State of California
Public Utilities Commission

Investigation Report
on
PG&E Mission Substation Fire and Outage

December 20, 2003, San Francisco

** REDACTED **

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Executive Summary

Background

On December 20, 2003, a fire in Pacific Gas and Electric Company's (PG&E's) Mission Substation caused an outage to more than 100,000 customers throughout San Francisco, including downtown retail stores filled with shoppers on a peak holiday shopping weekend. There was substantial smoke, but the fire that was the source of the smoke was not located for almost five hours.

PG&E did not call the San Francisco Fire Department (SFFD) until two hours after the first signs of trouble at the Mission Substation. SFFD firefighters arrived within minutes of being called, cleared the smoke, were unable to locate the fire that was the source of the smoke, and PG&E restored service to about one-half of its affected customers. Approximately one hour after service was restored to these customers, PG&E located the fire, once again, interrupted service to the customers it had just recently restored. The SFFD fought and extinguished the fire and PG&E once again began the task of restoring service to all of its affected customers. PG&E completed that task late in the evening of the next day.

The California Public Utilities Commission (CPUC) initiated an independent investigation immediately following the incident. The team that was selected was tasked with determining what happened, why it happened, and what could be done to prevent or minimize a recurrence of this type of incident, at the Mission Substation and any other indoor substations.

The CPUC's Consumer Protection and Safety Division's (CPSD) investigation team worked independently, but collaboratively with PG&E personnel, and monitored the content and status of PG&E's investigation and related findings. CPSD has also issued numerous requests for information (data requests) to PG&E, conducted in-depth joint interviews of PG&E and SFFD personnel, and conducted site inspections of the Mission Substation and the Golden Gate Control Center (GGCC).

Soon after undertaking the investigation of the 2003 fire, CPSD discovered that another fire had occurred at Mission Substation in 1996. CPSD's investigation team conducted a thorough analysis of both fires and found strikingly similar contributing factors and root causes. CPSD's team further determined that PG&E had not implemented the recommendations resulting from its own investigation of the 1996 fire. Key findings of the 2003/2204 investigation draw heavily from the investigation of both events.

CPSD's probing of the 1996 fire also caused PG&E to re-evaluate its own investigation of that fire. As a result, PG&E concluded it had not adequately followed through with recommendations from that investigation. CPSD finds it quite troubling that PG&E did not implement its own recommendations from its own investigation of the 1996 fire.

Description of Mission Substation

PG&E's Mission Substation is a three-story concrete building with a basement that serves customers in downtown San Francisco and parts of other districts within the city. The substation receives power from 115 kilovolt (kV) underground transmission lines. Transformers in the substation reduce the transmission voltage to 4 kV and 12 kV distribution voltages. Power is distributed to customers at this voltage through radial circuits and through network circuits having multiple sources.

Since 1992, Mission Substation has been unattended and is controlled from the Golden Gate Control Center (GGCC) in Daly City through a Supervisory Control and Data Acquisition (SCADA) system that enables remote monitoring and control of equipment. This includes monitoring of fire suppression equipment. The substation has heat-activated sprinkler systems around oil-filled transformers and high voltage circuit breakers for fire suppression, but has no fire suppression or detection system for the medium voltage equipment on the second and third floors.

Synopsis

At 3:51 p.m. on Saturday, December 20, 2003, a cable terminating in a switch cabinet on the second floor of Mission Substation experienced a short circuit of such magnitude as to cause the cable to explode. The circuit breaker protecting the cable opened and de-energized the circuit. PG&E's SCADA system registered alarms at the GGCC, reporting the circuit breaker operation and additional alarms that were caused by the cable failure. Because the cable was one of a redundant set of cables to a network circuit, no customers lost power. The explosion of the cable created smoke and vaporized debris, causing another short circuit in the energized metal bars leading from the top of the switch cabinet to the bus above the cabinet. The second short circuit ignited insulation around the metal bus bars and caused a bus circuit breaker to open and de-energize the burning bus.

PG&E personnel did not immediately investigate the alarms at Mission Substation because there was no customer outage. However, the GGCC did communicate the substation status to key PG&E management personnel.

At 5:24 p.m., the burning bus caused a short circuit in another switch cabinet, resulting in an outage to 3,112 customers.

At 5:42 p.m., a switchman sent to Mission Substation to investigate the outage reported smoke coming from the building. The GGCC updated PG&E management on the conditions at Mission Substation.

At 5:57 p.m., all transmission breakers at Mission Substation were opened by the San Mateo Control Center (SMCC), effectively de-energizing the substation and terminating power to almost 100,000 PG&E customers, a loss of 150 MW or 22 percent of the load in San Francisco.

At 5:58 p.m. PG&E Gas Dispatch notified the SFFD of the fire at Mission Substation and the SFFD entered the building minutes later. The SFFD vented smoke from the building and found no fire source; PG&E re-energized the transmission lines to the substation and began gradually restoring power to customers.

At 9 p.m., while restoring power, PG&E discovered more smoke and the SFFD found a fire on the first floor. After that fire was extinguished, the SFFD discovered the bus fire in the second floor switch room that had ignited the first floor fire.

At 10 p.m., Mission Substation was de-energized a second time to fight the fire in the second floor switch room. As a result, 102,000 customers were without power.

At 12:48 a.m., December 21, the substation was re-energized after the SFFD extinguished the fire. PG&E then began damage assessment, repair, and power restoration. By 11:45 p.m. power was restored to all customers supplied from the Mission Substation.

Key Findings

CPSD's investigation includes an analysis of how the equipment operated immediately before and during the fire. We also examined how PG&E personnel responded to the failure. There are 26 findings with recommendations related to PG&E equipment, systems, and work processes and procedures. The following comprise the major findings:

- The root cause of the incident was a cable failure in a switch cabinet. The cable failed explosively, which caused a bus located above it to catch on fire. Over time, vertically installed cable with oil impregnated paper insulation loses its insulating capability because the insulation dries out, resulting in a short circuit.

- The 1996 Mission Substation fire revealed that the insulation used in the auxiliary buses is flammable and does not self extinguish, but no steps were taken to mitigate this vulnerability. The auxiliary bus above the switch cabinets was normally energized, so when smoke and debris from a failed cable contaminated the air inside a switch cabinet, arcing occurred and ignited the flammable bus insulation.

- PG&E failed to follow three recommendations made in its 1996 Root Cause Analysis Report following its 1996 fire. At that time, PG&E did not have a formal management review process to track recommendations from root cause investigations. Had PG&E implemented its 1996 investigation recommendations, CPSD believes the cable failure on December 20, 2003 would not have resulted in loss of service to customers.

- PG&E operators did not have user-friendly SCADA screen displays or knowledge of operating procedures that prioritize audible, miscellaneous, and critical alarms that originated at Mission Substation. With over 1,800 alarms received a day at the GGCC, PG&E operators overlooked some alarms. Further, the GGCC did not have written operating procedures for addressing alarms, so operators had to rely on personal knowledge and experience to respond.

- PG&E had no written procedures for the loss of a network circuit. Although a similar network circuit failure caused the fire in 1996 and network designers assumed such a condition would be immediately investigated, PG&E operators did not have instructions to respond immediately to this event.

- PG&E had no written plan or procedures for coordinating emergency fire responses at indoor substations. The SFFD did not know who the PG&E person-in-charge was until four hours after the first SCADA alarm. Lack of coordination contributed to the delays in locating the fire and caused additional damage to equipment and substantial delays in restoring power to customers.

Recommendations

CPSD's recommendations include an analysis of how the equipment operated immediately before and during the fire and how PG&E personnel responded. The analysis led to conclusions on origin and propagation of the fire, operating procedures, fire coordination, as well as other organizational and cultural issues. We categorized findings as "physical" for findings that are equipment or systems related, and "institutional" for findings that are process or procedure related.

Recommended improvements resulting from the physical findings include:

1. Replace old, vertically installed, oil-impregnated paper insulated cables.
2. De-energize auxiliary distribution buses and conduct periodic testing.
3. Install smoke detection system and connect it to SCADA.
4. Improve SCADA monitoring interface at the control center.

Recommended improvements resulting from the institutional findings include:

- Provide written procedures and related training for responding to specific SCADA alarms.
- Ensure sufficient staffing is immediately available for investigation of circuit breaker alarms.
- Develop an emergency plan including coordination and communication with the fire department.
- Ensure executive management accountability for the evaluation and implementation of recommendations resulting from investigations and inspections.

- Establish methods to evaluate and implement new technologies and methods that can improve the safety, reliability, and effectiveness of system design, equipment, and procedures.
- Periodically report to the CPUC the status of the evaluation and implementation of all recommendations made herein until all recommendations have been addressed.

Investigation Report

This report contains, hereinafter:

- Chronology of Events—A detailed timeline of events during the incident.
- Findings and Recommendations—Analysis of the root cause of the fire and the reason for PG&E’s slow response to both the fire and customer restoration. Recommendations pertain to each listed cause and key finding. Some recommendations not only apply to Mission Substation but to the entire PG&E electric distribution system.
- Background—An overview of Mission Substation and related equipment and systems, and a description of operations.
- 1996 Mission Substation Fire—An overview of the event describing physical similarities with the 2003 fire, recommendations of PG&E’s 1996 Root Cause Analysis Report, and identification of common issues that impacted both events.
- Detailed Description of the Event—An account of the incident including technical details regarding what equipment failed, how other equipment was damaged, and how the fire was started, found, and extinguished.
- Appendices—A compilation of technical details, PG&E reports, and independent lab tests.

Chapter One: Chronology of Events

This section is a chronology of the significant events in the Mission Substation fire, from initial event to service restoration. Some time periods have been estimated based on the best available data.

Saturday, December 20, 2003

- 3:51 p.m.

  The X-1153 12 kV cable short-circuited. The failure caused the X-1153 circuit breaker to open and a SCADA[1] alarm activated at the Golden Gate Control Center (GGCC). The operator at the GGCC did not send anyone to the substation to investigate the cause of the circuit breaker operation.
- 5:24 p.m.

  The circuit breakers protecting the X-1109 and X-1162 cables opened automatically on short circuit. These were the second and third circuits lost since the initial X-1153 breaker alarms. A switchman was sent to the substation to investigate.
- 5:42 p.m.

  The switchman arrived at the substation and noticed smoke coming from the ventilation system. He opened both entrances to the substation, discovered heavy smoke, and communicated the situation to the GGCC.
- Between 5:42 p.m. and 5:55 p.m.

  The GGCC operator notified various agencies and individuals of the problem at Mission Substation. They included PG&E's San Francisco Gas Dispatch, the San Mateo Control Center (SMCC), the CPUC incident hot line, PG&E news department, substation maintenance on call supervisor and other PG&E personnel. The

[1] SCADA is an acronym standing for supervisory control and data acquisition. See section III.A.11 for a description of the Mission substation SCADA system.

GGCC operator requested that the SMCC de-energize Mission Substation so that the fire department could safely fight the fire.

- 5:57 p.m.

  The SMCC opened the transmission breakers and de-energized the substation; this interrupted service to about 100,000 customers.
- 5:58 p.m.

  PG&E San Francisco Gas Dispatch called the San Francisco Fire Department (SFFD).
- 6:05 p.m.

  The SFFD arrived at Mission substation. Firefighters using a thermal imaging camera entered the building to search for possible victims. They found no victims or source of smoke.
- Between about 6:05 p.m. and 7:30 p.m.

  Firefighters cleared smoke from the building with portable fans and did not find a fire.
- Between 7:46 p.m. and 7:49 p.m.

  SMCC reenergized the substation.
- 7:48 p.m.

  PG&E personnel restored power to the substation ventilation fans to assist in clearing smoke from the building.
- 8:26 p.m. to 8:50 p.m.

  PG&E re-energized satellite substations from Mission Substation, thereby restoring power to 49,600 customers.
- 9 p.m.

  PG&E employees discovered fire in the foreman's office[2] and notified the SFFD, which was in the process of leaving the substation.
- 9 p.m. to 9:36 p.m.

  The SFFD extinguished the fire in the first floor foreman's office, but smoke persisted.

[2] The foreman's office is adjacent to the control room.

- Between 10 p.m. and 10:16 p.m.

  The GGCC operator ordered the opening of all distribution circuit breakers and the SMCC opened all transmission circuit breakers. This de-energized the substation a second time. Again, service was interrupted to the 49,600 customers previously restored plus 2,600 additional customers supplied by a satellite station through Mission Substation. Approximately 102,000 customers were without power.

- 10:11 p.m.

  The SFFD discovered a fire burning on the 2nd floor.

Sunday, December 21, 2003

- Between 10:11 p.m. on December 20 and 12:59 a.m. on December 21

  The SFFD extinguished the fire on the second floor.

- 12:48 a.m.

  PG&E restored power to the substation from the transmission lines.

- Between 1:20 a.m. and 1:56 a.m.

  PG&E reenergized satellite substations and restored power to 49,600 customers.

- Between 2:07 a.m. and 6:44 a.m.

  PG&E restored service to another 29,500 customers.

- Between 6:44 a.m. and 11:45 p.m.

  PG&E personnel cleaned switch cubicles and restored them to service.

- 11:45 p.m.

  All customers were restored to service.

Chapter Two: Findings and Recommendations

There are 26 findings with recommendations relating to PG&E equipment, systems, and work processes and procedures. Key findings are categorized as "physical" for findings that are equipment or systems related and "institutional" for findings that are process or procedures related. "Status" of recommendations refers to actions PG&E has already taken to implement its own recommendations.

Physical Elements

1. PILC Cable Failure

<u>Finding:</u>

The root cause of the incident was a cable failure in a switch cabinet. The cable failed explosively, which caused a bus located above it to catch on fire. Over time, vertically installed cable with oil impregnated paper insulation loses its insulating capability because the insulation dries out, resulting in a short circuit.

<u>Recommendations:</u>

PILC cables of similar age and physical arrangement at Mission and other indoor substations may be near failure.

1. Replace all vertical runs of PILC cable at Mission substation.
2. Identify and replace similar vertical runs of PILC cables at other indoor substations unless PG&E can demonstrate through testing or other means that the probability of cable failure is low.

<u>Status:</u>

PG&E has replaced 22 vertical runs of PILC cable at Mission substation. PG&E completed work on 3/30/2004.

2. Smoke Detectors

Finding:

There were no smoke detectors at Mission substation at the time of the December 20, 2003 incident despite earlier recommendations by PG&E to install them in certain areas.

Recommendation:

Install smoke detectors at Mission substation covering areas with energized equipment to provide for early warning of a fire. The smoke detectors need to be connected to SCADA to provide the GGCC with indication of a fire in the substation.

Status:

PG&E expects smoke detection will be operational by 11/30/2004.

3. Bus Combustibility

Finding:

The insulation of the 12 kV distribution auxiliary buses is composed of flammable material. Once ignited, the bus insulation continued to spread and burn. The flammable insulation caused both the 1996 and 2003 fires to spread along the bus duct and damage more switch cabinets.

Recommendation:

Bus combustibility must be considered in a switchgear replacement program. Measures must be taken to reduce or eliminate conditions that would ignite the insulation.

Status:

PG&E expects to add combustibility criteria by 11/1/2004. Presently, PG&E has de-energized the auxiliary buses.

4. Fire Barriers

Finding:

Switch cubicle openings did not have barriers to contain smoke. In both the 1996 and 2003 incidents, smoke flowing through cubicle openings caused arcing between exposed, live electrical parts that ignited a fire.

Recommendation:

Seal switch cubicle openings.

Status:

PG&E completed penetration-sealing work on 6/3/2004.

5. Auxiliary Bus Energizing

Finding:

Both the 1996 and 2003 fires propagated beyond the fault because a short circuit arc on the N bus ignited the bus insulation. The arc occurred because the bus was energized. The bus was normally energized as a standby power source for the distribution switches.

Recommendation:

Energize the auxiliary buses only when they are needed. Perform periodic tests on the buses by energizing them to ensure the buses are operational when needed as an alternate source of power.

Status:

The M and N auxiliary buses have been de-energized as a normal operating condition at Mission Substation. PG&E is currently evaluating regular auxiliary bus testing.

6. SCADA Alarm Monitoring

Finding:

PG&E operators do not have user-friendly SCADA screens and interface that enable them to effectively monitor and respond to SCADA alarms and conditions.

Recommendation:

1. Study and redesign SCADA screen to improve response to alarms.
2. Ensure audible alarms are acknowledged individually.
3. Ensure audible alarms are silenced manually and are not automatically deleted after a time limit.

Status:

PG&E is studying SCADA screen presentation and plans to complete this by 5/31/05. Following the incident, PG&E implemented new procedures to include:

1. Dedicated computer monitor just for the SCADA alarm log,
2. Removal of bulk alarm acknowledgement,
3. Increased volume of the audible alarms,
4. Removal of automatic silence of an audible alarm, and
5. Standardized configuration for SCADA alarm display screens.

7. Multitude of SCADA Alarms

Finding:

The GGCC district operators cannot recognize, prioritize, and respond effectively when a large number of SCADA alarms arrive in a short period of time. This is why operators did not respond to the initial X-1153 and fire subsystem audible alarms.

Recommendation:

1. Create reporting and prioritizing criteria for all audible, miscellaneous, and critical alarms and status alerts that enables the operator to quickly assess them and respond effectively.
2. Verify the legitimacy of all SCADA alarms to eliminate unnecessary alarms.

Status:

In January 2004, PG&E published Substation Engineering Bulletin IB0211 that defined SCADA alarm types and alarm categories and the visual presentation of the alarms on the display screen. Additionally, PG&E modified equipment settings to improve the criteria used to determine the necessity for an alarm, thereby eliminating conditions that correct themselves and reducing the number of alarms. PG&E is studying existing alarms monitored by the GGCC and expects to complete work by 5/31/05.

8. SCADA Inputs

Finding:

SCADA has a single nonspecific alarm for the many auxiliary bus breakers, preventing an operator from determining which breaker generated the alarm.

Recommendation:

Ensure that each bus breaker is individually monitored by SCADA.

Status:

PG&E is evaluating additional SCADA input from 12 kV relays and breakers.

9. Relay Settings

<u>Finding:</u>

The 1162 circuit breaker tripped on reverse current when the voltage on the Section H bus fell to close to zero as the result of the fault in the X-1109 cubicle. The instantaneous units in the circuit breaker's overcurrent relays initiated the trip. Opening of the circuit breaker under these conditions is undesirable because it could unnecessarily cause customers to lose power.

<u>Recommendation:</u>

Disable the instantaneous units on relays in feeders to networks.

<u>Status</u>

PG&E has initiated a study to review relay settings and schemes for indoor substations network systems. The study is expected to be completed by 10/1/2005.

10. Fire Suppression

<u>Finding:</u>

Fire suppression equipment is adequate at Mission Substation, but it can be improved in key areas consistent with recommendations in PG&E's 1996 CES Substations Fire Project Report.

<u>Recommendation:</u>

1. Provide suppression protection for the basement, sub-basement area, and potheads as itemized in the 1996 CES-Substation Fire Project Report.
2. Ensure that deficiencies noted in system inspections are corrected and tracked in a timely manner.

Status:

Area-wide sprinklers are not installed for the potheads, basement cable spreading room, or sub-basement area at Mission Substation. Providing protection in the remainder of the basement and for the potheads is being considered. PG&E expects that evaluation will be completed by 7/31/2004.

11. Ventilation

Finding:

Roof fans can only be turned on manually at the fan location. The SFFD needed the fans to ventilate the building and were forced to use a ladder truck to access the building roof to operate the fans.

Recommendations:

Install remote controls for the roof fans and all other fans in the substation at a central, easily accessible location known to the SFFD.

Status:

PG&E expects to complete work by 12/31/2004.

12. Emergency Lighting

Finding:

The SFFD Rescue Squad Chief stated that there was no lighting in the substation when he was there. However, there is a minimum of emergency lighting powered by the station battery that automatically turns on when power is lost in the substation. When the rescue squad was in the building, the dense smoke likely diminished the intensity of the emergency lighting.

Recommendation:

Test the substation emergency lighting to identify all areas for which back up lighting is insufficient to facilitate a safe exit from the building during emergency conditions. Install additional or alternative lighting solutions for all areas identified.

Status:

PG&E is currently evaluating the use of additional emergency lighting at indoor substations and expects to complete plans by 12/31/05.

Institutional Elements

Operating Procedures:

13. Response to SCADA Alarms

Finding:

GGCC relied heavily on the individual knowledge and experience of operators in responding to specific SCADA alarms and system conditions. This contributes to inconsistent and possibly inefficient responses to emergencies.

Recommendation:

Establish written procedures and train staff to assess and provide immediate response to system emergencies. The procedures need to include responsibilities for the district management.

Status:

PG&E expects completion of operating procedures and training by 12/31/2005.

14. Staffing

Finding:

On weekday nights and weekends, staffing is reduced. In the event of a potentially serious event such as fire or multiple outages occurring during those times, delays in obtaining appropriate on-call staffing could cause consequences more severe than during a typically staffed weekday.

Recommendation:

1. Review staffing levels during after-hours and weekends to improve response to system emergencies.
2. Develop written procedures to assign responsibilities for district management to respond to emergencies outside of normal working hours.

Status:

PG&E expects to complete a review of staffing requirements by 12/31/2005.

15. Smoke Filled Substation Policy

Finding:

According to a 2003 bulletin, PG&E employees are not allowed to enter smoke-filled substations. Prior to the December 20, 2003 event, PG&E did not initiate discussions with the SFFD about specific details in the bulletin.

Recommendation:

PG&E and the SFFD should develop joint policy to support SFFD personnel working inside substations and incorporate decisions into existing operating procedures.

Status:

PG&E expects to review the existing bulletin and will finalize procedures by 11/30/04.

16. Response to Loss of One Network Feeder (N-1)

Finding:

PG&E had no written procedures for the loss of a network circuit. Although a single network circuit failure caused a fire in 1996 and network designers assumed such a condition would be immediately investigated, PG&E operators did not have instructions to respond immediately to this event.

Recommendation:

Establish written procedures and standards for GGCC, Substation management, System designers, and District Operations, Maintenance and Construction (OM&C) management to follow in (N-1) or greater occurrences.

Status:

In May 2004, PG&E issued a bulletin (2004PGM-6: Procedures for Tie-Cable and Network Feeder Failures) to all key personnel with specific instructions for immediate response to the loss of a single network feeder (N-1). The bulletin included interim procedures for the loss of two network feeders while PG&E creates a separate bulletin for that condition (N-2). PG&E expects to finalize written operating procedures by 12/31/04.

Fire Coordination:

17. Incident Command System (ICS)

Finding:

1. The SFFD did not know who the PG&E person-in-charge was until four hours after the first SCADA alarm.
2. PG&E did not have any written procedures that define this role when PG&E personnel respond to trouble at an unattended substation.
3. PG&E and SFFD had no prior agreements about how a proposed Incident Command System (ICS) would operate during a substation fire emergency.

Recommendation:

1. In collaboration with the SFFD, confirm roles and responsibilities of PG&E Person-in Charge (PIC) for substation events and develop related written procedures.
2. Investigate how PG&E command structure at a field substation complements the SFFD Incident Command System.
3. Train first responders (e.g., Troublemen, Cablemen, Electricians) to manage response with PG&E PIC and SFFD Incident Commander.

Status:

PG&E and SFFD conducted several meetings in the spring and summer of 2004 to discuss fire coordination issues. PG&E expects to finalize procedures by 12/31/05.

18. Emergency Response Planning

Finding:

PG&E and SFFD personnel were not guided by an agreed upon joint emergency response plan as recommended in the April 1996 CES-Substations Fire Project Report. This plan would provide information critical to firefighters during an emergency, such as maps, a list of hazards, emergency numbers, and locations of ventilation switches.

Recommendation:

1. Complete the joint emergency response plan with SFFD and meet with SFFD personnel at least once a year to review and update.
2. Decide location and owner of a Master Plan for each indoor substation in the Bay Area.
3. Conduct periodic walkthroughs and emergency drills to ensure up-to-date training of all personnel.

Status:

A proposed emergency response plan for Mission Substation is nearly complete. It will be used as a model to complete other joint emergency plans for other indoor stations by this fall. PG&E expects to complete emergency response plans for all indoor substations by 12/31/05.

19. PG&E and SFFD Communication

Finding:

Between the 1996 and 2003 Mission Substation fires, PG&E and the SFFD have had little communication on common issues and concerns. This resulted in ineffective substation fire response.

Recommendation:

1. Conduct joint PG&E and SFFD meetings to address lack of pre-planning, emergency response, communication, and training pertaining to fire response.
2. Develop process to ensure ongoing management supervision of activities and tracking of emergency action plans.

Status:

PG&E and SFFD conducted several meetings in the spring and summer of 2004 to discuss fire coordination issues. PG&E expects to finalize procedures by 12/31/05.

Management Tracking

20. 1996 Fire Root Cause Analysis Report

Findings:

1. PG&E failed to implement three recommendations made in its 1996 root cause analysis report.
2. At that time, PG&E did not have a formal management overview process to track recommendations from root cause investigations.
3. Had PG&E implemented the 1996 investigation recommendations, CPSD believes the cable failure on December 20, 2003 would not have resulted in an outage to more than 100,000 customers throughout San Francisco.

Recommendation:

Establish and enforce formal management tracking system to monitor incident root cause recommendations. For incidents with a significant public impact, meet with CPUC quarterly to discuss progress.

Status:

PG&E has named a project manager accountable to the Vice-President of Operations, Maintenance and Construction (OM&C) to ensure that root cause analysis recommendations are implemented and that results are regularly communicated to the CPUC.

21. 1996 CES-Substations Fire Project Report

Finding:

At the time of the 1996 fire, PG&E did not take action to improve fire detection and suppression in indoor substations that was recommended in the report.

Recommendation:

Re-evaluate the contents of the 1996 CES-Substations Fire Project Report and implement recommendations based on the outcome of the analysis.

Status:

PG&E is currently studying and implementing various recommendations contained in the report.

22. Operations Standard UA 1465-Events and Investigations Procedures

Finding:

PG&E has a slow and cumbersome process to review operating standards relating to incident investigation procedures.

Recommendation:

1. Complete review and approval of a revised draft of UO Standard S1465 that improves event investigation procedures for electric utility operations by 12/31/04.

2. Establish stringent deadlines for ongoing approval and distribution of revised standards that pertain to safety and reliability related areas.

Status:

As of April 15, 2004, PG&E is reviewing the standard but has no estimate of when the final revision will be reviewed or approved.

23. Technology Review

Finding:

PG&E has no systematic procedure to review and adopt new technology that can improve safety and reliability. Examples of technology related to this incident include barrier seal material and laser beam smoke detector technology for indoor substations.

Recommendation:

Implement a formalized process to ensure that current or state–of-the-art technology solutions are researched and recommended for safety and reliability concerns.

Status:

Following the December 20, 2003 incident, PG&E began to investigate alternative barrier seal material and laser beam smoke detector technologies for Mission Substation.

24. Restoration

Finding:

PG&E has no written restoration guidelines for Mission Substation and other substations. Reporting discrepancies existed regarding total number of customers affected during the course of the incident.

Recommendation:

1. Develop written restoration guidelines for all indoor substations with networks and tie cables.
2. Improve accuracy of Outage Information System (OIS) by implementing needed programming changes.

Status:

PG&E expects to implement guidelines by 12/31/2004.

25. Outage Communication

Finding:

Estimated Time of Recovery (ETOR) was underestimated during the incident resulting in overoptimistic feedback to customers about when their service would be restored.

Recommendation:

Continue to improve ETOR communication process pertaining to indoor substations and train personnel accordingly.

Status:

PG&E expects to complete guidelines by 12/31/04.

26. Event Related Costs

Finding:

PG&E and ratepayers would have saved millions of dollars if the fire had been detected sooner, resulting in less damage to the substation and a less extensive power outage.

Recommendation:

Review PG&E and CPUC investigation reports and implement recommendations in a timely manner to ensure that a similar incident does not happen again.

Status:

PG&E has named a project manager accountable to the Vice-President of Operations, Maintenance and Construction (OM&C) to ensure that action plans relating to the incident are implemented and that results are regularly communicated to the CPUC.

Chapter Three: PG&E Electric Operations

The control centers, including Golden Gate Control Center (GGCC), San Mateo Transmission Control Center (SMCC), and Transmission Operating Center (TOC) were involved in various aspects of the December 20, 2003 event. This chapter covers a brief description of those control centers.

1. Golden Gate Control Center (GGCC)

[redacted]

[redacted]

2. San Mateo Transmission Control Center (SMCC)

[redacted]

[redacted]

[redacted]

3. Transmission Operating Center (TOC)

[redacted]

Chapter Four: Mission Substation Facilities

1. General Description of Mission Substation

Mission Substation is an indoor substation contained in a three-story concrete structure with a basement[3]. The substation is located at the corner of Mission and 8th Street in downtown San Francisco. It provides power to approximately 100,000 customers. The area served by the substation is shown in Figure III-1, below.

Figure III-1. Areas served by Mission Substation.

Electrical power engineers, operators and maintenance personnel use what is known as a single line diagram to represent the arrangement of the components that make up the electrical network. A simplified single line diagram representing

[3] Mission substation has been in service since 1948

Mission Substation is shown in Appendix A. Refer to the single line diagram to see how the elements of the substation described below fit together.

[redacted]

2. SCADA

The SCADA system is PG&E's connection to the unattended Mission Substation. SCADA enables the control centers to remotely monitor and control system equipment such as voltage regulators, breakers, and switches. Both the transmission and distribution control centers utilize SCADA to view and access Mission Substation. Continuous and alert SCADA monitoring is critical to the safe, efficient, and reliable operation of its electrical system.

At the substation, SCADA operates through Remote Terminal Units (RTUs). The RTUs receive data through connections to every piece of equipment that needs remote management. The information consists of such data as voltage, current, breaker positions, and other equipment specific data. The RTUs also provide communication to equipment. Commands sent through RTUs include adjustments of voltage levels and operation of circuit breakers and switches. All distribution and transmission circuits have some level of remote management capability.

The RTUs also monitor information not pertaining to circuits. Emergency battery backup power for the RTUs is monitored in case the substation loses main power. The substation fire control system is also connected to the RTUs. SCADA receives data on fire system problems, heat detectors, fire system activation, and fire alarm activation.

At the control centers, SCADA operates through master computer stations, used by system operators to remotely manage the transmission and distribution system. Master stations receive all of the information gathered by the RTUs. Operators use graphical user interfaces, text log displays, and command line inputs to view and operate substation equipment.

When problems arise or conditions change in system equipment, the master stations report alarms. The alarms are displayed and categorized as “critical”, “status”, or “miscellaneous”. Fire alarms and breakers are critical; relays and voltage levels are status; non-critical and fire system problems (not activation) are miscellaneous.

Although SCADA monitors many inputs from the substation, it does not relay information on some specific details. For example, SCADA reports generic alarms for transformer conditions such as winding temperature, oil temperature, and oil level. However, SCADA does not differentiate between these problems. If a problem occurs, the control center sees only one alarm. Transformer problems are monitored and enunciated by a trouble panel, which is a panel at each transformer. Someone must physically go to the substation to determine the problem. Similarly, the fire protection system has generic alarms for problems (not activation) and must be investigated at a Fire Alarm Panel in Mission Substation.

3. Transformers

In power systems, transformers change the voltage to make for efficient transportation and distribution of power. In this report reference is made to 115 to 12 kV (115/12 kV) transformers. This means that the transmission voltage is reduced from 115,000 volts to 12,000 volts. Mission substation has five transformers to reduce the 115 kV transmission voltage to 12 kV distribution voltage, two transformers to reduce 12 kV to 4 kV, and two transformers to provide power for lights, fans, and other equipment inside the substation.

4. Distribution Feeders

The outgoing distribution feeders at Mission substation provide power to customers directly and also through satellite substations. The feeders are classified as radial, network, and tie circuits. A radial circuit has only one source of power feeding customers. If equipment in that circuit fails, power is lost to all customers served by the radial feeder. For example, if a radial distribution cable fails, all customers lose power until the cable is repaired or switching takes place to provide power from an alternate source.

In contrast, a network feeder is one of a set of redundant feeders, any one of which can fail without interrupting service. (Refer to Chapter Four, Section 7: "Networks".)

Lastly, tie cables do not feed customers directly, but provide power to satellite substations, which supply customers from 12 kV and 4 kV feeders.

5. Distribution Buses

The insulation of the 12 kV distribution auxiliary buses is composed of flammable material. Once ignited, the bus insulation continued to spread and burn. The flammable insulation caused both the 1996 and 2003 fires to spread along the bus duct and damage more switch cabinets.

Both the 1996 and 2003 fires propagated beyond the fault because a short circuit arc on the N bus ignited the bus insulation. The arc occurred because the bus was energized. The bus was normally energized as a standby power source for the distribution switches.

[redacted]

[redacted]

[redacted]

[redacted]

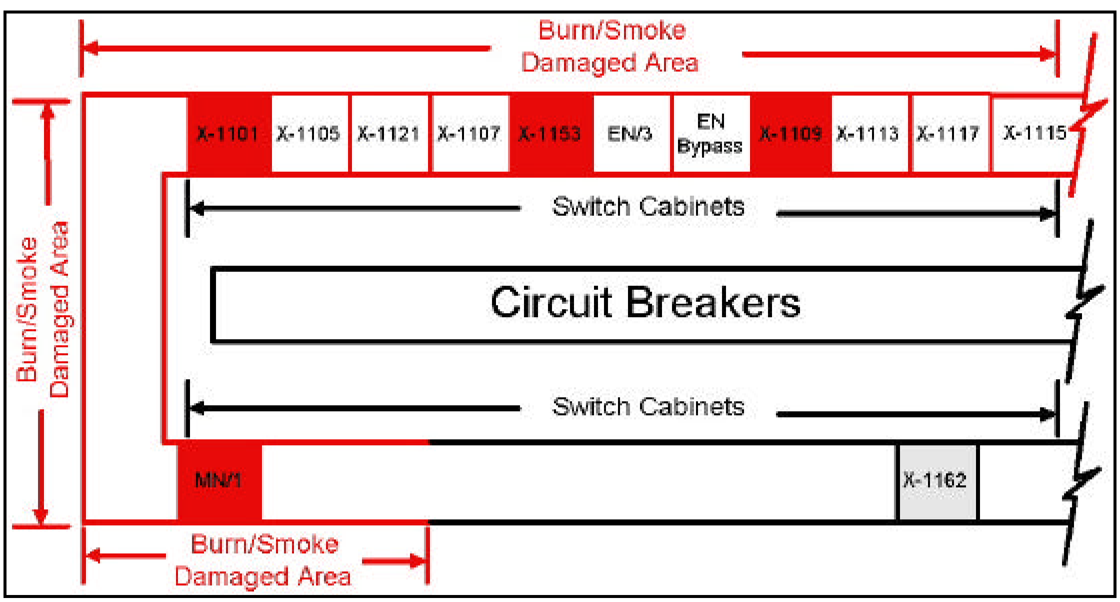

Figure III-2. Plan view showing a portion of the second floor switchgear area

6. Switch Cabinets and Associated Equipment

The root cause of the incident was a cable failure in a switch cabinet. The cable failed explosively, which caused a bus located above it to catch on fire. Over time, vertically installed cable with oil impregnated paper insulation loses its insulating capability because the insulation dries out, resulting in a short circuit.

Switch cubicle openings did not have barriers to contain smoke. In both the 1996 and 2003 incidents, smoke flowing through cubicle openings caused arcing between exposed, live electrical parts that ignited a fire.

Figure III-3 illustrates the X-1153 switch cubicle, essentially a sheet metal cabinet, with the N bus directly above it. Two three-phase switches are the main pieces of equipment in the cabinet. Each three-phase switch is operated as a group. This is depicted with the two dashed lines in the diagram. The bottom three-phase switch is normally closed, and the top three-phase switch is normally open. The arrangement allows for power to be fed to the X-1153 distribution cable from either Bus Section G or the N bus, thus allowing for flexibility of operation. For example, if the X-1153/2 circuit breaker needs to be repaired or replaced, the X-1153/3 switch is opened and the X-1153/5 switch is closed.

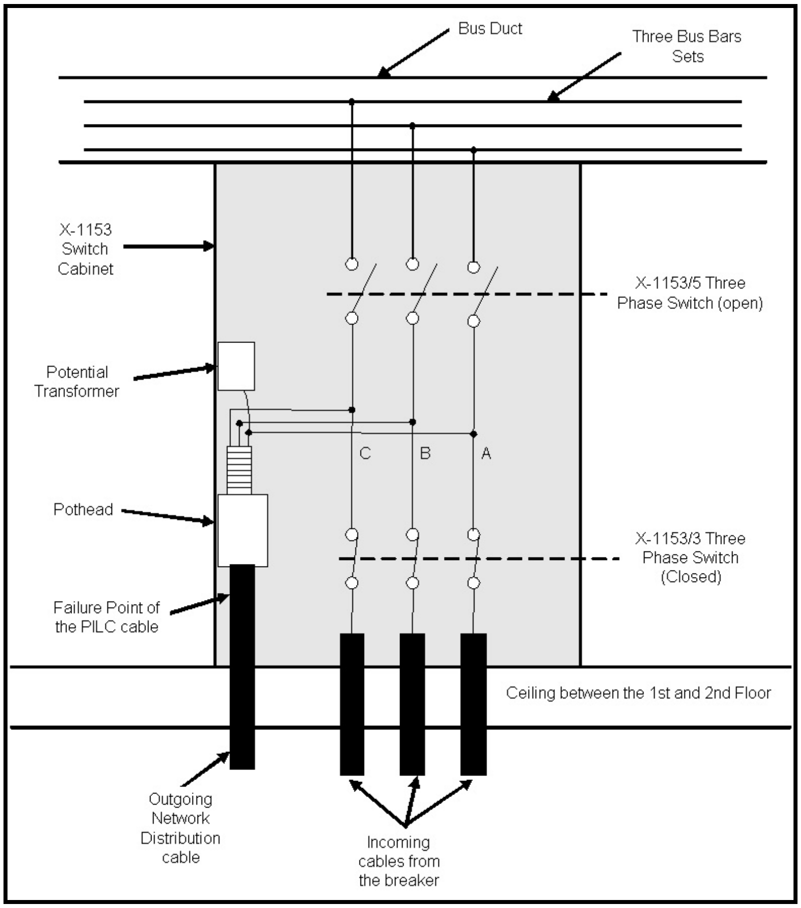

Figure III-3. The X-1153 switch cabinet with the N bus located on top

Other equipment in the switch cabinet includes a set of three cables coming from the circuit breaker up through the bottom of the floor that connects to the X-1153/3 switch, and one paper insulated lead covered cable (PILC) exiting the switch cabinet going out to the network circuit. Figure III-4 illustrates a typical PILC cable. Above the X-1153/3 switch, each phase is connected to the pothead with a metal bar. The outgoing network distribution cable terminates at the pothead and descends vertically to the basement, where it continues out horizontally to connect to the X-4 network. The PILC cable consists of three copper conductors contained in a single cable with a lead sheath and a neoprene jacket. Each conductor is insulated from the others by oil-impregnated paper. The cable was manufactured in 1963. The failure of the PILC cable near the pothead was the initiating event of the incident.

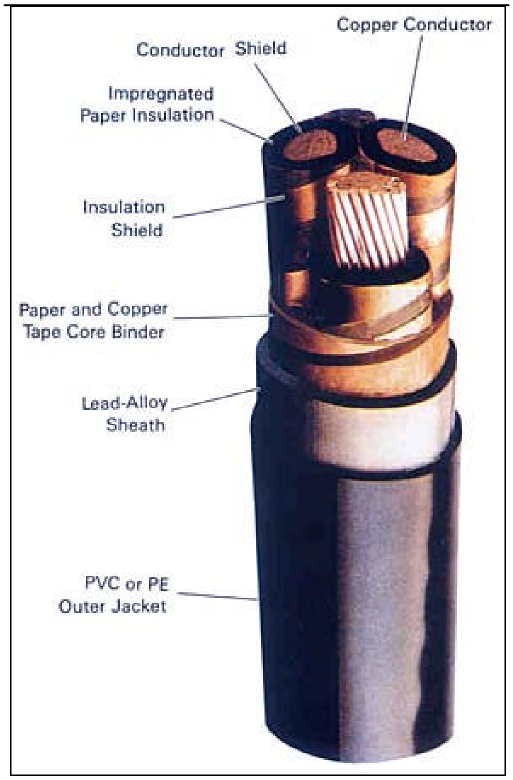

Figure III-4. A typical PILC cable[4]

Two other pieces of equipment shown in Figure III-3 are a pothead and a potential transformer. A pothead is a mechanical connector that reduces electrical stress at the cable termination point of the PILC cable. A potential transformer is a device used to measure voltage at a particular point in a circuit.

7. Networks

PG&E had no written procedures for the loss of a network circuit. Although a single network circuit failure caused a fire in 1996 and network designers assumed such a condition would be immediately investigated, PG&E operators did not have instructions to respond immediately to this event.

[4] Image copied from The Canadian Copper and Brass Development Association, http://www.ccbda.org/publications/pub23e/23e-Section3.html

Networks are used on the PG&E system to provide high reliability service to customers. [redacted]

[redacted]

8. Electric System Protective Equipment

a. Circuit Breakers

Circuit breakers are used to protect feeders from overloads and to protect the electrical system from short circuits in the feeders. They are special switches designed to interrupt the highest short circuit current they will encounter and to open automatically on either overload or short circuit in the feeder. Circuit breakers are also used at the termination of the 115 kV transmission lines that supply the substation. In this application, they protect the transmission lines and the high voltage network from short circuits inside the substation and are used as switches to turn off the power to the substation in case of major trouble. The 115 kV circuit breakers operate automatically in case of a short circuit and can be opened and closed manually by the high voltage operator at the SMCC.

b. Relays

The 1162 circuit breaker tripped on reverse current when the voltage on the Section H bus fell almost to zero as a result of the fault in the X-1109 cubicle. The instantaneous units in the circuit breaker's overcurrent relays initiated the trip. Opening of the circuit breaker under these conditions is undesirable because it could unnecessarily drop customer power.

A relay is used to detect overloads and short circuits and to automatically operate a circuit breaker when either condition exists. There are numerous types of relays. Those used with feeder circuit breakers are called overcurrent relays because they detect and operate when the current in the feeder is above a set value. Most overcurrent relays have an instantaneous element and a time element. The instantaneous element operates ("picks up") at a high value of short circuit current without any deliberate time delay: when the pick up threshold is reached, it operates in about one 1/60 of a second. The time element has a pick up time which varies with the magnitude of the short circuit current or overload, the higher the magnitude of the short circuit current or overload, the shorter the pick up time.

c. Network Protectors

To protect networks and the feeders that supply them, network protectors are used. They are similar to circuit breakers in that they will open the circuit to interrupt the current in the event of a short circuit in the load. In this case, the network will open the circuit on small or large magnitude current in the reverse direction, that is, from the network toward the substation. Reverse current will occur when there is a short circuit in the feeder or when the voltage at the substation bus to which the feeder is connected falls to a low value. This happened on 12/20/03 when there was a multi-phase short circuit in switch cabinet X-1109, which caused the voltage on bus section H to fall close to zero. Network feeder X-1162 was also connected to bus section H. When the voltage fell close to zero, the network protector being fed by the X-1162 feeder operated on reverse current.

9. Fire Detection and Suppression System

There were no smoke detectors at Mission substation at the time of the December 20, 2003 incident despite earlier recommendations to install them in certain areas.

Fire suppression equipment is adequate at Mission Substation, but it can be improved in key areas consistent with recommendations in the 1996 CES Substations Fire Project Report.

The existing fire detection systems are intended to protect major oil-filled equipment. However, they are not designed to protect the potheads, basement cable spreading room or sub-basement areas. The 1996 CES Fire Project Report itemizes these areas as areas to consider for further possible protection. At the time of the incident, there were no smoke detectors at Mission Substation. Nor were there any heat detectors in the specific vicinity of the fire.

On the first floor, there are individual water deluge systems in each of the rooms containing the five 115/12 kV transformers, the two 12/4 kV transformers, and the nine 115 kV oil circuit breakers. Each of the water deluge systems on the first floor is activated by the heat detectors associated with each water spray system, which consists of a dry pipe arrangement. A solenoid valve is upstream of the piping. With detection of heat from a fire, the solenoid valve actuates the deluge valve via a fire control panel (FCP). The open head nozzles spray water into the area containing the equipment where the heat was detected.

The basement also has a wet pipe fire sprinkler system that covers the 115/12 kV transformer heat exchangers. This system is operated by heat as sprinkler heads will fuse at 165 degrees. Heat is required at each location for the sprinkler to activate.

PG&E Corporation Insurance Department, Property Loss Control Group, establishes and monitors the installation, servicing, and adequacy of fire protection equipment at Mission Substation. This program is based on best industry practices, the requirements of the National Fire Protection Association, the California Code of Regulations, and Title 19. Installation/servicing requirements of fire protection equipment are addressed in the Corporate Fire and Risk Control Manual. The adequacy of fire protection equipment is addressed through internal and third party audits conducted to satisfy corporate expectations for property loss control and to satisfy insurance carrier requirements.

On June 17, 2003, an independent auditor performed an annual inspection and tests of the fire alarm-heat detection and deluge systems in accordance with the California Code of Regulations, and Title 19. No deficiencies were noted although reference was made to a needed 5-year service for the wet pipe sprinkler system in the basement. This work was scheduled for February 5, 2004.

10. Ventilation System

Roof fans can only be turned on manually at the fan location. The SFFD needed the fans to ventilate the building and were forced to use a ladder truck access the building roof to operate the fans.

The ventilation system consists of 12 fans. Two fans are on the roof, two fans are located in the mezzanine area between the first and second floors, and eight fans are located in the basement.

Power for the fans comes from the station service bus (house power). The service bus receives power either from a source internal to Mission substation or from an external source used as a backup power supply. When power is lost to the substation, house power can be restored using the alternate source of power, which comes from station I.

The fans are started from a motor contactor selector control box located near each fan. The selector control box has three selections: start, run and off. The fans must be started one at a time due to the large size of each fan. The selector must be put in the start position until the motor reaches a minimum speed, at which time the selector can be put in the run position. The ventilation fans can be turned off at each fan location. The fans can also be turned off at a control panel on the second floor, or by de-energizing the source for the second floor control panel, which is the station service bus.

11. Emergency Lighting

The SFFD Rescue Squad Chief stated that there was no lighting in the substation when he was there. However, there is a minimum of emergency lighting powered by the station battery that automatically turns on when power is lost in the substation. When the rescue squad was in the

building, the dense smoke likely diminished the intensity of the emergency lighting.

When there is a loss of main power at Mission Substation, minimal lighting for critical areas is automatically switched to DC battery backup power. These areas include the stairwells, exits, and the control room. There is no other source of emergency lighting.

Chapter Five: GGCC Operations

This chapter briefly discusses staffing policies for operators at GGCC and the level of staffing coverage that GGCC had during the incident. It also describes the SCADA screens that operators use to respond to alarms and how operators respond to numerous alarms on a daily basis.

1. Staffing

On weekday nights and weekends, staffing is reduced. In the event of a potentially serious event such as fire or multiple outages occurring during a weekend day or on a weekday after-hours, delays in obtaining appropriate on call staffing to physically assess the problem could cause more severe consequences than during a typically staffed weekday.

At the time of the incident, two operators, typical for weekend operation, staffed Golden Gate Control Center. The operators were monitoring the “A” desks. These positions monitor the electric system, update system status, direct switching, provide communication about the system, and monitor and operate SCADA. There are operators at the “A” desks at all times.

On weekdays, there are also operators at the “OK” desks for San Francisco and Peninsula Districts. These positions receive requests for clearances[5] and write the switching logs that will detail the steps to execute the clearances. The “OK” desk may also assist in emergency switching. The “OK” desks are not staffed on weekends or at night.

Additionally on weekdays, there may be mobile operators available to support the control center operators in the field or to assist the “OK” desks. In the field, the

[5] A clearance de-energizes a section of conductors for maintenance. A clearance can be a planned outage or service could be redirected from alternate sources to prevent an outage if possible.

mobile operators conduct switching for scheduled and emergency work for the control center.

At the time of the incident, there were three operators present at GGCC. Two operators stayed past their scheduled shift to complete switching and troubleshooting that was in progress at the time their relief arrived. One of these remained at GGCC and the other went to Potrero Substation to conduct switching. The two relief operators were at the GGCC at the time of the initial fire and X-1153 alarms.

The loss of the network feeder at the Mission substation did not require an immediate physical assessment so no one dispatched additional on-call personnel. PG&E management was alerted to the situation using text pages that went out to designated district management. Instead, PG&E did not physically investigate the X-1153 breaker trip until a second network circuit tripped and customers lost power. At that time, the operator at Potrero interrupted switching in progress and reported to Mission Substation.

If this incident occurred on a fully staffed weekday during daytime hours, personnel from District Operations, Maintenance and Construction, or other available on-duty operators would have been sent to Mission Substation immediately after the initial network circuit alarms or the fire system trouble alarms.

When the second network circuit and radial circuit were lost, it was only fortuitous that there was an operator in the field able to report to Mission Substation that late in the progression of the fire. Had the District Operator’s from the prior shift not stayed beyond their scheduled hours, there would have been further delays in alerting management to make the decision to call in more personnel.

Despite the delay in assessing the problem, there were no problems in obtaining other operators to work overtime and assist in restoration efforts. There were no operators on scheduled vacation or filling in as vacation relief on the days of the incident.

2. SCADA Alarm Monitoring

PG&E operators do not have user-friendly SCADA screens and interface that enable them to effectively monitor and respond to SCADA alarms and conditions.

Operators viewed each SCADA alarm as a single line of text on the District Operations display monitor in a “windows” like environment. New alarms appeared at the bottom of the log screen and older alarms scrolled to the top. Operators could scroll back on the SCADA log screen to see prior events. They could also use other specific substation windows that allowed them to remotely control or see the setting or condition of specific equipment. Typically, other windows were open on top of the log screen, hiding most of it so that only a few of the most recent bottom lines of the log screen were visible shown in Figure III-5.

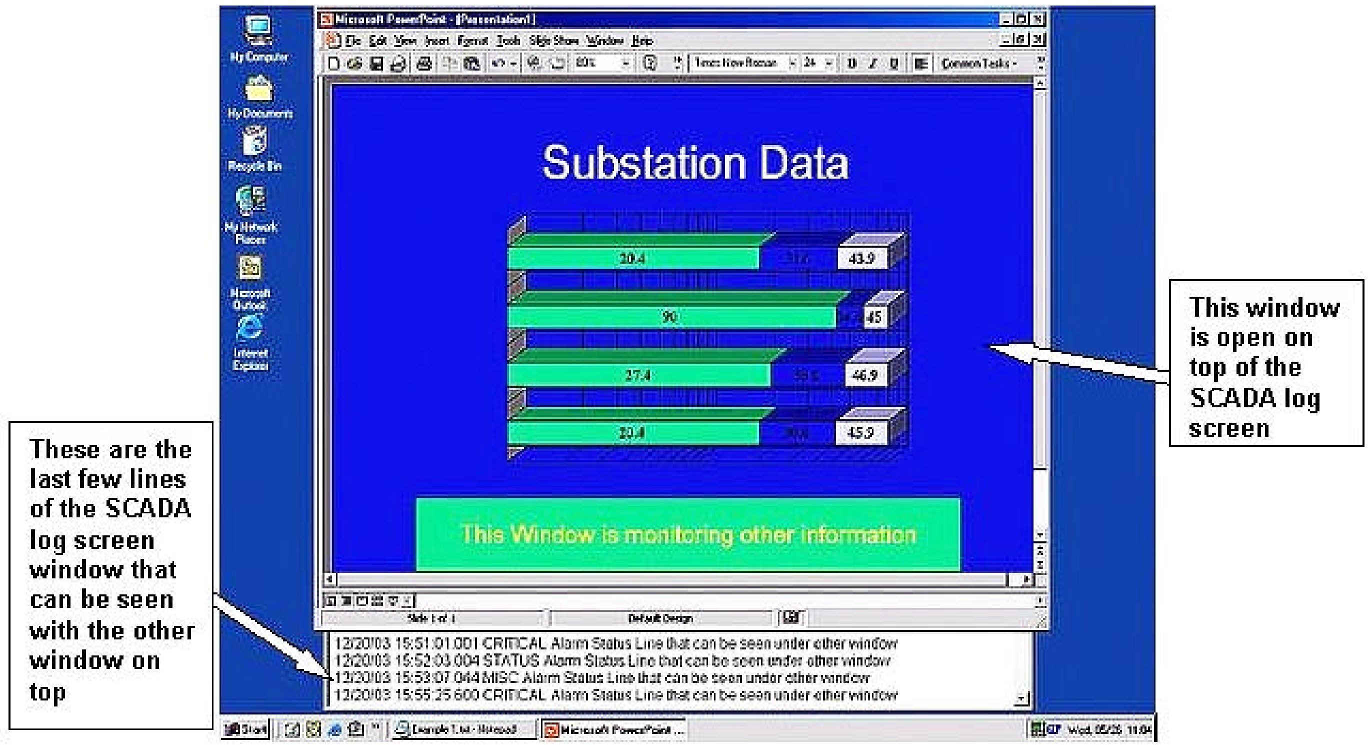

Figure III-5.[6] SCADA Screen Display

Often many alarms registered within seconds of each other since several substations could simultaneously post information to a SCADA log screen and a single condition can result in numerous different alarms. When this occurred, the operator might miss some alarms unless the operator scrolled back or closed windows so that the SCADA log screen was completely visible. Important alarms were highlighted with different colors to more easily distinguish them from other miscellaneous alerts or information but this would not help if the alarm scrolled out of view before the operator noticed.

Some alarms sounded an audible alert at the operator's station. The alert prompted the operator to scrutinize more carefully the entire SCADA log window. The audible alert stopped after several minutes without any interaction from the

[6] The illustration was created using Microsoft PowerPoint and Notepad. The screens in the picture are not from PG&E's SCADA graphical user interface.

operator and had a volume control that could lower the intensity of the audible alert. To silence the audible alert earlier, the operator clicked with a computer mouse on an “acknowledge” button in the SCADA log window. The operator did not have to acknowledge every individual alarm. The operator could also use an “acknowledge all” button to silence the audible alert and to acknowledge all alarms whether the operator viewed the specific alarms or not. The purpose of an acknowledge button was to ensure that the operator was aware of existing conditions that might require attention.

The alarms from the initial X-1153 cable fault that started the chain of events (before the fire) appeared on the SCADA log screen and sounded an audible alarm. The operator did not see or hear the alarms before the audible alarm timed out. For unknown reasons, the operator was not at the normal desk post at the exact moment when SCADA reported the alarms. The operator was not aware of the fault until a customer service representative called him ten minutes after the first X-1153 alarm. It was only then that the District Operator checked the SCADA log and saw that the X-1153 circuit breaker was open.

On December 20, 2004, a total of 558 audible alarms registered at the GGCC, including alarms resulting from the Mission Substation outage. Since all status alarms were audible even though they may not indicate an emergency or special notice and audible alarms eventually timed out, operators did not investigate every audible alarm.

3. SCADA Alarm Response

The GGCC district operators cannot recognize, prioritize, and respond effectively when a large number of SCADA alarms arrive in a short period of time. This is why operators did not respond to the initial X-1153 and fire subsystem audible alarms.

GGCC relied heavily on the individual knowledge and experience of operators in responding to specific SCADA alarms and system conditions. This contributes to inconsistent and possibly inefficient responses to emergencies.

SCADA has a single nonspecific alarm for the many auxiliary bus breakers, preventing an operator from determining which breaker generated the alarm.

The Operating Center Manual did not include instructions on what to do when a network circuit breaker opens. During interviews, operators explained that there was no formal procedure or instruction covering how operators should respond to specific alarms. There were many variables operators should consider when assessing the importance and significance of any particular alarm. The knowledge and experience of a District Operator was critical. For example, some factors an operator needed to consider before pursuing a definite course of action were the following: severity of alarm, type of alarm, existing outages to customers, or other network conditions. When the X-1153 circuit opened, there was no outage. Additionally, the operator's assessment of the alarms found that there were no other coinciding conditions that warranted immediate intervention. The operator notified the field operator to investigate after completing work in progress at Potrero substation.

Operating procedures for (N-1)[7] or (N-2) scenarios did not exist. As became apparent during the investigation, system designers and system operators did not have the same understanding of how to respond to either scenario. Substation engineering understood the loss of a single network feeder to require immediate attention. District Operator's understood the loss of a single network feeder to require attention as soon as available personnel could investigate.

[7] N-1 refers to a loss of one circuit in a network group. N-2 refers to a loss of two network circuits.

The GGCC did not immediately send an operator to investigate the open breaker on the network circuit, (N-1), because it was a weekend and the only operator or switchman available in the field was busy at another substation. The District Operator also paged key personnel to inform them that the X-1153 circuit was out, a major downtown customer reported power problems, and there was no outage on the network containing X-1153. The D.O. then notified an underground electrical foreman that the cable might need to be replaced before other scheduled work on the next workday. District management that received the page out did not direct additional personnel to assist the District Operator. The switchman in the field was not directed to immediately investigate the alarms at Mission substation until SCADA reported the loss of a second network circuit and a radial circuit dropped power to 3112 customers.

During interviews, the District Operator's emphasized that many system conditions affect the specific action one would take in response to a circuit breaker operating. Knowledge and experience of a District Operator rather than established procedures defined the response.

Chapter Six: Fire Coordination

In CPUC interviews with the SFFD Battalion Division Chief and Head of the Rescue Squad, he described several coordination problems that resulted in poor fire coordination at the scene of the incident:

1. Incident Command System (ICS)

It was not clear whom the PG&E Lead Supervisor or Person-In-Charge (PIC) was to coordinate with the SFFD Incident Commander.
PG&E did not have any written procedures that define this role when PG&E personnel respond to trouble at an unattended substation.
PG&E and SFFD had no prior agreements about how a proposed Incident Command System (ICS) would operate during a substation fire emergency.

According to the SFFD Battalion Division Chief, PG&E lacked a single reliable contact or person-in-charge (PIC) at the scene to supply critical information and knowledge necessary for the SFFD to implement effective emergency response activities. Necessary activities typically include the following: confirm the number of people inside, determine the extent of possible injuries, confirm what is known about the event and what to look for; identify potential hazards and flammables, apply lessons learned from previous fires (e.g. 1996 Fire); and review a floor plan and physical arrangements (ventilation switches, shut off and back up power). Emergency response is delayed and less effective in the absence of this information and knowledge.

During the incident, the Battalion Division Chief threatened to “flood the building top to bottom” if he did not get better coordination with a lead PG&E contact. He said that he had the impression that the person-in- charge kept changing. According to PG&E, an Electric Transmission Underground Supervisor finally took charge because of his knowledge and expertise in underground and indoor equipment, and his direct responsibility for substation equipment in San

Francisco. The SFFD did not know what PG&E Supervisor was in charge until the SFFD second visit—approximately four hours after the initial fire alarm. Once the PG&E supervisor took charge and identified himself to the SFFD, he was able to guide a Junior Battalion Chief over the radio to the rooftop exhaust fan power switch that was not easily accessible.

According to the SFFD, the Incident Command System is important since it provides a systematic development of a complete, functional Command organization designed to allow for single or multi-agency use that increases the effectiveness of Command and firefighter systems.[8] Major functions include planning, logistics, finance/administration, safety, and information for structural fire incidents. Roles and functions become more elaborate as the emergency increases in scope and intensity.

2. Emergency Response Planning

PG&E and SFFD personnel were not guided by an agreed upon joint emergency response plan as recommended in the April 1996 CES-Substations Fire Project Report. This plan would provide information critical to firefighters during an emergency, such as maps, a list of hazards, emergency numbers, and locations of ventilation switches.

At the time of the incident, PG&E did not have a written Mission Substation Emergency Response Plan or PG&E Facility Environmental Emergency Plan (FEEP) for Mission Substation as recommended in the April 6, 1996 CES-Substations Fire Project Report. This plan provides a detailed map of each floor indicating where high voltage breakers, banks and disconnects are located as well as where hazardous material such as lead acid batteries are located. It identifies various hazardous materials and high voltage equipment within the substation. It identifies combustibles such as insulating oil in the station transformers and lists fire suppression equipment that may be needed. It

[8] San Francisco Fire Department "ICS Fire Department Operations"

explains the preferred extinguishing agent to fight fires. At the time of the incident, firefighters' access to these written materials would have allowed them to conduct a more thorough inspection and more quickly respond to the emergency.

From interviews with PG&E, we learned that PG&E attempted to hand carry a draft Emergency Response Plan to the SFFD following the 1996 fire. However, efforts to coordinate joint meetings, confirm plans, and conduct related necessary training failed. When we asked the SFFD personnel about the issue, they said that they were unaware of the effort. They believed that PG&E's efforts did not receive priority because the concern was not escalated high enough in the SFFD organization.

According to interviews, the SFFD Incident Commander and Head of the Rescue Squad did not know there was a floor plan stored in an envelope on the inside of the substation door. Nor did they receive specific details pertaining to a similar fire that took place in 1996. If the firefighters had had access to a map of the substation, it is likely that they would have been more successful in using the infrared camera to detect hot spots and avoid high voltage areas. Further, if the firefighters had known about details relating to the 1996 fire, they could have been more effective in their search for the origin of the fire, which was in the same vicinity as the 1996 fire. The delay in locating the fire resulted in more extensive damage and contamination in the substation, and prolonged customer outages.

In terms of fire fighting equipment, the firefighters were initially using air chisels to cut open the bus duct to fight the fire. Other firefighters who were knowledgeable about the 1996 Fire recommended using socket wrenches to remove the bolts holding the duct panels together as they had done in 1996. The Incident Commander believed that they could have fought the fire better and faster if they had known this before and if they had more wrenches.

During the incident there did not exist an agreed upon policy regarding what extinguishing agent to use to fight the fire. PG&E asked the SFFD not to use water and to use dry chemicals or CO_2 exclusively. However, it was necessary to eventually use water since other approaches were not practical or effective.

Between the 1996 and 2003 Mission Substation fires, PG&E and the SFFD have had little communication on common issues and concerns. This resulted in ineffective substation fire response.

Since the 2003 fire, PG&E and SFFD have conducted several meetings in the spring and summer of 2004 to discuss the fire coordination issues. Meetings included a review of facility checklists, review of emergency response plans, substation and plant orientations, terrorist type drills, and training bulletins and updates. PG&E and SFFD also used these meetings as forums to brainstorm other potential fire coordination activities. Topics of discussion included annunciation of alarms and monitoring of fire detection system signals by a City Central Alarm Station, use of distinctive clothing to identify PG&E person-in-charge, and potential use of SCBA (Self Contained Breathing Units) by PG&E personnel. They have also discussed having real-time monitoring of closed circuit cameras inside Mission Substation.

PG&E also planned to initiate a fire department training program that will include “train the trainer” sessions to familiarize the SFFD with PG&E work practices, equipment and facilities. PG&E reviewed SFFD training materials and fire protection equipment.

3. Smoke Filled Substation Task Force

According to a 2003 bulletin, PG&E employees are not allowed to enter smoke-filled substations. Prior to the December 20, 2003 event, PG&E did not initiate discussions with the SFFD about specific details in the bulletin.

In response to an incident at Potrero Substation in April 2003, PG&E created a "Smoke Filled Substation Task Force" to develop guidelines regarding PG&E personnel entering smoke-filled substations. According to Safety, Health and Claims, previous guidelines were "vague" and "open to interpretation".

As a result of the task force review, PG&E developed an interim bulletin entitled "Entry into a Substation/Building that is on Fire or Suspected on Fire" in the summer of 2003. Its purpose was to "bridge identified gaps regarding employees entering a substation building where smoke or fire may be present, and to provide guidance to those employees until a formal process can be developed."

Although supervisors communicated this bulletin to employees in an appropriate tailboard format, it is not known when PG&E will incorporate the contents of the bulletin into formal policy. At the time of the posting of this bulletin, apparently PG&E did not formally meet with the SFFD to discuss the contents or related issues.

Chapter Seven: Restoration

PG&E has no written restoration guidelines for Mission Substation and other substations. Reporting discrepancies existed regarding the total number of customers affected during the course of the incident.

PG&E's restoration policy is to restore the greatest number of customers in the least amount of time, balanced by a requirement to restore service to small numbers of customers who have been out of power for a long period of time. In restoring service following the fire at the Mission Substation, PG&E personnel maintain that they followed a strategy of restoring as many customers as possible in the least amount of time.

As a result of the incident, PG&E believes that it needs to review its policy regarding what components of its distribution system including which radial, network, and tie-cable systems should be energized and in what order. PG&E energized the tie-cable circuits from the Mission Substation at approximately 2 a.m. This was appropriate since none of the equipment on the third-floor was damaged by fire or smoke and was available for service. After the tie cables were restored, there was an issue about whether or not to restore the network circuits or radial circuits next. PG&E decided to restore the radial circuits since more customers were involved. In hindsight, PG&E believes that this was the best approach.

However, PG&E believes that written guidelines are necessary to help personnel make these decisions when multiple distribution systems (e.g. radial, tie-cable, network) are involved. According to PG&E, the guidelines should note the following factors: timing of the outage (week-day vs. week-end, business hours vs. non-business hours), the nature of the damage (if any), and other factors discussed in the Company's Electric Emergency Operations Plan such as the presence of hospitals, fire departments, etc.

Chapter Eight: Outage Communication

Estimated Time of Recovery (ETOR) was underestimated during the incident resulting in overoptimistic feedback to customers about when their service would be restored.

During the incident, PG&E underestimated the time it would take to establish clearances, and clean and restore equipment while customers were out of power. Equipment that was either damaged or rendered inoperable due to soot or other debris from the fire, required extensive hand cleaning and follow-up inspections. A realistic restoration plan needs to take into account the extent of damaged equipment, equipment that needs to be cleaned, the number of switchgear cabinets that needed to be cleared for cleaning, available operational personnel that can work within switchgear cabinets, and the circuits required to energize each network group. Without this knowledge, PG&E provided an overly optimistic estimated time of restoration (ETOR) to customers.

During the incident, the OIS (Outage Information System) provided questionable information regarding the number of customers out of power. Since the incident, PG&E performed a manual workaround to correct the problem. PG&E plans to perform permanent programming changes in the OIS system in the future.

Chapter Nine: 1996 Mission Substation Fire

1. Description of the Event

As described in PG&E's report on the 1996 fire[9], at 12:34 p.m. on November 26, a 12 kV cable splice short circuited and caused an X-1117 circuit breaker to open. The breaker operation was reported by SCADA to the GGCC. The splice was located approximately six feet from the first floor ceiling, just below the opening in the floor at the bottom of the X-1117 switch cabinet.

The short circuit in the splice burned the cable insulation and produced much smoke, which rose through the floor opening into the switch cabinet. Once the cabinet filled with smoke, events occurred just as in the 2003 fire. Smoke caused contamination of the air and reduced the electrical resistance between phases of switch components. The reduced resistance resulted in a flashover between phases of the bus bars connecting the overhead N bus to the switch, causing insulation on the N bus to ignite. The short circuit on the N bus caused the bus breaker to open at 0:55 a.m. (also reported by SCADA).

Around 1:00 a.m. on November 27, a PG&E employee on night shift stopped at Mission substation to use the restroom. Before entering, he noticed smoke coming from the building. After leaving the restroom he saw smoke, heard alarms and saw cables on fire after investigating further. He went back to his truck and called the Golden Gate District Operator at 01:05 a.m. He then returned to the building and went up to the second floor switch room because he knew that was the path of the burning cable. The fire department and his supervisor soon joined him. The supervisor directed efforts to protect the equipment and provided fire fighters access to the switch cabinets. Sometime after 2:00 a.m., the fire department finished putting out the fire, which destroyed the X-1117 cabinet and a significant portion of the N bus as well as lightly damaging adjacent switch cabinets. Since the fire caused a short time service

[9] Mission Substation Circuit X-1117 Root Cause Analysis, 12/5/1996

interruption only to customers supplied through the X-1117 switch, the outage did not meet the reporting requirements of the CPUC so PG&E did not report the incident.

2. 1996 Fire Root Cause Analysis

PG&E's 1996 Root Cause Analysis (see Appendix B) listed three action items to minimize future fire damage that were not implemented:

1. Initiate a fire barrier penetration sealing program to seal openings,
2. Review procedures for quickly responding to abnormal conditions such as breakers operations to promptly identify potential problems,
3. Evaluate a cost effective method of smoke detection throughout the substation. A method of remotely monitoring alarms would also be reviewed.

The Root Cause Analysis also cited previous Insurance Division Property Loss Prevention Reports that make the same recommendations. The second and third action items, quick response and smoke detection, directly apply to the 2003 fire. In 1996, the Insurance Department realized that GGCC operators had no way of knowing through SCADA that a fire was burning in the substation. If the employee had not stopped at the substation on the night of the fire by chance only, the fire would have continued until more circuits were lost, as occurred in the 2003 fire. The Insurance Department stated that since the substation was unattended, at least one of the two recommendations would need to be implemented to prevent an undetectable fire from progressing.

3. Similarities to the 12/20/03 Event

Similar to the December 2003 fire, the overhead N bus burned and remote monitoring did not detect the fire. X-1117 is a network feeder so no customers lost power and no one was dispatched to the substation to investigate, although SCADA reported both the X-1117 circuit breaker and an EN circuit breaker had opened. Even though the initial fault differed from the 2003 fire, the immediate resulting events and response were virtually identical:

1. The incident occurred during reduced staffing hours.
2. SCADA reported a breaker opening on a network circuit and later on an auxiliary bus.
3. The failed cable splice produced smoke contamination that resulted in arcing in the N bus that ignited the bus insulation.
4. SCADA did not detect or report a fire burning in the unmanned substation.
5. PG&E did not immediately investigate the fault because it was only one circuit in a network (N-1).
6. The fire did not self extinguish.

It was not until the investigation of the 2003 fire that PG&E's fire expert recognized the 1996 fire did not self extinguish and the significance of this finding. It was commonly believed that fires involving electrical equipment typically self-extinguish because the fire consumes the relatively limited combustible materials. The 1996 Root Cause Analysis reported that the fire had to be extinguished by the SFFD and that a continuous, smoldering fire was unusual for a cable splice. The analysis did not specify that the smoldering fire was on the N bus and not at the cable splice.

PG&E did not document the relevance of the 1996 fire not self-extinguishing in the Root Cause Analysis. PG&E did not acknowledge the flammability of the insulation on auxiliary buses. Nor did it realize that the fault on the N bus that ignited the insulation occurred because the bus was normally energized.

The similarities between the 1996 and 2003 fire are important because they demonstrate that PG&E should have anticipated and been prepared for the 2003 fire. The 1996 fire showed PG&E that a single network circuit fault could result in a fire. It demonstrated the auxiliary bus insulation was made of flammable material that could be ignited by a short circuit and sustain a fire. It also showed that SCADA monitoring would not detect an active fire in the switch cabinets and N bus.

Chapter Ten: Management Overview Process

The following section is a description of the processes used to develop, implement, and track findings and/or recommendations pertaining to the following analyses: 1) 1996 Fire Root Cause Analysis; 2) 1996 CES-Substation Fire Project; and 3) Insurance Department Property Loss Prevention Reports. This latter item will be discussed in the context of Item 2) above. All of these analyses pertain to recommendations in the areas of fire prevention, fire detection and monitoring, and fire suppression.

The responsible owner of these recommendations is primarily Substation Asset Management. Standalone fire protection projects are prioritized and included in the annual workload plan with other projects. Authorization of expenditures for substations coincides with the delegation of authority tables that are based on the level of authorization required. For example, the Substation Asset Manager can authorize $300,000 in expenditures and the Substation Engineering Director can authorize $500,000.

1. 1996 Fire Root Cause Analysis

Had PG&E implemented its 1996 investigation recommendations, CPSD believes the cable failure on December 20, 2003 would not have resulted in an outage to more than 100,000 customers throughout San Francisco.

The Substation Asset Management Group prioritized the recommendations of the 1996 Root Cause Analysis and the recommendations of the Property Loss Prevention Reports. Criteria to prioritize the work consisted of the following:

- Life safety and oil related hazards;
- Continuity of operations; and
- Asset preservation.

Based on this prioritization, two recommendations including fire detection and sealing openings between floors were classified as continuity of operations—a lower priority than life safety and oil related hazards. The third recommendation, covering quicker response to SCADA alarms was classified as a lower priority as well.

Following the incident there was no mechanism in place to track the recommendations made in the 1996 Root Cause Analysis. According to defined areas of responsibility, the Substation Asset Management Group was responsible for the first two recommendations including fire penetration seals and smoke detectors and Division Operations was responsible for the third recommendation or immediate dispatch of personnel for alarms. The Asset Management Group forwarded the 1996 Fire recommendations to the San Francisco Division Manager, who was responsible for division operations. According to PG&E, a recent search for the transmittal letter was unsuccessful.

At a subsequent PG&E meeting, the head of Substation Management agreed to evaluate smoke detectors, and the Division Manager agreed to check with operations regarding an immediate dispatch of personnel for alarms. Substation Asset Management claimed that an informal assessment of the substation revealed that they could not reasonably install a fire detection system within fire code specifications. Although San Francisco City Code does not require smoke detection for the building, if it were installed, it would have to comply with NFPA 72, the National Fire Protection Association Fire Alarm Code.

PG&E said that they did not install smoke detection on the first floor ceiling since it has numerous beams and recesses that would require many sensors. Substation Asset Management and the Insurance Department claimed that the cost of installing sensors and connecting them to SCADA would be prohibitive until more affordable technology was available. A cost-benefit study of smoke detectors was not done and there was no formal follow up or communication between the Substation and Division Operations groups on this subject.

According to PG&E, there is no supporting documentation to track the recommendations made in the root cause report. Similarly, there is no supporting documentation that a quarterly or annual review of this event was performed in compliance with reporting guidelines in effect at that time.

2. 1996 CES-Substation Fire Project Report

At the time of the 1996 fire, PG&E did not take action to improve fire detection in indoor substations that was recommended in the report.

The April 1996, CES Substations Fire Project Report completed by the PG&E Insurance Division (prior to the December 1996 Fire) identified fire hazards associated with indoor substations and related substations.

Following are some examples:

1. Toxic Smoke: While cable insulation fires do not provide much heat, they typically generate a lot of smoke. Visibility is a major problem in fire-fighting activities and the products of combustion can be toxic depending on the cable insulation material. According to the report this poses a health threat to exposed individuals.

2. Highly Combustible Nature of Cable Fires: Cable insulation fires can easily promote spreading of fires from one area to another. Cable fires often spread to other areas not affected by the specific cable. Shorts in one cable routed with other cables often result in fire and can damage other cable. These fires are typically difficult to extinguish and may, in fact, re-ignite.

3. Concerns Related to Switchgear Equipment: Non-oil filled circuit breakers that reside in enclosed metal housings do not present the same hazards as oil filled ones, but they do contain combustible insulation. Due to a malfunction, an arc can occur. If this isn't detected early, a fire could result.

The Insurance Department initiated annual surveys to review the facility fire prevention program components and comment on the adequacy of fire equipment inspections and maintenance. Since the 1996 Fire, the Insurance Department completed surveys in 1997, 1998, 2000, and 2002. The 2000 and 2002 reports identified issues in the April 1996 CES-Substations Fire Project Report that were not yet resolved. This translates to a delay of approximately four to six years. Issues included the following:

- Provide an automatic detection system in the Control Room;
- Extend sprinkler protection to the oil filled potheads located in the same compartments as Oil Circuit Breakers (OCB's);
- Verify adequacy of the existing ventilation system for the Battery Room, with respect of the requirements of Article 64 of the Uniform Fire Code; and
- Install exterior bells for local annunciation of a fire, or verify acceptability of the existing condition with the local fire department.

In interviews with PG&E, a Principal Loss Control Engineer from the Insurance Department pointed out that the Department's role was an advisory one and that the authority to implement Insurance Department repeated recommendations rested with Substation Asset Management and Division Operations. The Principal Loss Control Engineer explained that they did not seriously consider automatic fire detection suppression recommendations since he was under the general impression that substation electrical fires typically "self-extinguish" and therefore do not require extensive firefighting intervention. During some follow up interviews with the PG&E Investigation Team, PG&E indicated that personnel were not fully aware of the fallacy of this thinking and asked to retract statements that indicated otherwise. (Also, refer to Chapter Nine “1996 Mission Substation Fire”, Section 3. “Similarities to the 12/20/03 Event”.)

3. Operations Standard S1465 “Event Investigation Procedures”

PG&E has a slow and cumbersome process to review operating standards relating to incident investigation procedures.

PG&E Utility Operations (UO) develops operations standards to ensure that all aspects of its operations are conducted in a safe and consistent manner. In addition to providing content, these standards contain information pertaining to issuing departments, utility operations sponsors, effective dates, and review dates.

The PG&E Utility Operations Standard S1465 “Event Investigation Procedures for Electric Utility Operations” effective 01/01 provides for event investigation procedures, reporting requirements, and implementation of recommendations associated with an event. Electric Transmission and Distribution (T&D) Engineering, Electric Control Center Operations (ECCO), Engineering and Planning (E&P), and Operations Maintenance and Construction (OM&C) are sponsors of this standard.

The required PG&E review date for S1465 is currently 1/03 but apparently PG&E did not begin this activity until 9/03. Changes are numerous and significant, but as of April 2004, it has not yet been reviewed or approved by PG&E management. PG&E does not know when the final version will be reviewed or approved.

A partial list of root cause report requirements include required communication to provide ease of preparation, consistency and quality of information, and management overview to ensure that reports are prepared in a timely manner, of consistent quality, and that action items are identified and implemented by responsible individuals. However, the 1996 version of this standard (E-TS-GOO8 effective August 1996) did not specify an adequate process for management to monitor remedial actions based on event report recommendations.

4. Technology Review

PG&E has no systematic procedure to review and adopt new technology that can improve safety and reliability. Examples of technology related to this incident include barrier seal material and laser beam smoke detector technology for indoor substations.

The 1996 Fire Root Cause Analysis recommended a cost-benefit analysis of the potential installation of smoke detectors with remote monitoring suitable for indoor substations. Without the benefit of performing this analysis, the head of Substation Management said that the only option available was the standard commercial detectors that would have to be installed at tremendous cost and involve complex wiring, spacing and physical arrangement, and remote monitoring (Ref: NFPA 72). For this reason, PG&E decided to not implement this recommendation. (Refer to Chapter Ten. “Management Review Process”.)

Following the 1996 Fire, PG&E was not aware of, nor did they research laser beam technology that is highly effective at less cost. The CPUC Investigation Team recently consulted various laser beam smoke detector vendors and found that this technology has been available for indoor electric substation for about 20 years. The beam technology currently used in several PG&E indoor substations in the East Bay Area was available as early as March 1994.

Similarly, 1996 Fire Root Cause Analysis recommended that a fire barrier penetration-sealing program to seal openings be implemented. In interviews, PG&E claimed that it did not have access to technology that would effectively accomplish this objective. Ideally, a product that is both intumescent (ability to expand with heat) and tolerant of high heat should be used. The only option at the time was a form of particleboard, which was considered too stiff. Short circuit conditions typically cause 12 kV cables to move and the sealing material would not flex or allow movement. PG&E suspended the program pending a search for a material appropriately designed for the application.

PG&E recently found that fire penetration materials made by 3M Corporation have the properties necessary to be an effective penetration fire barrier substance. The CPUC Investigation Team contacted 3M Corporation and found that the materials have been available since 1979.

Chapter Eleven: Event Related Costs

PG&E and ratepayers would have saved millions of dollars if the fire had been detected sooner, resulting in less damage to the substation and a less extensive power outage.

Following are significant known costs incurred as a result of the fire:

Cost Item	$
Substation Restoration and Reconstruction	
Capital	2,262,964
Expense	222,227
Third Party Tests and Investigations	
Bus Duct Exemplar Fire Test	4,470
Cone Calorimeter Tests	5,000
Engineering and Fire Investigations	
Bus Component Material Evaluation Tests	4,500
Fire Investigation Report by Independent Experts	Unknown
Claims (as of 7/23/04)	
Individual Claims	360,000
Business Claims	1,800,000
Third Party Legal Fees	Unknown
PG&E Labor Costs (Overtime)	Unknown
Total (Partial List)	4,659,161

Table XI-1. December 20 Mission Substation known fire related costs

PG&E paid nearly $4.7 million dollars for known costs pertaining to substation restoration and reconstruction, third party tests and investigations, and individual and business claims.

Chapter Twelve: Detailed Description of the Event

For references to specific pieces of equipment, refer to Figure III-2, single line diagram of the Mission Substation.

1. Cable Failure

The blackout of much of downtown San Francisco, which happened on December 20, 2003, started with a short circuit in the X-1153 cable where it enters the metal clad cubicle which houses switches 1153/3 and 1153/5. The cable, installed more than 40 years ago, was, and for most of its length still is, composed of a copper conductor with oil-impregnated paper insulation and a lead sheath. It rises vertically from below street level to the second floor of the substation where it enters the switch cubicle. In the course of time, the oil in the insulation under the force of gravity migrated down the cable, leaving relatively dry paper of significantly diminished insulating value at the top. The reduced insulation caused the short circuit in the cable. The resulting damage is shown in Figure XII-1.

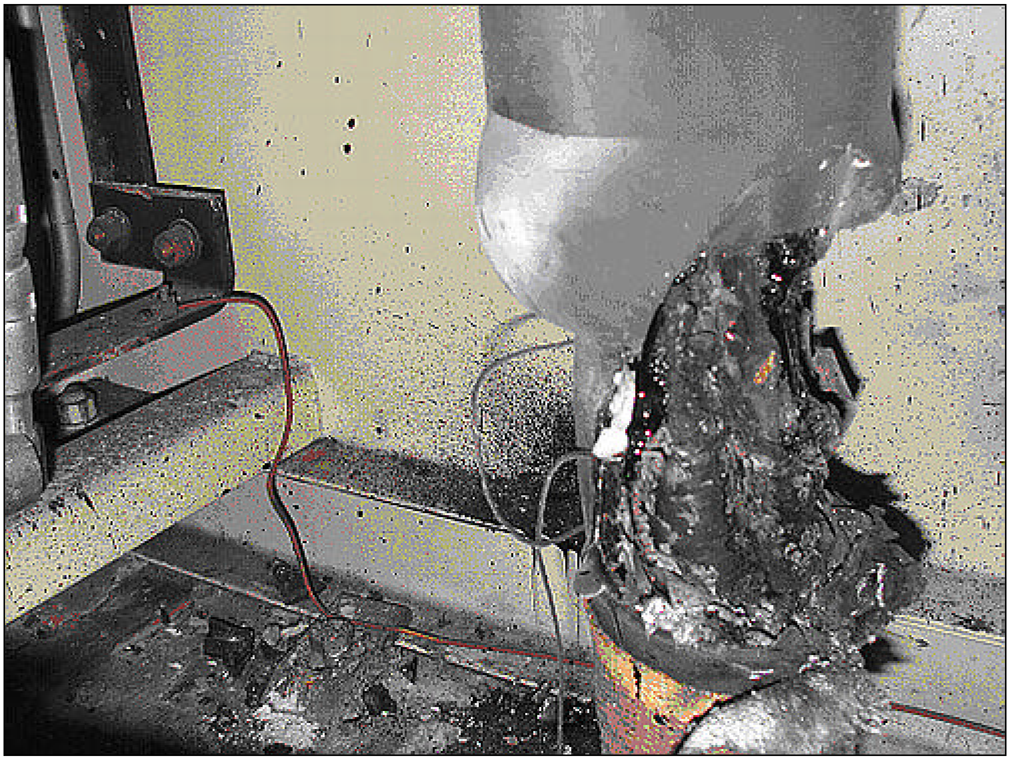

Figure XII-1. Damaged X-1153 cable

2. X-1153 Circuit Breaker Trip

Short circuit current in a 12.5 kV cable in the substation has a magnitude of up to 26,000 amperes. Comparatively, the current in a 100-watt light bulb is about 1 ampere. The short circuit at 3:51 p.m. on 12/20/03 was detected by the protective relays in a circuit breaker for X-1153, causing it to open (trip) automatically, thereby interrupting the flow of short circuit current in about one-tenth of a second.

3. Ignition of the N bus

The N bus is located above the switch cubicle. Extending from it into the cubicle are copper bars for connecting the bus to Switch 1153/5. (Refer to Figure XII-4 described above.) The burning of the cable insulation and sheath resulting from the short circuit produced gases of high electrical conductivity within the cubicle, which caused a second short circuit across the copper bars. The heat produced by this second short circuit close to the flammable insulation of the bus, ignited the insulation.

4. Section E Circuit Breaker Trip

The second short circuit was equal in magnitude to that in the cable (26,000 amperes) and was detected by the protective relays in Circuit Breaker EN/22, which energizes the N bus from Bus # 2, Section E, see Figure III-2. The protective relays caused the breaker to open, thereby interrupting the short circuit. The time was a fraction of a second after the opening of 1153/2. The damage to the X- 1153 cubicle from both short circuits is shown in Figure IV-2.

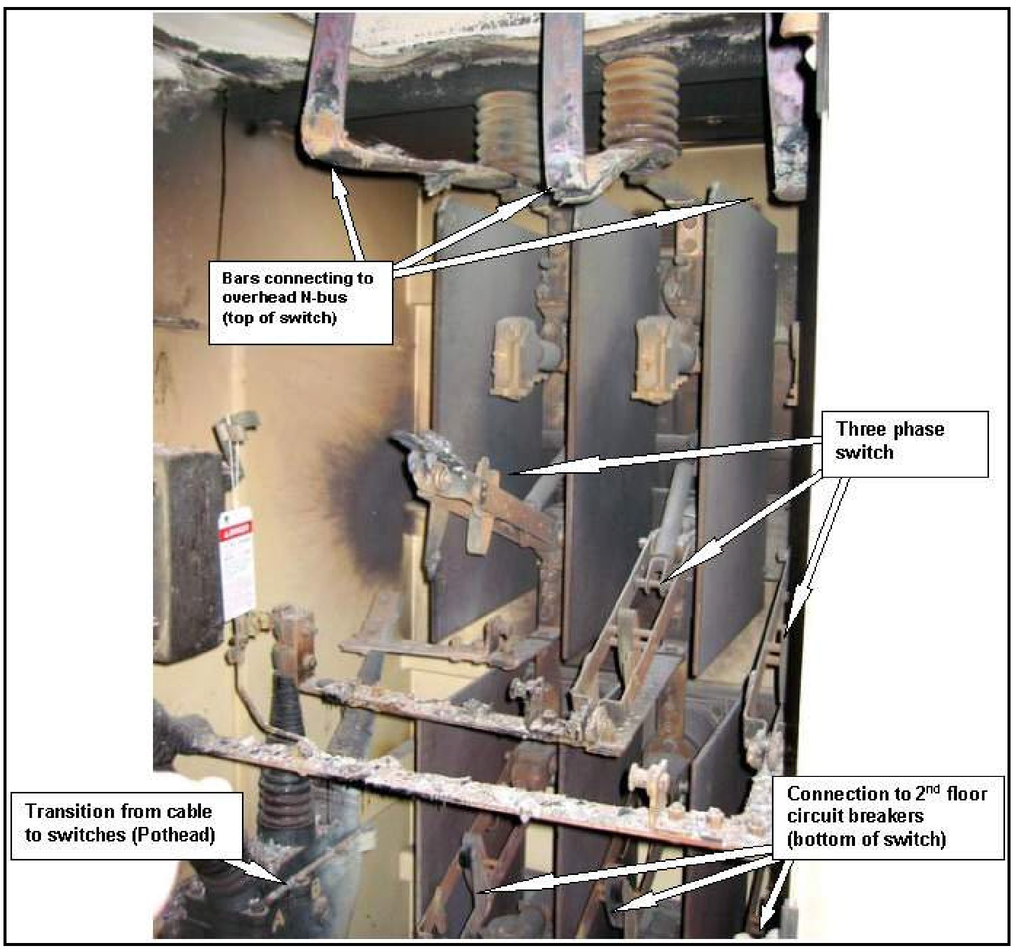

Figure XII-2. Damaged X-1153 cubicle

5. Initial Alarms

The Mission Substation is unattended and its primary functions are controlled from the GGCC in Daly City by means of SCADA. (Refer to Chapter Four “Mission Substation Facilities”, Section 2. “SCADA”.) SCADA reported the automatic tripping of X-1153 circuit breaker at the time of its occurrence by a message on the GGCC operator’s computer monitor. The automatic tripping of bus breaker was announced as the trip of a circuit breaker connected to the E Section bus, but the alarm notice did not specify which of the 28 circuit breakers connected to that bus section. At the same time, the operation of the X-1153 protective relays caused low voltage conditions on Buses 1 and 2 resulting in an alarm and further alarms of unspecified cause were received from 4 of the 5 transformers and the water deluge system. All told, at 3:51 p.m., the GGCC received 11 alarms from Mission Substation within 1 second. The short circuits were the direct cause of the circuit breaker trip and relay operation alarms, and it is now known, although at the time the operator had no way of telling, that the transformer and water deluge system alarms were caused by the voltage dip resulting from the short circuits.

6. Initial Operator Response

During the week, PG&E has mobile crews of maintenance personnel available to respond to substation trouble, but not on the weekends. On weekends personnel from the GGCC are dispatched to investigate trouble. However, the X-1153 circuit is only one of six circuits supplying the X4 network, which can meet peak load with only five supply circuits in operation. It was accepted procedure at the GGCC not to respond immediately to circuit breaker trips, which did not cause loss of load. Likewise, because there had been no report of a power outage, investigation of the trip of the circuit breaker connected to Bus Section E could be postponed, as could the source of the other alarms. The breaker trip alarm was transmitted by the operator's assistant to the operations supervisor, who also did not consider the event to be of sufficient importance for immediate response.

7. Power Problem Reported by Large Commercial Customer

The controls of large motors, such as the drives for air conditioning compressors, are known as motor starters. Their electrical contacts are closed by an electromagnet. When there is a significant dip in the supply voltage, current in the electromagnet drops and the motor starter opens, de-energizing the motor to prevent damage. As mentioned in Section 5 above, "Initial Alarms", a large magnitude short circuit will drop the voltage at the source bus to almost zero. At 4:02 p.m., a large commercial customer reported that its air conditioning chillers had shut down. On the assumption that the shutdown was due to a problem with supply voltage, the customer reported the incident to PG&E. We now believe the starter on the chiller motors opened due to the voltage dip caused by the X-1153 short circuit.

8. Propagation of Fire Along the N Bus

We believe that the short circuit across the bars connecting to the N Bus in the X-1153 switch cubicle started a fire in the N Bus above the cubicle and that the electrically conductive combustion products in the form of ionized gases propagated along the bus in both the Easterly and Northerly directions to the junction with Bus M and in the Westerly direction to the X-1115 switch cubicle. There are openings in the bus enclosure above the switch cubicles for the penetration of the bars that connect the bus to the switches. When the gas reached the X-1109 cubicle, it entered the cubicle and caused the short circuit described below.

9. X-1109 & X-1162 Circuit Breakers Trip

At 5:24 p.m., about an hour and a half after the trip of Circuit Breaker 1153/2, Circuit Breakers 1109/2 and 1162/2 opened automatically by action of their protective relays. Although the SCADA alarm record does not show a time separation between the two events, we believe the event started as a result of a short circuit across live parts in the X-1109 cubicle caused by the incursion of ionized gases and debris produced by the burning of the N bus. As mentioned above, a large magnitude short circuit across two or more bus bars will depress the voltage at the source bus to almost zero. As shown on Figure III-2, the source bus is Bus Section H. Also connected to this bus is Circuit Breaker 1162/2, which is connected on the load side to the X-4 network. In addition to being supplied by Feeder X-1153, which had been de-energized due to the fault in the cable, and by Feeder X-1162, the network is supplied by four other feeders connected to other bus sections. When the voltage on Bus Section E fell to near zero, the higher voltage on the other buses drove current in a reverse direction to normal flow through Circuit Breaker 1162/2. This current was detected by the breaker's protective relays, which caused the breaker to trip.

10. GGCC Response

Feeder X-1109 is not a redundant source connected to a network as are Feeders X-1153 and X-1162, but is a radial feeder (refer to Chapter Four "Mission Substation Facilities", Section 4. "Distribution Feeders"), the sole source for the loads connected to it. As a result of its de-energization, service to 3000 customers was interrupted. In addition, Feeder X-1162 was the second feeder to Network X-4 put out of service and there was the possibility that the remaining feeders would be overloaded. The operator, aware that service had been interrupted, dispatched a switchman, who had been working at the Potrero Substation, to Mission to investigate. Another operator at the GGCC tried unsuccessfully to contact an engineer for an opinion on possible overloading of the remaining feeders to Network X-4. This second operator also notified his supervisor and another operator of the conditions and these men started out for the control center.

11. 1109/2 Circuit Breaker Reclosure

Sixteen minutes after the X-1109 circuit breaker tripped, the operator reclosed it successfully, i.e., the breaker did not trip again and the load was restored. When feeders and the equipment connected to them experience short circuits caused by arcing between the exposed live parts, the fault can usually be cleared by a short time de-energization of the circuit. It was the policy at the GGCC to reclose radial feeders after automatic trips to take advantage of this fact.

12. Switchman Discovers Smoke

Twenty-one minutes after the trip of the X-1109 and X-1162 circuit breakers, the switchman arrived at Mission Substation and noticed smoke coming out of a ventilation opening. He opened the back door and smoke came out; whereupon he notified the GGCC operator, who told him to try the front door. When he opened the front door, he again saw smoke and notified the GGCC. The GGCC operator next asked PG&E's San Francisco Gas Dispatch to call the fire department. He called the San Mateo Substation and asked that all the 115 kV transmission circuit breakers be opened at Mission Substation to de-energize the substation. This was accomplished at 5:57 p.m., thereby isolating the energized transmission lines from the substation transformers. (Refer to single line diagram in Appendix A.) The result was that service to about 100,000 customers supplied from Mission Substation was interrupted and all equipment at the substation except emergency lighting was shut down.

13. San Francisco Fire Department Arrival

The first firefighters to go into the substation were a four-man rescue squad with a thermal imaging camera, whose mission was to look for possible victims of the fire. Although this crew did not have a floor plan of the substation, the crew walked through all the corridors of every floor of the building and found no victims nor did they find any fire. Additional crews entered the building with portable fans to dissipate the smoke. A PG&E employee transferred the source of the substation's internal power from the substation itself to remote Station I by opening 480V circuit breaker X/2 and closing 480V circuit Breaker Y/2, see the single line diagram in Appendix A. The building ventilation fans in the basement were turned on and a firefighter in an aerial bucket outside the building was raised to the roof to turn on the roof fans. All this ventilation cleared the smoke and, having found no evidence of fire, the firefighters started leaving the premises at around 7:45 p.m.

14. Initial Restoration of Power

While the firemen were clearing the smoke, a number of PG&E maintenance and operating personnel, including two maintenance supervisors and a maintenance foreman, who had been called to respond to the emergency, arrived on the scene at approximately 7:30 p.m. By this time, the first floor was sufficiently clear of smoke for PG&E personnel to enter the building. Their first task was to "clear the buses", i.e., to open all the 12.5 kV circuit breakers prior to an orderly restoration of power. After this was done, the GGCC operator had the transmission operator restore power to the substation by closing the 115 kV circuit breakers at 7:49 p.m. The GGCC then instructed the on-site personnel to close the circuit breakers on Buses 1 and 2 to restore power to satellite substations supplied from Mission Substation (Stations G, K, N, 6th Ave. and 8th Ave.). The result was the restoration of service to some 49,600 customers.

15. Discovery of Fire and Second Shutdown of Substation

As the firemen were leaving, a PG&E technician reported a fire in the foreman's office, adjacent to the control room. The firemen were called back and extinguished a paper and wood fire in records stored in a mezzanine above the foreman's office, immediately below Switch Cubicle X-1101. (Refer to XII-3.) However, smoke kept filling the area and it became evident that there was still fire in the building. The fire department requested that the building be de-energized a second time, but the PG&E maintenance supervisor in charge was reluctant to do so. The firemen began searching for the fire and after 15 or 20 minutes reported that the switchgear along the whole length of the South side of the switchgear room on the second floor was burning. The maintenance supervisor then asked the GGCC to have the substation de-energized again, and this was done by 10:16 p.m. The fire was in the N bus, which extends the length of the South wall of the switchgear room, curves around to the East wall and curves again to the North wall where it connects to the M bus through Switch MN/1, see Figure III-3. The firemen fought the fire with dry chemicals and when that didn't work, requested and were granted permission by the PG&E maintenance supervisor to use water, with which the fire was finally extinguished around midnight.

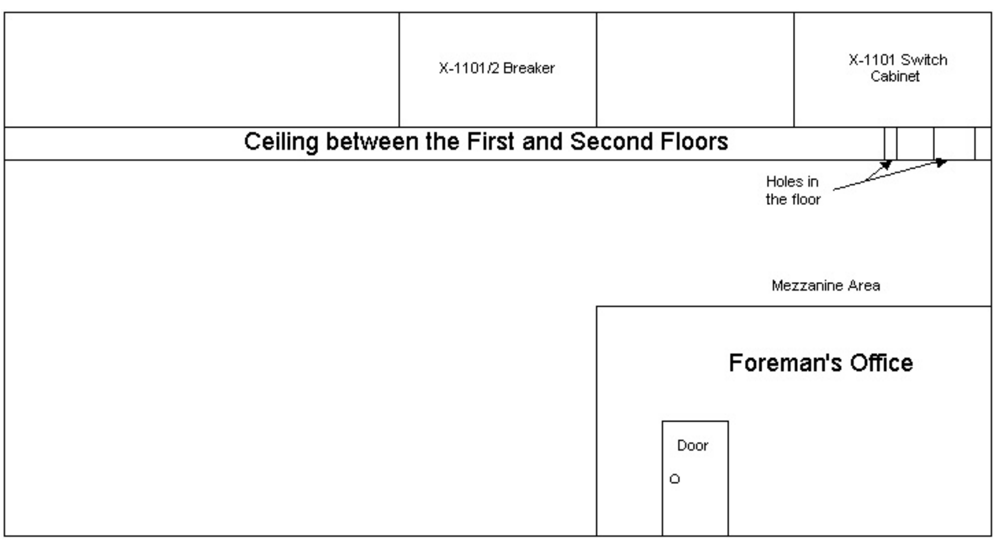

Figure XII-3. Cross section of substation underneath switch cubicle X-1101

16. Fire Damage

The fire destroyed the N bus (See Figure XII-4) and Switch Cubicle X-1101 (See Figure XII-5). Switch cubicles for X-1105, X-1109, X-1121 and X-1153, the cables connecting to them, and the cubicle containing the switch tying the M and N buses were all heavily damaged by fire, smoke and soot. Other equipment on the second floor, including the M bus, the switch cubicles connected to it and the circuit breakers, were contaminated with soot. (Refer to Figure XII-6.) The 115 kV equipment on the first floor, the 12.5 kV switchgear on the third floor, and the control room were not damaged.

Figure XII-4. N-Bus fire damage

Figure XII-5. Fire damage X-1101 switch cubicle

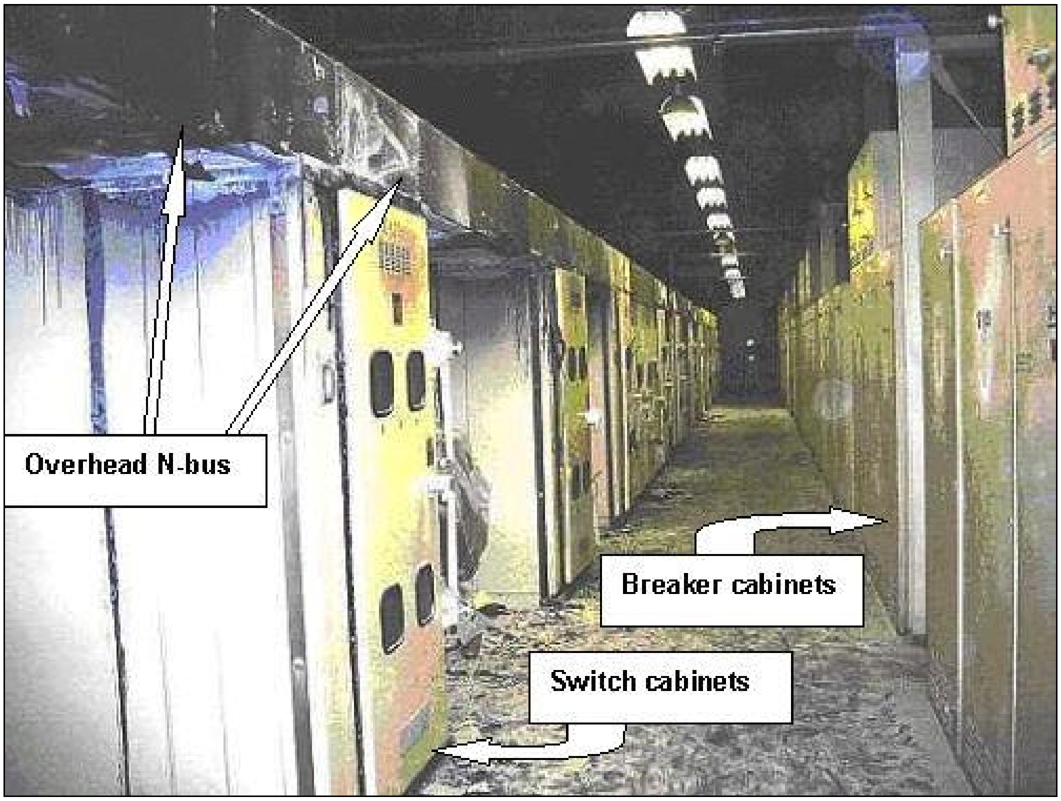

Figure XII-6. Soot and debris on second floor switch room

17. Second and Final Restoration of Power

After the fire was extinguished, PG&E began damage assessment and restoration. The PG&E maintenance supervisor went to the third floor and found no damage. The GGCC was notified and had the transmission operator restore power to the substation again at 12:48 a.m. on Sunday morning. Between one and two o'clock the circuit breakers in the third floor switchgear controlling the cables to the satellite substations were closed, restoring power to 49,600 customers. At 2 a.m. customers served from a 4 kV circuit were restored and by 4 a.m. switching to sources other than Mission Substation restored customers on the badly damaged X-1101 circuit. Meanwhile, two crews from PG&E's Protection and Coatings Division were cleaning equipment on the second floor. Between 5 a.m. and 5 p.m., customers served from non-network feeders were restored. Between 9 p.m. and midnight Sunday the two networks, X-3 and X-4, were re-energized, completing the restoration of power, approximately 30 hours after the first shutdown.

ACRONYMS

AC	Alternating Current
CAISO	California Independent System Operator
CES	Customer Energy Services (PG&E)
CPSD	Consumer Protection and Safety Division
CPUC	California Public Utilities Commission
DC	Direct Current
D.O.	District Operator (PG&E)
DOE	Department of Energy
ECCO	Electric Command Center Operations (PG&E)
EMS	Energy Management System
ETOR	Estimated Time of Restoration
FCP	Fire Control Panel
FEEP	Facility Environmental Emergency Plan (PG&E)
GGCC	Golden Gate Control Center (San Francisco Electric Distribution)
ICS	Incident Command System
kV	Kilovolt
MW	Megawatts
NFPA	National Fire Protection Association
OCB	Oil Circuit Breaker
OIS	Outage Information System (PG&E)
OMC	Operations, Maintenance and Construction (PG&E)
PG&E	Pacific Gas and Electric Company
PIC	Person in Charge (PG&E)
PILC	Paper Insulated Lead Covered
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SFFD	San Francisco Fire Department
SMCC	San Mateo Control Center (San Francisco Electric Transmission)
TOC	Transmission Operating Center
UO	Utility Operations (PG&E)
VAC	Volts Alternating Current
VDC	Volts Direct Current

Glossary

Action Plans/Strategy – Action taken after the event to prevent or reduce the probability of a similar problem occurring in the future or to correct an identified problem and other related problems that may exist. A useful action plan identifies who should do what and when, with a follow up on what strategies were effectively implemented.

Bus – electrically conductive path, typically a metal pipe or bar, which provides a common connection point for equipment.

Circuit – conductor or system of conductors through which electric current is intended to flow.

Circuit Breaker – device used to stop a flow of electricity automatically or manually. Circuit breakers are typically used to protect equipment when current exceeds a set limit or when a short circuit occurs. When a circuit breaker allows electricity to flow, it is closed. When a breaker stops electricity flow, it is open. Once a circuit breaker opens, it must be reset to close it.

CAISO – California Independent System Operator, authority responsible for the operation and control of the statewide electricity transmission grid.

Distribution – The local wires, transformers, substations, and other equipment used to distribute and deliver electricity to consumers from the high voltage transmission lines. Distribution voltages typically range from 4 kV up to 60 kV.

D.O. – District Operator that monitors and operates the electric distribution system from a control center.

Event – An unplanned major equipment failure that occurred within the PG&E's electric system.

Fault– An event such as a short circuit or ground that occurs on a circuit and causes relays and circuit breakers to operate.

Feeder – electricity distribution line that connects the substation to the distribution network supplying the consumers.

GGCC – Golden Gate Control Center. Located in Daly City, GGCC district operators manage the PG&E electricity distribution system in San Francisco and Peninsula districts.

Ground – A fault or unintentional connection that provides a low-resistance path between a point in a circuit and ground. A ground can drastically affect the operation of a circuit. A ground may damage or destroy equipment if excessive current flow results.

N-1 Condition – The loss of a single circuit.

Network Circuit – circuit with multiple power sources that divide the load demand among the multiple sources. Networks are used to increase reliability in the event that if one source is lost, the other sources can maintain the load demand until all sources are restored.

Network Protector – device like a circuit breaker used to stop electricity flow. Network protectors open a circuit in the event electric current is too low, too high, or in the wrong direction.

PILC – Paper Insulated Lead Covered [Cable]. PILC cable is typically composed of three stranded copper conductors: one for each phase of a three- phase electrical circuit. To insulate the phases from one another, each set of stranded conductor is wrapped in layers of oil-impregnated paper, and then bundled together in a lead sheath with a plastic jacket.

Radial Circuit – circuit with a single power source to supply the load demand. The circuit provides no power if the single source is lost.

Overcurrent Relay – device which detects an excess of current to automatically operate a circuit breaker.

Root Cause – The underlying event or condition that, if corrected, would prevent or minimize the probability of recurrence of the problem.

SCADA – Supervisory Control and Data Acquisition. A network of automated devices and controls that enables remote monitoring and management of electrical system equipment and components.

Short Circuit – typically, a fault or unintentional connection that provides a path for electric current between phase conductors. A short circuit can be either two or three-phase and drastically affects the operation of a circuit. If a short circuit is not interrupted, damage or destruction of equipment may result.

SMCC – San Mateo Control Center. SMCC district operators manage the PG&E electricity transmission system in San Francisco and Peninsula districts.

Substation – point in an electricity distribution system that receives high voltage from transmission lines and reduces it to lower voltage to send out over distribution lines.

Switch – device to stop the flow of electricity or to change the path of the flow of electricity.

Total Number of Customers Affected – The total number of bill-paying (metered) customers affected by a momentary or sustained electricity outage.

Transformer – device used to transform voltage levels to facilitate the transfer of power from a generating plant to the customer. Substations use transformers to reduce high transmission voltage to lower distribution voltage.

Transmission – The interconnecting electric lines that move high voltage electricity from where it is produced to the point of distribution to customers. Transmission voltages range from 60 kV up to 500 kV.

Trip, Tripping, Tripped - A circuit breaker **trip** occurs when a closed breaker detects an excessive electrical current and opens to stop the current.

Appendix A

Simplified Single Line Diagram of Mission Substation

Appendix B

PG&E Root Cause Analysis of 1996 Mission Substation Fire

Appendix C

Okonite Company Tests of PILC Cable