

## Lesson Learned

### Misoperation of 87N Transformer Ground Differential Relays Causing Loss of Load

#### Primary Interest Groups

Distribution Providers (DPs)  
Generator Operators (GOPs)  
Generator Owners (GOs)  
Transmission Operators (TOPs)  
Transmission Owners (TOs)

#### Problem Statement

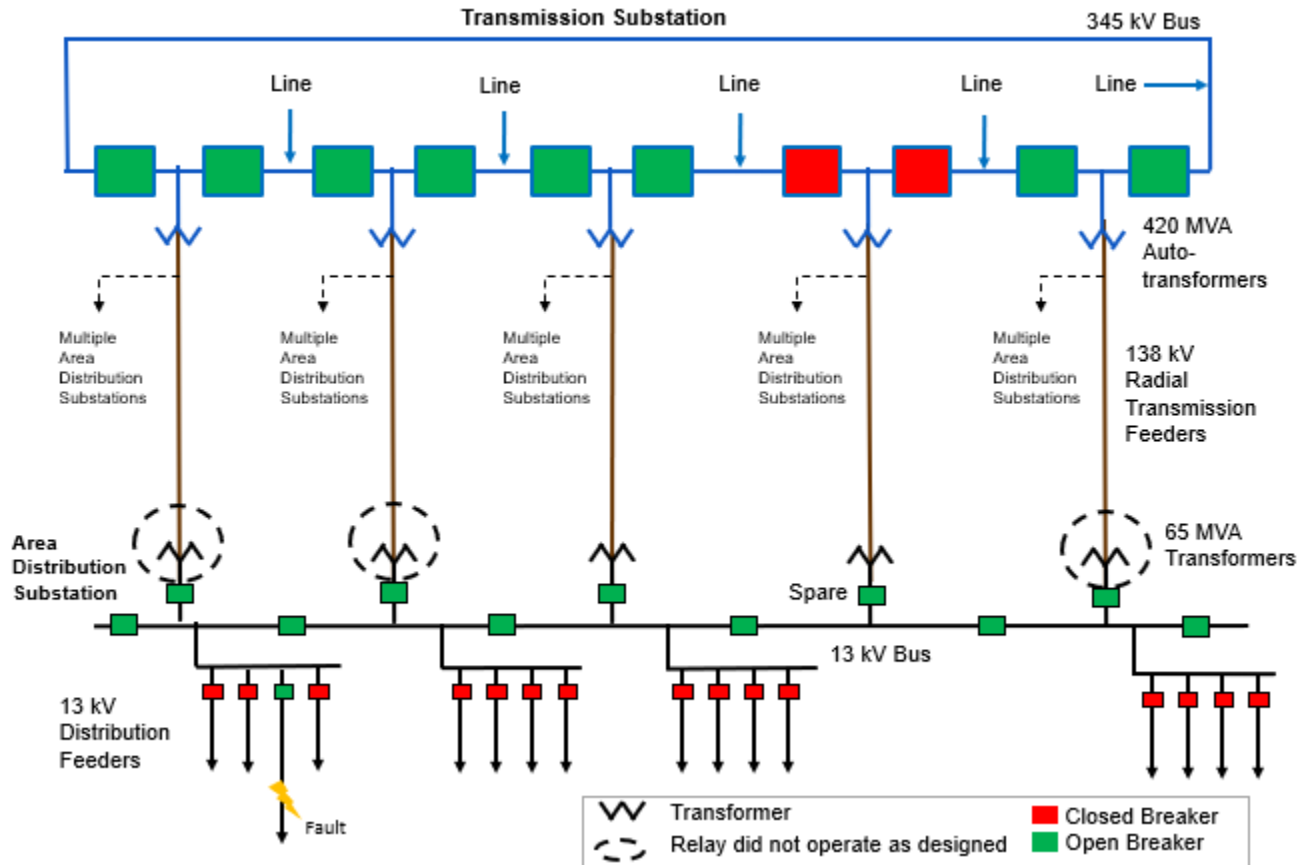
Gaps in implementing a modification and subsequent commissioning processes led to the omission of neutral connections for three separate transformer neutral differential relays, ultimately causing three simultaneous misoperations and a subsequent loss of load.

#### Details

A significant load area was supplied by a 345 kV transmission substation arranged in a ring bus configuration (see Figure 1) with 10 bus sections tied to one another by 10 circuit breakers. Five 345 kV transmission lines and five 345 to 138 kV auto-transformers were connected in an alternating supply-load arrangement wherein the lines serve as the supply and the auto-transformers draw load from the transmission system. The auto-transformers, rated at 420 MVA each, supply multiple area distribution substations via 138 kV radial transmission feeders. The area substations contained 65 MVA transformers that step down the voltage onto a common 13 kV bus that supplies many distribution load feeders. One of the multiple area substations is depicted in Figure 1.

Only four 65 MVA transformers can be connected to the 13 kV bus at any time, or the fault duty would exceed the breaker interrupting capability. The fifth transformer therefore serves as a spare on hot standby, energized on the high side, but with its low side 13 kV breaker kept open.

The loss of load event was initiated by a routine single-line-to-ground fault on one of the 13 kV distribution feeders. The protective relays on the feeder detected the fault and were in the process of clearing it by tripping the 13 kV feeder breaker connected to the area substation. Just prior to the completion of this tripping action, neutral or ground differential relays (ANSI/IEEE device designation: 87N) simultaneously misoperated on three of the four in-service transformers at the area substation.



**Figure 1: One-line Diagram of Transmission and Area Substations**

The relays protecting the 65 MVA transformers at the area substations need to transfer trip the 345 kV ring bus breakers at the transmission substation in order to clear the source. Thus, the associated 420 MVA auto-transformer and 138 kV radial transmission feeder are tripped in tandem with the area substation transformer by design. The misoperations of 3 87N relays at the area substation therefore resulted in tripping 3 420 MVA autotransformers at the upstream transmission substation and the opening of 6 of the 10 ring bus breakers.

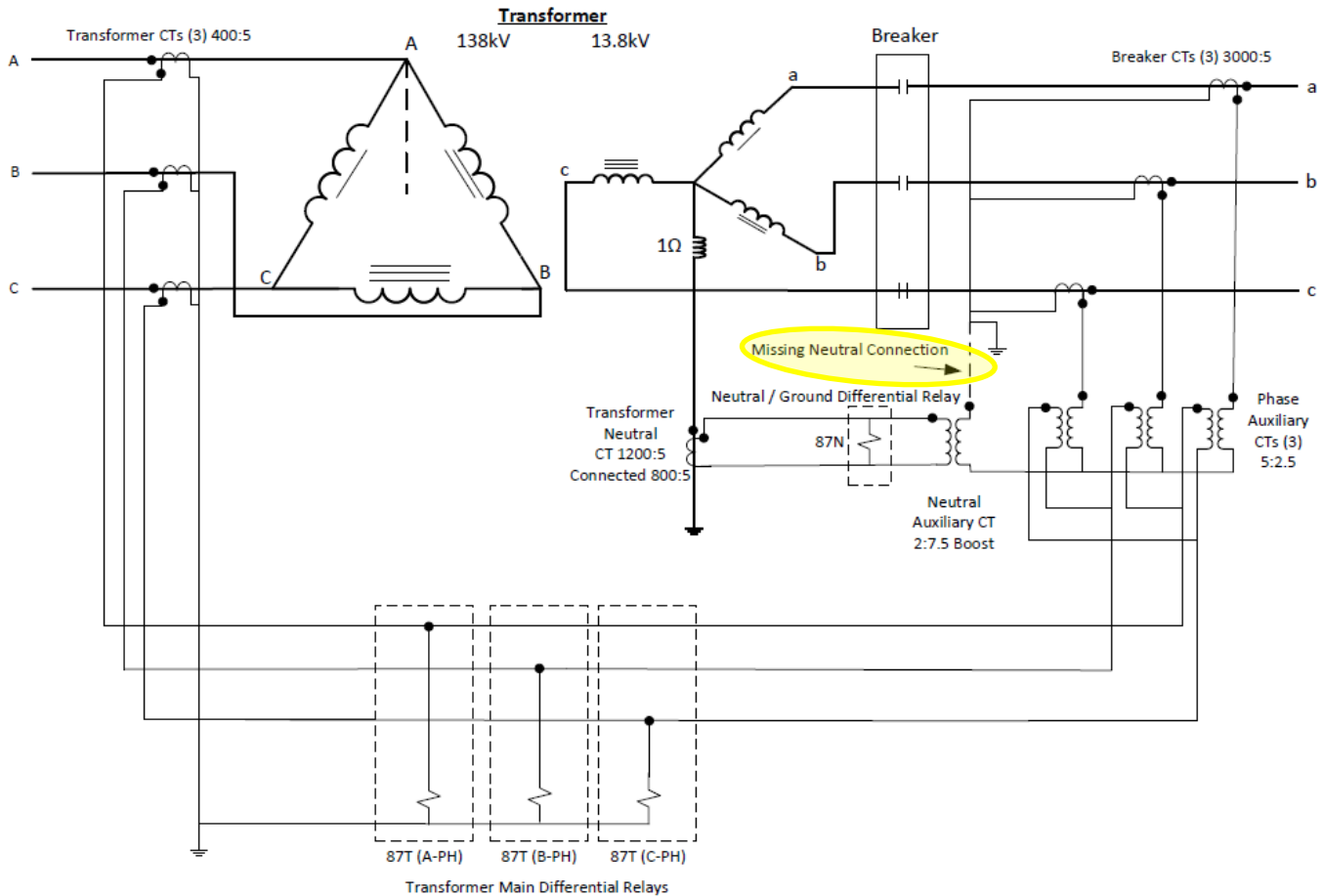
Immediately following the three 87N relay misoperations, the 13 kV distribution feeder breaker tripped to clear the fault in normal fashion. This was not a slow or stuck breaker scenario.

At this point, the entire load on the area substation bus was carried by the fourth and sole remaining in-service 65 MVA transformer. Within six seconds, prior to operators being able to switch in the hot standby spare transformer, the high-load current on the fourth transformer and resulting voltage drop across the transformer's impedance met the conditions to activate an automatic sectionalizing scheme on the 13 kV distribution bus. This segregated the area substation electrically into four segments, three of which already had lost their supply when the 87N relays misoperated, but this did not reduce the load current into the distribution network. The sectionalizing scheme then advanced to its next and final stage, tripping the

fourth transformer. That included opening two more breakers on the 345 kV ring bus at the transmission substation for a total of 8 out of 10.

The two 345 kV breakers that remained closed maintained the continuity of an important transmission path between two transmission feeders, permitting a portion of the load in the area to continue to be supplied to some of the area substations via the remaining autotransformer.

Event analysis and trouble-shooting determined that the three 87N relays on the area substation transformers misoperated due to an open or missing connection in the wiring between the 13 kV transformer secondary breaker current transformers (CTs) and the neutral auxiliary CT that supplies each 87N relay. This is depicted in schematic form in Figure 2. To function properly, the 87N relay requires inputs to compare the current through the transformer neutral itself to the ground current flowing through the secondary breaker as seen by the residual of the three phase currents. This missing connection unbalances the differential configuration.



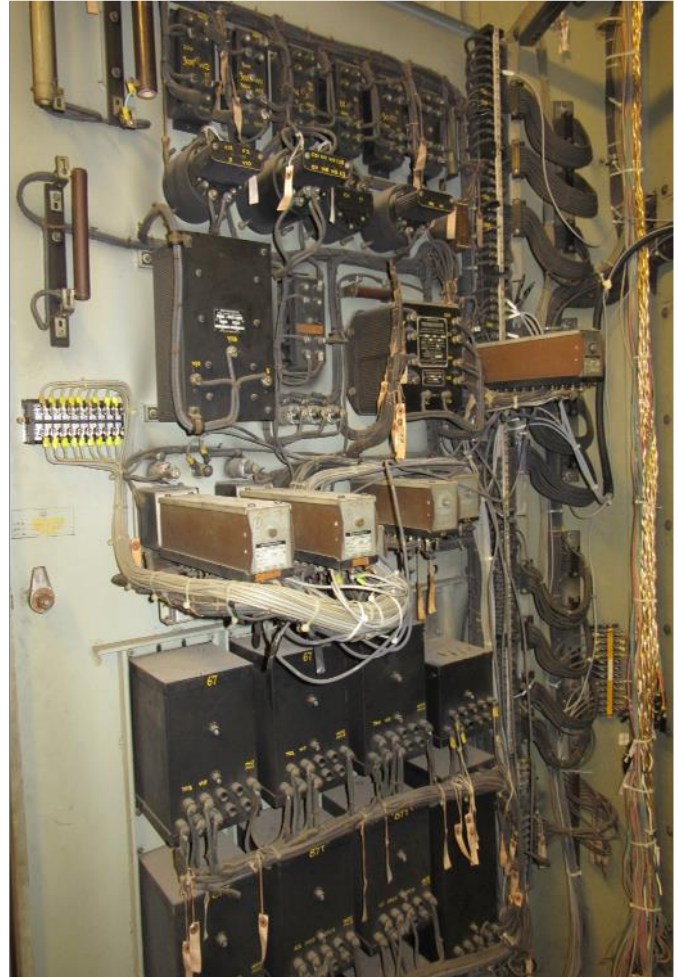
**Figure 2: Schematic Diagram of Transformer Differential Relay Protection**

Investigation found that the missing neutral connection occurred during a 13 kV breaker retrofit program undertaken many years after the substation was originally built. The vendor who performed the work opted to create a separate wiring diagram for the protective relay circuits that focused only on those portions of

the circuits being affected by the retrofit work. This separate diagram essentially took an excerpt of the overall transformer relaying circuit schematic and modified it to show connections to the upgraded breaker cabinet. It was intended to be used in conjunction with the original overall schematic, but it is believed that the wiring crew relied on it exclusively. This separate diagram lacked detailed terminal designations for the neutral-to-ground connection, thus one wire was landed on a termination where two were required.



**Figure 3: Relay Panel Under Test Following the Event (87N In Lower Left Hand Corner)**



**Figure 4: Wiring in Rear of Relay Panel**

The error in connection existed on three transformers at the area substation for 10 years prior to the event. Although several 13 kV faults had occurred in the local distribution system over those 10 years, none had a sufficient combination of magnitude and duration to activate the 87N relays. The fourth transformer also had its 13 kV secondary breaker replaced, but that upgrade work was conducted several years later by a different crew. The same issue was present in its schematic drawings, was discovered during their review, and corrected. Consequently, the fourth transformer didn't trip during the event. Unfortunately, this new crew did not check to see if the same error existed on the earlier retrofits.

It is noteworthy that the problem was discovered during a drawing review on the last of the four transformers to have their breakers replaced but wasn't discovered during commissioning tests on the first

three. Primary current injection testing to validate the CT circuits was conducted when the breakers were replaced, but it focused on the circuits associated with the 13 kV bus and feeders. The transformer relaying was thought to be only peripherally affected by the upgrade, so this was not examined thoroughly. Separately but significantly, neutral or ground differential circuits present perhaps the greatest challenges for testing because polarities and connections cannot readily be validated with balanced phase currents. The presence of auxiliary CTs in the circuit complicates the matter even further.

### **Corrective Actions**

The missing wiring was corrected (see Figure 5).



**Figure 5: Added Neutral CT Connection to Complete 87N Circuit Post-Event**

The first pair of process corrective actions were in the area of design and engineering. In order to reduce inconsistencies between drawings, a process was developed and implemented to redraw ac circuits with templates. This process change was aimed at reducing multiple drawings showing the same information for the same location. This avoids redundancy and the potential to introduce discrepancies between separate drawings. Furthermore, a set of human performance improvement checklists were expanded to support the review of critical circuits during the engineering phase of a project. The checklists adopt best practices from across the engineering departments.

Another area for improvement was in the standardization of commissioning testing for substation equipment and relay protection systems. The entity has two testing instructions in development to apply best practices from the industry and thereby prevent testing shortfalls. The two instructions include a guideline for commissioning and an instruction on primary injection testing methods. Both instructions are in draft form and are in the process of being vetted during actual construction projects now in progress.

Going forward, if a design discrepancy is found on a drawing or in the field, an “Extent of Condition” will be conducted. This involves assessing engineering drawing packages for similar projects to review and correct these discrepancies. This requirement will be captured in the design checklist during the engineering phase of a project. During the execution phase of a project, this requirement will be captured in the commissioning test instructions.

The underlying premise is that when a problem is encountered either in the design phase or the testing phase, the communication of the problem by way of feedback is essential to determining where else it may exist, thereby allowing it to be fully addressed to prevent reoccurrences elsewhere. The communication must be both within the organization that initially encountered the problem and between organizations that may be impacted either operationally or in terms of resources needed to mitigate the problem. The Extent of Condition approach is intended to weave this type of feedback into the fabric of conducting business, especially with respect to critical systems that have a direct bearing on safety and reliability of service.

When problems are uncovered that could potentially be encountered by other entities in the industry, these problems can and should be discussed in industry forums and, to the greatest possible extent, the pertinent information should be disseminated to the electricity sector. Discretion is needed to filter the problems that are worthy of communicating from those that aren't. In the case of this event, awareness of the root cause can clearly benefit the industry at large.

### **Lessons Learned**

The event offers to the industry the four lessons listed below some of which have already been discussed in previous sections of the document.

- Improve Project Design Processes:
  - Apply thorough design review and comprehensive testing procedures be to the modification of any relay scheme.
- Standardize Commissioning Test Instructions:
  - Use standardized commissioning testing for substation equipment and relay protection systems.
  - Reference NERC and IEEE guidelines for developing and performing commission testing plans.<sup>1</sup>
  - The testing procedures should ensure that every piece of the relay scheme is tested in part and as a whole to determine deficiencies before they become latent weaknesses, particularly in cases of neutral relay schemes. Unlike phase differential relay schemes, in-service current measurements cannot be readily taken to determine a missing current transformer neutral connection.<sup>2</sup>
- Provide Feedback to Supervision and Engineering when Problems are Encountered:
  - Use Human Performance tools (such as STAR and Peer Checking) to check and recheck the wiring and connections of a relay circuit in its entirety. If there is conflicting information, do not proceed in the face of uncertainty – get knowledgeable help (i.e., ask supervision or engineering).

---

<sup>1</sup> IEEE PSRC, WG I-25 “Commissioning Testing of Protection Systems” <https://www.pes-psrc.org/kb/published/reports/WG%20I-25%20Commissioning%20Testing%20of%20Protection%20Systems%205-10-2017.pdf>

<sup>2</sup> For additional insight into implementation and testing ground differential protection for transformers, see the paper “[Considerations and Experiences in Implementing Ground Differential Protection for Transformer Protection at TVA](https://www.pes-psrc.org/kb/published/reports/TVA%20Ground%20Differential%20Paper%20-%20GA%20Tech%20PRC%202009.pdf)” by Meyer Kao, Gary Kobet, and George Pitts. <https://www.pes-psrc.org/kb/published/reports/TVA%20Ground%20Differential%20Paper%20-%20GA%20Tech%20PRC%202009.pdf>

- Ensure accuracy and consistency of references provided for work – Avoid use of multiple drawings showing the same information for the same location to reduce the potential to introduce discrepancies that can occur between separate drawings.
- When a design discrepancy is found on a drawing or in the field, it needs to be reported to engineering so an “Extent of Condition” can be conducted.
- Engineering should have a formalized process for conducting an “Extent of Condition” review to help ensure a consistent and thorough review is performed.

NERC’s goal with publishing lessons learned is to provide industry with technical and understandable information that assists them with maintaining the reliability of the bulk power system. NERC is asking entities who have taken action on this lesson learned to respond to the short survey provided in the link below.

Click here for: [Lesson Learned Comment Form](#)

**For more Information please contact:**

[NERC – Lessons Learned](#) (via email)

[NPCC – Event Analysis](#)

Source of Lesson Learned:

Northeast Power Coordinating Council

Lesson Learned #:

20200401

Date Published:

April 14, 2020

Category:

Relaying and Protection Systems  
Transmission Facilities

*This document is designed to convey lessons learned from NERC’s various activities. It is not intended to establish new requirements under NERC’s Reliability Standards or to modify the requirements in any existing Reliability Standards. Compliance will continue to be determined based on language in the NERC Reliability Standards as they may be amended from time to time. Implementation of this lesson learned is not a substitute for compliance with requirements in NERC’s Reliability Standards.*