NERC
NORTH AMERICAN ELECTRIC RELIABILITY CORPORATION

Analysis of System Protection Misoperations

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RELIABILITY | ACCOUNTABILITY




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Preface

The North American Electric Reliability Corporation (NERC) is a not-for-profit international regulatory authority whose mission is to ensure the reliability of the bulk power system (BPS) in North America. NERC develops and enforces Reliability Standards; annually assesses seasonal and long-term reliability; monitors the BPS through system awareness; and educates, trains, and certifies industry personnel. NERC's area of responsibility spans the continental United States, Canada, and the northern portion of Baja California, Mexico. NERC is the electric reliability organization (ERO) for North America, subject to oversight by the Federal Energy Regulatory Commission (FERC) and governmental authorities in Canada. NERC's jurisdiction includes users, owners, and operators of the BPS, which serves more than 334 million people.

The North American BPS is divided into several assessment areas within the eight Regional Entity (RE) boundaries, as shown in the map and corresponding table below.

FRCC	Florida Reliability Coordinating Council
MRO	Midwest Reliability Organization
NPCC	Northeast Power Coordinating Council
RF	ReliabilityFirst
SERC	SERC Reliability Corporation
SPP RE	Southwest Power Pool Regional Entity
Texas RE	Texas Reliability Entity
WECC	Western Electricity Coordinating Council

Executive Summary

The *State of Reliability 2015* report found that protection system misoperations continued to be a significant contributor to automatic transmission outage severity.[1] In general, transmission system events with protection system misoperations were more impactful than other transmission events. They were also a significant contributor to transmission outage severity, indicating that a reduction in protection system misoperations would lead to an improvement in system reliability.

This report focuses on analysis of the top three protection system misoperation cause codes reported to the Regions and NERC in accordance with Reliability Standard PRC-004-2.1a to identify regional trends and provide guidance to protection system owners that experience a high number of misoperations. Across NERC, incorrect setting/logic/design errors accounted for 31% of all misoperations, followed by relay failures/malfunctions at 19%, and then communication failures at 13%. Microprocessor relays with incorrect setting/logic/design errors accounted for more than 20% of all misoperations in 2013 and 2014. This further supports the idea that setting/logic/design controls for microprocessor relays should be focused on.

Regional analysis indicates that from 2013 to 2014, SPP RE showed a statistically significant decrease in the misoperation rate (misoperations as a percentage of total operations) from 14.2% to 10.9% as did NPCC from 8.2% to 6.8%. RF showed a statistically significant increase in the misoperation rate from 11.4% to 13.5%. The misoperation rate could not be calculated for WECC since that Region did not report total operations for those years.

Specific NERC, RE, and industry actions are identified in this report to help achieve NERC's goal to reduce the rate of misoperations due to these causes by 25% by the end of 2017.

[1] http://www.nerc.com/pa/RAPA/PA/Performance%20Analysis%20DL/2015%20State%20of%20Reliability.pdf.

Introduction

The *State of Reliability 2015*[2] report noted a linkage between reported misoperations and transmission-related events and that a misoperation outage cause code is positively correlated with transmission severity[3] when outages do occur. The following are additional findings from analyses of misoperations:

- The top three cause codes assigned to misoperations since the first full year of data collection in 2012 are 1) incorrect setting/logic/design errors; 2) relay failures/malfunctions; and 3) communication failures.
- The total rate of misoperations across all Regions (excluding WECC), as a percentage of total operations during 2013 and 2014, was approximately 10%.
- The three most common causes of misoperations remain the same as last year. Over 60% of misoperations are caused by incorrect setting/logic/design errors, communication failures, and relay failures/malfunctions.

Three datasets are available to better understand the impact of misoperations on reliability. One dataset is comprised of the event reports that are submitted to the Regions and NERC through the event analysis program document[4] that was established by the Events Analysis Subcommittee (EAS). When misoperations are associated with reported system disturbances, NERC can then assess their actual impact on the BES and identify whether they were causal or contributory to the event through cause coding.

In 2014, there were 54 transmission-related system disturbances that resulted in a qualified event. Of those 54 events, 47 (about 87%) had associated misoperations. Of the 47 events, 37 of them (79%) experienced misoperations that were contributory to or exacerbated the severity of the event. In several cases, multiple misoperations occurred during a single disturbance.

In 2013, there were 71 transmission-related system disturbances that resulted in a qualified event reported via the NERC event analysis process. Of those 71 events, 47 (about 66%) had associated misoperations. Of these 47 events, 38 (about 81%) experienced misoperations that were contributory to or exacerbated the severity of the event. In several cases, multiple misoperations occurred during a single disturbance.

A second source of misoperations reporting occurs through TADS data collection. Misoperations that were identified as being caused by human error or relay failure are identified in TADS reporting. This occurs for transmission facilities operated at 200 kV and above.

A third source of misoperations reporting is via a database of all misoperations that occur on the BES (100 kV and above) that is collected on a quarterly basis by the Regions and NERC through compliance with Reliability Standard PRC-004-2.1a. This database provides a comprehensive set of data for all transmission and generation misoperations. It is submitted by the system protection owners and includes detailed information about the misoperation, including a description of the misoperation, its category, its causes, and the proposed corrective action and completion date.

This report focuses on analysis of the database of all protection system misoperations that occur on the BES (100 kV and above) that is collected on a quarterly basis by the Regions and NERC through compliance with Reliability

[2] http://www.nerc.com/pa/RAPA/PA/Performance Analysis DL/2014_SOR_Final.pdf.

[3] The severity of a transmission outage is calculated based on its assumed contribution of power flow through transmission circuits. A description of the calculation is provided in Appendix A of the *State of Reliability 2015* report.

[4] http://www.nerc.com/pa/rrm/ea/EA Program Document Library/Final_ERO_EA_Process_V2.pdf.

Standard PRC-004-2.1a. Specifically, analysis was performed on the top three cause codes to identify regional trends and provide guidance to protection system owners that experience a high number of misoperations with the desired outcome of lowering the overall rate of misoperations throughout North America.

This report documents the analysis that NERC staff performed on protection system misoperations and provides recommended actions that NERC and industry can take to reduce protection system misoperations and their impact on reliability.

Chapter 1 – Misoperation Data Analysis

Misoperation Data Reported

Figure 1 shows the misoperation rate by Region as reported in compliance with Reliability Standard PRC-004-2.1a. The misoperation rate reflects the ratio of misoperations to total operations for the entire BES, 100 kV and above. This ratio provides a stable way to trend the rate of misoperations, as opposed to a count of misoperations that can be influenced by weather and other factors. Total protection system operations was first requested with the fourth quarter 2012 misoperation data. Having the total number of operations for the reporting periods in 2013 allows for a consistent way to normalize and trend protection system misoperations over time. Information for WECC is not provided because WECC does not report the total number of operations.

Testing the hypotheses on the population proportion revealed three statistically significant changes in the misoperation rate between 2013 and 2014: an increase for the RF misoperation rate and a decrease for the SPP RE and NCPP misoperation rates.

The decrease of misoperations in SPP RE may be partially due to SPP RE's outreach efforts to increase the reporting of successful protection system operations. SPP RE established a goal of a 92% successful operations rate and has made this goal part of the SPP RE staff's performance matrix. SPP RE has presented its misoperation analysis, findings, and conclusions in workshops, SPP RE Trustee meetings, and the monthly newsletter. SPP RE participates in the System Protection and Control Working Group (SPCWG), which completed a white paper on its analysis of RE relay misoperations caused by communication failures, the primary root cause of misoperations in SPP RE. The SPCWG is working on an additional white paper on misoperations[5] caused by incorrect setting/logic/design errors, which is the second-highest root cause of SPP RE misoperations.

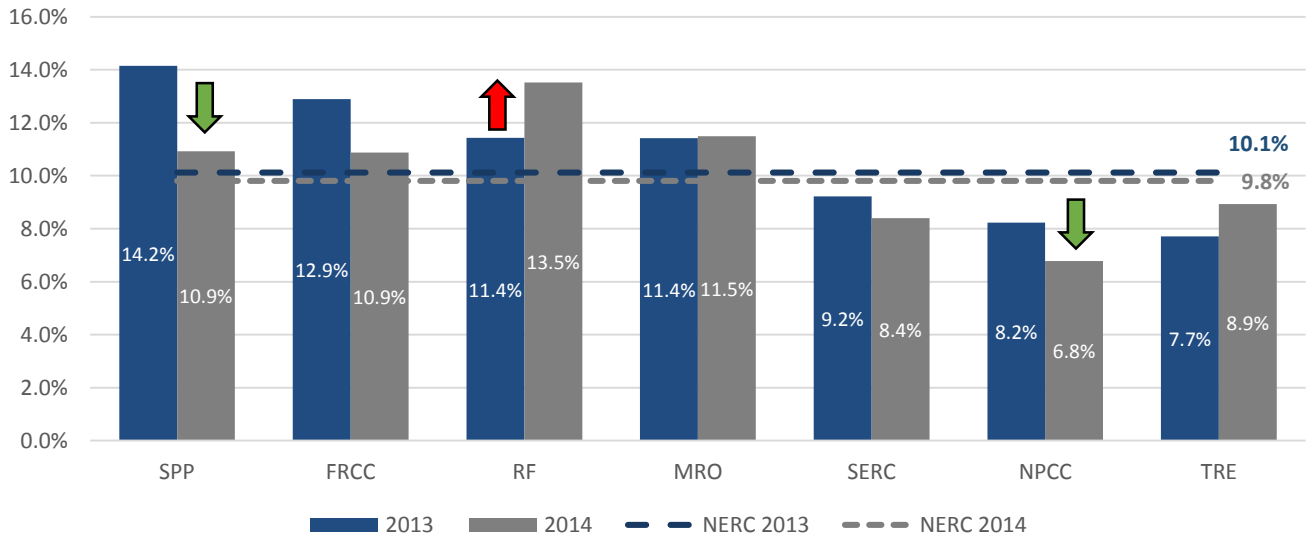

Figure 1: Year-over-year changes in misoperation rate by Region and NERC (2013 versus 2014)

[5] http://www.spp.org/section.asp?group=129&pageID=27

Figure 2 shows misoperations by month from January 1, 2012, to March 31, 2015. Overall, the trend is periodic, with peaks in the spring and summer months of all three years.

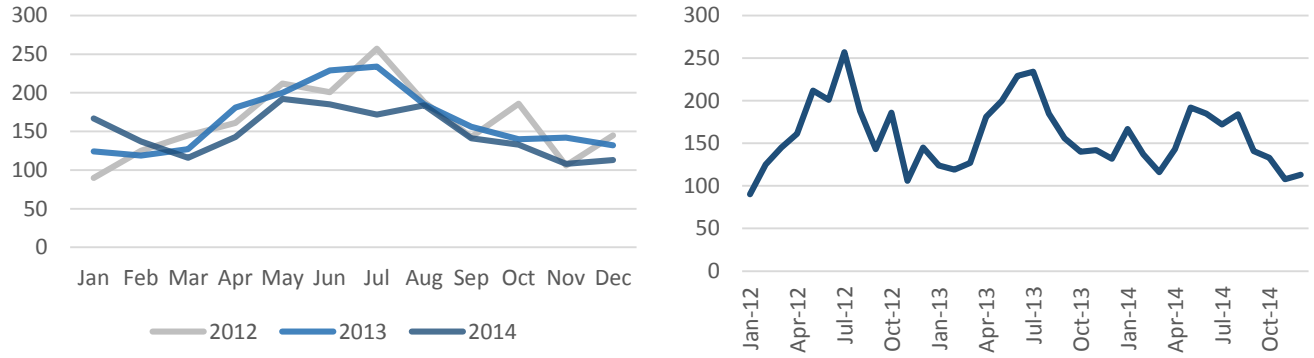

Figure 2: Misoperations by month (2012-2014)

Figure 3 illustrates the top-three misoperations cause codes assigned by the Transmission Owners (TOs): incorrect setting/logic/design errors; relay failures/malfunctions; and communication failures. These three causes have consistently accounted for over 60% of all misoperations from 2012 to 2014.

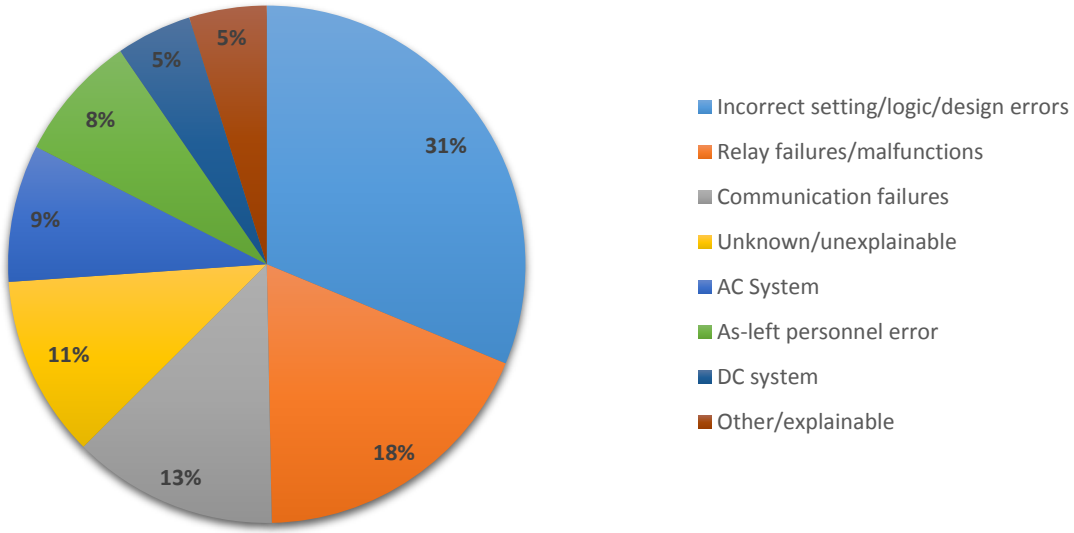

Figure 3: Misoperations by cause code from 2013-2014

Table 1: Misoperation Cause(s) by Year

Cause Codes	2012	2013	2014	Grand Total
Incorrect setting/logic/design errors	32%	31%	32%	31%
Relay failures/malfunctions	20%	18%	19%	19%
Communication failures	13%	14%	12%	13%
Unknown/unexplainable	11%	13%	10%	11%
AC System	9%	7%	10%	9%
As-left personnel error	8%	8%	8%	8%
DC system	6%	5%	5%	5%
Other/explainable	2%	5%	4%	4%

Misoperation Data Reported by Relay Technology

The misoperation data for 2013 and 2014 was analyzed by the type of protection system relay technology used: electromechanical, microprocessor, and solid state. Figure 4 shows that microprocessor relays with incorrect setting/logic/design errors accounted for over 20% of all misoperations in 2013 and 2014 combined.

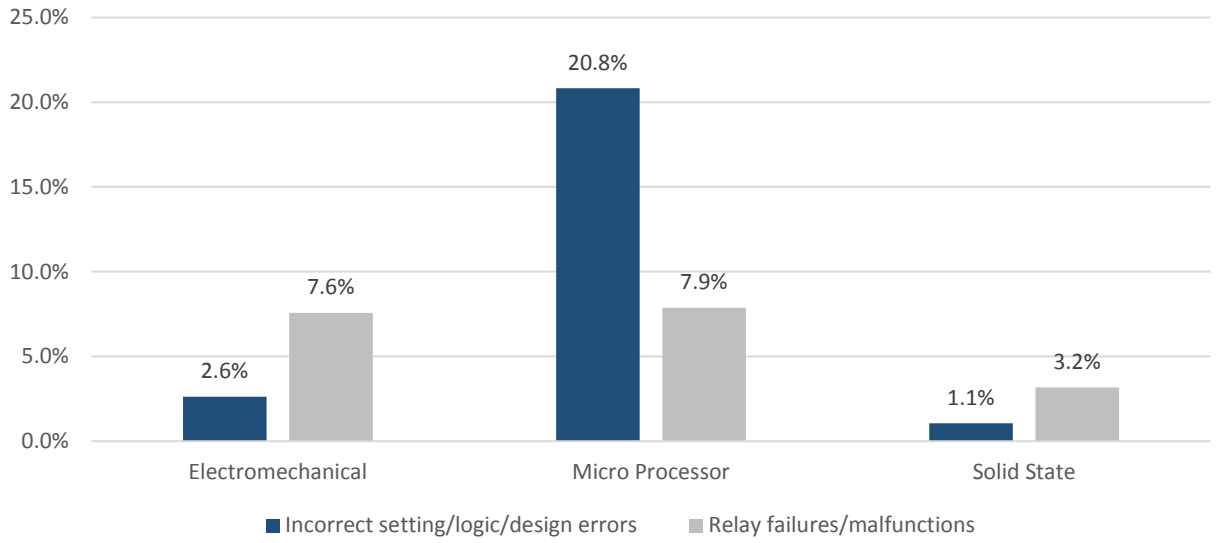

Figure 4: Total misoperations by relay technology 2013-2014

Statistical analysis was performed on the changes from 2013 to 2014 for the three largest cause codes of communication failures, relay failures/malfunctions, and incorrect setting/logic/design errors. While there were slight changes in all three, only the change in communication failures from 1.6% to 1.3% proved statistically significant. This is noted by the green arrow.

For the seven Regions combined, NERC had a statistically significant decrease in the misoperation rate for misoperations caused by communication failures and nonsignificant increases in the misoperation rate for the other two causes in the top three as shown in Figure 5. For the top three causes combined, the misoperation rate was unchanged (5.9% in 2013 and 2014).

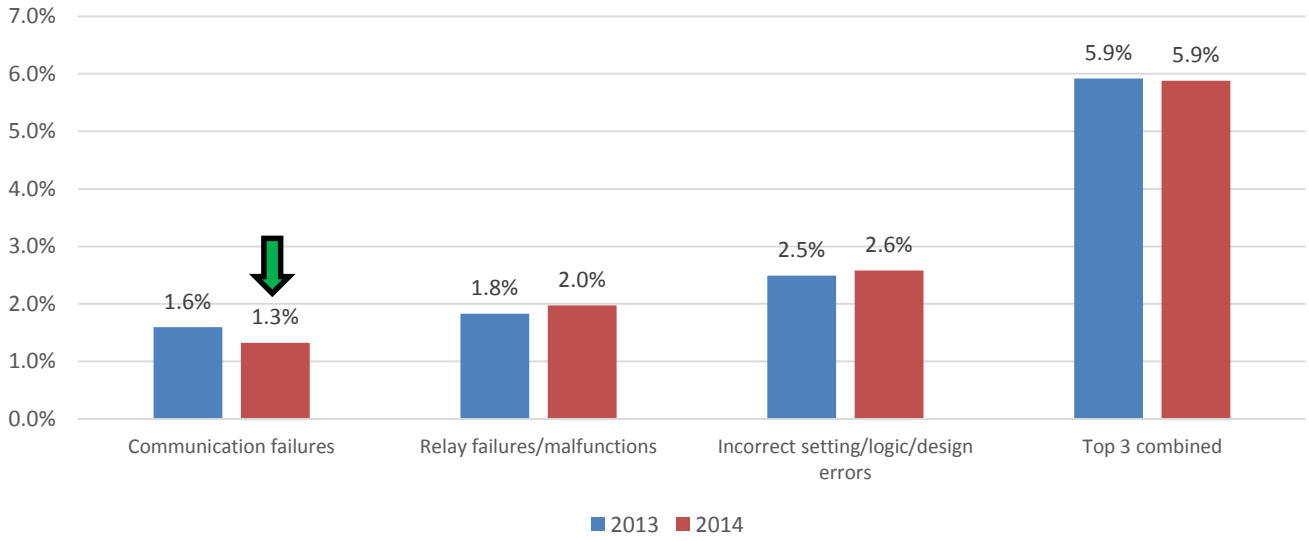

Figure 5: Misoperations rate by top three causes 2013-2014

Figure 6 shows the percentages of the total number of misoperations for the three largest categories of misoperation cause codes by voltage class. Misoperations due to incorrect setting/logic/design errors occurred more often at the 115kV, 138kV, and 230kV levels, with communication failures occurring more often at the 138kV voltage level. The data is not normalized.

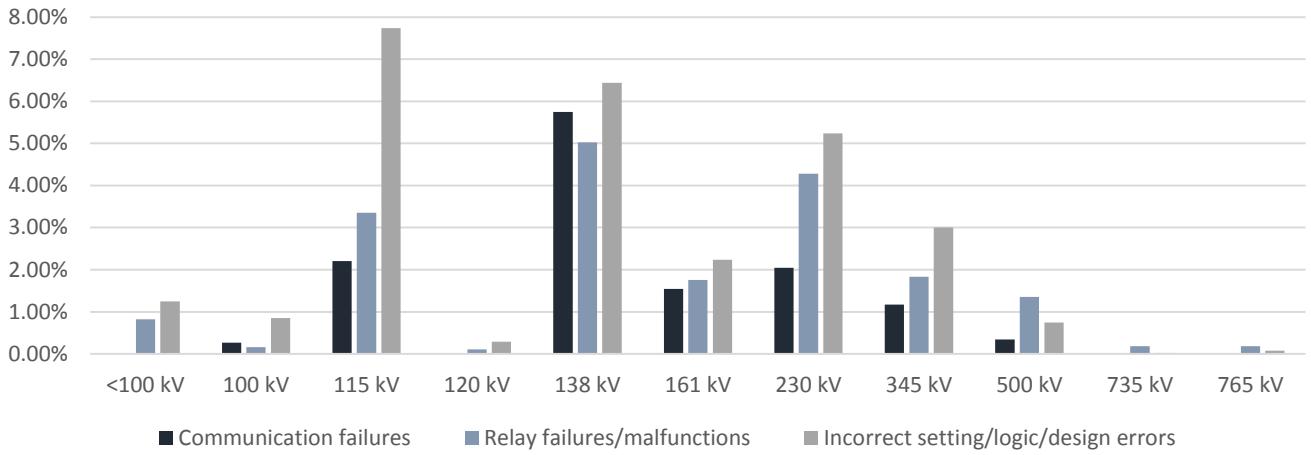

Figure 6: 2013-2014 misoperations by voltage class

Chapter 2 – Misoperations Data by Regional Entity

The reported misoperation data aggregated by the REs is provided in Figure 7. As before, the analysis is focused on the three largest misoperation cause codes (communication failures, relay failures/malfunctions, and incorrect setting/logic/design errors). Misoperations are presented as a percent of total operations in each Region. Misoperations caused by incorrect setting/logic/design errors were the largest contributor to the misoperation rate in five of the seven Regions. Information for WECC is not provided in this graph because WECC does not report the total number of operations. This further supports the idea that setting/logic/design controls for microprocessor relays should be focused on.

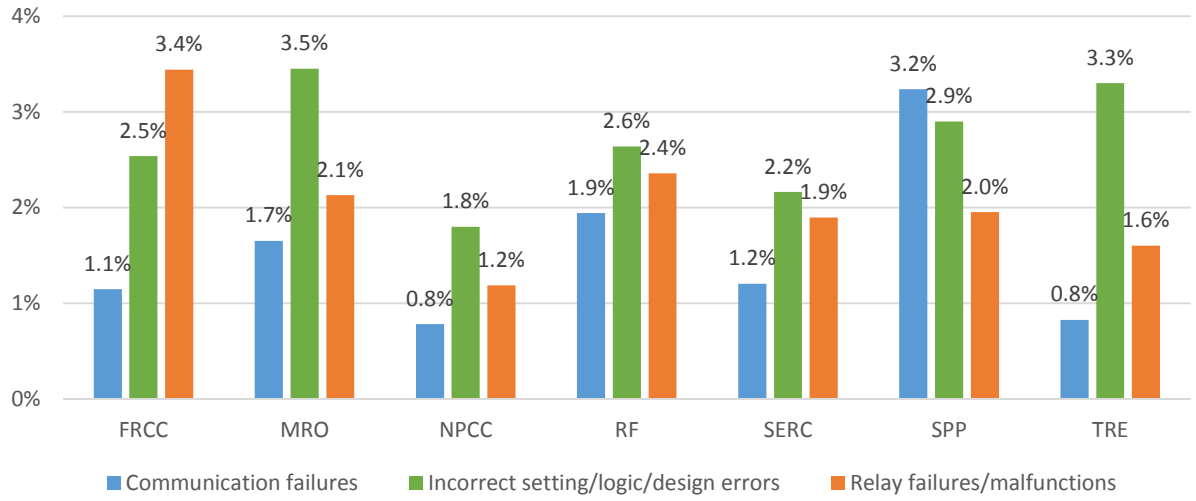

Figure 7: Misoperations rate by Regional Entity

The following sections provide protection system misoperation analysis for each NERC Regional Entity. No individual reporting entity within any Region is identified in this report.

FRCC Misoperation Analysis

FRCC had a statistically significant decrease in its misoperation rate for misoperations caused by communication failures and a nonsignificant increase in its misoperation rate for the other two causes. For the top three causes combined, FRCC had a decrease in its misoperation rate from 7.6% in 2013 to 6.7% in 2014, which was not statistically significant.

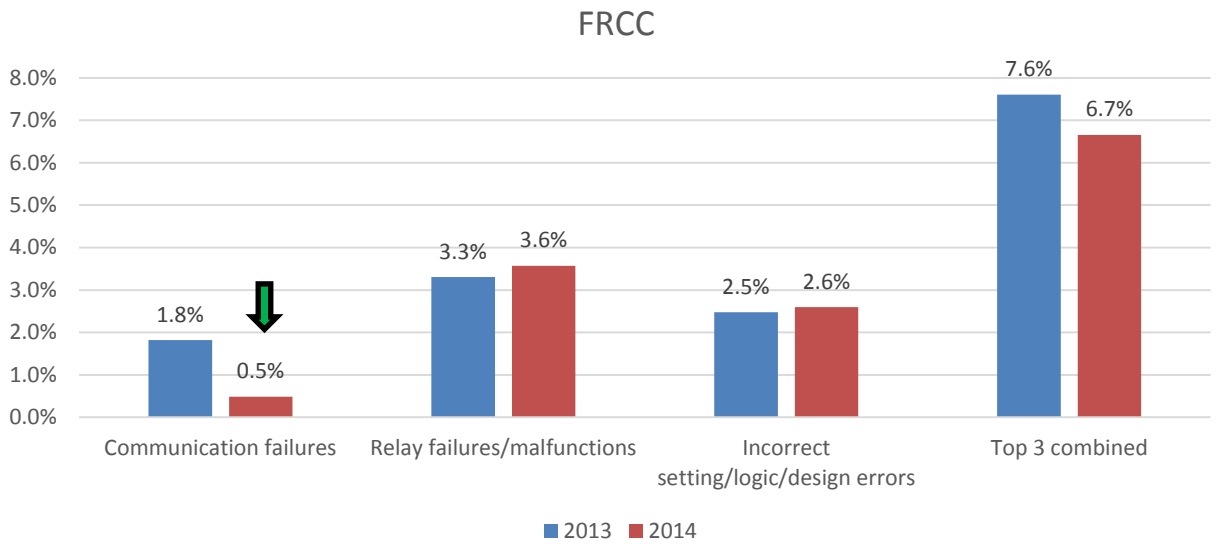

Figure 8: FRCC misoperations rate

MRO Misoperation Analysis

MRO did not have a statistically significant change in its misoperation rate for any of the top three causes. For the top three causes combined, MRO had a decrease in its misoperation rate from 7.6% in 2013 to 6.8% in 2014, which was not statistically significant.

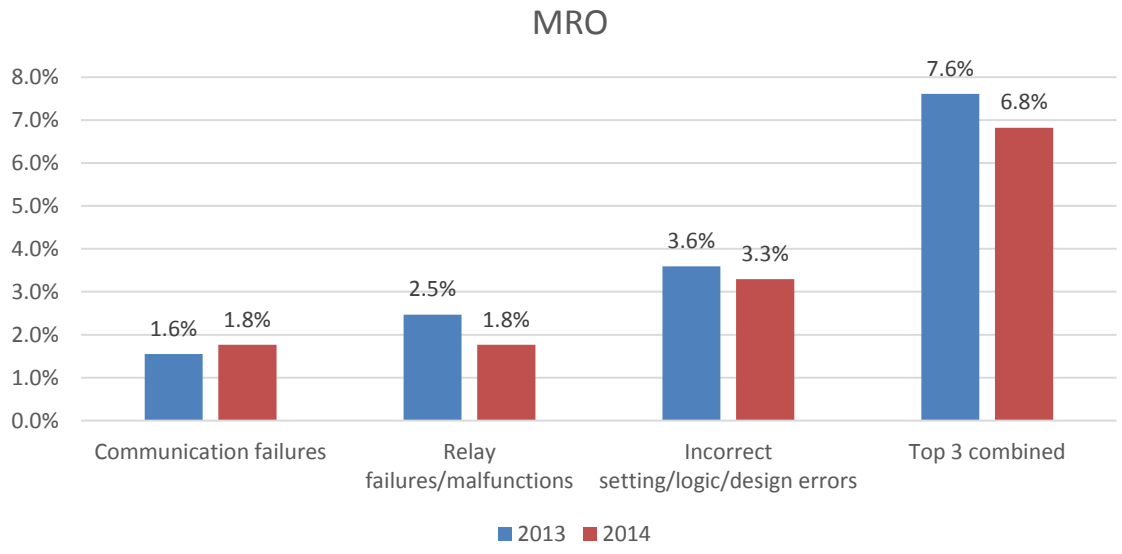

Figure 9: MRO misoperations rate

NPCC Misoperation Analysis

NPCC had a statistically significant increase in its misoperation rate from 0.9% to 1.6% for misoperations caused by relay failures/malfunctions and a nonsignificant decrease in misoperation cause for the other two causes in the top three. For the top three causes combined, NPCC had an increase in its misoperation rate from 3.7% in 2013 to 3.9% in 2014, which was not statistically significant.

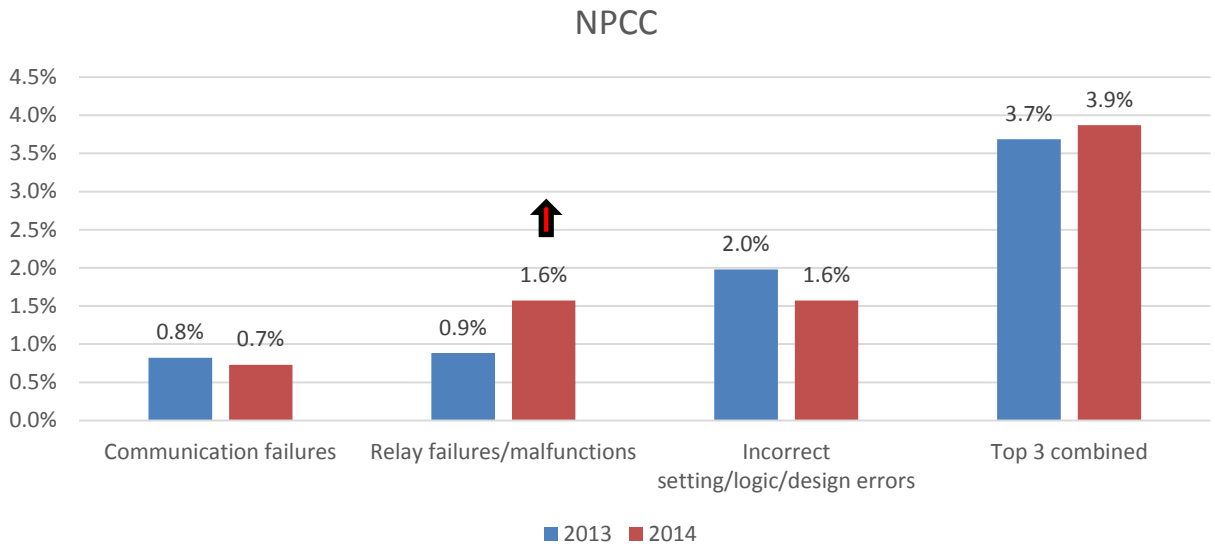

Figure 10: NPCC misoperations rate

NPCC has developed a set of sub-cause codes for the top two cause codes assigned to misoperations, incorrect setting/logic/design errors and relay failures/malfunctions. These sub-cause codes will allow for better analysis of the microprocessor relay misoperation data and help to tackle the large percentage of microprocessor relay misoperations, as shown in Figure 4 of the report. NPCC has also provided a regional perspective on NERC lessons learned on protection system misoperations and developed its own lessons learned from review of regional misoperations, which are then fed into further refinement of the NPCC protection design criteria.

NPCC requires a comprehensive set of protection design criteria (NPCC Directory No. 4) be applied to facilities on which faults or disturbances can have significant adverse impact such as:

- Instability
- Unacceptable system dynamic response, an oscillatory response to a contingency that is not demonstrated to be clearly positively damped within 30 seconds of the initiating event
- Unacceptable equipment tripping
- Voltage levels in violation of applicable emergency limits
- Loadings on transmission facilities in violation of applicable emergency limits

The NPCC protection design criteria ensure that no single point of failure can disable the composite protection system for these facilities. New or modified protection designs for these facilities are also reviewed by the NPCC Task Force on System Protection for conformity with the criteria, which include commissioning testing, before they are placed in service.

RF Misoperation Analysis

RF did not have a statistically significant change in its misoperation rate for any of the top three cause codes. For the top three causes combined, RF had an increase in its misoperation rate from 6.6% in 2013 to 7.3% in 2014, which was not statistically significant.

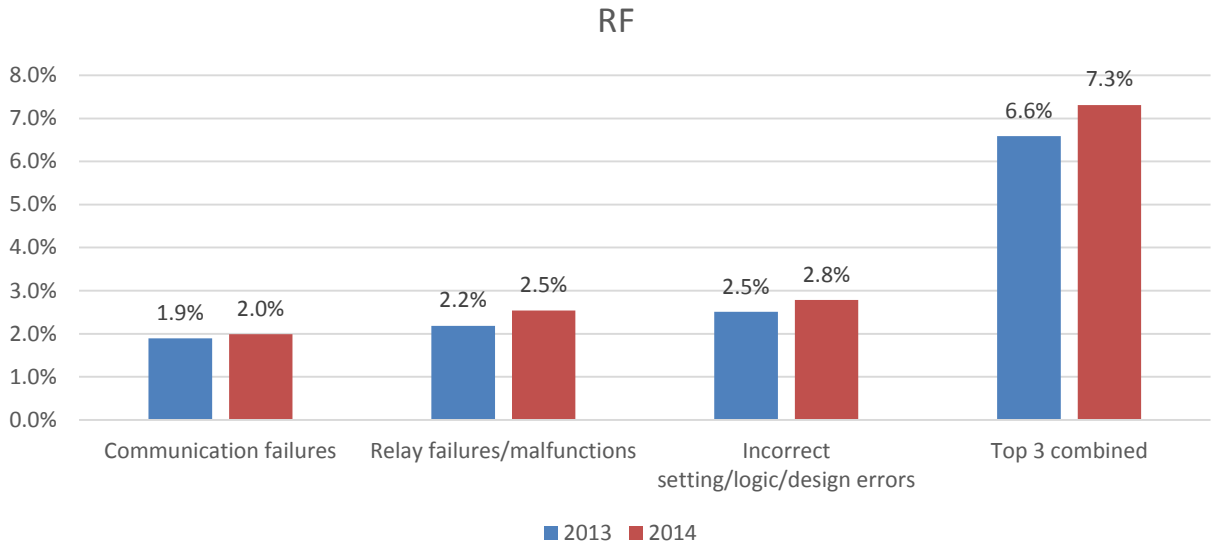

Figure 11: RF misoperations rate

In order to mitigate future protection system misoperations for these three top causes, RF conducted some outreach efforts to registered entities in 2015, which included providing some education regarding technical aspects of misoperations. RF conducted a training session for communication technicians, field personnel, and relay engineers, and the technical topics included power line carrier equipment and issues, protection work kits, and human performance aspects. RF also had a vendor provide training on polarization for microprocessor relays to its Protection Subcommittee. In addition, RF also conducted an internal controls evaluation (ICE) on one entity related only to misoperations.

In 2016, RF plans to conduct a short-circuit value comparison between TOs to verify the calculation of fault values in short-circuit models and to implement a peer review process for misoperation data. RF also plans to incorporate field personnel into its Protection Subcommittee membership. All of these efforts are intended to aid entities in their efforts to reduce protection system misoperations.

SERC Misoperation Analysis

SERC did not have a statistically significant change in its misoperation rate for any of the top three cause codes. For the top three causes combined, SERC had a decrease in its misoperation rate from 5.3% in 2013 to 5.2% in 2014, which was not statistically significant.

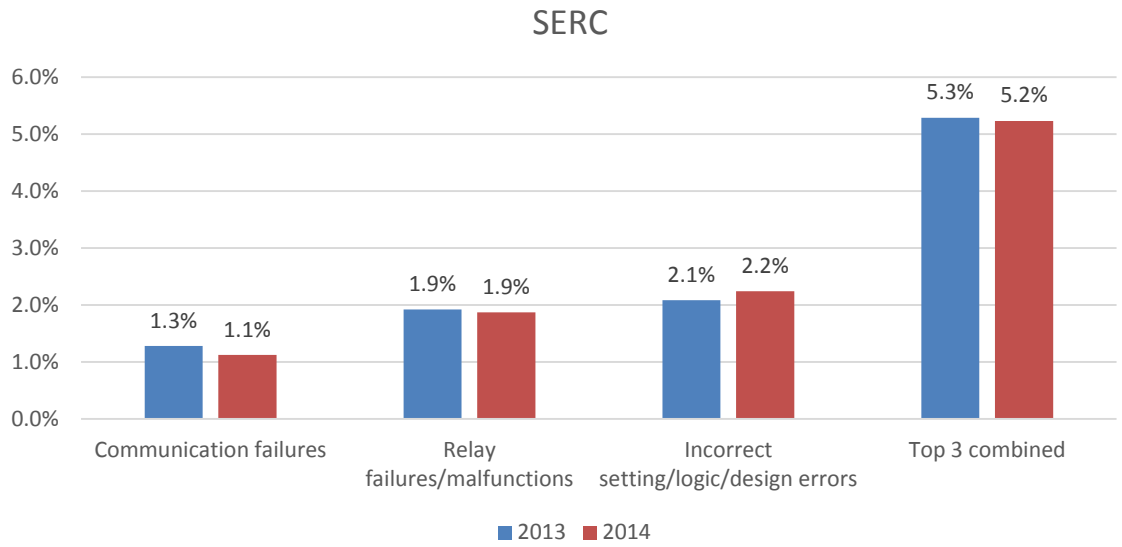

Figure 12: SERC misoperations rate

SPP RE Misoperation Analysis

SPP RE had a statistically significant decrease, as noted by the green arrow, in its misoperation rate for misoperations caused by communication failures from 3.9% to 2.4% and nonsignificant changes in its misoperation rate for the other two causes. For the top three causes combined, SPP RE had a decrease in its misoperation rate from 8.7% in 2013 to 7.4% in 2014, which was not statistically significant.

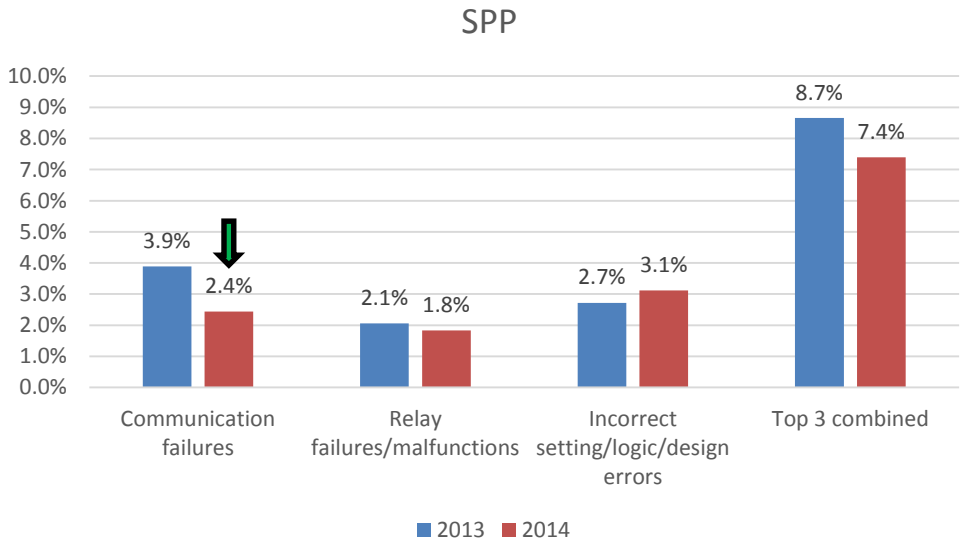

Figure 13: SPP RE misoperations rate

Texas RE Misoperation Analysis

Texas RE did not have a statistically significant change in its misoperation rate for any of the top three cause codes. For the top three causes combined, Texas RE had an increase in its misoperation rate from 5.7% in 2013 to 5.8% in 2014, which was not statistically significant.

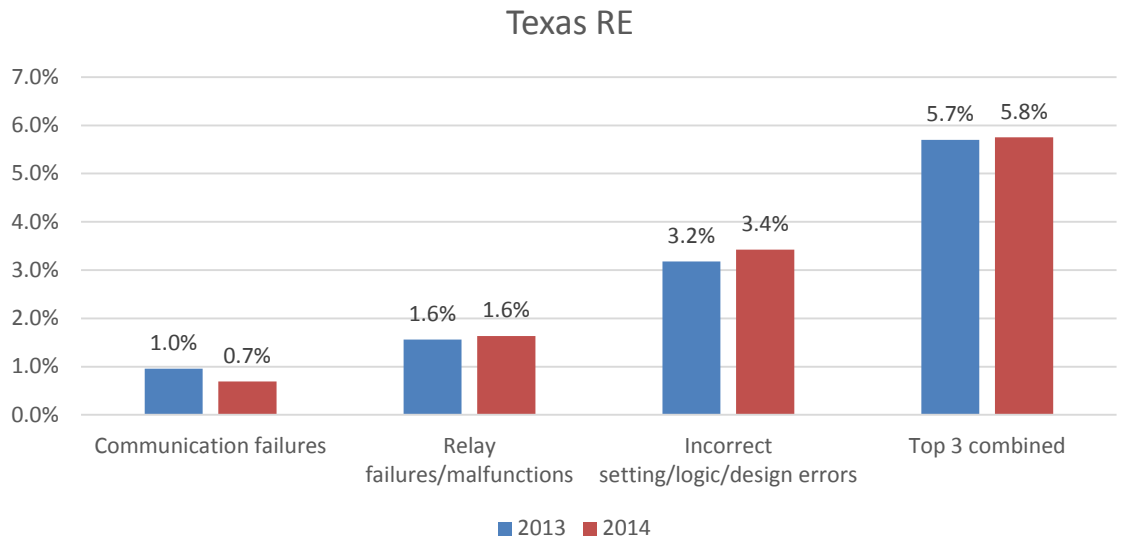

Figure 14: Texas RE misoperations rate

WECC Misoperation Analysis

The WECC Region does not collect total operation data, therefore its misoperation rate cannot be calculated. WECC reported a total of 306 and 321 misoperations for 2013 and 2014 respectively. WECC has assigned staff that are responsible for monitoring the misoperation submittals to ensure the information is accurate and detailed before submitting to NERC. WECC has a staff liaison for the Relay Work Group (RWG) who reviews all misoperations reports in closed session meetings to protect confidentiality of the information submitted by WECC entities. As part of their review, the RWG develops general observations from the data by class as well as document specific conclusions and recommendations. Additionally, the RWG has a small subgroup that reviews event reports associated with protection system operations, and from these reviews, they develop an annual report with conclusions and recommendations.

Chapter 3 – Recommended Actions

The *2014 State of Reliability* report noted that communication failures, relay failures/malfunctions, and incorrect setting/logic/design errors were the top three causes of relay misoperations. After evaluating the data, incorrect setting/logic/design errors is clearly a priority area for NERC to concentrate its efforts, followed by communication errors and relay failures on electromechanical relays. Below are specific suggestions and quantifiable efforts that address the specific areas to reduce relay misoperation failure rates. The goal is to reduce misoperations due to these three causes by 25% by yearend 2017. That would equate to reducing annual misoperations by approximately 325, reducing the overall misoperation rate from 10% to 8%.

Incorrect setting/logic/design errors

The NERC Protection System Misoperations Task Force issued a report in 2013[6] which identified that misoperations due to incorrect setting/logic/design errors can be reduced by: 1) peer reviews, 2) increased training, 3) more extensive fault studies, 4) standard templates for setting standard schemes using complex relays, and 5) periodic review of existing settings when system topography is changed.

Peer review consists of verifying that the relay settings meet the specifications of the relay and control application. When new relays are installed or major changes are made on existing relay schemes, a peer review by a person that has equal or greater experience should be performed to verify that the relay settings meet the specifications of the relay and control application. Increased training will also reduce the calculation and application errors that lead to relay misoperations. The IEEE Power System Relaying Subcommittee (IEEE PSRC) published a working-group report to provide additional technical guidance for quality control of protective relay settings.[7]

Events Analysis has discovered that incorrect ground instantaneous overcurrent settings on the 115-230kV systems are a leading cause of relay misoperations that lead to a NERC-qualified event. NERC is in the process of working with relay vendors and industry participants to create a white paper with some suggestions for both commissioning and testing to uncover limitations in current applications.

Communication failures

The design of a protection system involves balancing both dependability and security. Dependability relates to the degree that a relay or relay system will operate correctly, as in causing trips when desired. Security is the degree that a relay or relay system will not operate incorrectly, as in causing a false trip. Recent discussions with engineers from Schweitzer Engineering Laboratories (SEL) has revealed that the design of power line carriers that use directional comparison blocking has caused relays to trip at inappropriate times due to holes in the communication channel.[8]

Studies from SEL have shown that a directional comparison unblocking scheme provides better security, reducing misoperations. This analysis agrees with the work of the Protection System Misoperations Task Force.

Relay failures/malfunctions

There are known problems with drift in electromechanical relays, which can be effectively addressed by the following actions:

- Reduce maintenance intervals on electromechanical relays with known issues (e.g., KD relays).
- Replace these electromechanical relays with microprocessor-based relays.

[6] http://www.nerc.com/comm/PC/Protection System Misoperations Task Force PSMTF 2/PSMTF_Report.pdf.

[7] "Processes, Issues, Trends and Quality Control of Relay Settings," Working Group C3 of Power System Relaying Committee of IEEE Power Engineering Society, March 2007.

[8] Investigation and Analysis into the Misoperation due to Carrier Holes, John J. Meinardi, Florida Power & Light Co., and Miriam P. Sanders, PE – AMETEK Power Instruments, Copyright 2008.

Additionally, some microprocessor-based relays are nearing their projected end-of-life and are experiencing increased failures. Actively engaging manufactures in proposed solutions will be essential in the foreseeable future.

Overall activities

NERC is continuing activity on several projects to address protection system misoperations. The Reliability Issues Steering Committee (RISC) has identified system protection issues as one of the top-priority risks to reliability. NERC has focused its Reliability Standards efforts in this area with the completion of the relay loadability standards and the revised relay misoperation standard. NERC continues its efforts to develop a relay coordination standard. NERC Event Analysis continues to examine system events to identify those that are impacted by protection system misoperations to determine if action is needed to address trends and common modes of misoperations.

While the Protection System Misoperations Task Force spent considerable effort developing a report on their investigation, the results have not been actively communicated to industry. This vital information addresses many additional components of relay misoperations. In addition, NERC has historically published regional misoperations rates with no discussion of comparisons or solutions. Since the Regions have industry experts in committees that regularly discuss relay operations and can implement recommendations, NERC should engage those regional committees in developing potential actions to reduce misoperations.