ARC FLASH INCIDENT DUE TO FAULTY SUBSTATION GROUND GRID

Lyndal Cost
Alabama Power a Southern Company

ABSTRACT

This paper provides an in-depth analysis of the deterioration observed in a ground grid system at an Alabama Power Company facility. Ground grids are crucial for maintaining electrical safety and operational efficiency by providing a reliable grounding system for electrical equipment. The focus of this investigation is a single ground grid that showed signs of degradation. The findings revealed critical weaknesses in the ground grid that compromised its effectiveness and posed potential risks to both equipment and personnel. The paper discusses the immediate and long-term implications of the compromised ground grid on the facility's overall electrical infrastructure. Furthermore, it outlines a detailed remediation plan, including maintenance and replacement strategies, to restore the ground grid to its optimal condition and ensure the continued safety and reliability of the electrical systems.

INTRODUCTION

On Wednesday, March 27, 2024, a team was performing planned work to troubleshoot the X2 transformer bushing due to an elevated power factor identified by the bushing monitor at a distribution substation. The site has two 115/12.47 40 MVA banks. The work required isolating and power factor testing the number 1 bank transformer only. The switching plan included closing the bus tie then enabling the number 2 bank transformer to provide uninterrupted service to customers. Clearance was issued with the appropriate switching being completed, absence of voltage verified, and temporary grounds (TPG) applied per grounding procedures. One set of grounds was connected to all three phases and the neutral on the low side leads, and a second set of TPGs was connected to all three phases and to the ground on the high side leads.

Once clearance was obtained, after absence of voltage verified, and TPGs applied, the crew began the process of isolating the line leads from the transformer bushings. A journeyman electrician proceeded to disconnect/unbolt phase (X2) from the transformer and place the loose end of the lead onto the transformer's tank cover. As the lead made contact with the tank cover, an arc occurred, the sound of which was similar to an arc welder's arc, with significant sparks at the contact point. Immediately, the crew stopped all work activities and a "Safety Standdown" was initiated to investigate the cause and determine how to proceed safely.

The crew determined they needed to isolate the transformer neutral lead from the system to continue work. Additional TPGs were applied to bond the neutral and phase leads to the transformer ground. A clip-on amp meter measured 145 amps flowing in the TPGs passing through to the grounded transformer tank into the ground field. The crew then proceeded to safely test the transformer and bushings.

The subsequent investigation by the crew identified a defective cold abutment (CAD) weld connection below grade that compromised the grounding grid, resulting in a "floating neutral." The defective weld, which had possibly been compromised since the construction of the ground field, resulted in a break in the continuity of the ground field. An in-depth analysis of the deterioration, active causes, latent conditions, contributing factors, recommendations, and action items resulting from this event will be detailed in the paper.

EVENT LEARNING

Active Cause(s):

It was determined that the reliability/function of the grounding grid was compromised. An underground CAD weld between the neutral's isolated vertical riser and the grounding grid separated, breaking continuity. From inspection, it was determined that the CAD weld was defective from the time the ground field was constructed. Without ground field continuity, the neutral return current, from the distribution lines on Bank #1, traveled through the low side TPGs connected to the isolated phases. When the X2 phase was unbolted and the loose end placed onto the transformer tank, it provided a path through the tank's case ground. This resulted in the arc. The failure of the CAD weld resulted in a "floating neutral." The diagram in Figure 1 helps to illustrate the fault condition.

Latent Conditions/ Contributing Factors:

The grounding scheme at the substation was compromised and ineffective, with the defect not being apparent before work began. Much of the grounding grid is underground, making it difficult to detect issues like broken wires or connections. There is no requirement to test the grounding scheme for continuity before starting work. A poorly made CAD weld connection between the neutral and the ground grid worsened over time, leading to a complete separation between the substation neutral bus and the ground grid (See Figure 2). This condition likely existed for years. Previous copper thefts necessitated repairs to the grounding grid, and subsequent testing found additional structures not bonded to the ground grid, although this did not contribute to the incident. There are no current formal preventive maintenance inspections for underground grounding grids, with the current strategy being run to failure.

The grounding design resulted in a single point of failure, with the neutral having a single riser attached to the grounding grid and insulated from adjacent steel structures. This created a deficient grounding scheme. The Substation Design Criteria Manual now requires the insulated neutral bus to be grounded in two locations for redundancy.

Neutral wires are not required to be physically disconnected when preparing for clearance, with temporary grounds being the preferred practice. However, this can lead to a false sense of security if there is a breach in continuity. Unless feeders are perfectly balanced, neutral current will flow between the feeder neutrals, substation neutral bus, and ground field, provided there is continuity to ground. If the neutral ground riser lacks continuity, the neutral will be floating, posing a risk to employees.

The Substation Design Criteria Manual was revised in 2015 to address this issue, stating that the insulated neutral bus should be grounded in two locations for redundancy. However, the manual uses the word "should" instead of "shall," and the management of change was inadequate, failing to audit substations for deficiencies and make necessary upgrades.

WORK PRACTICES: WHAT WENT WELL

All employees were wearing the standard PPE required for the task. Clearance was issued with the appropriate switching being completed and temporary grounds applied per grounding procedures. The crew initiated a "Stop Work," safely conducted troubleshooting, and collected detailed information for the investigation. The wire at the failed connection was preserved for future analysis.

ADDITIONAL DISCOVERY

After repairing the deteriorated connection on the #1 Bank, the entire ground grid was tested, revealing additional issues.

- The #2 bank high-side circuit switcher had no earth ground reference. Each structure leg had a ground riser, however they were bonded to each other and not the ground field. See Figure 3.

- The #1 distribution capacitor bank had high resistance on each of the four ground risers. Further investigation revealed that all four risers were bonded together with a single common connection to the ground grid, which was compromised, instead of four individual connections. See Figure 4.

RECOMMENDATIONS

Issue a safety alert to communicate details of the incident and emphasize the importance of verifying grounding integrity before beginning work. Highlight the risks associated with compromised grounding schemes and floating neutrals.

Create work orders to inspect each substation for the presence of an insulated neutral ground riser. If an insulated neutral is found, follow safe work practices to bond the insulated neutral riser to the structure leg ground. Name the activity "Inspect for Insulated Neutral Riser & Bond." Implement inspections and the practice of taking corrective actions as required to bond the insulated neutral riser to the structure ground. Document corrective actions in the "Comments" section of the work orders and close them.

Require ground grid testing following any new construction, excavation/digging, copper theft, and confirmed lightning strikes to the bus or equipment resulting in ground field damage.

Recommend changes to the Southern Company TPG Committee to ensure adequate continuity of the TPG connection to ground before installation.

Benchmark testing will be completed within four years and routine testing every eight years thereafter.

Ensure that work methods and training are up to date regarding the proper installation of CAD welds for ground grids in substations. Reinforce the importance of self-checking and peer checking by Construction and Maintenance personnel before covering buried ground grid connections.

CONCLUSIONS

Ground grids are:

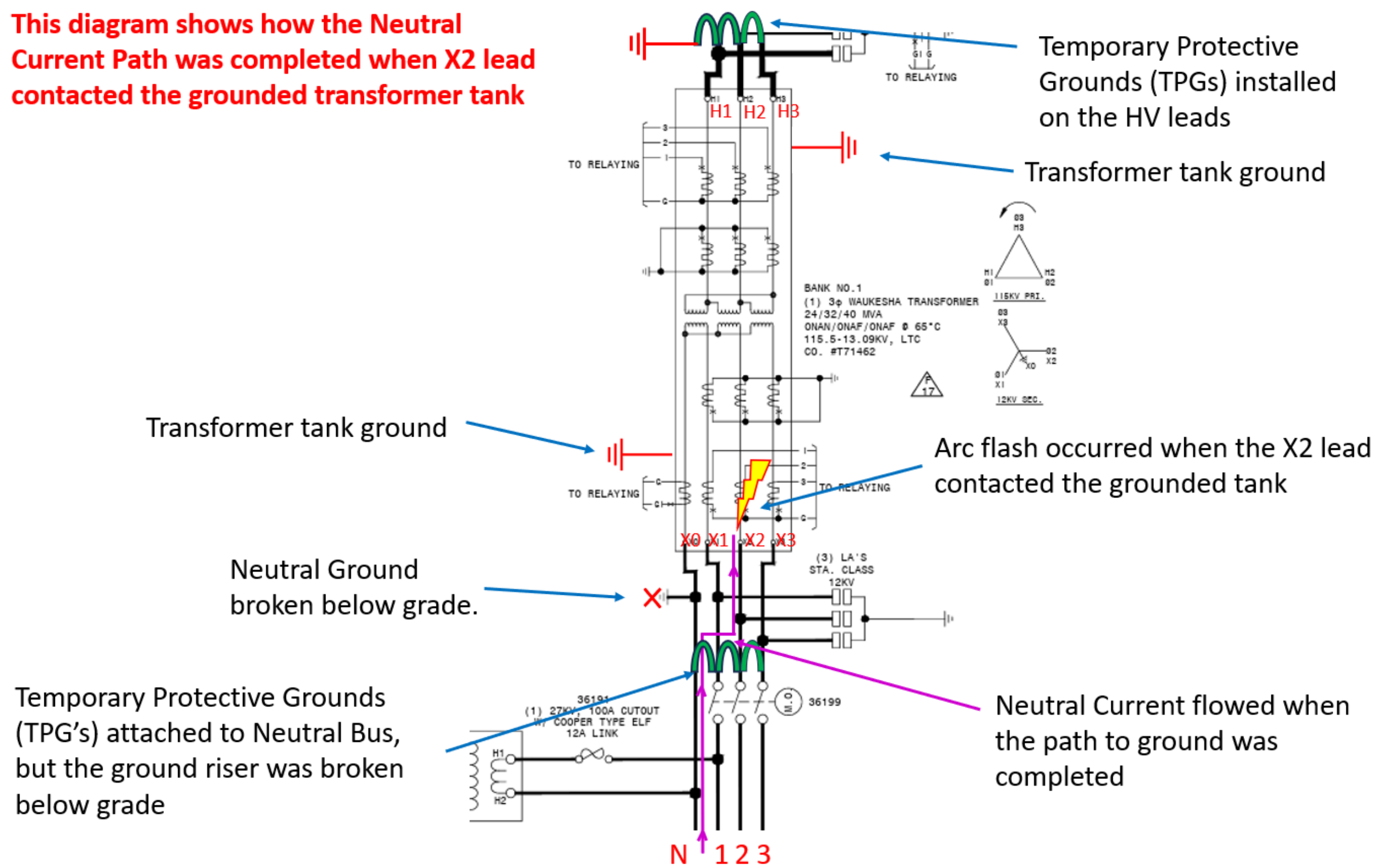
- Easily forgotten and ignored

Ground grids are critical systems for the:

- Safety of substation personnel and the public
- Protection of equipment
- Operational security

A ground grid is complex and should be regularly tested.

Do you know the condition of your substation ground grids?



This diagram shows how the Neutral Current Path was completed when X2 lead contacted the grounded transformer tank
Temporary Protective Grounds (TPGs) installed on the HV leads
TO RELAYING
H1
H2
H3
Transformer tank ground
TO RELAYING
BANK NO.1
(1) 3φ WAUKESHA TRANSFORMER
24/32/40 MVA
ONAN/ONAF/ONAF @ 65°C
115.5-13.09KV, LTC
CO. #T71462
115KV PRI.
12KV SEC.
Transformer tank ground
Arc flash occurred when the X2 lead contacted the grounded tank
TO RELAYING
TO RELAYING
X0
X1
X2
X3
(3) LA'S
STA. CLASS
12KV
Neutral Ground broken below grade.
Temporary Protective Grounds (TPG's) attached to Neutral Bus, but the ground riser was broken below grade
36191
(1) 27KV, 100A CUTOUT
W/ COOPER TYPE ELF
12A LINK
36199
Neutral Current flowed when the path to ground was completed
N
1
2
3

Figure 1

The cad weld appeared to have high porosity and missing much of the expected weld material indicating that this defect likely occurred when the station was constructed.

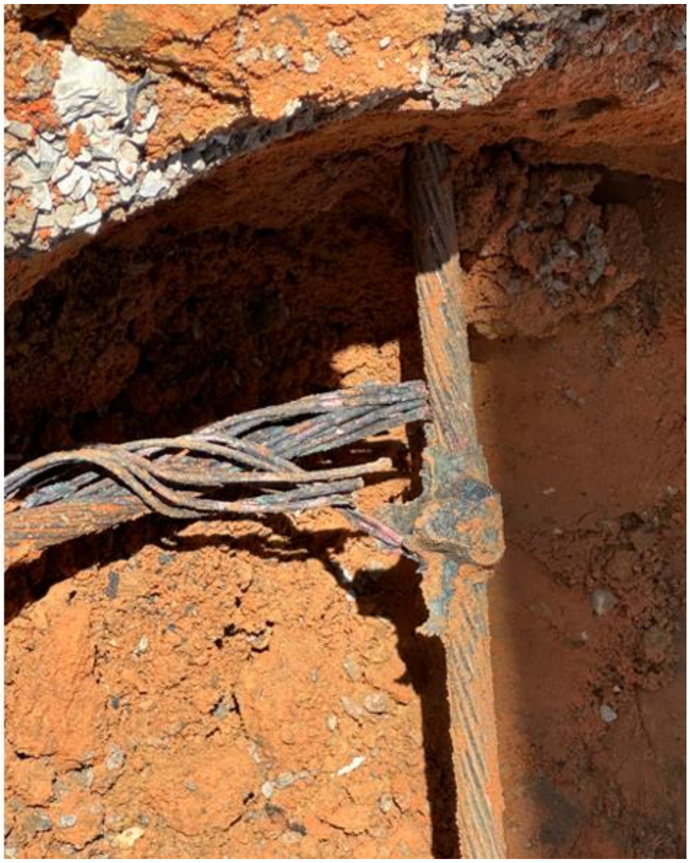


Figure 2

The Bank #2 High Side Series 2000 Circuit Switcher (#19992) structure had no earth ground reference on either of the two support legs. Each leg was bonded together with a common ground wire, but neither was connected to the Ground field.

If Bank 2 were removed from service and the HV leads grounded, one of these two risers would have been used to ground the transformer.

Figure 3

The Bank #1 distribution Capacitor Bank had high resistance readings on each leg of the structure going to the Ground field. All four grounding wires were bonded together to a single common wire that had a bad connection to the Ground grid.

Figure 4

BIOGRAPHY

Lyndal Cost has 41 years of experience at Alabama Power. He has 13 years of experience refurbishing power transformers and load tap changers. He has 29 years in the equipment test group, where he held the positions of Substation Specialist, Team Leader and is currently The Equipment Test Supervisor. His group performs electrical testing, oil analysis, infrared testing, corona scans, battery testing, drone inspections, CBM monitor installations, factory equipment inspections and major equipment field repairs.