Enclosure 1

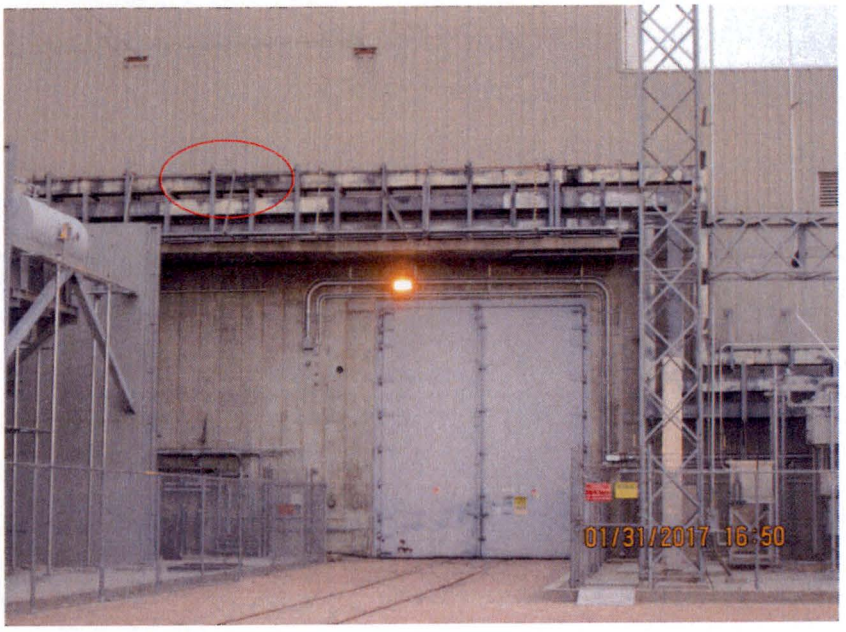
Apparent Cause Evaluation – CR-CNS-2017-00223, Rev. 2
"Phase-to-Phase Fault of ESST Non-Segregated Bus"

Cooper Nuclear Station
Brownville, Nebraska

LOWER TIER Apparent Cause Evaluation - B(L)

Phase-to-Phase Fault of ESST Non-Segregated Bus

Condition Report CR-CNS-2017-00223 Rev. 2



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J. Dykstra (Revision 2)

Event Date: 1/17/2017
Report Date: 2/17/2017
Rev 2: 10/26/2017

Contents

1.0 Problem Statement

On 1/17/2017, with the plant in mode 1, CNS experienced a phase-to-phase fault of the non-segregated bus on the secondary side of the Emergency Station Service Transformer (ESST) resulting in the loss of function of the ESST and entry into a seven day technical specification action statement (LCO 3.8.1, Condition A).

2.0 EFE/HPER/NCV Issues

Does this ACE report require an Equipment Failure Evaluation (EFE)? (See procedure steps 5.3[3](c) and 5.4)	☒ Yes	☐ No
IF Yes, THEN complete 0-EN-LI-119-01 Equipment Failure Evaluation, **AND** attach in ActionWay. Ensure the results are also discussed in the Event Description or Analysis. **IF No, THEN** an EFE analysis is not required.		

Was an HPER assigned & performed for this CR? (See procedure step 5.3[3](c))	☐ Yes	☒ No
IF Yes, THEN ensure results of the EN-HU-103 HPER are discussed in the Event Description.		

Is this ACE a result of an NRC finding or NCV as documented in an Inspection Report?	☐ Yes	☒ No
IF Yes, THEN complete the NCV Checklists within this Evaluation template. **NOTE: THIS IS A POTENTIAL NRC FINDING**		

3.0 Event Description

On 1/17/2017 at 1644 hours the Control Room received Annunciator C-2/C-10 "EMERGENCY TRANSFORMER UNDERVOLTAGE", followed immediately by C-3/G-3 "161KV SWYD TROUBLE", C-1/G-6 "BKR 1FS AUTO CLOSURE NOT PERMITTED" and C-4/G-1 "BKR 1GS AUTO CLOSURE NOT PERMITTED". The Control Room entered Abnormal Procedure 5.3GRID, and Technical Specification LCO 3.8.1 Condition A, Required Action A.1, A.2, and A.3. At 1711 hours the Control Room received a report from the NPPD Operations Center that the cause of the alarm was a loss of the Emergency Station Service Transformer (ESST) due to an apparent 3-phase fault on the secondary side of the transformer. At 1716 a Station Operator reported that an

area of the non-segregated bus duct on the secondary side of the ESST, exterior to the Turbine Building, was slightly discolored and at an elevated temperature (using a thermal imager).

The ESST was not loaded and no ESST-related switching activities were occurring at the time of the event. The NPPD Operations Center promptly analyzed the fault and determined that the circuit protection operated correctly. Other than the fault itself, there were no equipment malfunctions, human performance errors or procedural deviations involved in the event.

Figure 1: ESST Non-Segregated Bus top, SSST X-Winding bus bottom

The Emergency Station Service Transformer (ESST) tripped by opening of breaker 604 on overcurrent protection. NPPD-Operations Transmission Protection was able to analyze information from the protection relays and concluded that an 866 amp fault current was present on the 69kV line (the primary side of the ESST) , and therefore the secondary side of the ESST (4160V Bus) saw a 13,000 Amp fault. Relay 11-604 first detected a C-A phase fault for 1-2 cycles which then developed into a 3 phase fault which tripped after approximately 1 second. The protection worked as designed to isolate the fault.

Upon investigation it was determined that the fault location was on the 4160V non-segregated bus work just north of the Turbine building railroad door.

Figure 2: As-Found condition of fault location

Initial inspection of the fault location showed the bottom aluminum cover of the non-segregated bus duct was found to have a hole with material from the bus/insulation found on the SSST X-Winding bus duct below (See Figure 1). The SSST bus duct was discolored but intact. The fault occurred at a location where a lower glastic bus support insulator is located. (See Figure2) Based on the location of the fault it was determined that the entire non-segregated bus should be cleaned and inspected per procedure 7.3.41, EXAMINATION AND HIGH POT TESTING OF NON-SEGREGATED BUSES AND ASSOCIATED EQUIPMENT.

Figure 3: Tracking on bus supports in Non-Critical Switchgear Room

During examination of the bus, signs of tracking across some of the bus supports were found along with signs of corona damage in proximity to the point where the bus supports make contact with bus. (See Figure 3)

Related Conditions

Additional Condition Reports tied to this evaluation are:

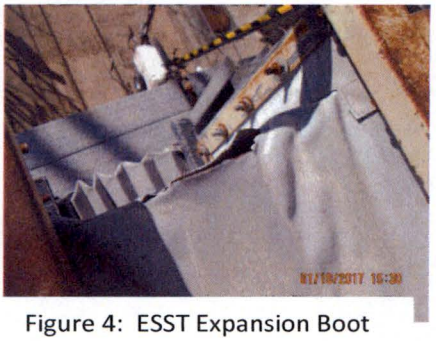


Figure 4: ESST Expansion Boot

CR-CNS-2017-00239: The ESST expansion boot above the Turbine building railroad door was found to have a hole in it. See Figure 4.

Relationship to issue: During inspection of the fault the ESST boot was found to have a hole in it along the top west edge. Inspection of the bus duct showed no signs of water intrusion or foreign material due to the hole in the boot. Based on the boot being approximately 30 feet from the fault location and no signs of foreign material this did not contribute to the fault. There is no conclusive information to refute or support the conclusion that the damage to the boot was caused by the fault and resulting pressure transient. The boot was patched per work order 5173717 and was later replaced by work order 5175321 on 5/2/17.

CR-CNS-2017-00240: Inspection of the ESST non-segregated bus shows the bottom cover to have a hole in it with the side covers having some buckling due to the effects of the fault. Inspections of the aluminum bus bars show that all three phases have some damage at the area by a bus support piece. The 3M insulation was also noted to be black in the area of the bus work.
Relationship to issue: This CR was written to document the as found condition of the fault location. This was damage directly related to the event and was repaired by WO 5173718.

CR-CNS-2017-00252: There are spots in ESST Non Seg Bus that are missing insulation where the bus supports are.
Relationship to issue: During inspection it was found that there were locations that the insulation located by the bus support insulations had worn through to expose the bus bar. This was evaluated below as a potential contributor to the event. All damaged insulation was repaired by work order 5175718.

CR-CNS-2017-00253: Requirement not met: In the exterior sections of the Emergency Transformer non segregated bus, multiple spots of the bus insulation is rubbed through at the fiberglass supports. This includes places that were repaired under WO# 5002481, in March of 2015, with additional tape.
Relationship to issue: This is similar to CR-CNS-2017-00252, other than this condition report notes that the tape repairs performed in 2015 were already starting to see degradation. This will be evaluated in analysis section.

CR-CNS-2017-00257: Under the fault location on the ESST non-segregated bus there is a structural support U channel. This saw heat from the fault and therefore is recommended to be replaced.
Relationship to issue: A structural support piece location right under the fault location saw heat damage from the fault. This is directly due to the fault and the U channel support was replaced by work order 5173717.

CR-CNS-2017-00279: While performing work order 5173718 inspection of the ESST non-segregated bus. Found one insulator in enclosure 8 burnt and showed signs of tracking. Notified supervision and engineering. Craft replaced insulator and installed rubber grommets on all three phases. Many other areas were taped and repaired in enclosures #2, #4 and #11.
Relationship to issue: Signs of tracking near the bus support pieces were noted. See Figure 2. This will be evaluated in the analysis section of this evaluation.

Figure 5: Non-Critical Switchgear room

CR-CNS-2017-00281: Surface corrosion was found on the inside of the ESST non-segregated bus in the non-critical switchgear room. This is surface contamination only and does not affect the structure of the bus.
Method of Discovery: Inspection of ESST bus
Relationship to issue: Surface contamination was found on the inside of the bus duct in the non-critical switchgear room. See Figure 5. This is evidence there is condensation/humidity inside of the bus duct. This is not directly related to the fault but humidity contributes to the tracking mechanism.

CR-CNS-2017-04126: NRC SRI provided observations relative to the apparent cause evaluation and information associated with conditions discovered following completion of the initial evaluation, such as discrepancies in the hi-pot methodology.
Relationship to issue: Revision 2 of apparent cause includes observations from NRC SRI.

CR-CNS-2017-04960: 2017011-01- The NRC identified a preliminary low-to-moderate (White) finding with two NRC-identified apparent violations of TS 5.4.1.a, for the failure to implement and maintain Maintenance Procedure 7.3.41, "Examination and High Pot Testing of Non-Segregated Buses and Associated Equipment," Revision 10, during testing and inspection of the emergency station service transformer 4160V bus bars. This will be evaluated in the analysis section of this evaluation.

Additionally, as an extent-of-condition action resulting from the subject event, a complete inspection of the SSST x-winding non-segregated bus was performed in September 2017. CR 2017-05788 resulted from that inspection, which identified surface corona discharge, and tape repairs for nicks in the insulation. Three additional condition reports (summarized below) documenting discrepancies/questions associated with that inspection, were tied to this CR. This evaluation also addresses these Condition Reports.

CR 2017-05802 - SSST Bus inspection SRI questions. Questions were raised by the inspector concerning the conduct and results of the inspection of the SSST non-segregated bus, and CNS provided the requested information. See Attachment 3 for further discussion.

CR 2017-05766 - Oily film on SSST bus insulation, indoors. Bus insulations were found with an oily film on it, on the bus located in the SE corner of the non-critical switchgear room. As noted in the operability review of the condition report, 'This type of condition has been evaluated previously in CR-CNS-2005-3946. The description of the condition then was described as the drips of "varnish" like material that cover the entire outside surface of the insulation. The evaluation from Southwest Research Institute concluded that the discoloration of the insulation (burn marks or varnish) does not prevent the insulation from performing the function of insulating the energized conductors from the ESST. The insulation was successfully tested by an AC Hi-pot test to confirm that the insulation was still serviceable prior to being returned to service. As such, the presence of discoloration on the insulation is not a degraded or non-conforming condition.'

CR 2017-06310 - SSST Non-segregated bus repair follow-up. This Condition Report documented repair of certain sections of the SSST bus that were not noted in previous condition reports. Tape repairs and cleaning of discoloration were performed under Order 5203744. The as-found condition of these sections were similar to those noted in CR 2017-05788

4.0 External (and Fleet) Operating Experience

Review of industry operating experience resulted in identification of the following failures of non-segregated bus work.

SER5-09 "6.9kV Non-segregated Bus failure and complicated SCRAM." Review of this SER showed the failure was due to overheating of the center bus bar at the flex connector. The CNS failure did not occur at the bolted connections and therefore this is not directly related.

OE 300896 discussed a fault of a non-segregated bus at St. Lucie due to a ventilation screen falling on to the bus bars due to corrosion. No foreign material on the bus bars contributed to the event at CNS.

OE308782 discussed fault on non-segregated bus at ANO, due to degradation of the flex link connector. ANO did note corona as a contributing cause due to no putty being used around bolt heads prior to taping. The faults at CNS did not occur at the flex links or at a bolted connection.

OE 321391 Brunswick had a phase to ground fault on the non-segregated bus between the startup and 4kV bus. This was due to water intrusion through a degraded seal between the bus duct and the start-up transformer bushing box. The faults at CNS did not occur due to water intrusion. The bus duct surrounding the bus bars is not sealed on the bottom to allow any water intrusion to drain out.

IER 14-46 "Multiple Electrical Faults resulted in Explosion of Unit Auxiliary Transformer and Automatic Scram" This IER recommended verifying that adequate PM are in place to inspect the non-segregated bus for electrical faults, such as visual inspection for corona effects. This IER was evaluated under CR-CNS-2014-05841, which concluded that CNS meets all recommendations of the IER by performance of existing preventive maintenance tasks as developed through industry guidance, operating experience, and implementation of the metal Enclosed Bus Inspection Program in accordance with License Renewal commitments (as discussed below).

Summary of External Operating Experience

Review of external OE shows there have been faults associated with non-segregated bus throughout the industry. The majority of the causes for these faults are either at a bolted connection, foreign material in the duct, or water intrusion. IER 14-46 did recommend verifying that adequate PMs were in place. CNS has a 10 year frequency PM to inspect the bus ducts and the ESST bus duct had been previously inspected / tested in 2015.

5.0 Extent of Condition

As discussed in the Event Description, the entire ESST non-segregated bus was inspected and cleaned per Maintenance Procedure 7.3.41 following the event. Signs of tracking across some

of the bus supports were found, along with signs of corona damage on the bus insulation in proximity to the support pieces. These conditions were corrected under CM Orders 5173717 and 5173718.

Systems Description

Similar non-segregated bus work is located on the Startup Station Service Transformer (SSST) in both the 3000A X-Winding and 2000A Y- winding busses and also, on the Normal Station Service Transformer (NSST) 3000A X- Winding and 2000A Y- winding busses. The SSST bus work takes the same path to the non-critical switchgear room as the Emergency Station Service Transformer (ESST) bus work. The order of the busses along the wall is ESST on Top, SSST X-Winding in middle and SSST Y-Winding on bottom. The SSST Y- winding bus is normally energized with one Reactor Recirculation pump loaded. This provides current flow which results in some heating in the bus. Both the ESST and SSST X-Winding are normally energized, but not normally loaded.

ESST Transformer Testing

Because the subject event concerned a fault current supplied by the Emergency Station Service Transformer (ESST), the transformer was tested to verify no damage occurred. Doble testing was performed on the transformer and bushings along with Transformer Turns Ratios (TTR) and Sweep Frequency Response Analysis (SFRA) testing. This testing was performed by work order 5115615 and was satisfactory. Two Dissolved Gas Analysis (DGA) samples were also taken and sent to the lab for analysis. Both tests were satisfactory with no increase in gassing seen. A Furan analysis test was also performed on the oil with no increased degradation seen in the paper insulation of the transformer. Also, the external Current Transformers (CTs) and external Potential Transformer (PTs) were Doble Tested and TTR tested satisfactory under the same work order.

SSST Non-Segregated Bus

The SSST non-segregated bus insulation was replaced in 1995 by WI 95-3603. The insulation was replaced with 3M heat shrink insulation on both the X- and Y-winding buses. Inspections of the SSST non-segregated bus work were performed in 2009 and 2017 by work orders 4458028 and 5069489. This is done per a 520 week (10 year) PM 800000020628. The results of the inspections are summarized below with a detailed report of the 2017 inspection results included in Attachment 4.

2009 SSST Bus Inspection

During the 2009 inspection minor discrepancies were noted but corona/damage on bus support pieces was not observed comparable that found during the ESST bus 2005 inspection. A summary of condition reports written during the SSST inspection follows:

CR-CNS-2009-03753- A broken support strap on the bus cover near the 1BS cubicle in the switchgear was weld repaired.

CR-CNS-2009-03705- Where the bus crossover for phasing occurs near 1AS the insulation supports were noted to be loose and not touching the bus bar. Also, noted was that on the C phase the support had gouged into the insulation. From review of pictures of this area, no corona was found in the area. The gouged area was repaired and the bus support insulators were rounded out to provide a better fit in the area.

CR-CNS-2009-03752- Exposed bus bars was found near the 1DS Breaker at a bolted connection. This is exposed bus at a 90 degree turn. No discoloration was found in the area and it was tape repaired.

CR-CNS-2009-03704- Inspections revealed bus bar connection boots by the 1BS breaker where the boots cover the connections are sliding allowing a small segment of the bus to be exposed. Bus bar boots were taped to verify they would stay in the place properly.

During the 2009 inspection of the SSST bus the 3M heat shrink insulation is still the original red color and tape repairs to the insulation at the bus support pieces were not necessary per review of time confirmation, condition reports and procedure discrepancies.

2016 SSST Testing

The SSST non-segregated bus was hi-pot tested after modifications were completed for installations of the new SSST in RE29 (October 2016) by Order 5064990, operation 0880. This test was satisfactory with no discrepancies.

2017 SSST Bus Inspection

In June 2017, a spot check was performed by work order 5178820 (CR-CNS-2017-00223-CA-008) under the location of the ESST fault. Minor surface corona discoloration was found but was cleaned with no impact to the insulation. Also, one nick was found in the insulation and a tape repair was made. No damage was found to the insulation due to corona and no signs of tracking were present.

During the week of September 25th, 2017, Cooper Nuclear Station (CNS) performed an inspection of the two 4160V, non-segregated buses that delivers power from the Startup Station Service Transformer (SSST) to the four non-safety-related switchgears, A, B, C, and D. The inspection was performed per Preventative Maintenance work order 5069489 which is performed on a ten year frequency. The inspection includes a visual inspection of the buses insulation, bus connections and structures. The inspection also performs Hi-Pot testing and Low-Resistance testing to further validate that the bus is isolated from ground and that all the bolted connections are in good condition. The bus was inspected using Revision 14 of Maintenance Procedure 7.3.41, which required 100% visibility of the bus bar insulation.

As a result of the inspection ten (10) condition reports were generated that documented twenty-three (23) identified issues. Attachment 4 provides details for each of the condition reports.
A majority of the issues identified in the condition reports concerned what is called mechanical damage. The most common cause of mechanical damage is past maintenance activities. Mechanical damage results in gouged or cut insulation from the installation of support pieces or tool marks. Damage from corona discharge was also identified on the bus insulation. A majority of the corona discharge damage was in the form of discoloration. As long as there was no appreciable depth to the corona damage and only discoloration was present, cleaning using an alcohol-based cleaner was the only action performed. Any defect found that was deemed to be more than superficial was repaired per work order 5203744. Full detailed 2017 SSST non-segregated bus inspection results are included as an Attachment.

NSST Non-Segregated Bus

The NSST also has similar non-segregated bus. The insulation in this bus was replaced in 1991 by WI 91-2590 and was last inspected in RE27 (2012). There is a 5 cycle (10 year) PM to inspect NSST Non-segregated bus per 800000004953. During the inspection in RE27 some minor conditions were found and repaired.
A summary of the condition reports generated as a result of this inspection is given below:

> CR-CNS-2012-08165- A dime sized notch of insulation was found pushed down, nicking the insulation from the bus support insulators, exposing the aluminum bus bar. This was tape repaired per 4847754. There was no evidence of the white corona per review of pictures of the inspection.
>
> CR-CNS-2012-08167- Found 5 bus supports insulators on the 3000A bus loose. The bolts were in place but had not been adequately tightened. Work order 4847754 tightened the supports.
>
> CR-CNS-2012-08168- Found nicks in the insulation of the NSST non-segregated bus. The nicks did not result in any aluminum showing from the bus. These areas were tape repaired per 4847754.

The NSST is a normally energized and normally loaded bus. From review of the inspection findings in RE27 and pictures, the bus was found to be in overall good condition.

Conclusion

Compared to the ESST bus that failed in January 2017, the NSST and SSST buses inspected in 2012 and 2017 do not exhibit any signs of tracking along the supports similar to that which was found on the ESST supports. Additionally, the corona discoloration found is significantly less than that observed on the ESST insulation in 2017, with no observed corona damage on the NSST buses. A comparison of the SSST 2009 and 2017 inspections shows that there was minimal degradation between inspection periods. Comparing the SSST results with the NSST 2012 inspection results demonstrates that the that the SSST and NSST buses are in good

condition with only minor issues identified, none of which credibly threaten the buses' ability to perform their function. The majority of the issues were caused by mechanical damage of the 3M insulation by contact with the glastic support bar. SSST corona damage that was discovered was limited to surface discoloration that was easily cleaned with alcohol. Corona resulting in minor damage by erosion of the 3M insulation was conservatively repaired with shrink tape. There were no instances of corona damage that perforated the 3M insulation found on either the NSST or SSST buses. As such, the condition of the insulation and supports indicate that the buses will remain serviceable until the next scheduled NSST and SSST bus inspections, currently scheduled for 2022 and 2027 respectively.

6.0 Analysis

Timeline

September, 1989 - NRC Information Notice (IN) 89-64, "Electrical Bus Bar Failures", issued. This IN was issued due to repeat failure throughout the industry on NORYL insulation. Response to the IN included inspections of the non-segregated bus work and creation of the 7.3.41 procedure for inspection of the bus work.

April, 1990 - MWR 90-1898. The first bus to be inspected as a result of IN 89-64 was the SSST. During this inspection discrepancies were noted. The expansion boot was noted to have standing water on the top and bowed down in the middle. Also noted was that there were several cracks found on the bus insulation. Based on inspection results it was determined that the insulation on all the non-segregated bus work should be replaced.

1993 - The ESST insulation was replaced in 1993 by ESC 90-332B. This replaced the original NORYL insulation due to cracking at the bolted connections and the support sections. This was replaced with 3M heat shrink insulation. Concurrently, the bus was inspected under MWR 92-2988.

November, 2001 - Order 4189460 examined the Normal Station Service Transformer non-segregated bus, in accordance with Maintenance Procedure 7.3.41.

April 2005 - Order 4416692/4442409 an inspection was performed in 2005 by WO 4416692 and 4442409 on the ESST bus and discoloration was found on the insulation which was evaluated by CR-CNS-2005-03946. As noted in the time confirmation for 4416692, 'After 70% of the visual inspection of the emergency bus was completed, the system engineer suspended the PM. The remainder was spot checked in several locations prior to suspension. The same visual discoloration was noted where the shrink meets the insulating dividers was continuously observed. The system engineer with vendor recommendation decided to perform a Hi-pot of the bus to ensure the integrity of the shrink insulation'. AC Hi-pot testing was performed under Order 4442409. The initial test was unsatisfactory, in that the test equipment tripped at about

7KV, due to limitations of the test equipment. Time confirmations did not include the AC Hi-pot test voltage, but the work instructions specified 14KV.

May 2005 - CR 2005-03946 evaluated discoloration of the ESST bus insulation near the support pieces, and noted that the OEM reported the discoloration was likely early signs of corona degradation. Further discussion of CR 2005-03946 is included in a separate section, below.

May, 2009 - Order 4458028 examined the Startup Transformer X-winding non-segregated bus, in accordance with Maintenance Procedure 7.3.41.

April, 2011 - Order 4740703. This order implemented CED 6029940, to install the Supplemental Diesel Generator (SDG). The activity required modification of the ESST non-segregated bus. Following modification, both a DLRO of the bolted connections, and an AC Hi-pot of the entire bus was performed. The AC Hi-pot was performed satisfactorily at 14KV, after M&TE with sufficient test current capacity was obtained. The initial Hi-pot testing failure, due to the limitations of the M&TE used, was documented and evaluated under CR 2011-03762 (dispositioned as a non-CAP item). CR 2011-03839 documented delays in completing the work as scheduled, because of difficulties with the test equipment, and because corona damage was observed on the ESST bus. CR 2011-03681 identified discoloration on the bus insulation, and noted this condition had been previously identified by CR 2005-03946.

October, 2012 - Order 4847754 examined the Normal Station Service Transformer non-segregated bus, in accordance with Maintenance Procedure 7.3.41.

March 23, 2015 - Revision 10 of Maintenance Procedure 7.3.41 was made effective. Among other changes, this revision changed the bus testing method from meggering to Hi-pot testing at 14KV.

March 23-29, 2015 - The ESST bus was inspected by work order 5002481, using MP 7.3.41 Revision 10. During this inspection multiple CR's were written due to findings during the inspections. All were dispositioned by revising the Order, or by closing based on actions taken.

> CR-CNS-2015-01731 was written for wear on the bus insulation where the bus supports are located resulting in exposed aluminum. The condition report was dispositioned as a work item. Revision 2 of WO 5002481 added steps to use Raychem HVBT tape to make repairs to insulation.
>
> CR-CNS-2015-01743 was written due to the flex links above the railroad door found corroded. Revision 3 of WO 5002481 removed, cleaned, re-silver plated the connecting surface and reinstalled the flex links.
>
> CR-CNS-2015-01745 was written for black insulation on the bus bar. This was cleaned per 7.3.41.

CR-CNS-2015-01746 identified a cracked cover on the vertical run closest to the building where there is a 1 inch overlap that goes over the side of the bus duct. This was repaired with silicone to seal the cover.

CR-CNS-2015-01790 was initiated by Maintenance expressing concerns regarding the number of discrepancies discovered during the inspection, and the resulting maintenance resource demands, and recommended that engineering evaluate the need for insulation replacement and bus duct 'overhaul' to enhance long-term reliability. The condition report was trended.

CR-CNS-2015-01817 identified a failure of the initial hi-pot test performed per 7.3.41. Unlike previous bus Hi-pot issues, this failure identified an actual degraded bus condition. This Hi-Pot was performed after repairs were made to all conditions discovered during the inspection. The bus was split and tested in segments until the location of failure was found. Tape repairs were made to the damaged insulation which was located on the outdoor portion of the non-segregated bus in the vertical section next to the non-critical switchgear room. After repairs were made, a Hi-Pot of the entire bus was completed satisfactorily, at 10KV. The change from 14KV to 10KV was implemented via a field revision to the work instructions. MP 7.3.41, which required an AC Hi-pot test voltage at 14KV, was completed by noting the change as a discrepancy, and a procedure change request was initiated. The CR was closed based on actions taken, without evaluating why an AC Hi-pot test which was satisfactorily performed in 2005 and 2011 failed in 2015.

January 2017 - CR 2017-00223 identified the ESST bus fault, examination, repair and testing were performed per Orders 5173717 and 5173718.

May, 2017 - Order 5185158 re-performed ESST bus Hi-pot testing with phases not under test grounded, for 1 minute.

May, 2017 - CR 2017-02164 identified questions from the NRC regarding AC Hi-pot test methodology for the non-segregated buses.

June, 2017 - Order 5178820 performed a spot check of the SSST X-winding bus.

September, 2017 - Order 5069489 examined the Startup Transformer X-winding non-segregated bus, in accordance with Maintenance Procedure 7.3.41.

Equipment Failure Evaluation

The ESST Non-Segregated bus is a Criticality 1 component and was verified to have the correct criticality specification. A review of system and component monitoring plan shows there are

currently no trends associated directly with the non-segregated bus and due to the nature of non-segregated bus, there are no trendable parameters that should be monitored.

The adequacy of the PM program was reviewed and showed that PMs are in place to inspect and detect issues at an adequate frequency. There is no EPRI PM basis for inspection of Non-segregated bus. Maintenance plan (MP) 800000019968 performs an inspection per Maintenance Procedure 7.3.41 of the bus duct and looks for signs of degradation/aging on a 10 year frequency. This is an adequate frequency based on past operating experience if corrective actions adequately repair identified discrepancies noted and the inspection is adequate.

No predictive maintenance (condition monitoring) is performed on the non-segregated bus. The non-segregated bus is fully enclosed and therefore thermography cannot be performed without removing bus covers.

The adequacy of work practices was reviewed. The work instructions used to perform the inspection are in Maintenance Plan 800000019968, which directs examination per Maintenance Procedure 7.3.41. Post Work Testing for the maintenance was reviewed, and it was determined that Hi-Pot testing is the best test available to ensure that the insulation system is left in satisfactory condition.

The design of the ESST non-segregated bus has a physical separation between the bus bars of 6.5 inches center to center on each phase per drawing 0109D4798 Sh 1. The aluminum bus is 5/8 inches wide therefore there is 5.875 inches of clearance between each bus bar. Per the National Electrical Code (NEC) 2014 edition table 490.24 Minimum Clearance of Live Parts, phase to phase, for 4.16kV for indoor applications, the minimum clearance is 4.5 inches. Considering outdoor applications, a minimum clearance is 7 inches. Based on the non-segregated bus being enclosed but in an outdoor application with no heater and not normally loaded the higher clearance would be more appropriate and therefore the insulation system would be required. The design of the ESST non-segregated bus meets existing codes.

During review for adequacy of design and operation, the design was determined to be adequate but additional actions were deemed to be justified to help prevent corona from occurring between the insulation and the bus bar support. As discussed below, 3M and Calvert Installation Services (CIS) recommended installation of silicon boots (grommets) in 2005 due to the discrepancies noted but no action was determined necessary at the time.

Review of adequate parts showed this failure was not attributed to a parts discrepancy. All parts needed for normal work were available and no parts were determined to have failed due to vendor quality or workmanship.

Review of the adequacy of the long range plan shows that there were no plans associated with the non-segregated bus work. The bus did not fail due to an aging or obsolescence concern. Corona is a long term degradation means. The bus was inspected in 2015 per maintenance

procedure 7.3.41 and failed 2 years later. The inspection, if performed with enough detail, should support bus operation for 10 years without failure.

Failure Mode

Per "EPRI NMAC Switchgear and Bus Maintenance guide" corona is defined as "ionization of the nitrogen in the air caused by an intense electric field." Corona occurs due to three main conditions: geometric factors, spatial factors and environmental conditions. Geometric factors include the sharp corners of the bus support insulators, spatial factors include the air gap between the bus bars and bus support insulators and environmental factors include the humidity/condensation in the bus duct. Once corona insulation damage has perforated the insulation, electrical tracking has the potential to develop. Any contamination such as humidity or condensation on the bus supports contributes to the potential for tracking.

With respect to this event, it's concluded that corona was present at the non-segregated bus support pieces. Corona occurred because the bus was energized, and because of the spatial relationship between the bus and the bus support pieces. Partial discharges, resulting from corona, occurred that degraded the bus insulation in proximity to the bus support pieces. Tracking on the surface of the bus support piece occurred over time, and the combination of degraded bus insulation at the bus support pieces, together with tracking on the bus support pieces between buses, caused the phase-to-phase fault. A detailed discussion of the failure mode is included as Attachment 6 to this evaluation.

Programmatic Impact

CNS is committed to establishing and maintaining a metal enclosed bus inspection program (reference USAR Appendix K, Section 2.1.22), as an aging management program in support of License Renewal. The scope of the program is inspection of non-segregated bus between the emergency station service transformer and 4.16 kV switchgear buses (1F and 1G), and the non-segregated bus between the start-up station service transformer X-winding and 4.16 kV switchgear buses (1A and 1B). The inspections include the bus and bus connections, the bus enclosure assemblies, and the bus insulation and insulators. This program was implemented consistent with the guidance contained in NUREG-1801 (Rev. 1), Section XI.E4, Metal-Enclosed Bus. The NUREG program description does not include discussion of Hi-pot testing, or other specific electrical testing (with the exception of resistance measurements of the bus bolted connections). The current revision (Rev. 2) of NUREG-1801 was reviewed, and similarly contains no additional discussion of electrical testing.

As discussed below, NFPA 70B provides useful insights regarding preventive maintenance programs for electrical equipment, including metal-enclosed buses. CNS is committed to implementing its Fire Protection Program in accordance with NFPA 0805, which includes a number of NFPA codes incorporated by reference. NFPA 70B is not required by NFPA 0805.

Regulatory Impact

As documented by CR 2017-05960, Inspection Report 2017011 (see Attachment) includes the following findings, characterized as apparent violations:

> *"1. A violation of Technical Specification 5.4.1.a, for the failure to implement inspection instructions to examine the emergency transformer bus insulation for discoloration and repair the associated components on March 23, 2015"*
>
> Information was provided to the inspector(s) that indicated that corona-related degradation was a slowly developing failure, and that degradation would have been present during the 2015 bus inspection. As a result, inspectors concluded that the 2015 ESST bus inspection was inadequate, but also concluded that the inspection procedure itself (Maintenance Procedure 7.3.41) was adequate to allow identification of corona-related bus insulation degradation, and questioned whether the inspection failure was related to training, inadequate corrective actions taken to address identified conditions, a failure to use internal operating experience, and/or inadequate bus testing.
>
> *"2. A violation of Technical Specification 5.4.1.a, for the failure to maintain adequate instructions for performing high potential testing of the emergency transformer bus bars between March 23, 2015 and April 18, 2017."*
>
> The inspectors determined that IEEE Standard C37.23-2003 was applicable to ESST bus testing, that the test methodology performed as part of the 2015 bus inspection was not consistent with that standard, and further concluded that the 2015 testing would not have identified the degraded ESST bus insulation. The IEEE standard recommends testing at approximately 14KV, for 1 minute, with the other two buses grounded. The 2015 testing consisted of AC Hi-pot testing at approximately 10KV on each bus, for 30 seconds, without grounding the other two buses. A conclusion of the Inspection Report was that this method of testing prevented identification of a potential fault path between phases. This issue is further discussed below.

Test Methodology

CR 2017-02164 identified an NRC concern regarding hi-pot testing of the ESST non-segregated bus, following failure and repair. Three issues were identified: the required duration of the test, the configuration of the bus during testing, and the test voltage value applied. MP 7.3.41 specifies AC Hi-pot testing at test voltage value of 10kV. At the time of the 2015 bus inspection, the Hi-pot test was conducted for 30 seconds, with the adjacent buses ungrounded. A revision to Maintenance Procedure 7.3.41 was made to resolve the first two issues (test

duration and bus configuration), but the value of 10KV test voltage was retained within the Maintenance Procedure.

With respect to test voltage values, the response to this Cat C condition report referenced IEEE Standard C37-23. As discussed in CR-CNS-2017-02164, the "rule of thumb" for hi-pot testing is to subject the product to twice its normal operating voltage, plus 1,000 Volts. For 4160V this is 2 X 4160 + 1000 = 9320V. This is then rounded to achieve a 10kV test voltage. Review of IEEE Standard C37.23, referenced in the condition report response, indicates the standard describes three different types of testing:

> Design Test: Those tests made to determine the adequacy of a particular type, style, or model of ME bus or its component parts to meet its assigned rating and to operate satisfactorily under normal service conditions or under special conditions, if specified. NOTE: Design tests are made only on a representative apparatus to substantiate the ratings assigned to all other apparatus of basically the same design. These tests are not intended to be used as a part of the normal production.
>
> Production test: Test made for quality control by the manufacturer on every device or representative samples, or on parts or materials required to verify during production that the product meets the design specifications and applicable standards.
>
> Field tests: Tests made after the assembly has been installed at its place of utilization.

The three types of tests discussed within the standard, design, production, and field tests, are applicable to design and manufacture of metal-enclosed buses, or following installation or modification.

AC Hi-pot testing (also known as dielectric strength testing) is a go-no go test, and its results are not trendable. A test failure is identified by a test equipment overcurrent trip, which occurs following an insulation failure and resulting insulation damage. It is considered more risky than a DC hi-pot test, because it necessarily produces higher values of test current, due to the capacitive effect of the equipment being tested (charging current). Therefore, if bus insulation breaks down during the test, higher values of test current would likely result in more significant bus damage. For this reason, AC Hi-pot testing is considered a potentially destructive test.

Maintenance Procedure 7.3.41 was revised in 2015 (Rev. 10) to perform AC Hi-pot testing on the non-segregated buses at 14.4 KV. Prior to that revision, testing of the buses was insulation resistance testing (meggering). The justification for the change was that the length of the buses made meggering impractical, because the test equipment couldn't provide enough charging current. During the 2015 ESST bus inspection, the test voltage value was revised by a field revision to the work instructions, to 10KV, and change request to MP 7.3.41 was submitted. The procedure was subsequently revised to reduce the test voltage to 10KV in January 2017 (Rev. 11), referencing ANSI Standard C50.10. That ANSI/IEEE standard recommended a test voltage

of twice line voltage plus 1000V (or approximately 10KV), for new windings of synchronous machines (for example, generators).

Neither IEEE C37.23, nor ANSI Standard C50.10 is applicable to periodic testing of metal-enclosed buses. A directly relevant standard is NFPA 70B-2016, "Recommended Practice for Electrical Equipment Maintenance". Section 20.4.8 of that standard includes recommendations regarding testing of metal-enclosed busways, and the relevant discussion is copied below:

> 20.4.8.1 Insulation resistance testing should be performed in accordance with 11.9.2.3 *(meggering)*.
>
> 20.4.8.2 If there is uncertainty concerning the adequacy of the insulation after insulation resistance testing, a high-potential test should be conducted. (See 11.9.3.1.) Normal high-potential voltages are twice rated voltage plus 1000 volts for 1 minute.
>
> 20.4.8.3 High-Potential Testing for Metal-Enclosed Busway. High-potential tests in accordance with IEEE C37.20.1, Standard for Metal-Enclosed Low-Voltage Power Circuit Breaker Switchgear, and IEEE C37.23, Standard for Metal-Enclosed Bus and Calculating Losses in Isolated-Phase Bus, should be conducted at 75 percent of the rated insulation withstand levels shown in Table 20.4.8.3. Because this might be above the corona starting voltage of some busways, frequent testing is undesirable.

The standard's recommendations are to perform meggering of the bus, and if desired, a Hi-pot test of the bus in addition. The Hi-pot test voltages should be (in this case) 10KV. Periodic Hi-pot testing at 14.4KV is 'undesirable', because that voltage may result in corona or accelerate the deleterious effects of corona. AC hi-pot testing of the non-segregated buses at 10KV is appropriate, because of the competing concerns of 1) providing adequate assurance that the bus has been adequately maintained and can be returned to service, and 2) reducing the potential for degrading or significantly damaging the bus as a result of the test. The procedure change that lowered this test voltage should have included a more thorough discussion, as well as the response to the subsequent Cat C condition report (CR 2017-02164), mainly with respect to the potential risks associated with AC Hi-pot testing.

Regarding bus configuration during testing Section 6.2.1.1 of IEEE Standard C37.23 for design tests states "test voltages shall be applied between each phase individually and ground in the following manner... c) For other types of bus, between each phase and ground with the other phases and the enclosure grounded." CNS testing in procedure 7.3.41 did not require grounding of phases not under test, and discussions with cognizant personnel indicate that, during the 2015 inspection, phases not under test were not grounded. Also, CNS testing in accordance with procedure 7.3.41 only required the voltage to be held for 30 seconds versus a minute due to a hold-over from megger testing. NFPA 70B-2016 and IEEE C37.23 both show that the test voltage values given are for a test duration of 1 minute.

It is concluded that the test voltage value of 10KV is adequately supported by industry guidance and standards, in particular NFPA 70B-2016. IEEE Standard C37.23 provides useful information regarding AC Hi-pot testing of metal-enclosed buses, but is not directly relevant. The change from 14KV to 10KV during the 2015 ESST bus inspection was performed following a test failure at 14KV, which necessitated extensive troubleshooting and repair, and discussions with personnel involved in that change indicate that the change was motivated by a concern that excessive test voltage may have caused the fault, rather than identifying a point of degraded bus insulation. However, it should be noted that the ESST was successfully hi-pot tested at 14KV in 2005 and 2011, so the 2015 test failure at that test voltage value could have prompted a more thorough evaluation of the cause.

With respect to the subsequent phase-to-phase bus fault, the test duration, and particularly the failure to ground the adjacent buses during the test, was a more significant error. It is possible that, even if the testing had been performed with the appropriate adjacent bus configuration for 1 minute, but at a higher than appropriate voltage, the test may have passed. However, it is concluded that the testing errors in 2015 reduced the probability of discovering (and correcting) the degraded bus insulation that eventually resulted in the 2017 bus fault. After identification of test methodology errors, as discussed above, the ESST non-segregated bus was successfully Hi-pot tested at approximately 10KV in May 2017, under Order 5185158, with the adjacent buses appropriately grounded, and a test duration of 1 minute.

CR-CNS-2005-03946

As discussed above, indications of ESST bus insulation damage were identified during the 2005 inspection, and the resulting evaluation of CR-CNS-2005-03946 represents the relevant internal operating experience with respect to the subject event. That Condition Report noted that discoloration of the bus insulation near the bus support pieces, and that the original equipment manufacturer advised that the discoloration was a probable indicator of corona degradation.

CR 2005-04036 was tied to the resulting apparent cause evaluation, and that Condition Report noted several additional concerns, including 1) the bus support pieces were found too tight on the bus insulation, such that movement of the bus bars due to thermal expansion was in question; 2) missing bus insulation underneath the bus support pieces; 3) concerns with the physical configuration of the Hi-pot test set; 4) use of a Hi-pot testing with insufficient capacity; 5) lack of guidance of Hi-pot test duration; and 6) water present in the bus enclosure.

The apparent cause evaluation performed for CR-CNS-2005-03946 included a problem statement describing discoloration of the ESST bus bar insulation around the bus support pieces, and also evaluated a number of other observed conditions found during the PM inspection (described above); including noting that the amount of insulation material found missing or damaged was greater at the bus support piece locations. The apparent cause was determined to be 'Corona effects being enhanced with moisture are causing accelerated degradation in the 3M insulating material.'

Two actions characterized as enhancements were identified - to determine and implement correct Hi-pot test methodology, and to revise the inspection PM's to include cleaning (of the insulation).

More significantly, the corrective action plan included the following:

- Evaluate the adequacy of the existing design of the bus, including H&V considerations of the bus enclosure. This action was closed by stating the existing design conformed to design requirements. Notification 10438420, which was an engineering request to install bus duct heaters, was cancelled.

- Determine a plan to address damaged areas of insulation, and consider insulation replacement and installation of silicon boots. This action was closed by generating two additional corrective actions, to track replacement of a third of the bus insulation from the ESST to the first vertical rise, and to perform a complete inspection of the remainder of the bus. Based on evaluation of damaged insulation sample and its significance (discussed below), these actions were closed with no action taken.

- Remove and evaluate a sample of damaged insulation. A sample was evaluated by Southwest Research, and concluded that the discoloration was superficial, and easily removed. A new action was created to revise Maintenance Procedure 7.3.41 to clean the discoloration of the bus insulation, if present.

The evaluation of CR 2005-03946 determined that bus insulation was not required, which was in error. It also concluded that even if the insulation failed, the bus bar spacing would prevent a phase to phase fault. That conclusion only considered the bus bar spacing, and did not consider the potential for tracking on the bus supports. Although the 2014 version of the National Electric Code (NEC-2014) specifies a minimum phase-to-phase clearance of 7 inches for this equipment at 4KV rated voltage, an analysis was performed, based on an extrapolation of Table 17-4 "Minimum Electrical Clearances for Standard BIL Outdoor Alternating current" of the standard Handbook of Electrical Engineers (Thirteenth Edition), that concluded that minimum clearance was 4.8 inches.

The substantive result of CR 2005-03946 was an incorrect conclusion that bus insulation was not required, due to the spacing between the buses. That conclusion failed to consider the potential impact of tracking across the bus bar supports.

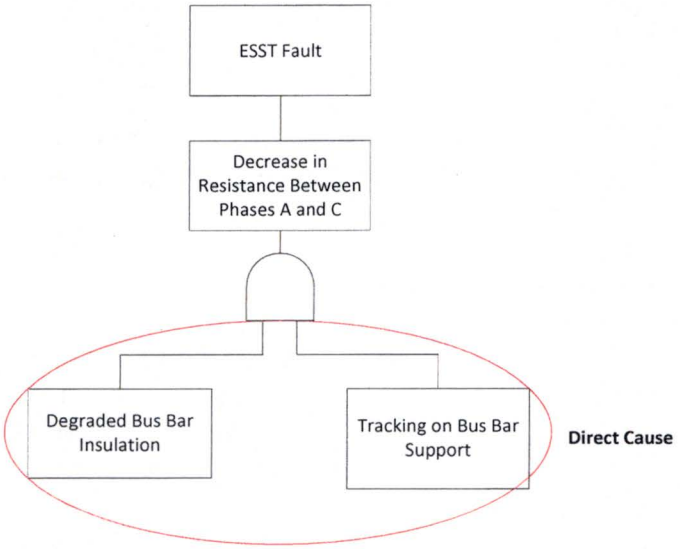
Cause Analysis

This Analysis was conducted using Failure Modes and Effects Analysis (FMEA), Equipment Failure Evaluation (EFE), and Why Analysis Logic Tree (WALT).

Direct Cause:

Degraded bus bar insulation combined with the formation of tracking on the bus bar support provided a path for current between phases of the ESST bus.

The Direct Cause is depicted in the WALT below.



The Direct Cause was present in 2017 because it was not identified in 2015 during the conduct of Procedure 7.3.41, Revision 10, EXAMINATION AND HIGH POT TESTING OF NON-SEGREGATED BUSES AND ASSOCIATED EQUIPMENT.

Review of 7.3.41, Revision 10, revealed that the procedure lacked precise guidance related to the extent of the inspection and the identification of bus damage or deficiencies. The procedure provided direction to remove bus bars 'as needed' to facilitate cleaning. This left the decision regarding whether to remove and examine the portion of the bus bar concealed at the interface with the support piece to the judgment of the Electrical Maintenance personnel.

Prior to 2016, Electrical Maintenance personnel did not receive training on Bus Maintenance as Training processes had identified Bus Maintenance as a task that did not require training. Subsequent to the 2015 inspection, maintenance training on non-segregated bus inspections was established. The lack of training with respect to corona damage left Electrical Maintenance personnel without the knowledge needed to make consistent judgements required by the procedure and increased the likelihood for errors in that regard.

Engineering personnel did not understand the potential significant effects of corona in conjunction with tracking. This lack of understanding resulted from the incorrect belief that the bus bar insulation was not needed and that damage to it was not a significant issue; this belief was based on flawed conclusions developed in CR-CNS-2005-04936.

Apparent Cause

Lack of organizational understanding of the possible failure mechanisms of the ESST non-segregated bus.

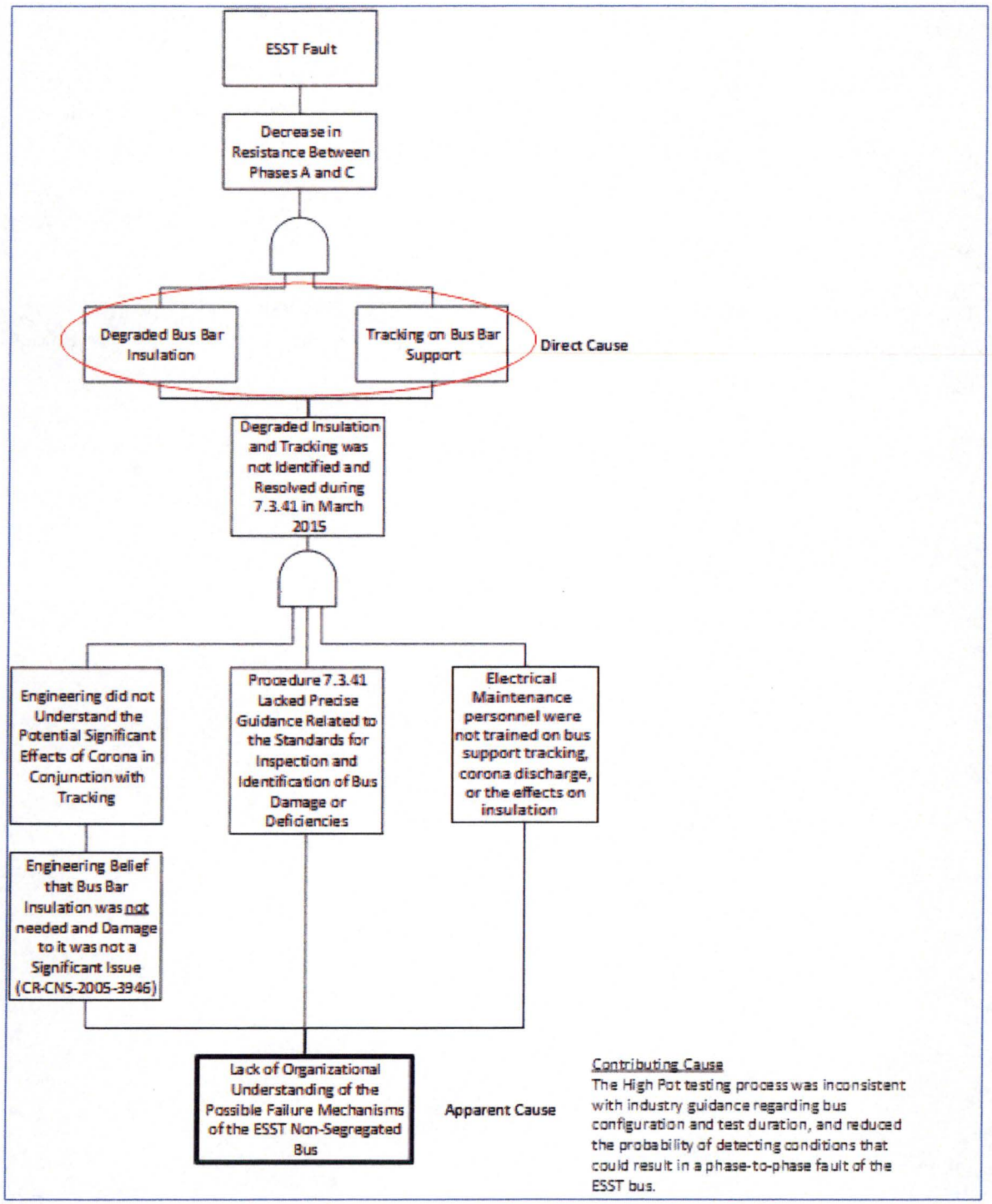
> The knowledge gap in the organization (Engineering and Maintenance)with respect to corona discharge, associated tracking, and their effects on insulation and bus failure were not well understood, leading to decisions that failed to maintain the reliability of the ESST bus.

Contributing Cause

The High Pot testing process was inconsistent with industry guidance regarding bus configuration and test duration, and reduced the probability of detecting conditions that could result in a phase-to-phase fault of the ESST bus.

The Why Analysis Logic Tree developed from this evaluation is provided on the next page.

Why Analysis Logic Tree



7.0 Corrective Action Plan

Immediate actions were taken on the ESST bus to minimize corona from forming at the locations where any degradation was found. This was done by installing a grommet over the support to minimize the air gap between the support and the bus bar. This also removes the sharp corners of the bus support insulators. Figure 6 shows a repaired section of the bus, where a tape repair has been made and grommets installed. Any support brackets with degradation on them were replaced and the support brackets bus side edges were coated with Synthite AC-46 which will minimize the formation of tracking. There were a few bus support insulators in the Critical Switchgear room that were not accessible for coating. The critical switchgear room is a climate controlled environment. Inspection findings showed no damage to insulation and therefore no coating is required on bus support insulators.

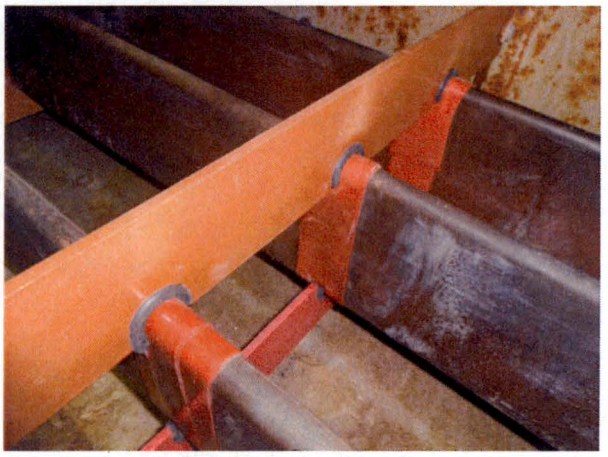


Figure 6: Grommets installed at tape splice location

Immediate corrective actions were taken to repair the ESST bus bar and duct sections that were damaged during the fault and also to inspect and repair the entire ESST bus. During inspection, tape repairs were made to the damaged insulation, grommets were installed in those locations to minimize corona, and the bus support insulators were coated on bus side edge to minimize tracking. Based on the extent of corona and tracking on the ESST bus, it is proposed that the bus bars be reinsulated, and new supports installed as required.

CR-CNS-2017-02164-CA-001 revised Maintenance Procedure 7.3.41 to include grounding the phases not under test and holding the test voltage for 1 minute.

A complete SSST X and Y-Winding inspection was performed in September 2017, and further verified the extent of condition. See Attachment 4. Prior to this inspection, a pre-job brief/tabletop review of inspection criteria and expectations was conducted. This included review of OE from the previous ESST bus fault.

The advisability of installation of heaters within the bus enclosure to minimize moisture, was considered. On further review, it is appropriate to perform a more detailed study of the configuration of the non-segregated buses, in order to ensure that their long-term reliability is enhanced to the extent practicable.

Similarly, reducing or eliminating the air gap between bus insulation and the bus support pieces may preclude corona from occurring to an extent which could challenge the long-term reliability of the ESST and SSST buses. This action is prudent.

Maintenance Procedure 7.3.41 was revised to ensure complete inspection of the insulation between the bus supports and the bus, which was effective during the 2017 SSST inspection.
Conclusion:

There is an outstanding action from the original apparent cause evaluation to re-insulate the ESST bus. In addition, there are new actions to reduce or eliminate the air gap between bus bar insulation and the bus support pieces on both ESST and SSST buses. These actions are being performed to enhance long term reliability of the bus. These actions provide a means to reset the condition of the ESST bus bar insulation and provide a preventive measure to minimize corona damage in the future for both ESST and SSST buses.

In order to address the knowledge gaps associated with corona discharge, tracking, and effects on bus insulation, Training Needs Analyses have been performed and concluded that training is appropriate for the organizations involved in non-segregated bus inspection and repair activities (Engineering & Maintenance).

As a result of lessons learned during recent bus inspections, it is prudent to provide further clarification within Maintenance Procedure 7.3.41 on how best to identify conditions of potential concern.

The aggregate of the actions associated with training and procedural changes will address the fundamental apparent cause of "Lack of Organizational Understanding". By incorporating the learnings of this event into training and procedures, the knowledge will be institutionalized to ensure future inspections successfully detect and correct conditions which threaten the reliability of the non-segregated buses.

Actions Completed

APPARENT OR CONTRIBUTING CAUSE, OR EXTENT OF CONDITION ISSUE	Actions Completed	Date Completed
Repair Condition	5173717- Repaired the ESST bus duct damaged by the fault	1/23/2017
AC/EOC	5173718- Examine the ESST Non-Seg 4160 Emergency Bus	1/23/2017
EOC	5115615- Perform CNS ESST Maintenance	1/21/2017

AC/EOC	CAT B-EOC: Inspect SSST X- Winding bus below the ESST bus fault, to look for damage, and spot check for corona damage	11/1/2017
CC	CR-CNS-2017-02164-CA-001 Update Procedure 7.3.41 to have the phases not under test to be grounded and the 10kV test voltage to be held for 1 minute	10/7/2017
AC	Provide additional instruction in Procedure 7.3.41 step 4.10.8 to specifically call out looking for tracking on insulator support pieces. Add steps to inspect and replace grommets if signs of degradation are present. Add steps to remove all supports to inspect for damage under the support. Add to information section OE on ESST fault.	7/14/2017
EOC	Maintenance Pre-job Brief/Tabletop review of inspection expectations prior to SSST non-segregated bus per 7.3.41 (WO 5069489)	9/22/17
EOC	Inspected and repaired SSST non-segregated bus per 7.3.41 (WO 5069489)	9/28/17
AC	Performance and Training Needs Analysis for Engineering and Maintenance completed to determine the appropriate training related to corona discharge, bust support tracking, and effect on bus insulation.	10/29/17

Corrective Action Plan

Identified Cause	Corrective Actions	Responsible Dept.	Due Date
AC	CAT B-AC: Replace 3M insulation on the ESST non-segregated bus. Reference SIPD Project #1455.	SED	11/23/2018 (LTCA for RE30)
AC	Revise Maintenance Procedure 7.3.41, to provide clearer inspection criteria, specifically with respect to support piece tracking and	MNT	2/1/2018

	corona effect on bus insulation.		
AC	Develop and implement training in accordance with SAT process related to non-segregated bus failure mechanisms, specifically with respect to corona and support piece tracking.	MNT	4/30/2018
General	Perform an engineering study, using independent industry expertise, on the advisability of space heaters and periodic replacement of bus support pieces in the ESST non-segregated metal-enclosed bus. Initiate follow-up actions based on results of study.	DED	6/1/2018
General	Review current method of repair versus replacement of damaged bus insulation. Initiate additional actions to ensure the appropriate insulation repairs are incorporated in 7.3.41.	SED	2/1/2018
AC	Develop and implement training (Just-in-time) in accordance with SAT process related to non-segregated bus failure mechanisms, specifically with respect to corona and support piece tracking.	SED	4/30/2018
General	Reduce or eliminate the air gap between the bus insulation and bus support pieces, on the ESST non-segregated bus. This action will include any required engineering documentation to support the action.	DED	11/23/2018
General	Reduce or eliminate the air gap between the bus insulation and bus support pieces, on the SSST non-segregated bus. This action will include any required engineering documentation to support the action.	DED	8/1/2018

Effectiveness Review Plan

LO Number:
Method: Inspect a representative sample of the ESST non-segregated bus in accordance with Maintenance Procedure 7.3.41.
Attributes: Following ESST bus insulation replacement, damage to bus insulation due to corona, and indications of bus support tracking, should not occur.
Success: No indications of significant corona damage, or tracking on the bus supports, on the ESST non-segregated bus following inspection and successful hi-pot testing

Timeliness: Bus re-insulation is planned for RE30. Corona damage and support tracking is considered a relatively long-term degradation mechanism. The inspection must be performed with the bus de-energized.	
Owner Group: MNT	**Due Date: November 2020**

LO Number:
Method: Inspect a representative sample of the SSST non-segregated bus in accordance with Maintenance Procedure 7.3.41.
Attributes: Damage to bus insulation due to corona, and indications of bus support tracking, should not occur.
Success: No indications of significant corona damage, or tracking on the bus supports, on the SSST non-segregated bus following inspection and successful hi-pot testing.
Timeliness: Corona damage and support tracking is considered a relatively long-term degradation mechanism. The inspection must be performed with the bus de-energized.
Owner Group: MNT — **Due Date: November 2020**

8.0 Trend Data

Cause Codes

Apparent Cause(s): OP4A - Insufficient Details

Contributing Cause:

Other Codes

INPO Binning codes: MA2 - Conduct of Maintenance

Safety-Culture Codes

Safety Culture Impact Codes: H.9 - Training

9.0 References

Documents Reviewed

TR-1013457 EPRI NMAC Switchgear and Bus Maintenance Guide

Information Notice 89-64 Electrical Bus Bar Failure

WI 90-1898 Inspection of Non-Segregated Bus (Startup Side)

CR-CNS-2005-03946 ESST Bus Discolored

5002481 REV-5 EXAM 4160V NON-SEGREGATED BUSWORK

National Electric Code (NEC) 2014 Edition

Standard Handbook for Electrical Engineers (Thirteenth Edition), Donald G. Fink and H. Wayne Brady, July 31 1993

IEEE C37.23-2003 IEEE Standard for Metal-Enclosed Bus

NFPA 70B-2016, Recommended Practice for Electrical Equipment Maintenance

IEEE High Voltage And Electrical Insulation Engineering

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10.0 Attachments

Attachment 1 - FMEA ESST

Attachment 2 - Equipment Failure Evaluation

Attachment 3 - CR 2017-05802 Response

Attachment 4 - SSST Bus Inspection Results

Attachment 5 - Inspection Report 2017011, Excerpt

Attachment 6 - ESST Fault Mechanisms