RELIABILITY FIRST

2025 Misoperation Assessment

Drafted by: ReliabilityFirst Staff

Reviewed by: Protection Subcommittee

September 2025

Table of Contents

Introduction

The North American Electric Reliability Corporation (NERC) has identified in its 2025 State of Reliability Report that Protection System Misoperations are an area of concern to reliability of the Bulk Electric System. The reliability concern is if a Misoperation were to occur, it can significantly increase the severity of an event.

NERC has and continues to track annual Misoperation rates for each Regional Entity, which are calculated as the percentage of total Misoperations over the total protection system operations. NERC uses this rate to evaluate the performance of protection systems across the Electric Reliability Organization (ERO). The purpose of the Protection System Misoperations metric is to calculate a Misoperations rate and determine the relative performance of all protection systems so NERC can identify trends, both positive and negative.

NERC and the regions have created a new metric that considers the risk a Misoperation poses to the Bulk Electric System. The metric, called the Misoperation Impact Score, takes into consideration the following: Voltage Class, Misoperation Category, Misoperation Cause and Equipment Type. This report examines both the Misoperation Rate and the Misoperation Impact Score.

> *Protection System Misoperations ("Misoperations") are defined in the NERC Glossary of Terms as "the failure of a Composite Protection System to operate as intended for protection purposes." Misoperations include a composite protection system's failure to operate, delay in operating, or operating when not required during either a fault or non-fault condition. Misoperations contribute to, and tend to exacerbate the impact of, automatic transmission outages, which adversely affect the reliability of the bulk power system (BPS).*

The ReliabilityFirst Protection Subcommittee (RF-PS) initiated the development of this report to keep focused on and perform a biennial review of Misoperation cause categories. As part of this review, a thorough assessment of the top three cause categories within the ReliabilityFirst footprint is included. The intent of the analysis is to develop key findings and recommendations within the ReliabilityFirst footprint to improve the reliability of the Bulk Electric System (BES) and drive the Misoperations rate down.

Purpose

The RF-PS performs peer reviews of the quarterly Misoperation data reported to NERC under Section 1600 for registered entities in the ReliabilityFirst footprint. The RF-PS performs a yearly analysis and multi-year 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 ReliabilityFirst stakeholders, including ReliabilityFirst's Reliability Committee (RF-RC), member entities, and beyond.

The RF-PS focuses on the causes of Misoperations to identify trends and reduce future Misoperations. The impact of a Misoperation on the BES was not considered in the evaluation. Rather, the impact of a Misoperation on the BES is captured through the Event Analysis Process if the Misoperation is involved in a reportable event.

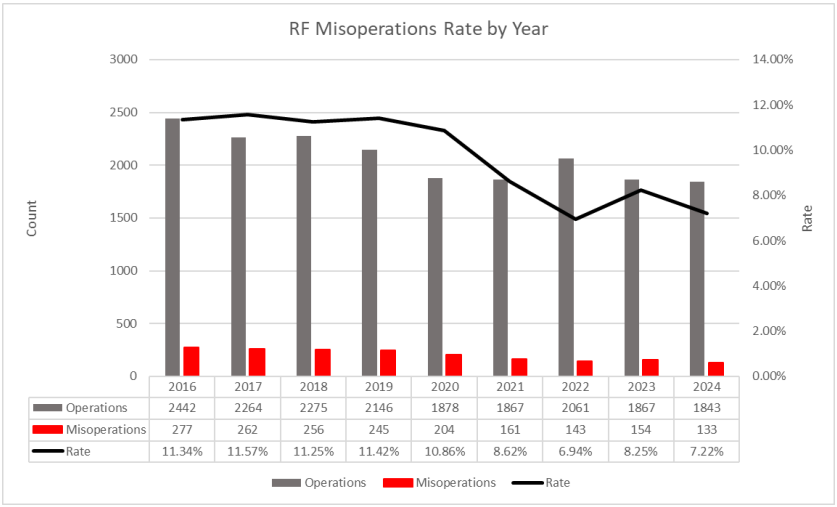
Data and analysis

The Misoperation data used for this analysis was gathered in previous years and analyzed in 2025 with trending data from Jan. 1, 2020, to Dec. 31, 2024.

- The dataset was obtained by ReliabilityFirst from the NERC Misoperation Information Data Analysis System (MIDAS) 1600 reporting template with defined categories and causes.
- The 2024 Misoperation data is reviewed quarterly through a peer review process by a subset of the RF-PS followed by resubmittals of clarification and corrections. The 2024 data was compared to data collected since 2020 for trending and analysis.
- The reported corrective actions, event description and cause of the Misoperation were used to assist in root cause identification.

Misoperation by year and by quarter

For the ReliabilityFirst region, the total annual number of Misoperations has continued to trend downward. The trend of Misoperations from 2016 to 2024 for the ReliabilityFirst region is shown in Figure 1.



	2016	2017	2018	2019	2020	2021	2022	2023	2024
Operations	2442	2264	2275	2146	1878	1867	2061	1867	1843
Misoperations	277	262	256	245	204	161	143	154	133
Rate	11.34%	11.57%	11.25%	11.42%	10.86%	8.62%	6.94%	8.25%	7.22%

Figure 1: ReliabilityFirst Total Misoperations, 2016 to 2024

Looking at Misoperations at the quarterly level in Figure 2 shows Misoperation rates (shown by the red bar) are higher in the Q1 and Q4 time frames due to lower protection system operations during those quarters. For Q4 specifically, transmission outages are reduced due to a reduction in environmental causes (e.g., lightning and vegetation). Overall, the Misoperation rates across all quarters are on a downward trend. In particular, Misoperations for Q1 are exhibiting a significant downward trend over time.

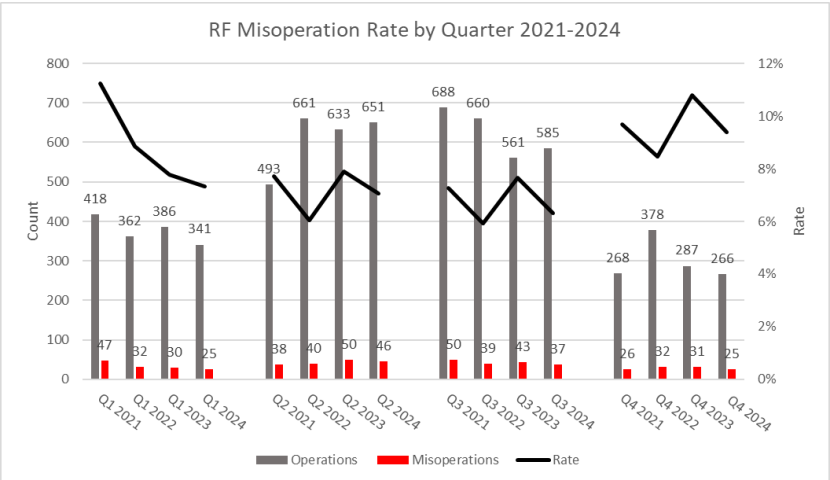
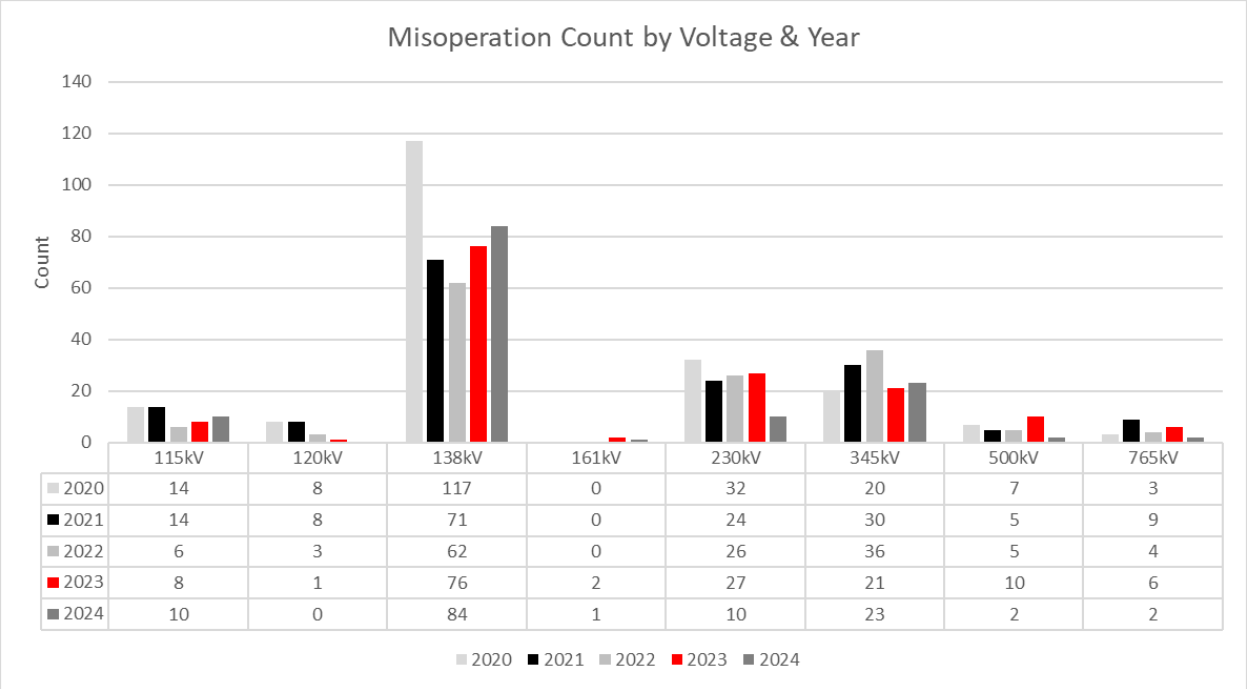


Figure 2: ReliabilityFirst Misoperations by Year and Quarter, 2021 to 2024

Misoperation by voltage class

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. The number of Misoperations by voltage class is shown in Figure 3.



	115kV	120kV	138kV	161kV	230kV	345kV	500kV	765kV
2020	14	8	117	0	32	20	7	3
2021	14	8	71	0	24	30	5	9
2022	6	3	62	0	26	36	5	4
2023	8	1	76	2	27	21	10	6
2024	10	0	84	1	10	23	2	2

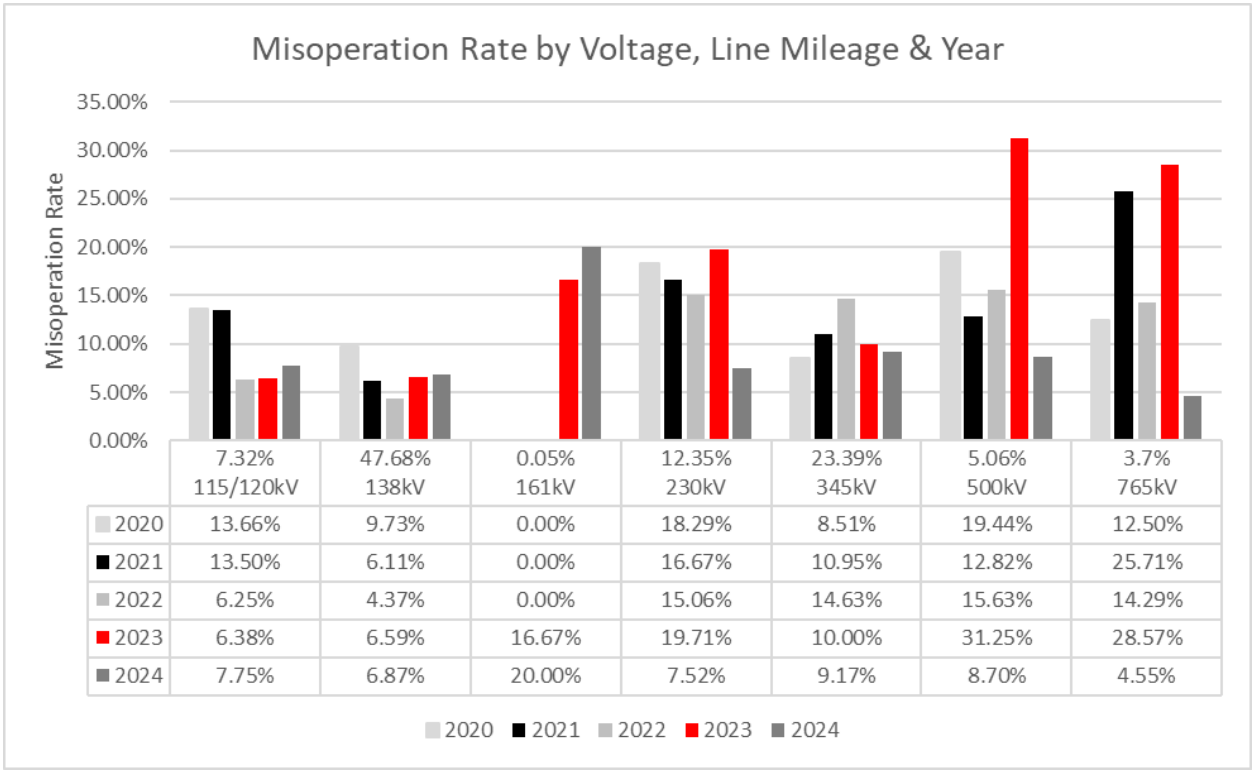
Figure 3: Misoperation Trending by Voltage Class, 2020 to 2024

One area of concern when breaking down the Misoperations by voltage class is the slight increase of Misoperations in the 138kV voltage class the last two years, all other voltage classes have been steadily decreasing over time. For the 138kV voltage class, the Protection Subcommittee members did provide some feedback that there are programs to replace line relays being implemented. This may show an improved trend for 138kV facilities in the future. RF plans to monitor this data to confirm improved performance based on these replacement programs.

Misoperation rate by voltage class and line mileage

When looking at Figure 4 below, the percentage of line mileage per voltage class can be found just above the Voltage Class legend. The 138kV voltage class makes up 47.68% of the line mileage in the RF footprint. As shown in the previous figure, the 138kV voltage class has the highest Misoperation count but has one of the best overall Misoperation rates of all the Voltage Classes ranging between 4.4% in 2022 and 9.7% in 2020. The 500kV and 765kV Voltage Classes have 5.1% and 3.7% of the line mileage in the RF footprint, respectively, and are consistently at the upper end of the Misoperation rates of all the Voltage Classes with lows around the 12% mark and highs close to or above 30%.

Note that the higher Misoperation Rate for 500kV and 765kV facilities are not a large concern due to the low number of Misoperations overall. When comparing Misoperation count and rate by Voltage Class, the focus for RF-PS members would be to reduce the 138kV Misoperation count.



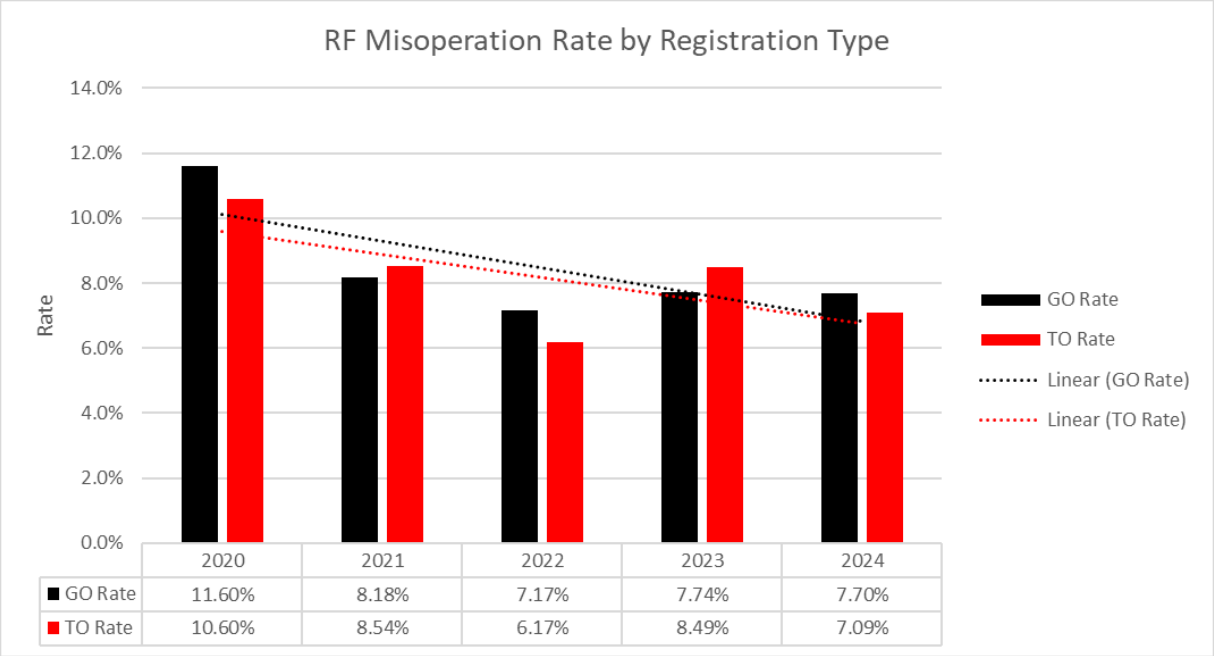
	7.32% 115/120kV	47.68% 138kV	0.05% 161kV	12.35% 230kV	23.39% 345kV	5.06% 500kV	3.7% 765kV
2020	13.66%	9.73%	0.00%	18.29%	8.51%	19.44%	12.50%
2021	13.50%	6.11%	0.00%	16.67%	10.95%	12.82%	25.71%
2022	6.25%	4.37%	0.00%	15.06%	14.63%	15.63%	14.29%
2023	6.38%	6.59%	16.67%	19.71%	10.00%	31.25%	28.57%
2024	7.75%	6.87%	20.00%	7.52%	9.17%	8.70%	4.55%

Figure 4: Misoperation Rate by Voltage Class and Line Mileage, 2020 to 2024

Misoperation by registration type

RF also looks at the Misoperations in its footprint for performance differences between Generation Owners and Transmission Owners.[1] From 2020 to 2024, both Generator and Transmission Owners have had steady performance improvement with a decrease in annual Misoperations when looking at the linear trendline in Figure 5 below. These trends may be a result of the historical outreach related to Misoperations performed by RF, which typically involved Transmission Owners, but in recent years has also included Generator Owners. It should be noted that some of these entities have put in significant time, effort, and resources with targeted implementation plans to effectively improve Misoperation performance.

Another difference between Generation Owners and Transmission Owners is the quantity of operations that Generation Owners typically have. Due to the physical attributes of a generation plant, operations of protection systems are much less common here than transmission lines that have much more exposure to weather and environmental impacts, which ultimately yields more operations. A single Misoperation at a generation plant has a much bigger impact on its Misoperation rate than it would have for a typical Transmission Owner.



	2020	2021	2022	2023	2024
GO Rate	11.60%	8.18%	7.17%	7.74%	7.70%
TO Rate	10.60%	8.54%	6.17%	8.49%	7.09%

Figure 5: ReliabilityFirst Misoperations by Registration Type, 2020 to 2024

[1] Entities that have a mixed registration of transmission and generation assets are classified as Transmission Owners in this analysis.

Misoperation by equipment type

Figure 6 provides trend data from 2020 through 2024 of Misoperations by equipment type. Overall, these trends depict that equipment exposure (i.e., the larger the amount of equipment there is, the greater the potential is for a Misoperation to occur) correlates to the number of facilities placed in the field. Lines, transformers, and breakers accounted for 79% of the Misoperations in 2024.

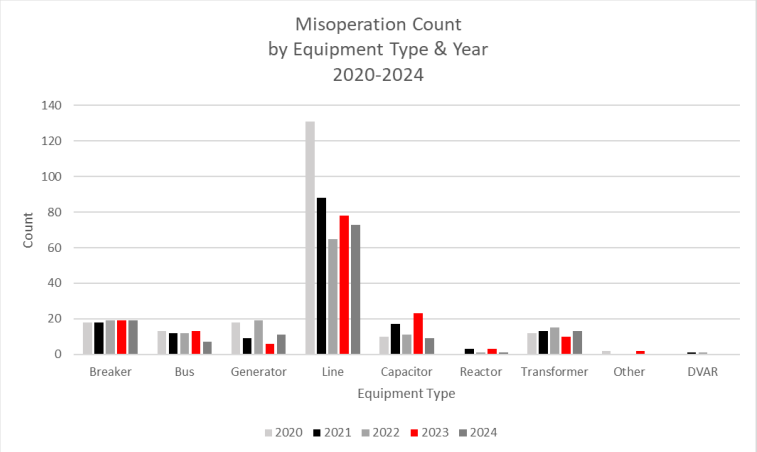


Figure 6: 2020 to 2024 Misoperation Trending by Equipment Type

Capacitor bank Misoperations

Over the five years of data, Misoperations of shunt capacitors across the ERO as a whole are trending upward, as shown in Figure 7. However, this trend has not been the same in the RF footprint, where these types of Misoperations have been relatively steady over this period, apart from a one-year jump in 2023.

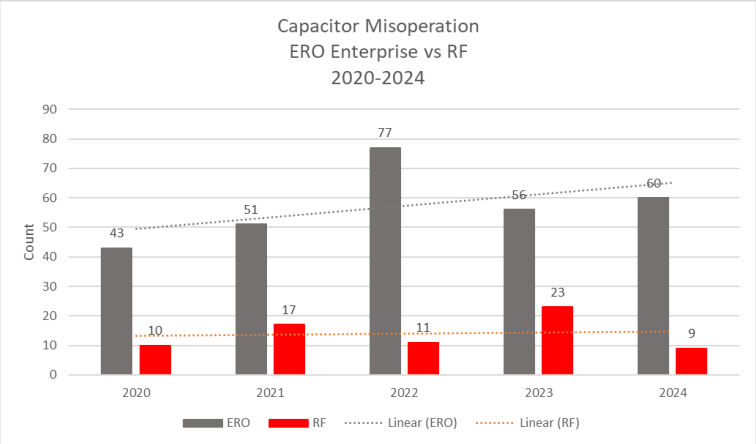
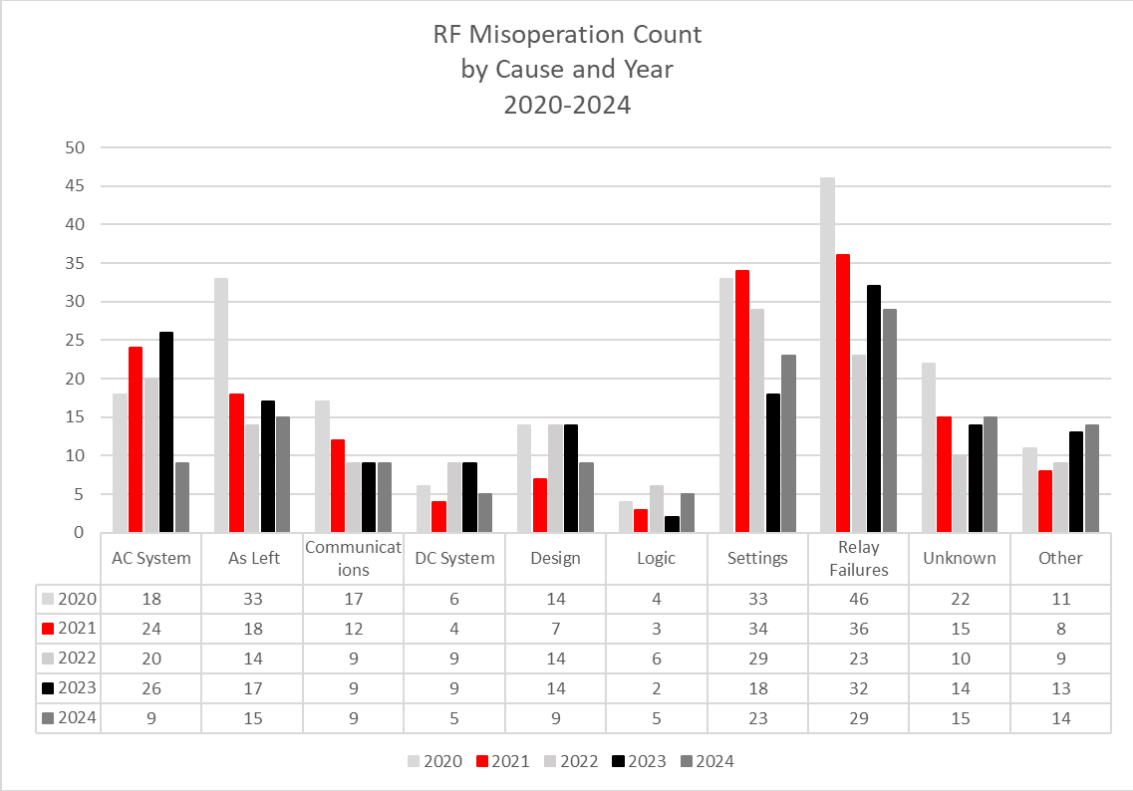


Figure 7: ReliabilityFirst Capacitor Bank Misoperations

The issue continues to be primarily associated with voltage differential protection. Several entities within the RF region have performed an extensive investigation and identified several issues relating to Misoperations of capacitor banks (e.g., microprocessor relays utilized had a design limitation for ungrounded capacitor banks, improper wiring of potential devices, incorrect settings associated with overvoltage protection, and protection design did not account for switching performed at the substation). These issues have been prioritized and proactively mitigated with improvements to system infrastructure or post-event process improvements.

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 8 shows the distribution of Misoperations as reported by cause category.



	AC System	As Left	Communications	DC System	Design	Logic	Settings	Relay Failures	Unknown	Other
2020	18	33	17	6	14	4	33	46	22	11
2021	24	18	12	4	7	3	34	36	15	8
2022	20	14	9	9	14	6	29	23	10	9
2023	26	17	9	9	14	2	18	32	14	13
2024	9	15	9	5	9	5	23	29	15	14

Figure 8: Misoperations by Cause Category, 2020 to 2024

Looking solely at counts over the last four years, "Relay Failures" was the largest category, followed by "Incorrect Settings." A large part (38%) of all Misoperations fell into these two categories. When looking at the remaining categories that are tracked and trended, "AC System" and "As-Left" account for the next 24% of Misoperations. These four categories accounted for about 62% of all the total 2024 Misoperations. "Incorrect Settings" primarily consist of a human performance issue, whereas "Relay Failures" typically stem from a relay performance issue. The other two cause categories ("AC System" and "As-Left") can be attributed to a mix of human performance and equipment or material problems.

Further assessing the categories by 1) human performance and 2) equipment or material, would group "Incorrect Settings," "Logic Errors," "Design Errors" and "As-Left" together, and "AC System," "Communications," "DC System" and "Relay Failures" together. Evaluating the two groupings shows that:

1. 39% of all Misoperations can be attributed to one of the cause categories related to human performance:
    a. Incorrect settings,
    b. Logic errors,
    c. Design errors,
    d. As-left personnel error.
2. 44% of all Misoperations can be attributed to a protection system component type category:
    a. AC system,
    b. Communications,
    c. DC system,
    d. Relay failures/malfunctions.
3. 17% of all Misoperations can be attributed to the "Unknown" and "Other" categories.

Also noted in the assessment were the categories of "Unknown/unexplainable" and "Other/explainable." The "Unknown" category is of particular interest because it remains high even with the slight trending upward the last two years and these Misoperations are at high risk of reoccurring because the system problem was never found.

Further analysis indicated that Misoperations related to Relay Failures did not seem to significantly impact quarterly Misoperation performance within the RF region.

The RF-PS 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 forget to update based on findings. The RF-PS encourages entities to incorporate Misoperation updates into their reporting processes to ensure data integrity.

Misoperation HP Performance

Figure 9 breaks down Misoperations into three major cause categories: Equipment Failure[2], Human Performance[3], and Unknown/Other. Human performance accounted for 39% of the Misoperations within the ReliabilityFirst footprint over the past five years. These types of Misoperations are caused by any incorrect action traceable to employees and/or contractors for the development of documentation (i.e., drawings, diagrams, and prints), implementation of physical design, relay settings, testing, and maintenance.

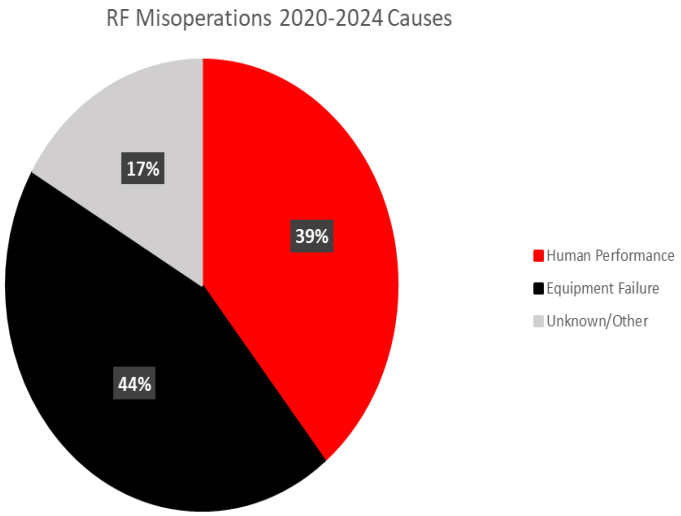
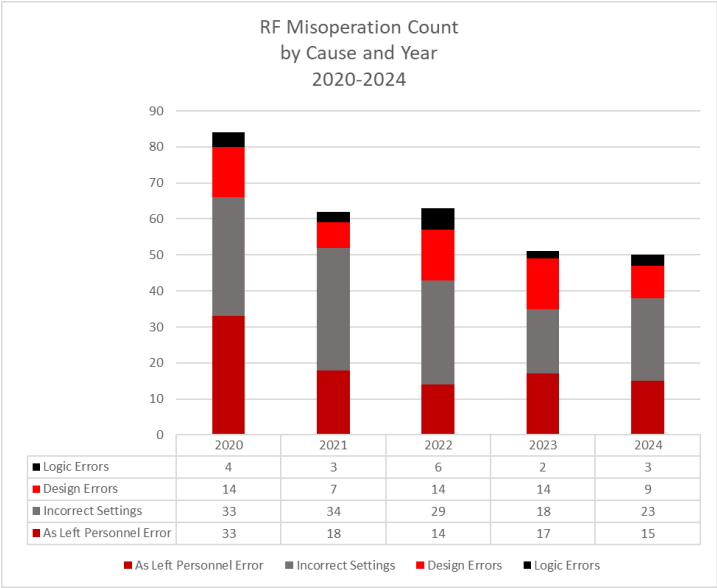


Figure 9: Misoperations Causes, 2020 to 2024

Although the five-year average proportion for human performance-related Misoperations stands at 39%, the year-to-year comparison below shows a slight decrease in the proportion of human performance-related Misoperations. Within MIDAS, there are several error causes related to human performance, which are shown in detail in Figure 10. Over the past four years, the overall number of human performance-related Misoperations has been reduced year-to-year. One potential reason for a downward trend in human performance-related Misoperations may be due to legacy protection system designs and philosophies proactively being reviewed and updated in the field.



	2020	2021	2022	2023	2024
Logic Errors	4	3	6	2	3
Design Errors	14	7	14	14	9
Incorrect Settings	33	34	29	18	23
As Left Personnel Error	33	18	14	17	15

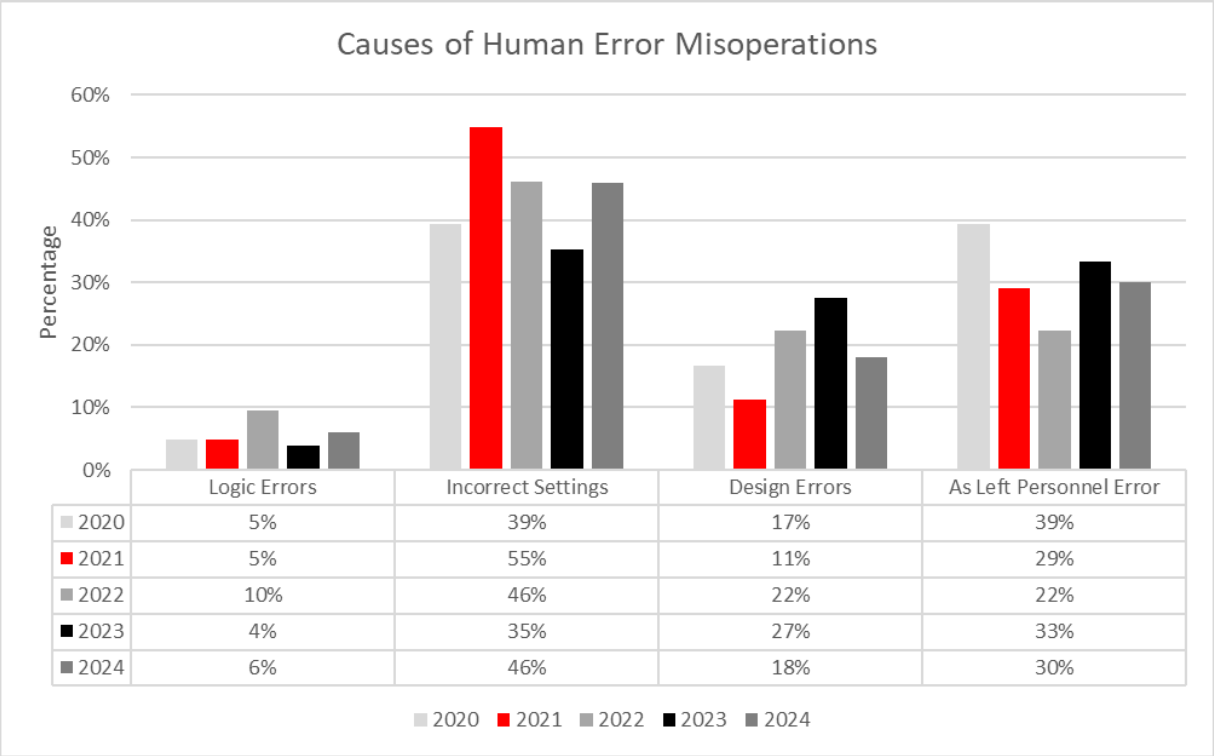
Figure 10: Misoperations HP Performance by Cause, 2020 to 2024

As shown in Figure 10, logic errors and design errors have displayed a consistent trend over time. However, "As-Left Personnel Error" and "Incorrect Settings" have consistently remained at the top of these causes. "As-Left Personnel Error" Misoperations occur after the implementation of maintenance or construction procedures (i.e., commissioning), which include test switches being left open, wiring errors, carrier grounds left in place, and settings placed in the wrong relay. Since these types of activities usually occur during commissioning activities, RF has already developed plans to focus on continued outreach on this topic. In fact,

[2] Equipment Failure categories include AC System, DC System, Communication Failure, and Relay Failure.
[3] Human Performance categories include As-Left Personnel, Design, Logic, and Settings Errors.

FERC, NERC, and Regional Entity staff (including RF) released a Joint Review of Protection System Commissioning Programs report in 2021. RF continues to disseminate and share the content of this material with industry partners to help spread awareness and improve performance in this area. "Incorrect Settings" cause includes Misoperations due to errors in issued setting, including those associated with electromechanical or solid-state relays and the protection element settings in microprocessor-based relays (excluding logic errors discussed in the Logic Error cause code). This includes setting errors caused by inaccurate modeling.

Figure 11 below shows the same four human performance causes by year and percentage of the overall human performance Misoperations.



	Logic Errors	Incorrect Settings	Design Errors	As Left Personnel Error
2020	5%	39%	17%	39%
2021	5%	55%	11%	29%
2022	10%	46%	22%	22%
2023	4%	35%	27%	33%
2024	6%	46%	18%	30%

Figure 11: Misoperations related to human performance by year and percentage of total human performance Misoperations

Misoperation Risk Score

The Misoperation Risk Score is meant to show how much risk each Misoperation poses to the Bulk Electric System (BES) – the higher the score the more risk to the system. For more details on how the Misoperation Risk Score is calculated, please consult NERC's paper on Misoperations Impact Score.

Figure 12 below is a box and whisker chart. The X in the box is the mean value, blue line is the median, the top of the box is the third quartile (75%), the bottom of the box is the second quartile (25%), the top horizontal line represents the maximum value (most risk), and the bottom horizontal line represents the minimum value (least risk). For instance, in 2024 there was a Misoperation that scored a 0.94. This Misoperation failed to trip a generator connected to the BES at 345kV during a fault and was caused by an As-Left Personnel Error. This posed a greater risk to the BES as the Failure to Trip could have damaged the generator.

The goal for RF-PS members would be to reduce the median/mean impact score to below 0.6 and eliminate numerous outliers that pose a higher risk to the BES.

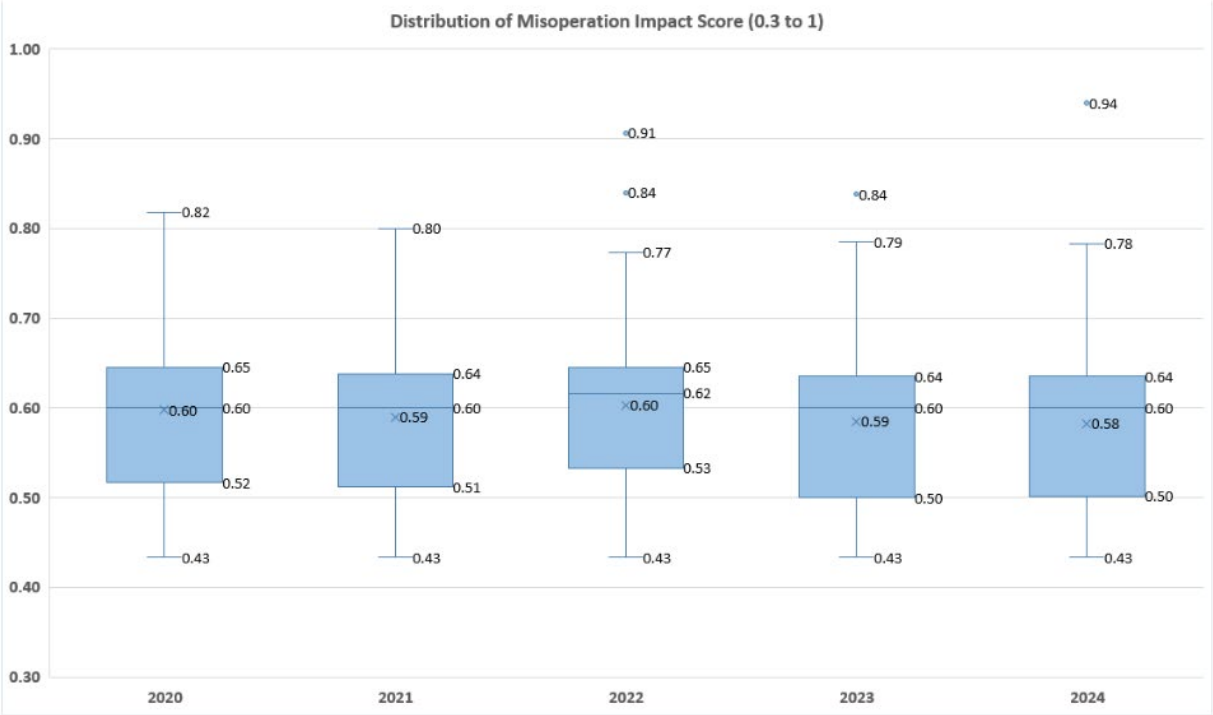


Figure 12: Misoperations by Cause Category, 2020 to 2024

Conclusions

The trend data, as illustrated in Figure 1, indicates that total Misoperations have slightly trended downward over the past several years, starting with a high of 277 Misoperations in 2016, which has decreased to a low of 133 Misoperations as of 2024. Relay failures and incorrect setting errors are the leading causes of Misoperations within the ReliabilityFirst region. When considering broader categories like Human Performance, Equipment Failure, or Uknown/Other, Equipment Failures have been the leading cause for Misoperations between 2020-2024 within RF.

The analysis performed for this report indicated a slight increase in Misoperations for the 138kV voltage class while all other voltage classes have been steadily decreasing over time. The 138kV voltage class makes up 47.68% of the line mileage in the RF footprint, which results in a large amount of Misoperations at this voltage level. For the 138kV voltage class, the Protection Subcommittee members did provide some feedback that there are programs to replace line relays being implemented. This may show an improved trend for 138kV facilities in the future. RF plans to monitor this data to confirm improved performance based on these replacement programs.

Another observation from the analysis is that due to the limited number of Protection System Operations on 230kV and above facilities, the Misoperation rate tends to be higher. However, the Misoperation count is smaller and decreasing over time and is not a concern. In addition, Generator and Transmission Owners have had steady performance improvement with a decrease in annual Misoperations.

Prior to 2020, capacitor bank Misoperations have been problematic for ReliabilityFirst. However, the 2020-2024 data shows that RF performance has improved over time for these Misoperations while the rest of the ERO has struggled.

Recommendations

The previously reviewed metrics within this report indicate improved overall performance year-over-year for Misoperation rate and count within the ReliabilityFirst footprint. It is believed that the quarterly reviews of Misoperations by the RF-PS have a positive impact on performance. In order to enhance this benefit, RF-PS members present interesting Misoperations cases during their quarterly meetings that may benefit the other members with lessons learned from them. The RF-PS members should continue this practice. In addition, here are some other recommendations that may help improve Misoperation performance within the RF footprint:

- Explore the possibility of targeted replacement of legacy communication schemes with fiber optic communication, where feasible. The adoption of fiber optic communication systems has enhanced the speed and precision of protection system operations.
- A common operational challenge is the tendency to quickly re-energize equipment after a protection event without conducting thorough diagnostics. This urgency, often driven by the need to restore power to the grid, can result in repeat Misoperations. To avoid unnecessary repeat Misoperations, the RF-PS recommends implementing practices to quickly identify Misoperations and quickly take actions to mitigate further Misoperations. This could include expediting and obtaining the necessary outages to perform adequate troubleshooting. Note that this does not necessarily translate to quickly implementing Corrective Action Plans, but more so ties to establishing best practices to investigate and restore elements back to service while reducing Misoperation risk and maintaining safety and system reliability.
- The NERC MIDAS User Group has written 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 RF-PS 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. Where applicable, this leads to better lessons learned for industry once additional root cause investigation is performed. RF can explore reviewing the language in event descriptions using natural language processing to perform better analysis related to this issue.
- The RF-PS, through discussion, identified concerns related to various workforce management challenges associated with Misoperation performance. The protection

engineering workforce is undergoing a generational shift. As experienced engineers retire, organizations face challenges in onboarding and training new personnel. The steep learning curve for protection system design and coordination increases the risk of human error in settings development and system studies. Without structured mentorship and knowledge transfer programs, these workforce transitions can lead to increased Misoperations and reduced system resilience. Here are additional items for consideration related to this topic:

- Structured mentorship programs – Facilitate knowledge transfer from retiring engineers to new hires.
- Peer reviews – This includes settings review, model accuracy, and the process of performing coordination studies. Peer reviews should be performed by individuals with qualified backgrounds to optimize results.
- Automated validation tools – Implement software tools to verify protection settings and coordination.
- Post-event diagnostic protocols – Require comprehensive inspections before re-energizing equipment.
- Ongoing PRC standards training – Train new employees on revised standards to ensure latest policies are being practiced.
- Technical training – Perform continued training for the adoption and integration of new technologies related to protection systems (i.e., inverter-based resources, new relay technologies, digital substations, etc.).
- Lessons learned – Incorporate lessons learned into setting criteria, designs, and training.

While the urgency to maintain grid reliability and economic performance is understandable, it must be balanced with thorough diagnostics and robust engineering practices. Addressing workforce challenges and leveraging regulatory improvements are key to reducing Misoperations and enhancing the resilience of the BPS.