# Analysis of NPCC Protection System Misoperations

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## Abstract

This paper summarizes the efforts coordinated at Northeast Power Coordinating Council (NPCC) to identify and reduce protection system misoperations within the NPCC Region. A comprehensive analysis of reported NPCC protection system misoperations within NPCC from 2013 through 2016 has been completed. The NPCC results were compared to other NERC Regions, using data available from the NERC Misoperation Information Data Analysis System (MIDAS).[1]

[1] This analysis by NPCC and the charts in this report can be slightly different from NERC because of the timeline that the data was gathered from the system.

## Introduction

A protection system reliability program to investigate the root cause of misoperations, implement corrective action plans, systematically code the causes of misoperations, and trend them can greatly benefit the protection system owner over time. The experience at NPCC indicated that such a program can effectively improve the overall protection system performance and therefore lower the risk of a potential outage to the power system.

This paper presents the analysis of misoperations reported by protection system owners in NPCC Region over a period of four years from 2013 through 2016. The analysis was also compared to and shared with two other Regions' reported misoperations.

## Definitions

<u>*Protection System*</u> [3]
• *Protective relays which respond to electrical quantities,*
• *Communications systems necessary for correct operation of protective functions,*
• *Voltage and current sensing devices providing inputs to protective relays,*
• *Station dc supply associated with protective functions (including station batteries, battery chargers, and non-battery-based dc supply), and*
• *Control circuitry associated with protective functions through the trip coil(s) of the circuit breakers or other interrupting devices.*

<u>*Protection System – Element Basis*</u> [4]
*Element Basis One or more protection groups; including all equipment such as instrument transformers, station wiring, circuit breakers and associated trip/close modules, and communication facilities; installed at all terminals of a power system element to provide the complete protection of that element.*

<u>*Protection System - Terminal Basis*</u> [4] *One or more protection groups, as above, installed at one terminal of a power system element, typically a transmission line.*

<u>*Protection Group*</u> [4]
*A fully integrated assembly of protective relays and associated equipment that is designed to perform the specified protective functions for a power system element, independent of other groups. Notes: (a) Variously identified as Main Protection, Primary Protection, Breaker Failure Protection, Back-Up Protection, Alternate Protection, Secondary Protection, A Protection, B Protection, Group A, Group B, System 1 or System 2. (b) Pilot protection is considered to be one protection group.*

Protection System Operation [2]

*1. The correct operation of protection systems associated with isolating a faulted system element.*

*2. The correct operation of protection systems associated with isolating equipment for non-fault conditions such as power swings, over excitation, or loss of field (excluding control functions performed by a protective relay; e.g., when a reverse power relay is used to trip a breaker during generator shutdown).*

*3. The unintended operation of protection systems for a fault outside the zone it is designed to protect.*

*4. The unintended operation of protection systems for a non-fault condition.*

*5. Any failure of a Protection System to operate for its intended function such as clearing a fault within the zone it is designed to protect.*

Protection System Misoperation [3]

*The failure of a Composite Protection System to operate as intended for protection purposes.*

Composite Protection System [3]

*The total complement of Protection System(s) that function collectively to protect an Element. Backup protection provided by a different Element's Protection System(s) is excluded.*

Element [3]

*Any electrical device with terminals that may be connected to other electrical devices such as a generator, transformer, circuit breaker, bus section, or transmission line. An Element may be comprised of one or more components.*

Misoperation Rate

*The number of Misoperations (incorrect protection system operations) divided by the number Protection System Operations (the total of correct and incorrect protection system operations) times 100%.*

## Misoperation Categories and Causes

This analysis was conduct based on the following four categories and eight causes of misoperation:

| **Misoperation Categories** [2] | |
|---|---|
| **Failure to Trip** | Any failure of a Protection System element to operate when a fault or abnormal condition occurs within a zone of protection. |
| **Slow Trip** | Any failure of a Protection System element that is slower than planned to operate when a fault or abnormal condition occurs within the zone of protection. |
| **Unnecessary Trip during fault** | Any unnecessary Protection System operation for a fault not within the zone of protection. An example of this type of Misoperation is an over-trip due to lack of coordination between Protection Systems. |
| **Unnecessary Trip other than fault** | Any unnecessary Protection System operation when no fault or other abnormal condition has occurred. |

| **Cause(s) of Misoperation** [2] | |
|---|---|
| **Incorrect setting/logic/design errors** | This category includes misoperations due to “engineering” errors by the protection system owner. These include setting errors, errors in documentation, and errors in application. Examples would include uncoordinated settings, incorrect schematics, or multiple CT grounds in the design. |
| **Relay failures/malfunctions** | This category includes misoperations due to improper operation of the relays themselves. These may be due to component failures, physical damage to a device, firmware problems, or manufacturer errors. Examples would include misoperations caused by changes in relay characteristic due to capacitor aging, misfiring thyristors, damage due to water from a leaking roof, relay power supply failure, or internal wiring/logic error. Failures of auxiliary tripping relays fall under this category. |
| **Unknown/unexplainable** | This category includes misoperations where no clear cause can be determined. Requires extensive documentation of investigative actions if this cause code is utilized. |
| **Communication failures** | This category includes misoperations due to failures in the communication systems associated with protection schemes inclusive of transmitters and receivers. Examples would include misoperations caused by loss of carrier, spurious transfer trips |

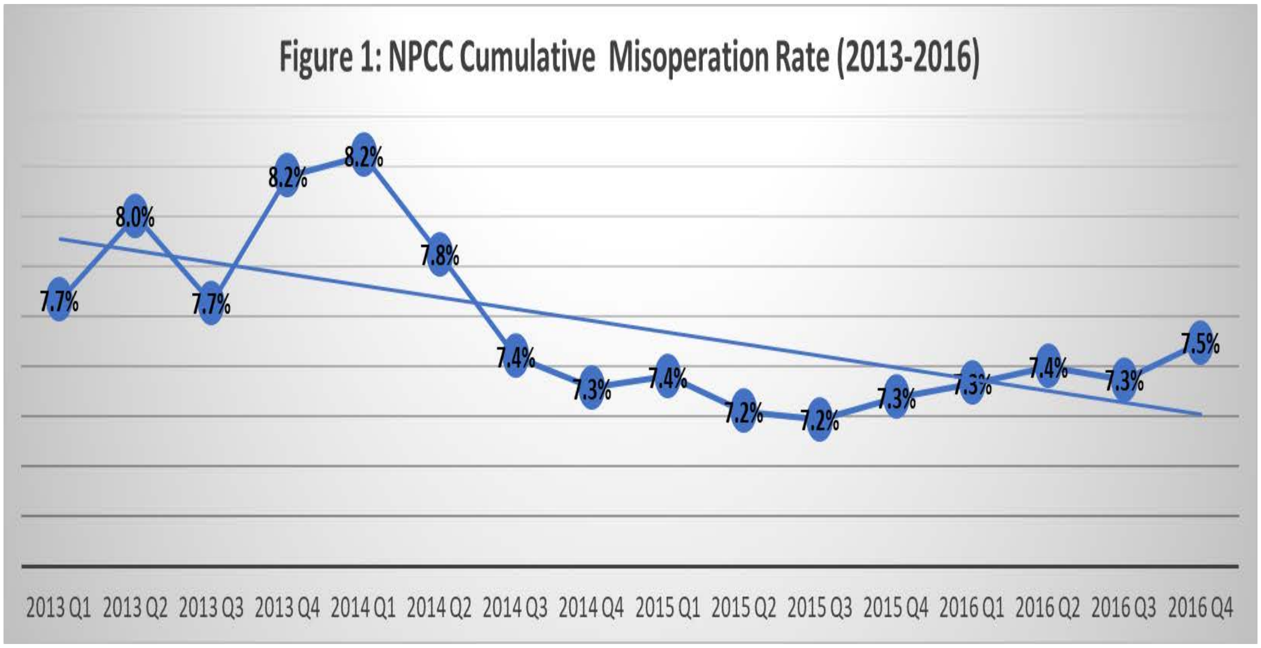
| | |
|---|---|
| | associated with noise, Telco errors resulting in malperformance of communications over leased lines, loss of fiber optic communication equipment, or microwave problems associated with weather conditions. |
| **DC system** | This category includes misoperations due to problems in the 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. |
| **AC system** | This category includes misoperations due to problems in the ac inputs to the protection system. Examples would include misoperations associated with CT saturation, loss of potential, or rodent damaged wiring in voltage or current circuit. |
| **Other/Explainable** | This category includes Misoperations that were determined to have an identified cause but they do not fit into any of the above categories. For example, temporary changes in network topology that because of their low probability of occurrence are not accounted for in the design of the Protection System. |
| **As-left personnel error** | This category includes misoperations due to the as-left condition of the protection system following maintenance or construction procedures. These include test switches left open, wiring errors not associated with incorrect drawings, carrier grounds left in place, or settings placed in the wrong relay, or incorrect field settings left in the relay that do not match engineering approved settings. |

## Analysis of NPCC Misoperations

In 2011, NPCC formed the Protection System Misoperation Review Working Group (SP-7) to review all reports of protection system misoperations. The review by SP-7 ensures that the root causes are appropriately categorized and coded. The Working Group also reviewed each corrective action plan to determine the reported issue(s) is/are addressed in the misoperation report.

It was not until 2013 when the number of protection system operations associated with the number of reported misoperations was available to calculate the Misoperation Rate.

Figure 1 showed NPCC cumulative Misoperation Rate on a quarterly basis from 2013 to 2016. The trend line indicated an average of 0.175% decrease in the Misoperation Rate each year from 2013 to 2016.




During this period, NPCC recorded 10,632 protection system operations, of which 797 were misoperations.

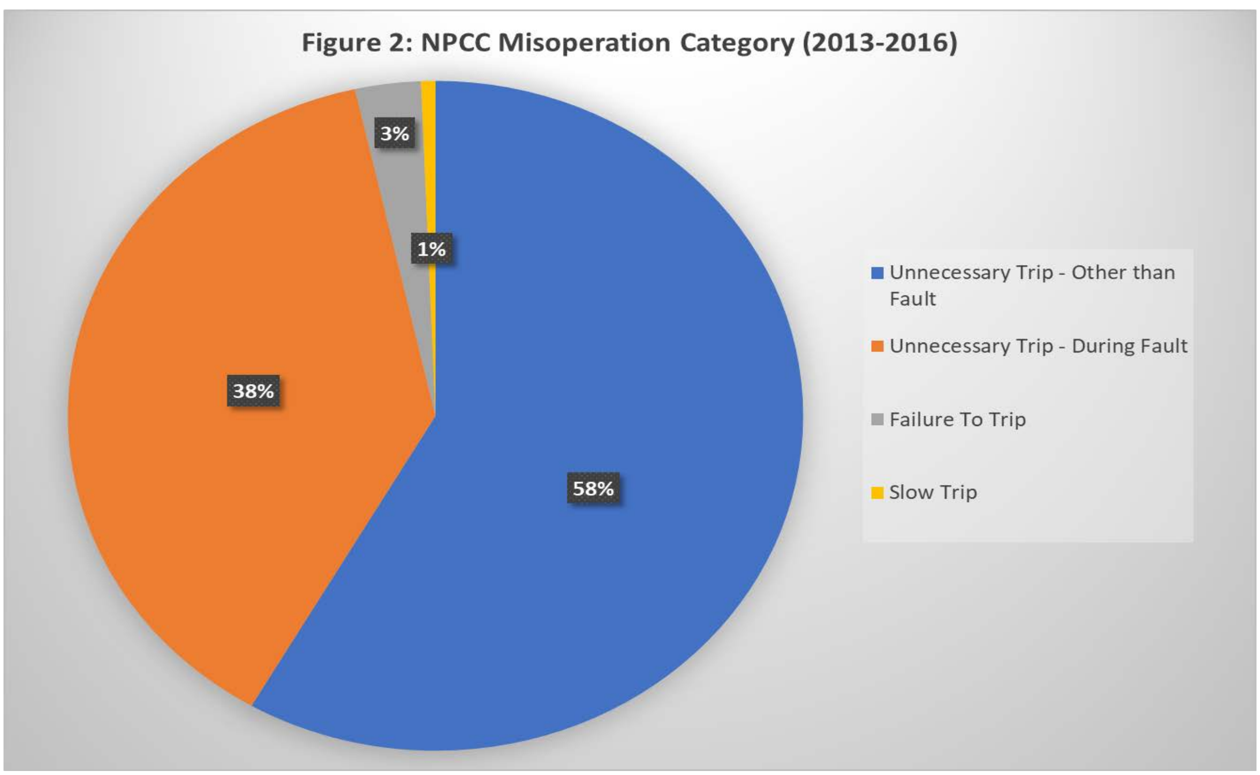
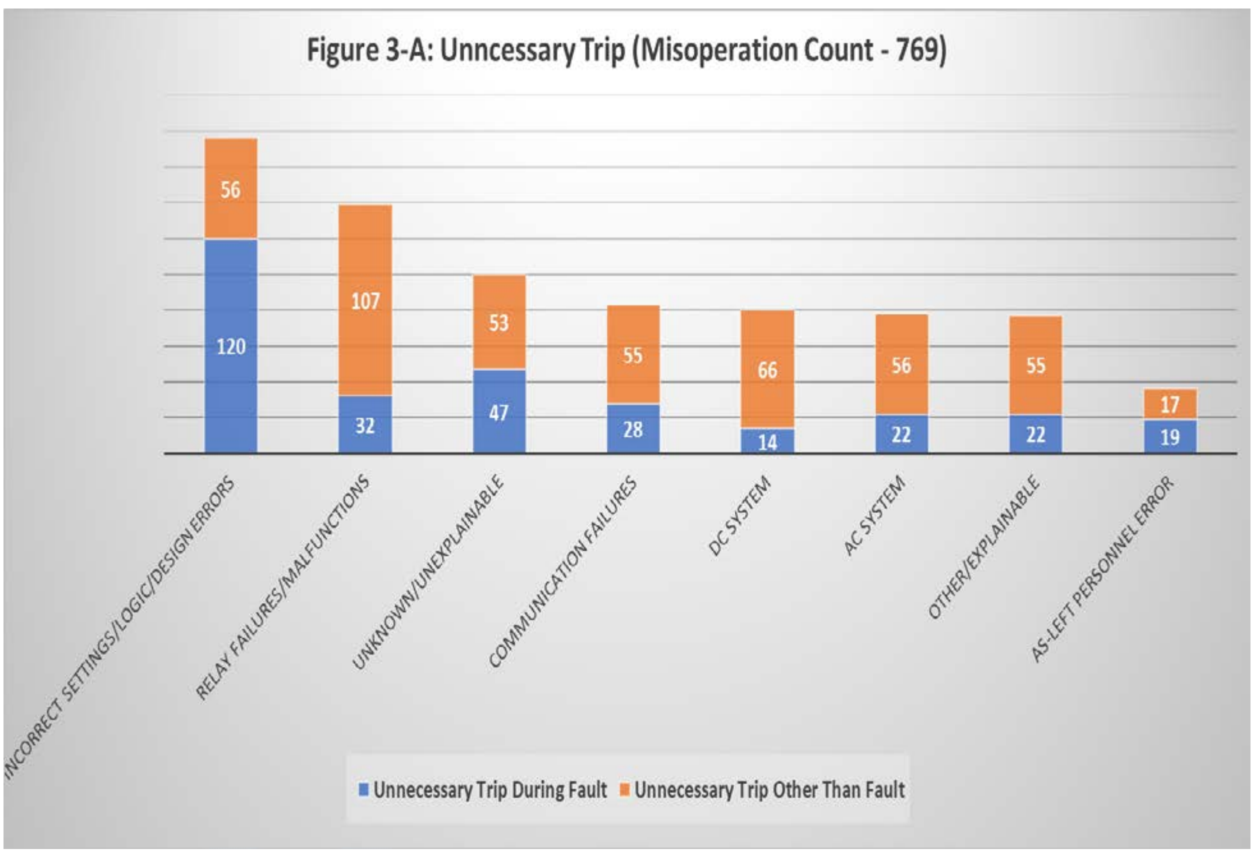


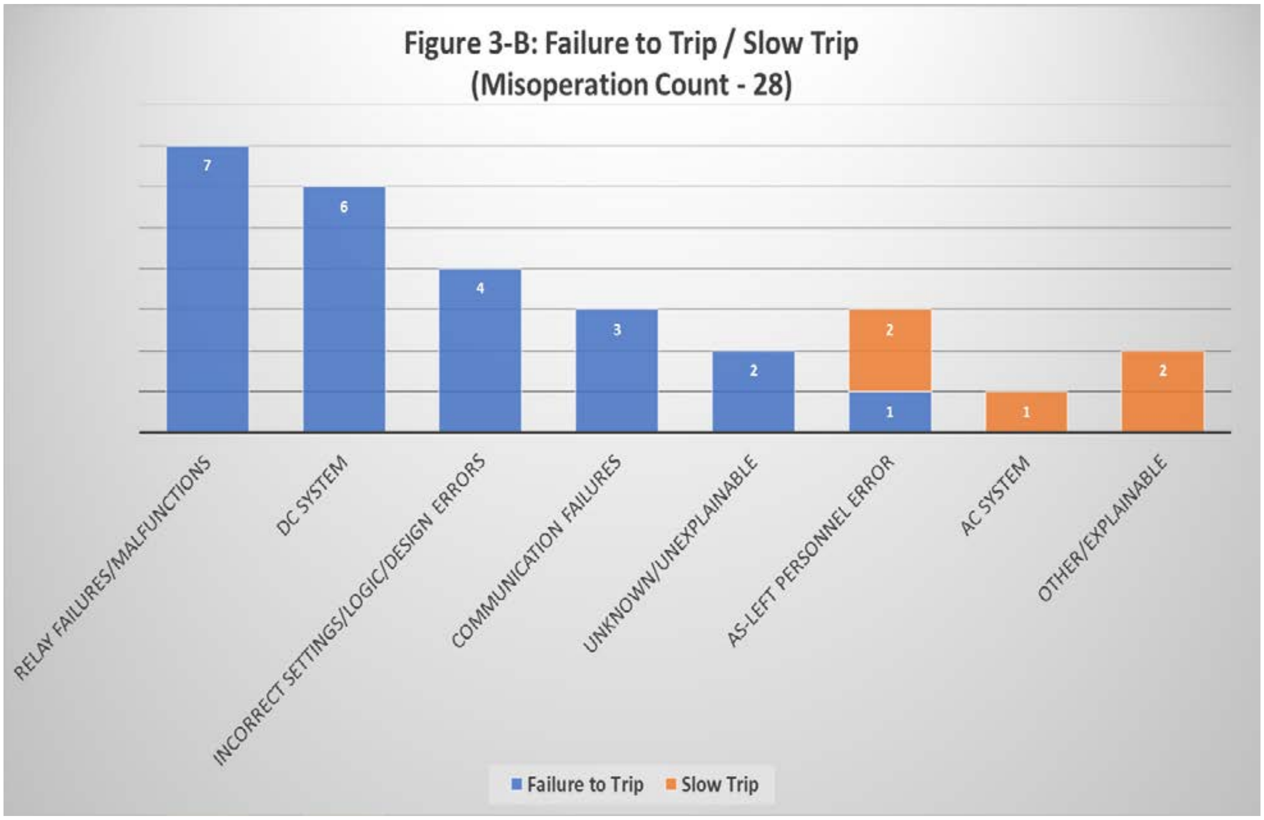
Figure 2 above showed the percentage associated with each of the four categories of misoperation. The causes associated with these categories of misoperation were plotted in the charts in Figure 3-A for Unnecessary Trip and Figure 3-B for Failure to Trip and Slow Trip. Unnecessary Trip accounted for 96% of all misoperations. As can be seen in Figure 3-A, the three highest causes for Unnecessary Trip were:

1. Incorrect settings/logic/design errors
2. Relay failures/malfunctions
3. Unknown/unexplainable

Failure to Trip and Slow Trip accounted for 4% of all misoperations with the following three highest causes shown in Figure 3-B:

1. Relay failures/malfunctions
2. DC System
3. Incorrect settings/logic/design errors






## Comparison of NPCC Misoperation Analysis to Two Other Regions

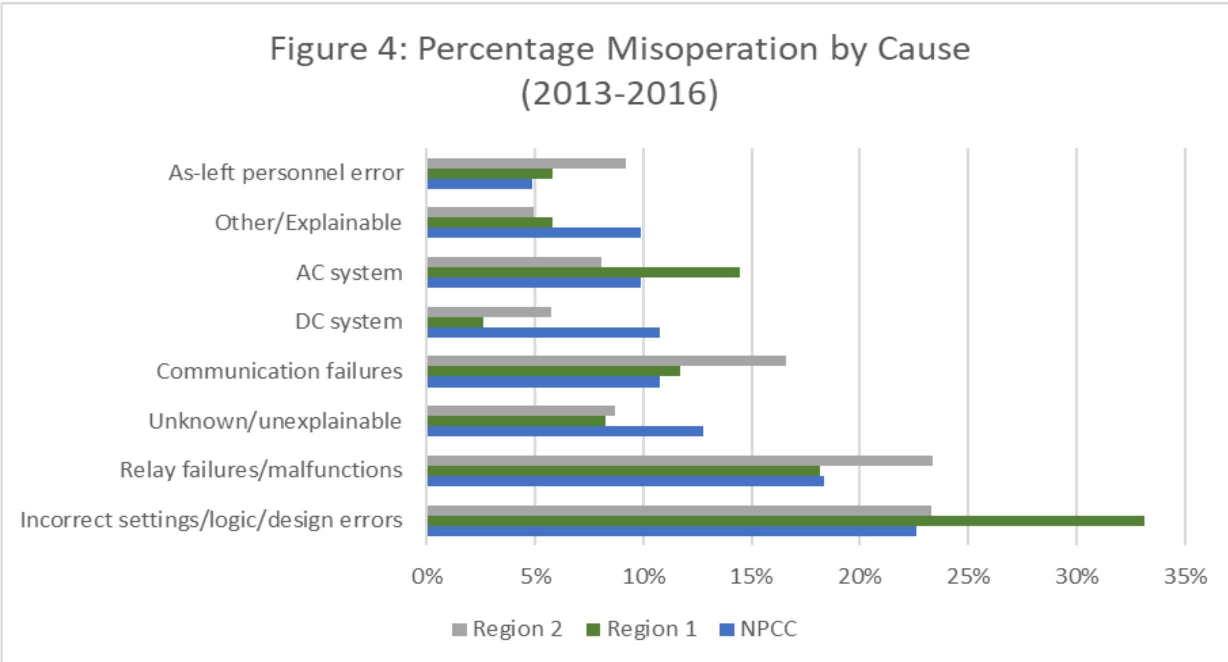
In 2017, NPCC performed a comparative analysis of its misoperations with two other Regions. Figure 4 compared the percentage of misoperation by causes among the three Regions. The highest two causes are Incorrect settings/logic/design errors and Relay failures/Malfunctions for all three Regions. Areas of improvement which have been identified for the top two causes include:

*For Incorrect Settings/Logic/Design Errors:*

1. *Provide training*
2. *Standardize process for relay settings*
3. *Establish peer review of relay settings*
4. *Improve coordination between neighboring utilities and at generator interconnections*
5. *Review setting with respect to polarization and mutual coupling*

*For Relay Failures/Malfunctions:*

1. *Put in place obsolete relay replacement program*
2. *Develop corrective action plans with relay vendors*




The third highest cause in Figure 4 was specific to each Region. NPCC experienced Unknown/Unexplainable as its third highest cause; Region 1 had AC System failures as its third highest cause; and Region 2 had Communication failures as its third highest cause. NPCC has initiated special effort to further review the Unknown/Unexplainable misoperation cause.

Reports on the top two causes included information on the relay technology. Based on this information, the flow chart below showed how the data in Table 1 was developed to compare the misoperations by relay technology associated with the category of Unnecessary Trip only.

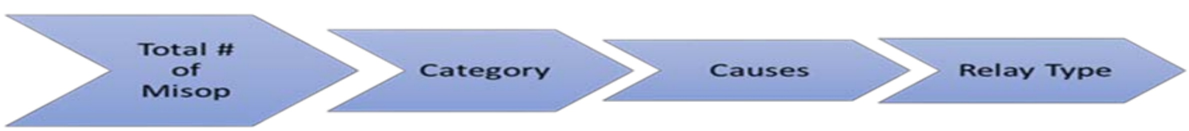



**Table 1: Comparative Analysis of Relay Technology**

| Region | Total # Misop | Category: Unnecessary Trip | Cause: Relay Failures & Setting/Logic/ Design Errors | Micro-processor | Electro-mechanical | Solid State |
|---|---|---|---|---|---|---|
| **NPCC** | 797 | 96.1% (766) | 40% (310) | 75% | 17% | 8% |
| **Region 1** | 616 | 94% (579) | 51% (295) | 73% | 12% | 16% |
| **Region 2** | 1407 | 93% (1308) | 48% (622) | 59% | 34% | 7% |

It is interesting to note from this comparative analysis that, if other factors were relatively the same, the differences in the percentages of misoperation among the three Regions for the microprocessor relays, electromechanical relays and solid-state relays may indicate NPCC has more microprocessor relays than Region 2 and more electromechanical relays than Region 1. In the effort to reduce misoperations, NPCC and its members also developed sub-cause codes below for Incorrect Setting/Logic/Design Errors and Relay Failures and collected additional information on microprocessor relay misoperations. Since 2016, NPCC SP-7 Working Group has engaged relay manufacturers to assist in addressing the issues found in microprocessor relays.

| **Incorrect Setting/Logic/Design Errors** | **Relay Failures/Malfunctions** |
|---|---|
| 1. Incorrect Numerical Value Specified<br>2. Incorrect User-Programmed Logic Specified<br>3. Incorrect System Coordination<br>4. Incorrect Physical Design<br>5. Failure to Update Firmware Version by User<br>6. (Communication) Programming/Logic Error<br>7. Continuous Reboot<br>8. Other | 1. Power Supply Failure/Malfunction<br>2. AC I/O Module Failure/Malfunction<br>3. Digital I/O Module Failure/Malfunction<br>4. Communication Module Failure/Malfunction<br>5. (Communication) Loss of Synchronism<br>6. Self-Diagnostic Failure/Malfunction<br>7. CPU Processor Failure/Malfunction<br>8. Continuous Reboot<br>9. Incorrect Manufacturer Programming ("Bug")<br>10. Incorrect Manufacturer Design<br>11. Incorrect Manufacturer Documentation<br>12. Unknown<br>13. Other |

Figure 5 below compared cumulative Misoperation Rate among the three Regions. NPCC Misoperation Rate averaged through the end of 2016 at 7.5% compared to Region 1 at 11.2% and Region 2 at 13%. This plot could be used as a performance indicator for the overall protection system reliability.

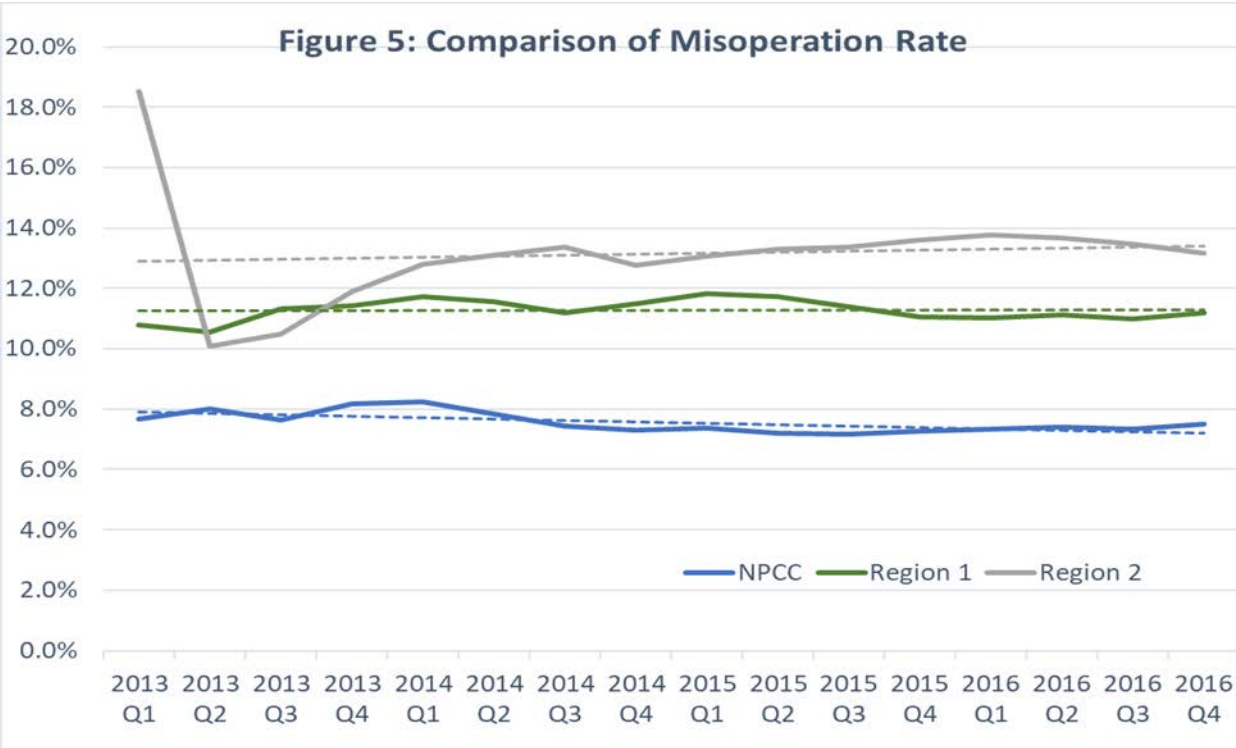
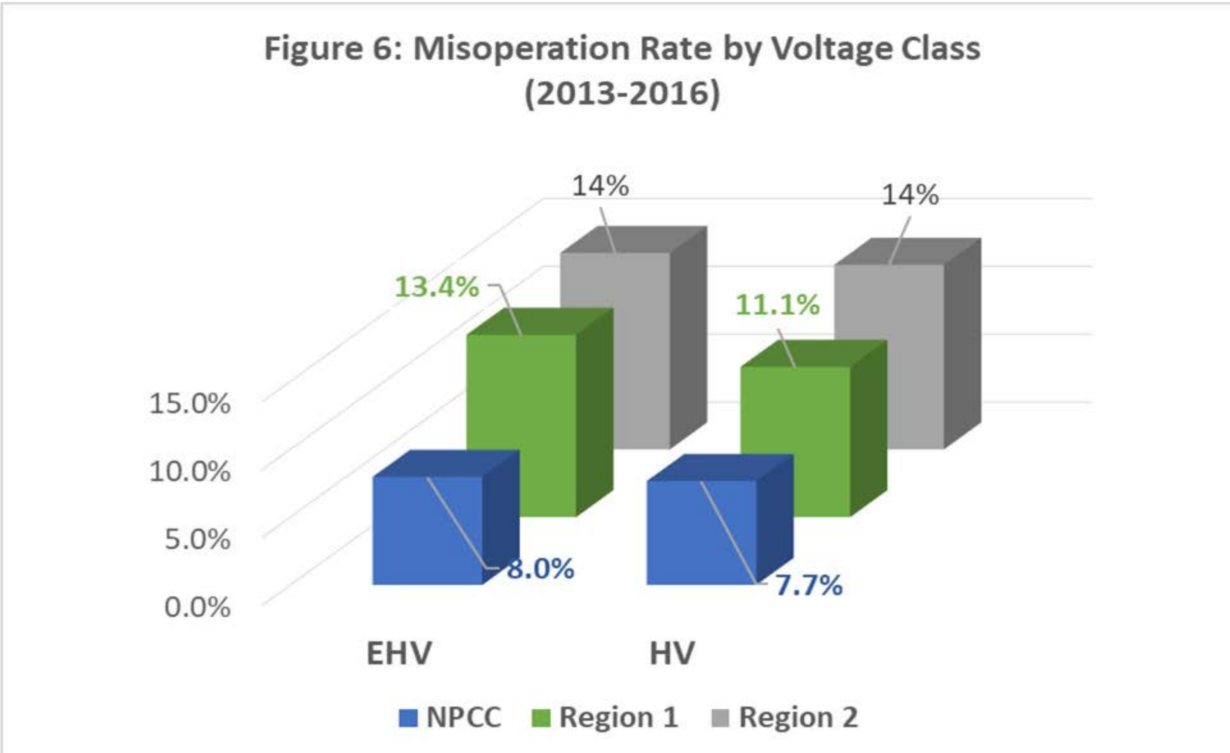
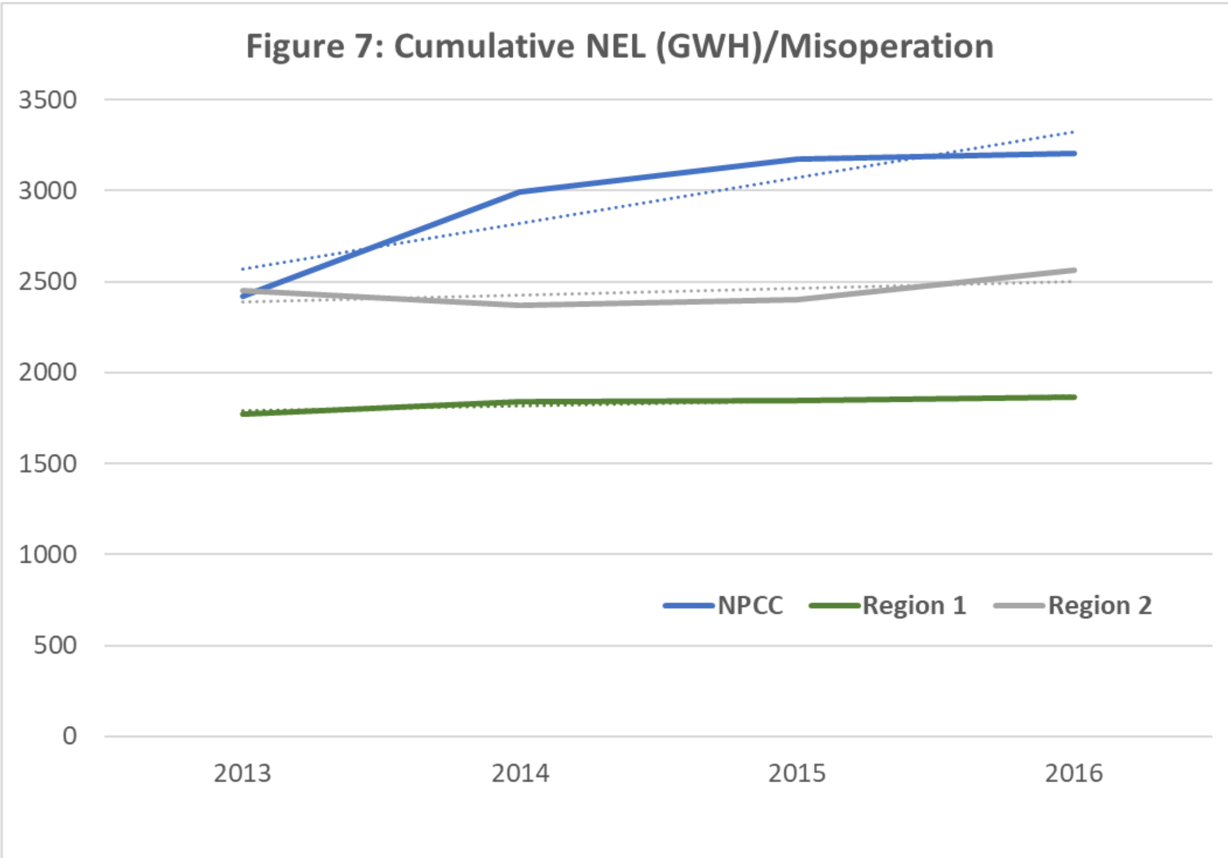



Figure 6 below compared the Misopertions Rate based on the following voltage classes from the submitting entity's reports:
- EHV: 345 -765 kV including HVDC
- HV: 100 to 230 kV

The Misoperation Rate by voltage was calculated by dividing the number of misoperations reported in its voltage class by the number of protection system operations reported in that voltage class. This chart provided additional insight into the Misoperation Rate presented in Figure 5 in term of Misoperation Rate by its voltage class.




The analysis in Figure 7 compared the annual Net Energy for Load (NEL) in GWH per annual number of reported misoperations in each Region as another performance indicator. NPCC plot showed noticeable improvement in the NEL per Misoperation over the four-year period, despite the NPCC NEL data showed an average decrease of 6,600 GWH/year. The total NEL for Region 1 showed an average increase of 745 GWH/year and for Region 2 an average decrease of 4,813 GWH/year.




## Conclusion

This analysis quantified the different causes of misoperations and correlated the various categories of misoperations to those causes. The analysis shed light on the misoperations experienced in NPCC including the types of relays that failed or involved in the misoperations. The result of the analysis showed where additional efforts should be focused to further reduce protection system misoperations and therefore reduce the risk of potential widespread disturbance on the power system. The lowering of the Misoperation Rate and increasing NEL/Misoperation over the four years period corresponded well with the efforts taken together by NPCC and its members. The analysis of NPCC protection system misoperations was shared with and compared to misoperations reported in two other Regions.

## Acknowledgement:

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## References

[1] NERC Misoperation Information Data Analysis System – Extraction of data in April 2017

[2] NERC Protection System Misoperation Reporting Template, effective through 2016.

[3] NERC Glossary of Terms – Updated January 31, 2018

[4] NPCC Glossary of Terms – November 3, 2017

## Authors:

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