SUBSTATION GROUNDING SYSTEM EVALUATION CONDUCTED BY VIRGINIA POWER

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INTRODUCTION

A properly designed, installed and maintained grounding system is the basis for establishing a safe and reliable substation. Improper grounding has the potential effects of creating:

1. Poor relay coordination.

2. Decrease in lightning arrester protection for power transformers and distribution get aways.

3. Increase in ground potential rise and mesh voltages.

4. Undesirable current flow in non-intentional ground paths.

HISTORY

Over the years, Virginia Power has used various grounding hardware components in the installation of ground grids. Each change was with the intent of providing the best corrective action to a given installation problem, and with putting grounding connection problems to rest. Unfortunately, that was not the case. In 1991 Virginia Power spent $320,000 repairing or replacing substation ground grids and in 1992 an additional $290,000.

In order to better understand our plight, some historical information will be of benefit. Prior to 1974 a meggar test was performed on each riser as an indication of the integrity of the ground grid. In 1974 as the result of a paper presented at a Southeastern Electric Exchange conference, Virginia Power started using a high current (300 amps A.C.) injection test procedure. The early findings were numerous with many conditions that could have jeopardized personnel or created operating problems if not corrected. The early success of this testing obscured the degree of degradation and the need to establish more stringent acceptance criteria.

During the late 70's and 80's, Virginia Power was involved in an aggressive construction program, and in several areas the construction outpaced the ability of the work force to perform the ground grid integrity acceptance test. As the construction projects were curtailed in 1990, manpower became available to investigate problems which were felt to be grounding related.

As a result of the quantity of connector problems discovered, a pilot program was started to develop D.C. test criteria for a more effective evaluation of grid connectors. The D.C. test method was necessary to eliminate the influence of inductance of the grid conductors and the normal A.C. current flows in an energized substation grid.

During this period we also performed an evaluation of the exothermic welding process to determine the cause of the problems previously experienced with its use. After several trial installations and the change from the use of seven strand hard drawn #4/0 copper conductor to the use of 19 strand soft drawn #4/0 copper conductor, the exothermic process was reinstated as the only approved below grade connection for use in substation construction.

In 1992 a study was initiated to evaluate select substations in each of our five divisions to determine the physical condition of the ground grid system. This project was originally compiled of 17 substations selected on the basis of having histories of transient disturbances and equipment component failures believed to be caused by grounding deficiencies.

The study was performed in conjunction with refining the new D.C. test procedure based on computer modeling of seven substation ground grid systems. The computer was utilized to calculate the actual substation ground grid voltages and currents resulting from D.C. current injection.

The preliminary testing indicated that 700 of 4500 (15.6%) risers had questionable readings. Of these, 230 (5.1%) were determined to have unacceptable connections. The other 470 risers were influenced by damaged segments or bad connections nearby and actual installation routing that deviated from design.

INITIAL TEST FINDINGS

1. Construction activities and SCADA installation in existing stations had damaged the existing grid system and severed equipment ground risers creating isolated grid sections and inadequately bonded grid sections. **FIGURE 1**

2. Distribution circuit neutrals were not bonded effectively to the grid.

3. Transformer and capacitor neutral connections were deteriorated.

4. Transmission line and substation shield wires terminations were deteriorated. **FIGURE 2**

5. Grid segments were not installed and the grid was not installed as designed.

6. Damage and deterioration created excessive current to flow in non-intentional ground paths (galvanized conduit, interphase piping and control wire cable trays). **FIGURE 3**

GROUND SYSTEM HARDWARE PROBLEMS PRIOR TO 1991

1. Exothermic Welding Process

   a. Installers and inspectors were not always properly trained.

   b. Mixed various vendors materials without regard to compatibility and used wrong size and type of weld metals.

   c. Did not properly clean or dry conductors prior to welding process creating blow-back and contaminated welds with voids.

   d. Improper storage of weld metals.

e. Improper cleaning of molds, use of improper molds for conductor sizes, and prolonged use of worn out or damaged molds.

f. Molds were not properly adjusted or fully closed. **FIGURE 4**

* 2. Compression Connections

a. Compression tools did not apply sufficient compressive forces. **FIGURE 5**

b. Use of incorrect dies.

c. Connector was not properly installed. **FIGURE 6**

d. Conductor was not properly cleaned.

e. Lack of corrosion inhibitor or inhibitor failure. **FIGURE 7**

f. Repeated high current surges deteriorated connections.

3. Bolted Connections

a. Most low resistivity corrosion resistant materials provide low clamping forces could not withstand the expansive forces generated by the corrosion process. Others were installed with too little clamping force or over-stressed to yield point of the fastener. **FIGURES 8 & 9**

b. Connector was not properly installed. **FIGURES 10 & 11**

c. Conductor was not properly cleaned.

d. Lack of corrosion inhibitor or inhibitor failure.

e. Repeated high current surges deteriorated connections.

OTHER FACTORS THAT INFLUENCE DETERIORATION OF GRID INTEGRITY

1. Older substations were not designed to adequately handle today's fault currents.

2. Lack of communicating importance of preventing damage to grounding grid systems by contractors utilized by other company construction departments such as power stations, distribution and transmission. **FIGURE 12**

CHANGES AND BENEFITS RESULTING FROM EVALUATION (1991-1992)

1. Properly installed exothermic welded connections exhibited no measurable increase in resistivity after many years of service. It was found that poor workmanship and damage caused by construction activities created previous problems with the exothermic connections.

2. Many mechanical and compression connectors on ground rods were found loose. It is now standard procedure to make exothermic welded connections from conductor to ground rod.

3. Exothermic welded connection are now made on rod to rod connection to eliminate loose couplings and stripped threads.

4. Various manufacturers of cable locators proved beneficial in locating substation ground grid systems. This is a two-fold benefit for future substation work in that it can be used to determine location and depth for repairs and can prevent damage created by construction activities.

REPAIRS VERSUS REPLACEMENT

It is labor intensive to make extensive repairs to an existing substation of significant size where grid spacings and conductor size may not be adequate for present fault current levels. It is often less labor intensive and more cost effective to overlay a new grid that meets today's criteria. Although partial overlays and high current ground bus overlays can be cost effective and delay major grid expenditures.

PRESENT AND FUTURE FOCUS

We have fully implemented the D.C. test methodology and are testing substation ground grids on a priority basis. Repairs or corrective actions are made to immediate safety concerns found involving high probability of personnel exposure. As test results are evaluated a schedule and course of action will be developed for inclusion in the corporate five year plan.

In the fall of 1993 testing will begin of the substation ground systems effectiveness in handling high frequency transients.

FIGURE 9
Current path starting to experience thermal damage and gradual increase of connector resistance.

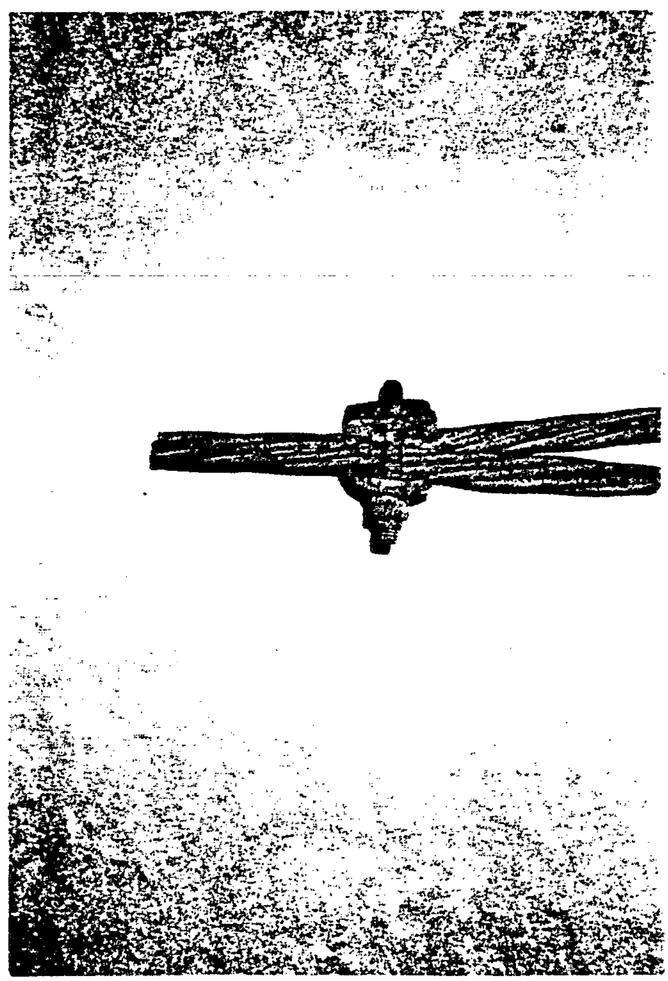

FIGURE 10
Conductors not properly installed between saddles of the connector, creating high resistance current paths.

FIGURE 11
Angle of the ground riser conductor caused the self torquing head to shear prior to properly seating the wedge to provide clamping force.

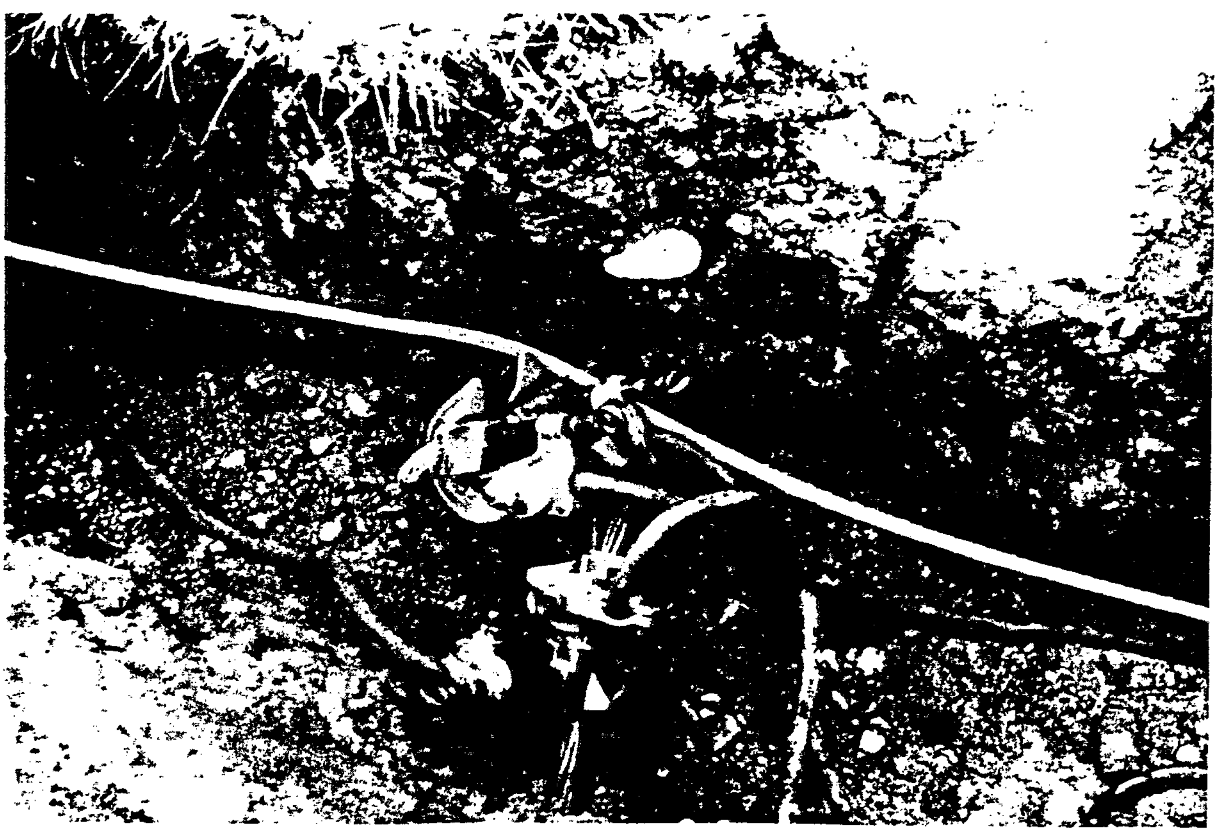

FIGURE 12
Damage to switchyard ground ties to power station, due to installation of water line.

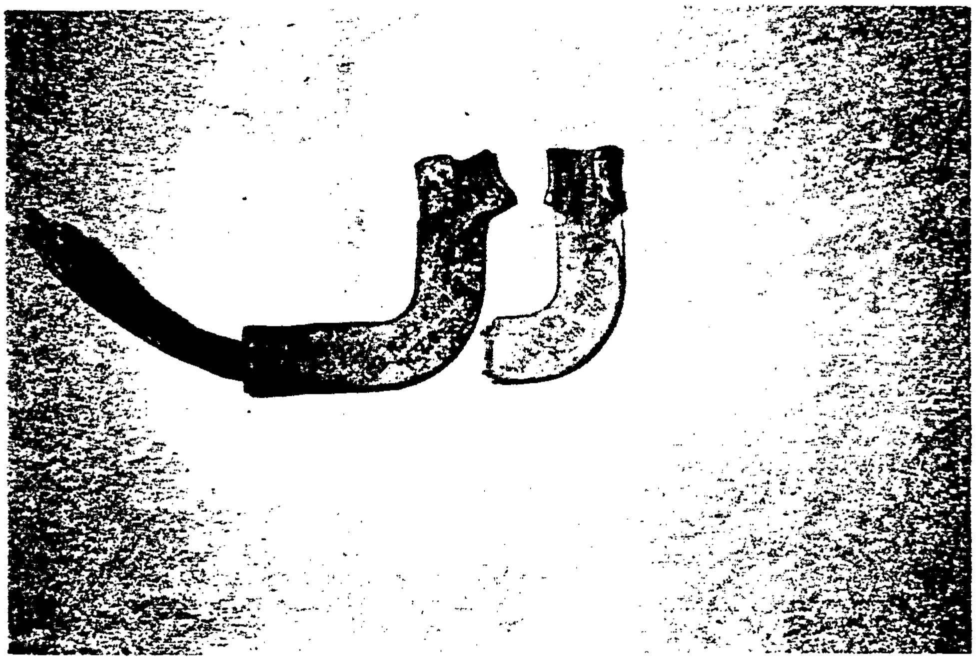

FIGURE 7
Current path corroded due to inhibitor failure.

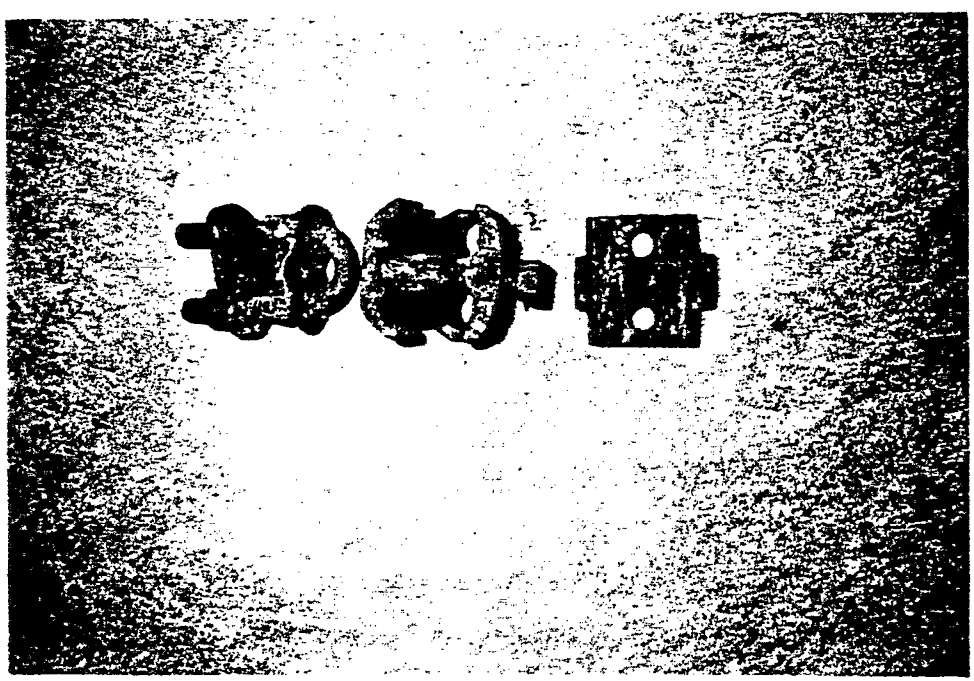

FIGURE 8
Inhibitor failure allowed expansive forces of corrosion to create high resistance current path.

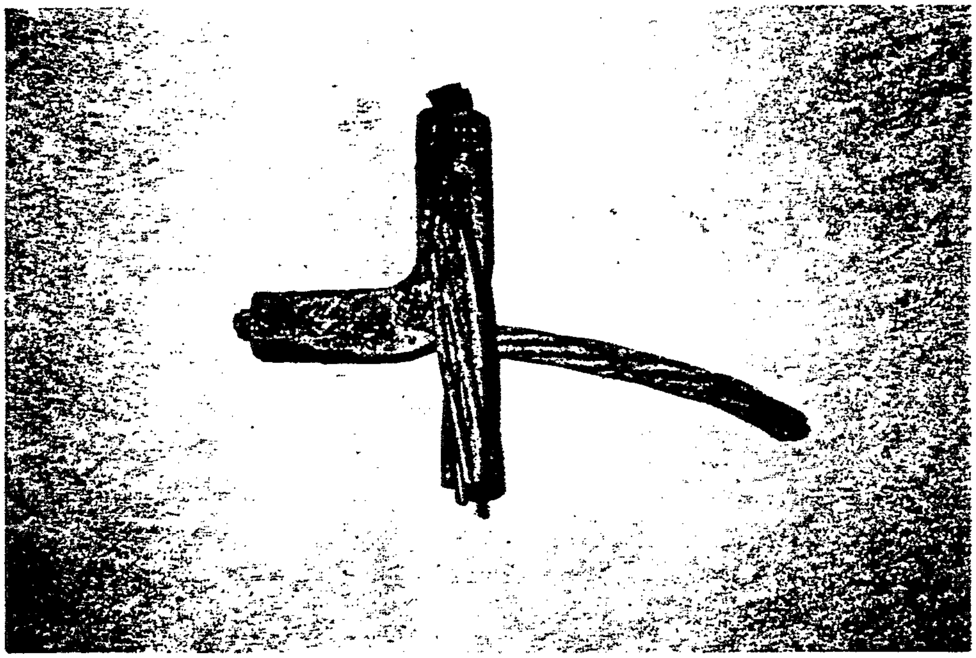

FIGURE 5
Conductor was not fully enclosed due to insufficient compressive force.

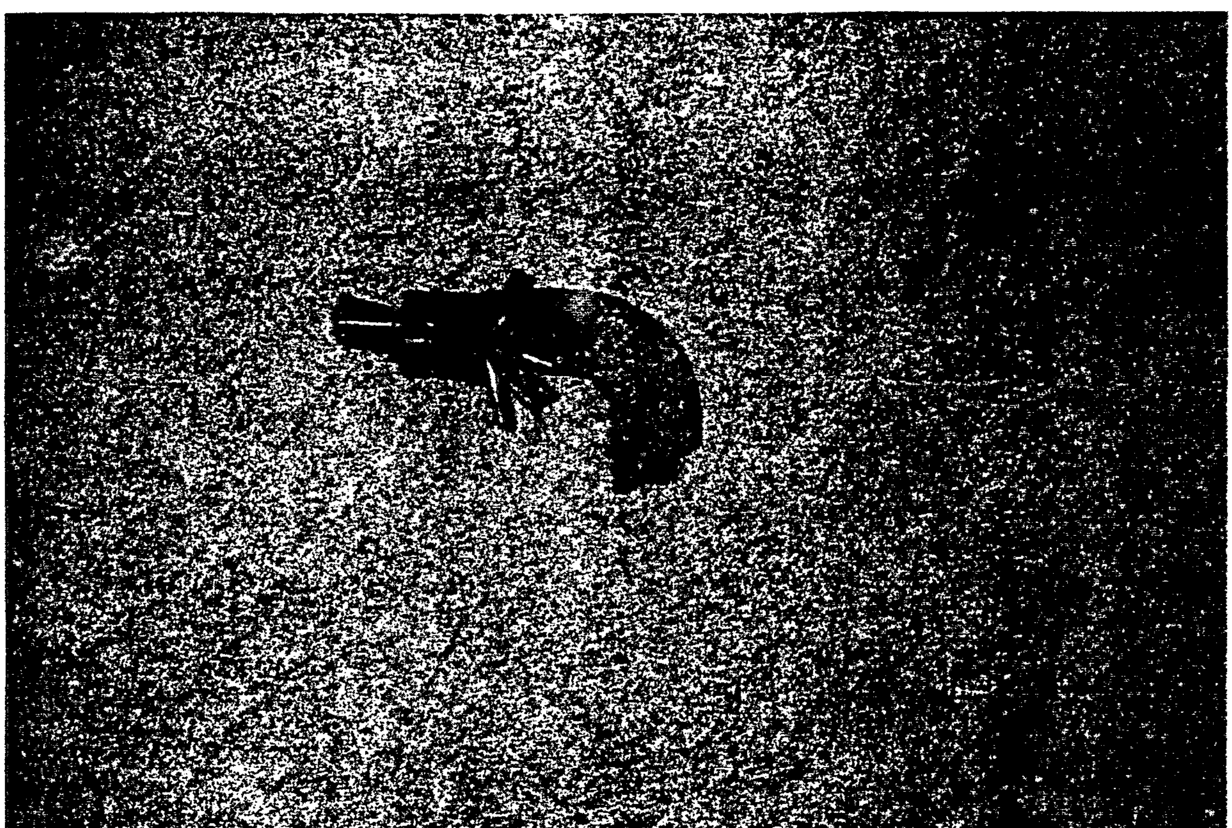

FIGURE 6
Connector was not properly installed on conductor, exposed stranding prevented die from closing correctly.

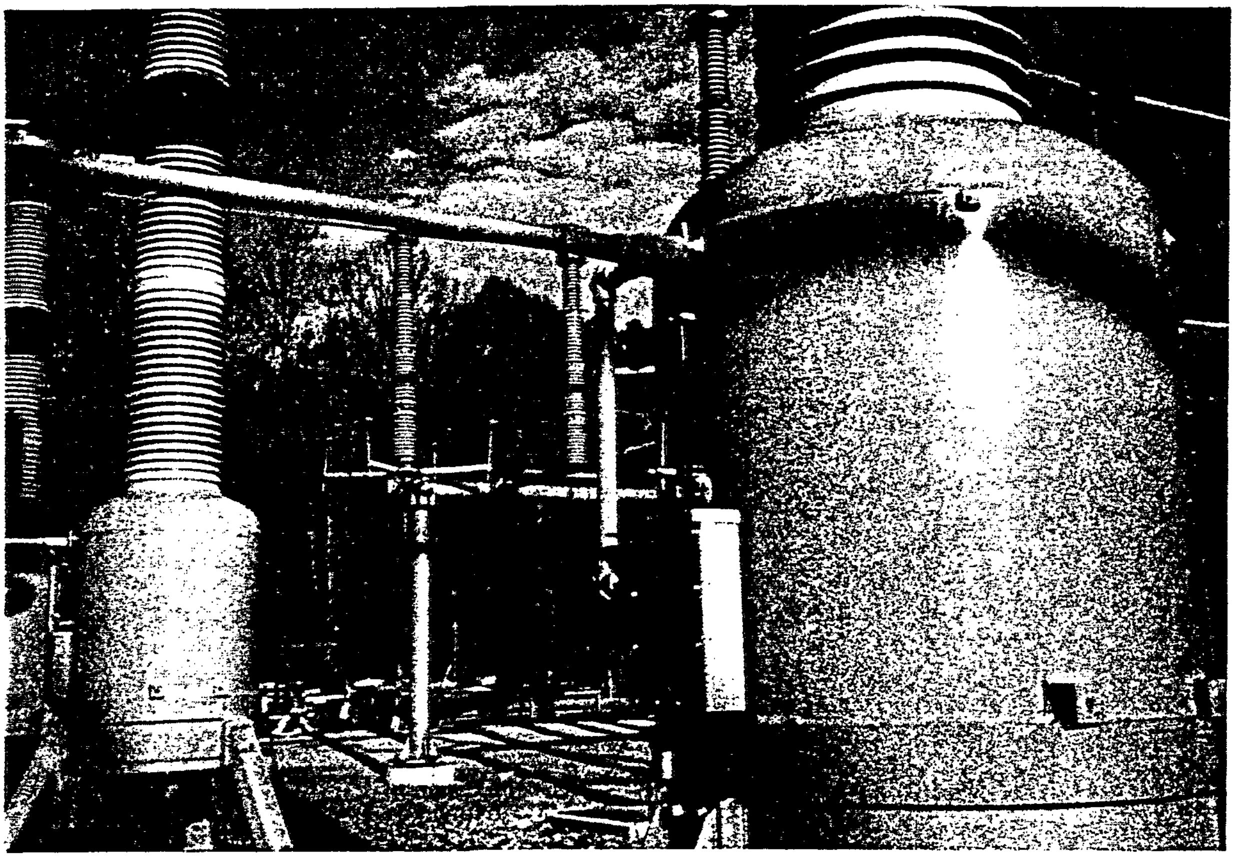

FIGURE 3
Damage to grid isolated 500 kv CT, creating non-intentional ground path through the conduit and 1/8 inch stainless steel tubing in the SF_6 system.

FIGURE 4
Bad exothermic connection created by not insuring mold was fully closed.

FIGURE 1
Grid severed by foundation contractor.

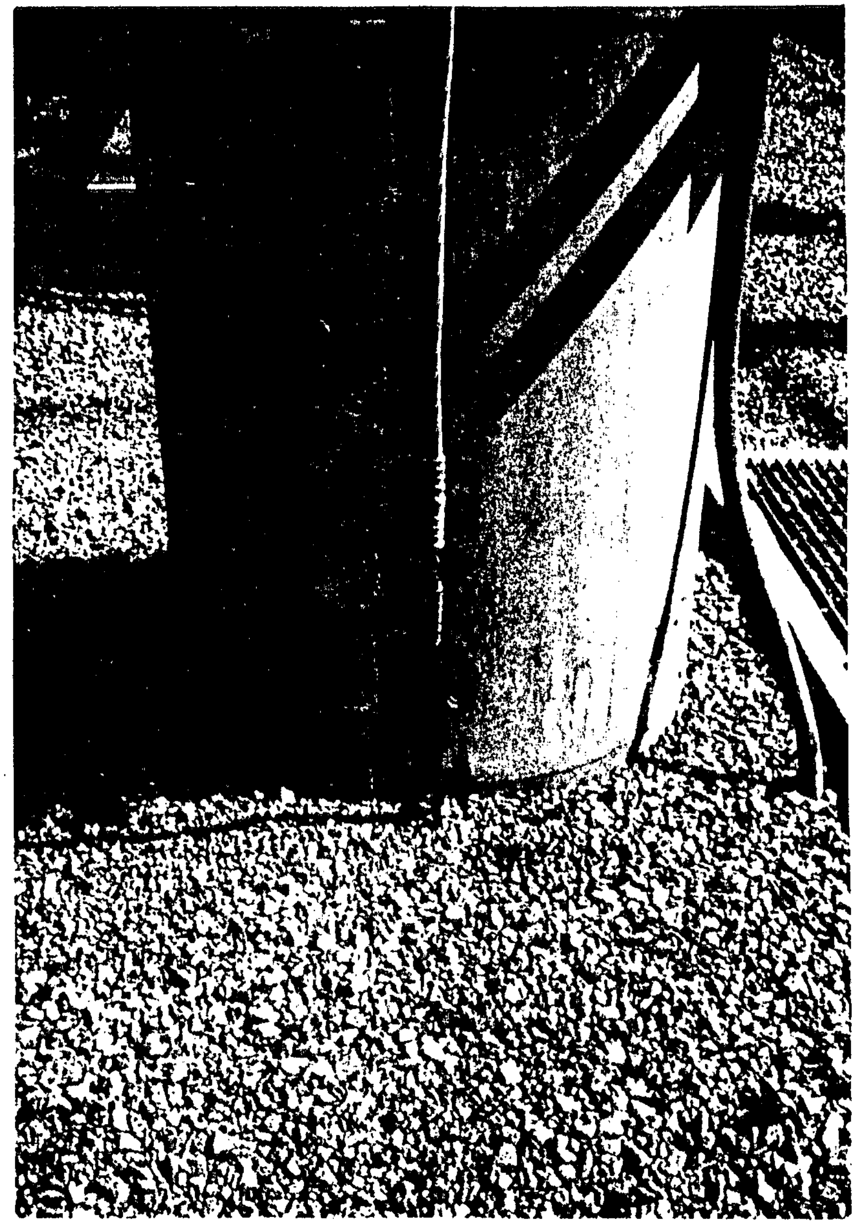

FIGURE 2
Transmission line shield wire splice interface deteriorating (4/0 aluminum to 4/0 copper).