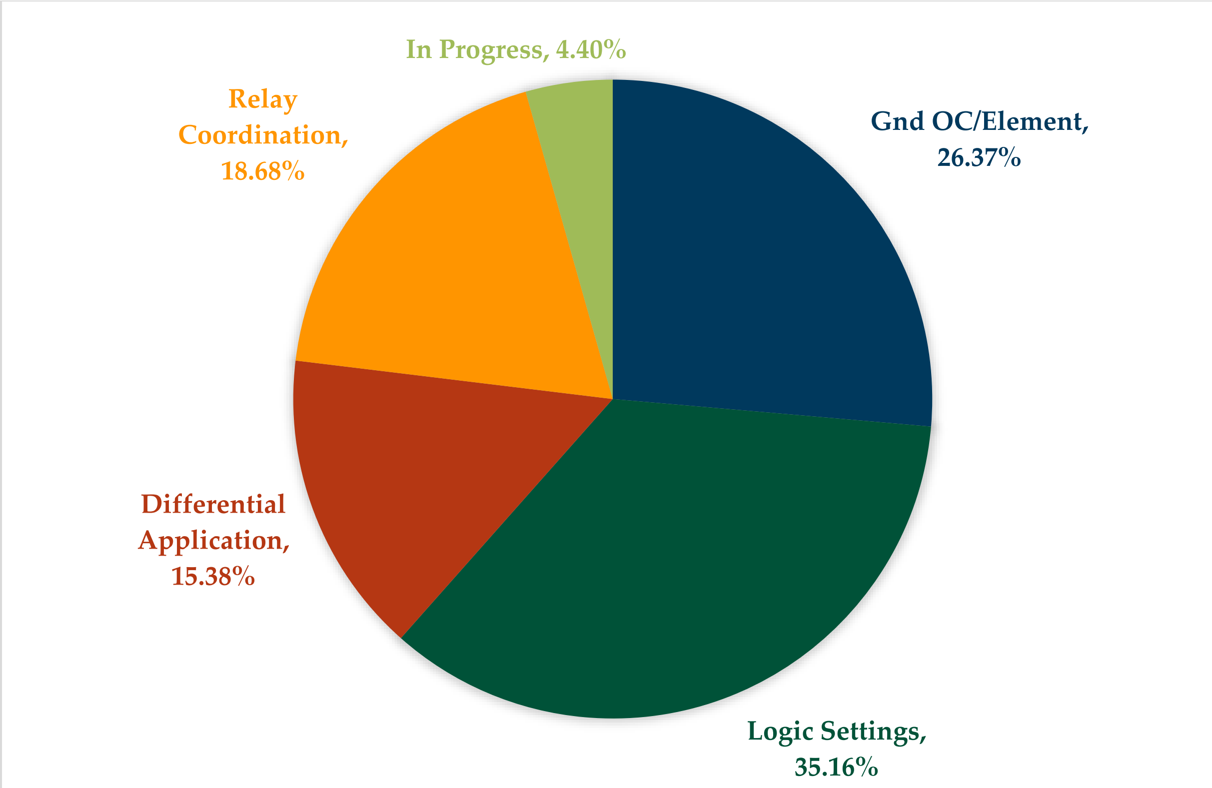

Figure 9: 2021 Settings and Logic/Design Errors by Root Cause

Incorrect Setting/Logic/Design Errors Misoperation Conclusions and Recommendations:

Entities should:

- 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 applied, and the elements for the application are enabled.
- Develop standards/guides for fault studies and a process for reviewing new and existing settings to ensure changes to the system do not result in misoperations. The recently effective standard PRC-027 addresses the periodic review of Protection Systems.
- Establish a training program for protection schemes and applications.
- Develop an applications-based testing method and apply as a quality assurance measure to new and modified relay applications.
- Recommend Real-Time Digital Simulator (RTDS) testing on EHV circuits and series compensated lines.

Additionally, entities should review the IEEE Power System Relaying Subcommittee report to provide additional technical guidance for quality control of protective relay settings; "Processes, Issues, Trends and Quality Control of Relay Settings" (Working Group C3 of Power System Relaying Committee of IEEE Power Engineering Society, March 2007).

AC Systems

There were 30 misoperations attributed to "AC systems" for 2021. AC system failures when averaged (23.8/yr.) over the last five years is the third leading cause of misoperations in the Western Interconnection. The following discussion identifies the drivers of the misoperations for the AC systems cause.

The 2017-2021 trend of AC failures has been relatively flat, with a reduced number in 2020, Figure 10.

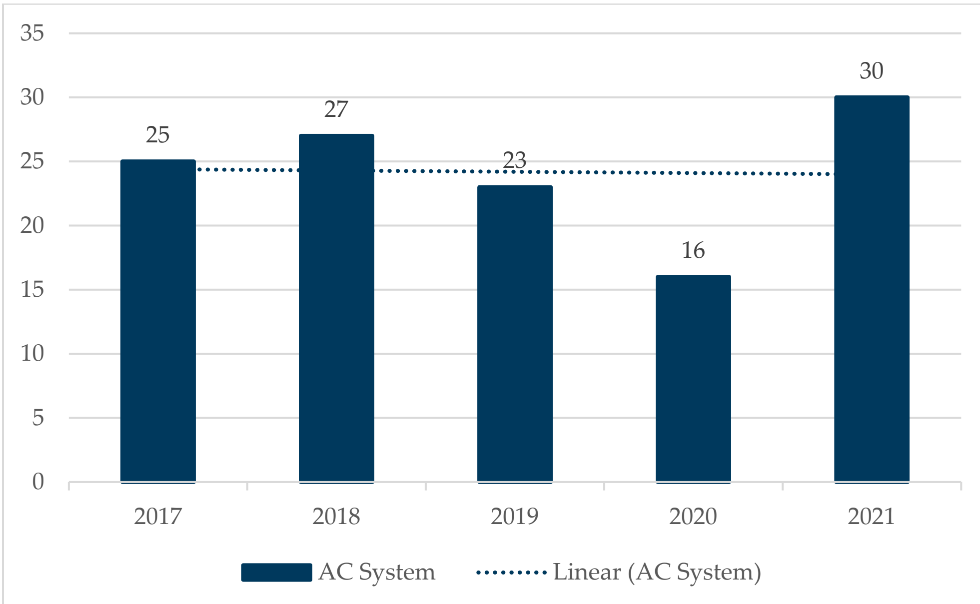

Figure 10: AC Systems Misoperation Totals, 2017 through 2021

Through the entity's reported descriptions of the misoperations and the corrective action plans, the RWG was able to break AC systems into various triggers. The largest source of misoperations in 2021 was CT/PT wiring/connection issues at 54.8%, followed by PT failure (19.4%) and Relay CT/PT Signal lost/distorted (13%), Figure 11.

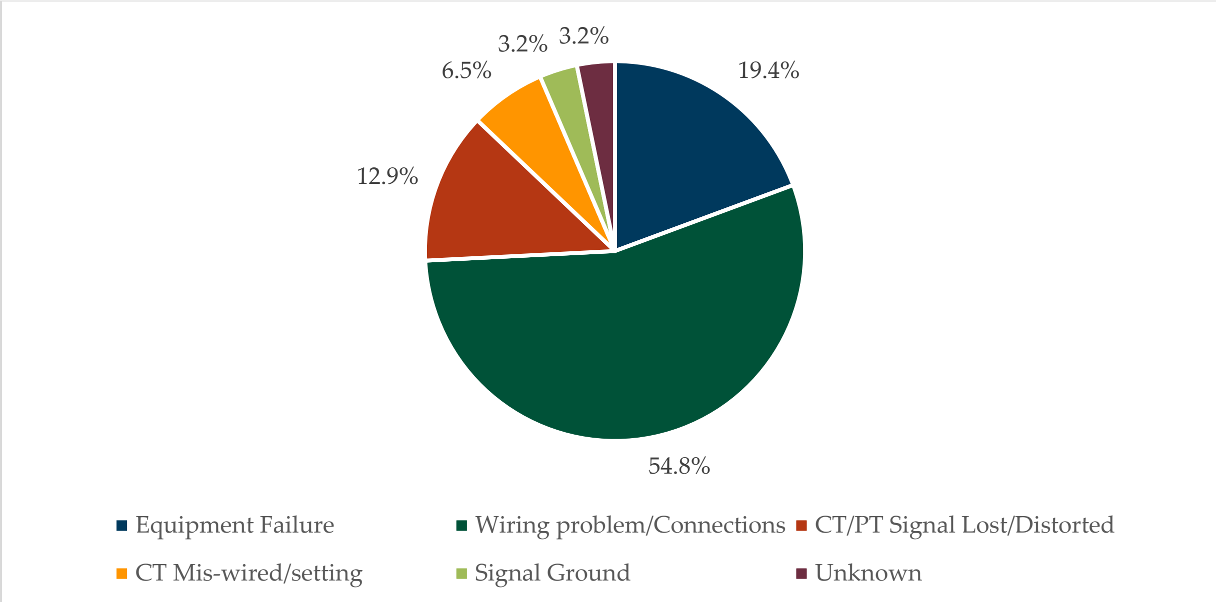

Figure 11: 2021 AC System Misoperations by Failure Mode

Seventy percent of the AC System Misoperations were categorized as Unnecessary Trip—Other than Fault. A majority of the Unnecessary Trip—Other than Fault are attributed to CT/PT Wiring/Connections issues. Highlighting the top three triggers from the 2017–2021 indicates that Wiring problem/Connections, by average, is the leading cause, shown in Figure 12.

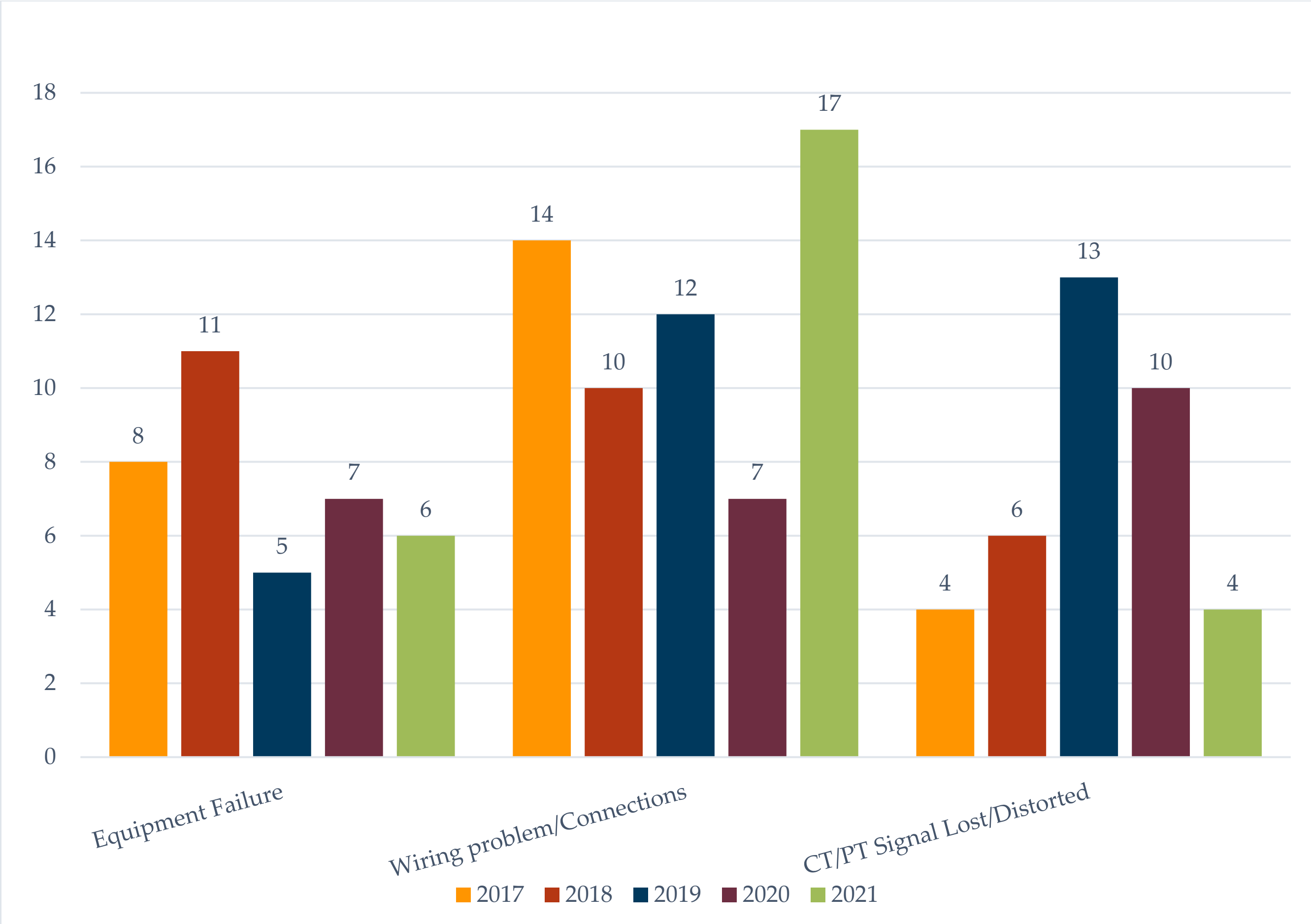

Figure 12: AC Misoperation 2017-2021 trend by Failure Mode

The Wiring problem/Connections and CT Mis-wired should be identified either during commissioning or through maintenance practices,

AC System Misoperation Conclusions and Recommendations:

Entities should 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. In many cases a proper insulation test during the commissioning process can find these problems. The IEEE I-25 "Commissioning Testing of Protection Systems" is a helpful guide to incorporate into commissioning practices.

Relay Failures and Malfunctions

There were 30 misoperations attributed to "Relay failures/malfunctions" in 2021. Figure 13 shows the number of misoperations for this cause is higher than the previous two years, but significantly lower than in 2017 and 2018.

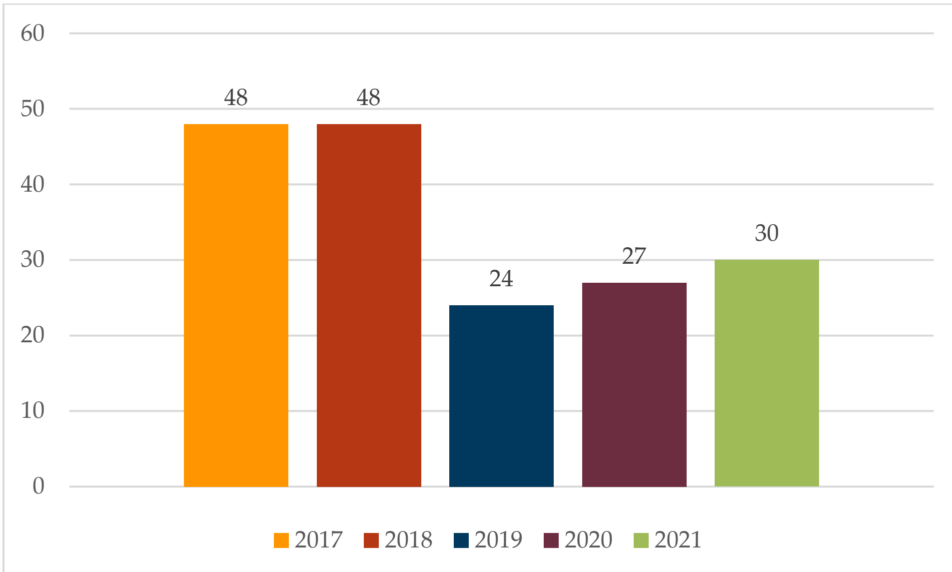

Figure 13: Relay Failures and Malfunctions, 2017-2021 Trending

Figure 14 shows the distribution of these misoperations by relay technology. Microprocessor relays continue to be the most common relay type associated with relay failures. They consistently represent 60% to 70% of all relay failures. Overall, relay failures have declined for the years 2019, 2020, and 2021 compared to 2017 and 2018. Interestingly, there has not been a significant change in the percentage of failures attributed to microprocessor relay type during the last three years. Since all new installations employ this relay type, it is believed that they will continue to represent a greater and greater percentage of the total relay inventory, which may result in representing a greater percentage of the relay failures as well. Since a complete inventory of relays is unavailable, we cannot say whether these relays have a higher failure rate than other relay technologies.

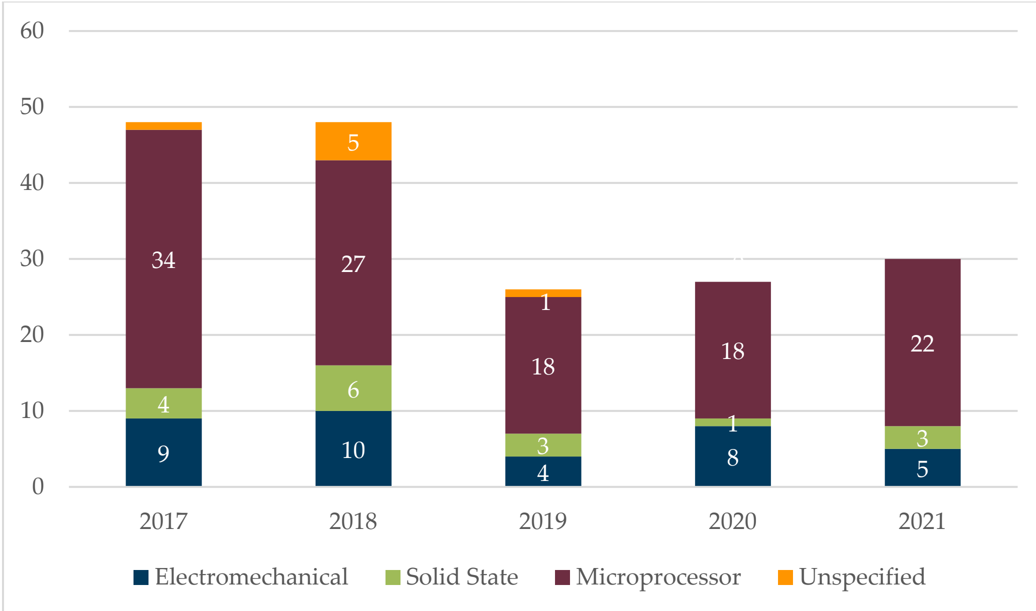

Figure 14: Relay Failures and Malfunctions by Equipment Type

For the 2021 “Relay failures/malfunction” the sub-cause column and information provided in free form cells gave insights into some common types of relay failure. There were several electromechanical relays that were found out of calibration. Calibrating these relays is covered under PRC-005 maintenance programs. We recommend entities track this type of failure and consider decreasing the time between maintenance cycles for relays with a history of calibration drift. It was also observed that many relay failures resulted in initiating an output. Entities should review whether some inputs should be supervised by other quantities or have a time delay before assertion added to potentially avoid unintended operations. Another observation noted was that many data submissions did not provide enough detail in the description to identify what failed within the relay, or the entity did not know. Most 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 an entity’s system that are prone to the same type of failure. This can also help the manufacturer identify and correct issues with their products.

Reported relay failures for 2021 were analyzed as a function of the technology versus the misoperation category in Figure 15. Most relay failures caused an “Unnecessary trip—other than fault,” indicating these failures are prone to cause a trip without a fault present. This cause often has a lower impact than a failure of a relay to detect and clear a fault from the system. We were pleased to see no failure or slow trip misoperations in 2021.

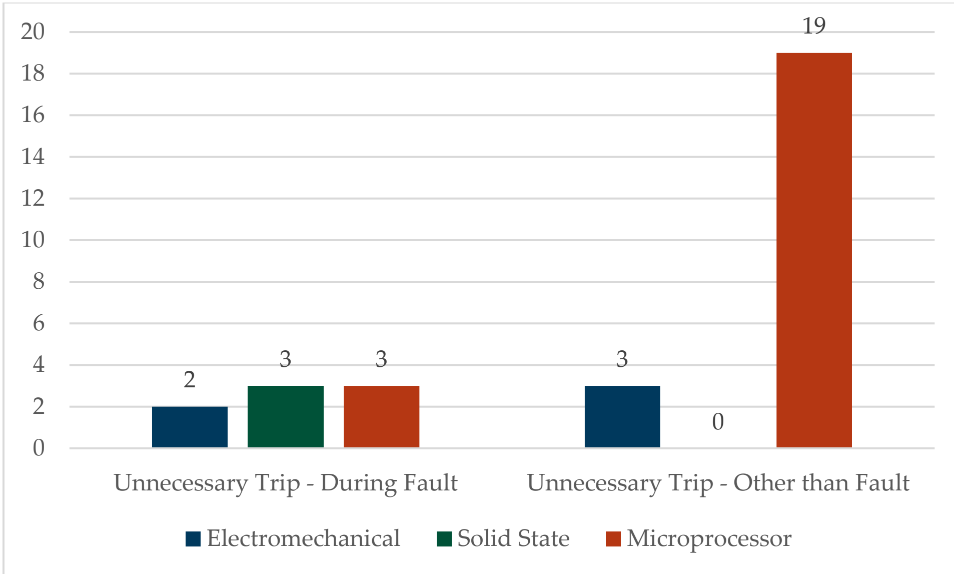

Figure 15: 2021 Relay Failures/Malfunctions Misoperations by Category

Figure 16 shows previous years are similar to 2021, in that most relay failures result in an "Unnecessary trip—other than fault." Failure to trip and slow trips remain at low levels through the trending timeframe.

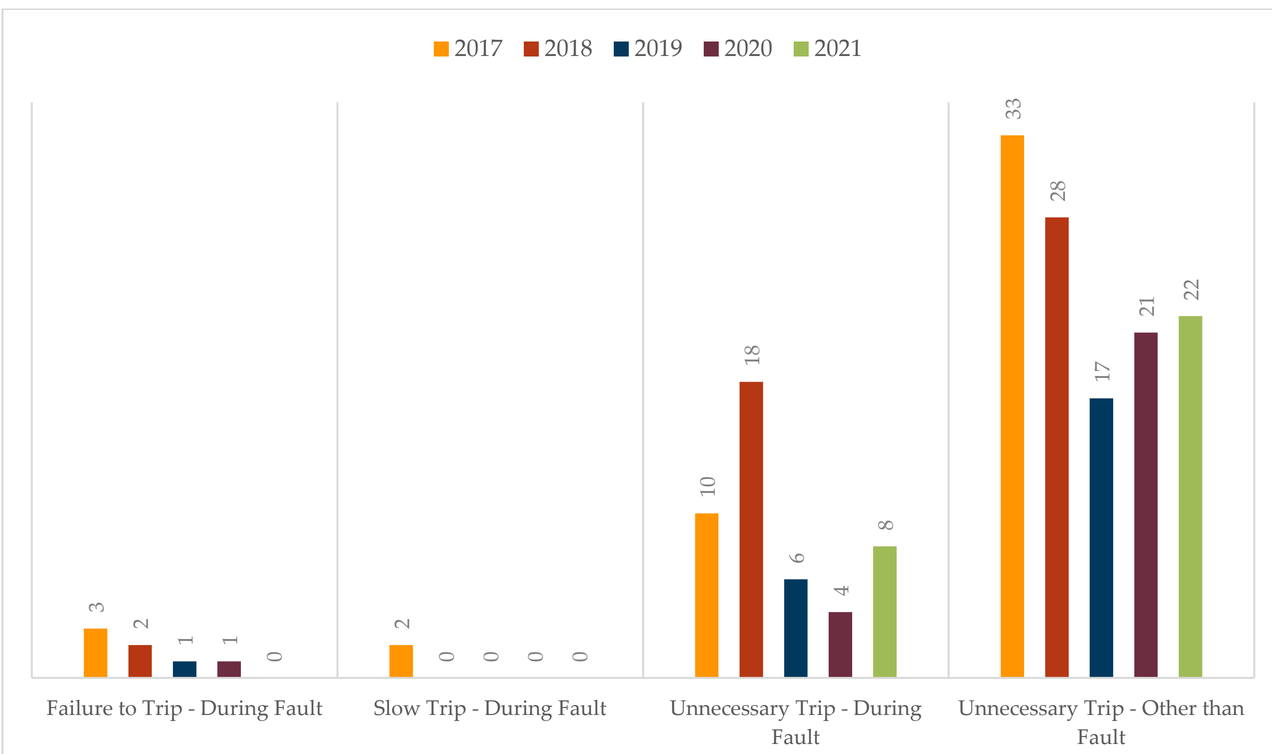

Figure 16: Relay Failures/Malfunctions Misoperations by Category, 2017-2021 Trending

Relay Failures/Malfunctions Cause Category Conclusions and Recommendations:

Determining the actual causes of misoperations is critical to identifying root causes, which then determines the proper corrective action to apply. This can help determine whether you are dealing with a singular occurrence, or whether corrective actions need to be taken across all similar installations in the system. Many entities either replaced the relay as the planned corrective action, with no further investigation, or are working with the manufacturer to understand the cause. As root causes are found, the fixes should be applied on similar Protection Systems throughout the entity's system.

Conclusions

The trending of 2017 through 2021 indicates that the total misoperations has had a slight downward trend over the past five years—284, 267, 244, 200, and 226—though, the total increased slightly between 2020 and 2021. "Incorrect setting/logic/design errors" is still the leading cause of misoperations within the Western Interconnection. The RWG believes the majority of misoperations due to setting errors are preventable. Best practices to avoid settings errors include using peer reviews, proving increased 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. NERC PRC-027 has requirements for periodic reviews and is intended to reduce the number of misoperations in the future.

The NERC 1600 reporting template added sub-cause categories in 2018 to the "Incorrect setting/logic/design errors" and "Relay failures/malfunctions" at the request of NPCC and SERC. Although the sub-cause entry is not required, entities who provide this data will allow the industry to better perform trend analysis on misoperation causes and allow targeted use of resources to address potential misoperation causes.

The NERC MIDAS User Group has drafted a Data Reporting Instructions manual which has improved the quality of misoperation reporting by providing examples to the entities' main compliance contacts and the engineering staff performing the analysis. The RWG found that while event descriptions continue to improve, they are still lacking in establishing 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. A quarterly review of misoperations by the RWG is beneficial and should continue.
2. A best practice Webinar on Protection System event review by the RWG members may help emphasize the importance of this task and provide entities within the Western Interconnection a learning opportunity.

3. The RWG maintains that entities should 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.
4. 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.
5. Develop standards/guides for fault studies and a process for reviewing new and existing settings to ensure changes to the system do not result in misoperations. The recently effective standard NERC 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.
6. Establish a training program for personnel who work on protection schemes and applications.
7. Develop an applications-based testing method and apply as a quality assurance measure to new and modified relay applications.
8. As root causes are found for "Relay Failures," the corrective action should be applied on similar Protection Systems throughout the entity's system.
9. To avoid leaving incorrect settings on a relay, the technicians performing the work should compare the "As-Left" settings on the relay to the desired settings given by the setting engineer.