A minerals research contract report
February 1981

BuMines OFR 154-81

DEVELOP GROUNDING PRACTICES FOR METAL/NON-METAL MINES

Bureau of Mines Open File Report 154-81

Contract J0308025
West Virginia University

BUREAU OF MINES★UNITED STATES DEPARTMENT OF THE INTERIOR

Minerals Health and Safety Technology

NOTICE

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO. BuMines OFR 154-81	2.	3. Recipient's Accession No. PB82-137308

4. Title and Subtitle	5. Report Date
Develop Grounding Practices for Metal/Non-Metal Mines	February 27, 1981
	6. U.348001
7. Author(s) Wils L. Cooley and Herman W. Hill, Jr.	8. Performing Organization Rept. No.
9. Performing Organization Name and Address Electrical Engineering Department Engineering Experiment Station West Virginia University Morgantown, WV 26506	10. Project/Task/Work Unit No. 11. Contract(C) or Grant(G) No. (C) J038025 (G)
12. Sponsoring Organization Name and Address Office of the Director--Minerals Health and Safety Technology Bureau of Mines U.S. Department of the Interior Washington, DC 20241	13. Type of Report & Period Covered Contract research, 11/1/79--12/31/80 14.

15. Supplementary Notes

Approved by the Director, Bureau of Mines, for placement on open file, November 10, 1981.

16. Abstract (Limit: 200 words)

This report analyzes electrical accident data in the metal-nonmetal mining industry. Accidents are categorized to determine the root causes. Special attention is given to accidents associated with inadequate or defective grounding of mine power systems. Recommendations are made concerning proper grounding practice, especially for dredges and for quarries in hard rock or sand. The costs of instituting the recommended practices are estimated for model mine power systems which are based on field data obtained from 37 mines and several electrical contractors. The expected benefits of various suggested safety practices are also estimated.

17. Document Analysis a. Descriptors

Metal-nonmetal mining
Electrical grounding
Mine safety

b. Identifiers/Open-Ended Terms

Safety ground bed
Safety ground system
Ground check monitor
Electrical accidents
Electrical hazards

c. COSATI Field/Group 08I, 09

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Unlimited release by NTIS.		235
	20. Security Class (This Page)	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

DISCLAIMER

FOREWORD

This report was prepared by West Virginia University Engineering Experiment Station, Morgantown, West Virginia under USBM Contract J0308025. The contract was initiated under the Metal and Non-Metal Mine Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Mr. Roger L. King and Mr. Dean H. Ambrose acting as Technical Project Officers. Mr. Alan G. Bolton, Jr. was the Contracting Officer for the Bureau of Mines.

This report covers work recently completed under the contract during the period from November 1, 1979 to December 31, 1980. The report was submitted by the authoris in February 1981.

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CHAPTER I

INTRODUCTION

1.1 NEED FOR THE STUDY

The metal/non-metal mining industry uses a great deal of electric power in the recovery and processing of many materials. Although the amount of power consumed is not unusual compared to other industries, this power is often utilized in situations and under conditions which are unlike those found in other industries. Much equipment is portable or mobile, and as it and the mining site move the mine electrical system is continuously being reconfigured. The equipment is subject to extreme environmental conditions of mud, water, dust, temperature extremes and mechanical shock. And it is often repaired by persons who have such a broad range of duties that they have no time to become "expert" electricians.

All of the conditions above suggest that mine electrical systems pose a special hazard to those who repair them and to those who simply use electrically powered equipment. Indeed, while mine electrical accidents cannot compare in frequency to those caused by slips and falls of material, they do constitute a significant source of injury and death. From January 1970 through December 1979, for instance, 96 men were electrocuted in the industry, while at least ten times that number were injured.

At the time this study was commissioned it was believed that a significant number of the electrical accidents and fatalities resulted from improperly grounded electrical equipment, especially in mines which employed dredges or were located in areas where the earth was a very poor electrical conductor. If so, then improved electrical practice with respect to grounding techniques could reduce electrical hazards and thereby reduce the number of accidents and deaths.

1.2 SCOPE OF WORK

The tasks undertaken were to verify that improper grounding did contribute to electrical accidents and deaths and then to make recommendations concerning system grounding and ground check monitoring to alleviate the problem. The verification task involved a detailed study of electrical accidents which had occurred throughout the industry. Unfortunately the statistics kept by the MSHA Health and Safety Analysis Center often did not provide sufficient detail to properly evaluate the impact of grounding practice, so that it became necessary to study the original accident reports. Even then, the contributory factors to the accident were difficult to determine with certainty. And since a great effort was being expended to read accident reports, it was decided to attempt to list the contributory conditions for each accident studied. Making recommendations on grounding requires a thorough knowledge of the conditions that exist in the field and the types of equipment in use. This information was gathered by visiting approximately 37 mines of various sizes and types throughout the United States. The data gathered was then used to develop "model" mine power systems to be used in assessing the impact of recommended changes, both anticipated cost to the industry and expected benefit. The original study was expanded in this area also, so that data was gathered to assess the benefits and costs of electrical system changes other than those associated with grounding. Once the costs and benefits of grounding practices were estimated, grounding recommendations were made.

1.3 SUMMARY OF TASKS

The scope of work outlined above was carried out as a series of nine related tasks. These are summarized here as an introduction to the detailed material which follows in the rest of the report.

1.3.1 Accident Profiles

In order to determine whether or not improper grounding was a cause of a significant number of mine electrical accidents, it became necessary to develop a means of identifying or describing each accident in a way which would show clearly its important characteristics. Although a detailed analysis was available from the MSHA Health and Safety Analysis Center (HSAC), this analysis did not appear to provide the desired information in a form which would lend itself to the type of analysis contemplated. The decision was made to study each accident by reading the original reports and to form a new analysis profile which would differ from the HSAC profile.

An effort was made to construct an "event tree" which would provide a clear illustration of the events which lead up to electrical accidents and fatalities. This event-tree was developed from a consideration of the activities a miner might be engaged in at the time of the accident. Since the number of possible activities was quite large, not much detail could be included. The event-tree was useful, however, in clarifying thinking about hazardous equipment versus careless behavior as contributors to accidents.

Despite often-quoted statistics indicating that 85% (or some similar number) of accidents are due to human error, the research team felt that this generalization tended to evade the issue as to whether or not power systems could be made safer. It was estimated from the event tree that nearly all accidents were attributable primarily to a single cause-they were caused by negligent behavior or an unrecognized hazard, but rarely both. A technique was developed for analyzing an accident by determining what unrecognized hazard existed (if any) or what type of human error (if any) was directly responsible. The human error was classified as "negligent behavior". Chapter II covers in detail the development and use of this technique for categorizing electrical accidents.

1.3.2 Accident Statistics

Once a method had been developed for usefully describing electrical accidents, accident reports were obtained for the years 1975, 1976, and 1979. A few reports from 1977 and 1978 were obtained also. Fatal accident reports from the period 1970 through 1979 were studied also. In order to provide statistics which were as unbiased as possible, the data set used for statistical analysis did not include the extra years of fatal accidents obtained or the few other "interesting" accidents obtained from 1977 and 1978, but was obtained by taking all electrical accidents for 3 years, yielding a total of 405 reportable electrical injuries. These accidents were then studied in detail to determine what portion were attributable to poor grounding, negligent behavior, and other identifiable characteristics. Chapter III contains the results of these statistical analyses, showing the types of hazards involved, types of negligent behavior, severity of injuries, types of mines which sustain the most accidents, types of injuries which are fatal, job title of the injured person, age, and work experience. Some of these statistics were developed simply because the data were readily available, but most were used to estimate the effectiveness of the safety improvements discussed in Chapter V.

1.3.3 Mine Visitations and Models

To study the accident statistics is to see only one facet of the overall problem of mine electrical safety, since these reports only show those aspects of the power system directly related to accidents. The equipment in daily use and the routine practices which do not lead to accidents do not appear. In order to gain an understanding of all aspects of the metal/non-metal mining electrical equipment and practice, field visitations were made to a total of 37 mining operations scattered throughout the United States. Particular emphasis was put on visiting dredges and quarries located in areas of high electrical resistivity.

Once these visits had been made to gather data concerning electrical equipment and practice, the information was used to construct three mine electrical power system "models" which generally represented the extractive part of the industry. These models were 1) an underground hard-rock mine, 2) a dredge mine and plant, and 3) a surface mine. These models were designed to be complex enough to sustain the types of electrical accidents which occur in the mine environment, but simple enough to allow a detailed estimate to be made of the cost of altering and maintaining the system. The details of this phase of the study are discussed in Chapter IV.

1.3.4 Electrical Accident Countermeasures

Once electrical accidents and fatalities had been analyzed to show what were the principal hazards which appeared to exist in the industry, it became a logical extension of that work to develop a series of engineering changes that could be instituted to reduce or eliminate each identifiable electrical hazard. These changes in the electrical system (or in some cases changes in procedure) were called "electrical accident countermeasures". Each accident was studied and one or more countermeasures were identified. After this was completed, all countermeasure descriptions were condensed into 25 specific changes. These countermeasures are listed in Chapter V.

1.3.5 Countermeasure Impact Assessment

Attempting to assess the impact of particular countermeasures on the industry accident rate was the most difficult aspect of the entire study. It was quite subjective, and hence likely to have the largest degree of error. The results are shown in Chapter V.

There are two principal reasons why it was so difficult to assess the benefit to the industry of various countermeasures:

1) Any particular countermeasure or safety program will not be perfectly implemented throughout the industry. There will always be individuals or companies that willfully or unknowingly compromise the effectiveness of any safety system. How effective a particular countermeasure would be might depend heavily on company policy, MSHA enforcement procedures, and other variables. Although the choice is clearly too optimistic, we assumed that each identified countermeasure could be implemented with 100% effectiveness throughout the industry. The expected benefits are, therefore, overestimated by an unknown amount.

2) The details of many accidents were too sketchy to provide a clear idea as to whether a particular countermeasure would or would not have prevented the accident. The decision was made as the combined engineering judgment of several knowledgeable people, but often the true cause of an accident remainded in doubt.

1.3.6 Countermeasure Cost Assessment

The cost of the industry of countermeasure implementation could not be determined specifically, since there is tremendous variability in practice throughout the country. Instead, a measure of relative cost to the industry was indicated for each countermeasure. This was determined by using the three mine models developed in Chapter IV. Equipment cost, installation cost, and annual maintenance cost were determined for each countermeasure for each model mine. Data was obtained from manufacturers, suppliers, and mine operators to aid in cost assessment. Chapter VI shows the results of these calculations, in which mine production was also estimated in order to get a rough estimate of countermeasure cost per ton of production.

1.3.7 Cost-Benefit Ratios

While it would seem highly desirable to divide countermeasure benefit by countermeasure cost to provide an indication of countermeasure effectiveness, this was not done for several reasons.

1) The benefits were not computed in dollars, but in terms of reduced accidents and lives saved. No major effort was expended to assign a monetary benefit to a life saved or a lost workday prevented. Surely a fatal accident costs the employer in excess of $1,000,000, but we have no way of estimating the cost to society.

2) As mentioned previously, the expected benefits are probably overestimated by a significant but unknown amount.

3) The costs were established for the model mine power system. An extrapolation to the entire industry can only crudely indicate actual costs.

It cannot be emphasized too strongly that the numbers given show relative rather than absolute values and should be used accordingly.

1.3.8 Grounding Guidelines

A special effort was made throughout the study to consider in greater detail those accidents which were related to power system grounding. Chapter III, for instance, provides additional detail concerning accidents related to hazard H1, energized frame.

The statistics of accidents related to grounding are significantly different from the average, particularly with respect to severity. While only about 7% of all electrical accidents studied (75, 76, and 79) were fatal, almost 21% of those related to grounding were fatal. If the accidents were not fatal, they were usually minor. This indicates one of the most important characteristics of an electrical shoch accident; it is like Russian Roulette. You are either uninjured or you are dead.

Of the 85 fatal accidents that were studied in detail, about 15% of these were attributed to inadequate or improper grounding.

Since inadequate or improper grounding produces a moderate number of electrical accidents, a large percentage of which prove to be fatal, additional effort was expended to make specific detailed recommendations for implementing those countermeasures which relate to grounding. Chapter VIII contains those recommendations as a set of guidelines for the industry.

1.3.9 Ground Wire Monitors

Specific grounding recommendations were made in Chapter VIII. Many of these recommendations suggest that a continuous ground wire be utilized to eliminate many shock hazards. Since safety depends upon the integrity of this wire, some way must be found to verify this integrity. Ground wire monitors are often recommended. Since the ground wire can be monitored in various ways, most of which are not equivalent, Chapter IX gives a clear picture as to what kinds of ground wire monitors should be used in various situations, and how effective they are likely to be.

CHAPTER II

ACCIDENT PROFILES

One of the more important tasks in making recommendations to reduce accidents is to develop a detailed accurate representation of accidents which have occurred. One cannot devise a way to prevent an accident unless he understands how it happens. While each accident is unique, many accidents appear to have the same important characteristics, and would therefore be impacted similarly by engineering changes. In order to provide a clear indication of how accidents occurred, as series of exercises were carried out which resulted in the development of accident profiles.

2.1 EVENT-TREE ANALYSIS

A review was made of the known activities of mine personnel with respect to electrical equipment or equipment which could become energized. These activities were used to generate a graphical description of the possible events surrounding those types of accidents which occurred in the mining industry. Figure 2.1 shows a diagram of the broad classes of accidents which can occur based on MSHA accident categorization techniques. Most of these accidents are not electrical. Electrical accidents appear mainly in two categories, radiation (flash burn), and contact-no impact (electric current, extreme temperature). Several other categories might contain a few electrical accidents. Since electrical accidents appear in at least two distinct categories, but are not the only type of accidents which occur in these categories, the MSHA classification scheme was dropped in favor of our own. An example of an event tree for electrocution-type fatal accidents only is shown in Figure 2.2.

It turned out that all of the electrocutions studied (essentially all fatal electrical accidents are electrocutions) could be broken down into the small number of categories shown in Figure 2.2. When the 96 electrical fatalities which occured from 1970 through 1979 were analyzed, about 24% of them appeared to be attributable to energized equipment frames. Table 2.1 gives a short description of each of these accidents and an indication of the category (from Figure 2.2) into which it was placed.

While useful in showing that many of the fatal accidents were related to improper or inadequate grounding, this event tree did not really show enough detail to be useful in formulating recommendations to prevent their occurrence. A tree of expanded detail was constructed as shown in Figure 2.3. In order to make this tree manageable, the various events were given code names, which are explained in detail in Table 2.2. It was assumed that any accident could be associated primarily with a single hazard and/or a single type of negligence. If multiple causes were permitted the tree became too unweidly.

It turned out that these code names used in the accident event-tree became the basis for all the accident categorization work which followed. This work is described in more detail below.

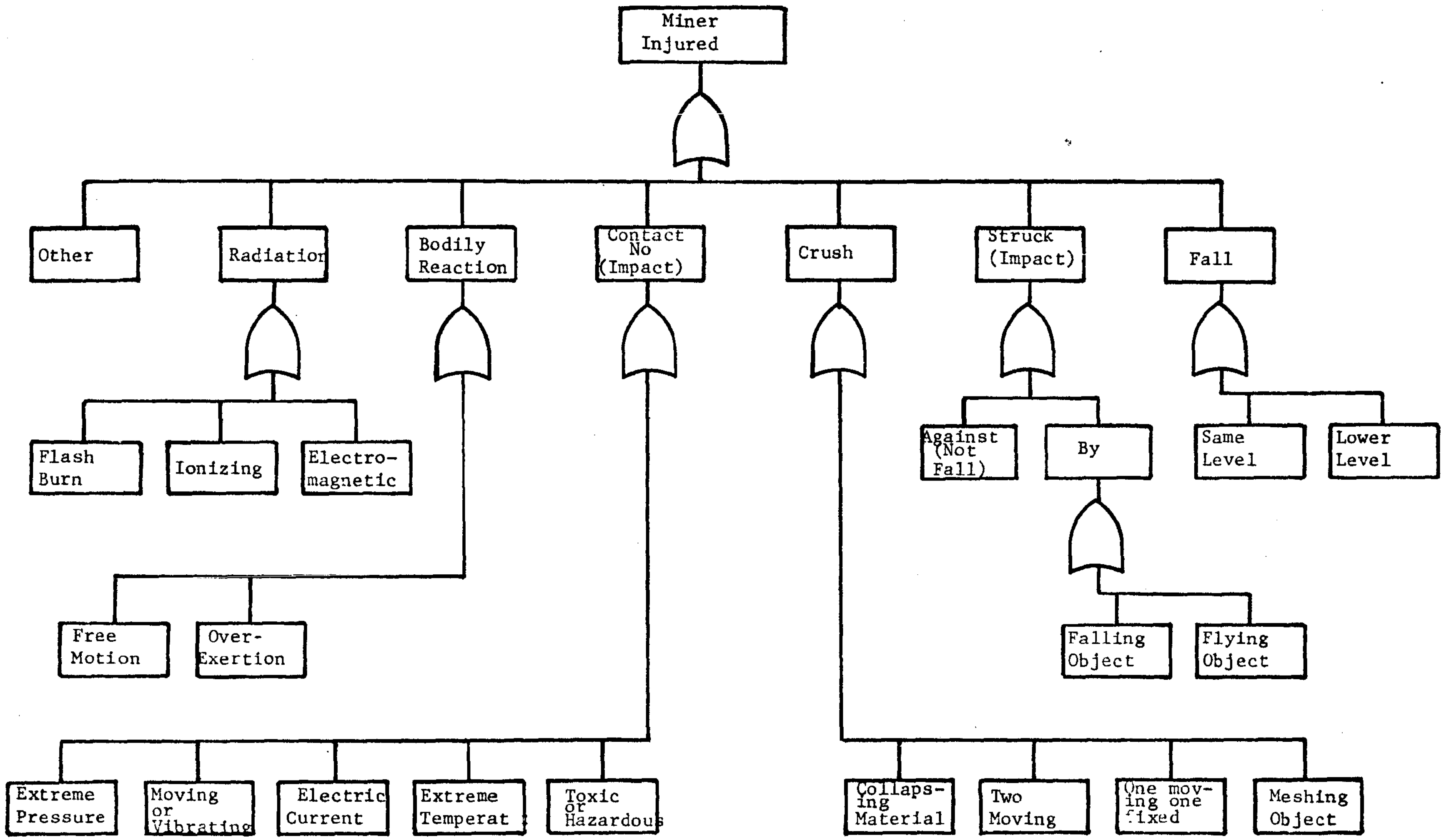
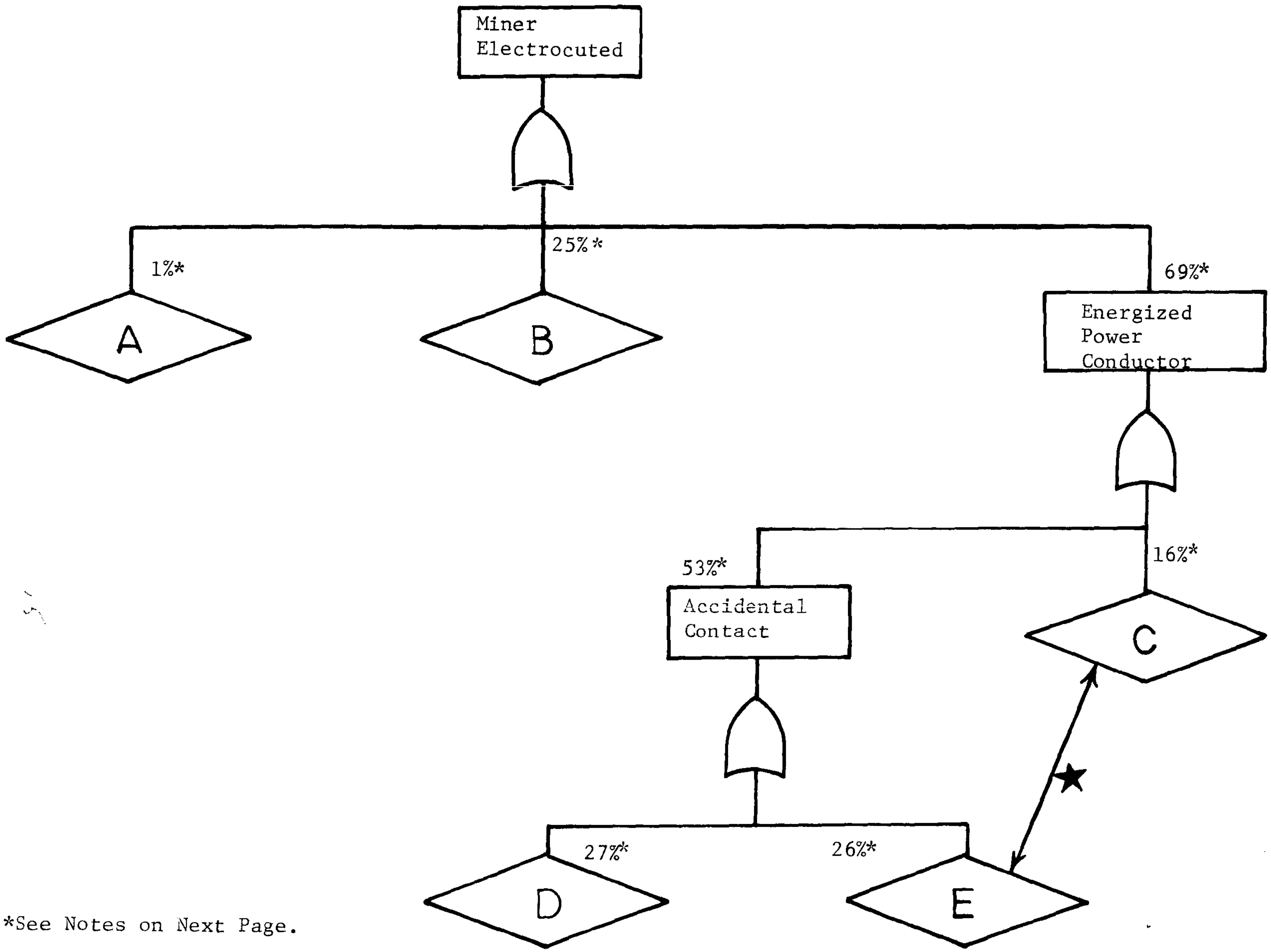


FIGURE 2.1. - Mine accident tree.



*See Notes on Next Page.

FIGURE 2.2. - Mine electrical fatality event tree.

Notes for Figure 2.2 (description of fatal electrical accidents).

A. Shock caused by current flow as the result of voltage gradients in non-metallic objects.

B. Shock caused by touching normally unenergized portions of equipment to which a fault has occurred from wiring normally associated with that equipment.

C. Shock caused by purposefully contacting directly or via a tool a conductor which would normally be energized. Purposefully contacting the insulation of an energized conductor, which insulation proves to be defective, is herein classified.

D. Shock caused by inadvertently and indirectly contacting an uninsulated power conductor via a conducting object such as a vehicle body, unconnected pipe, or other metallic object which would ordinarily be assumed to be at ground potential.

E. Shock caused by inadvertently contacting an uninsulated power conductor directly or with a hand tool, where contact was not required to perform the work undertaken.

F. Not electrical shock, unclassified, or unknown.

* The percentages shown indicate the relative number of fatalities in each category.

★ Many accidents occurring while work was being performed on energized circuits may be classified as either C or E, depending on whether the contact was a slip or an actual purposeful contact with the energized conductor itself.

TABLE 2.1. - Fatal electrical accidents - metal/non-metal beginning 1970

1970

1. [D]* Laborer with 8 months experience electrocuted when hoist rope he was handling from the ground contacted a 12 kV line.

2. [E] An electrician's helper was electrocuted when he contacted 2300 V slip rings while working on a shovel.

3. [E] A miner was electrocuted when he contacted a 275 Vdc trolley wire while climbing out of an empty mine car.

4. [D] A drill helper was electrocuted when the boom of his drilling rig contacted a 13 kV line.

5. [F] A boring machine operator died from inhaling smoke from an electrical fire.

6. [E] A car loader with one day of experience on this job was electrocuted when he contacted a 370 Vdc trolley wire.

7. [D] A mechanic's helper was electrocuted when he raised an aluminum irrigation pipe into a 13 kV line while looking for a rabbit.

8. [D] A mechanic was electrocuted when a conveyor section he was guiding to a new location contacted a 13 kV line.

9. [D] A laborer was electrocuted when his survey rod contacted a 13 kV line.

10. [D] A drill operator was electrocuted when his mobile rotary drill contacted a 7200 V line.

11. [E] A journeyman electrician was electrocuted when he contacted a 2400 V line while repairing a defective grounding resistor.

12. [D] A drill foreman was electrocuted when he drove his vehicle under a high voltage line with the mast up.

13. [D] A mine superintendent was electrocuted when he attempted to rescue a drill foreman who was electrocuted when his mast contacted a high voltage line.

14. [D] A drill helper was electrocuted when the mast of a mobile drill contacted a 7600 V line.

1971

15. [B] A desander operator was electrocuted when he touched a 2300 V OCB which was inadequately grounded to the building.

16. [B] A foreman was electrocuted by 440 volts when he simultaneously contacted a phase conductor within a enclosure and the enclosure itself

*Letters in brackets refer to classification on previous page.

Table 2.1 (continued)

which had a short to another phase wire.

17. [B] An electrician's helper was electrocuted when he contacted an improperly grounded junction box which was shorted to 110 V.

18. [D] A truck driver was electrocuted when he grabbed a detonator leg-wire that had become suspended from a 7200 V line.

1972

19. [C] A worker was electrocuted when he attempted to make an electrical connection in an energized switch box.

20. [B] Worker was electrocuted when he touched a pipe at one phase potential while his metal boat was at another phase potential.

21. [E] A truck driver was electrocuted when he contacted a 57 kV line while attempting to clear a phone line from a boom 5 feet away.

22. [C] A worker was electrocuted when he grabbed a cable with a defective splice to prevent a fall.

23. [B] A company president was electrocuted when he attempted to throw the switch to an ungrounded water pump while standing in the water.

1973

24. [F] A worker drowned after falling in water as a result of receiving a shock from a switch.

25. [D] A truck driver was electrocuted after he raised his dump bed into a power line.

26. [E] A worker was electrocuted when he placed his head and hands inside a junction box on an energized circuit.

27, and
28. [B] Two workers were killed while checking a pump while an electrical storm was in the area.

29. [E] A worker was electrocuted when he contacted 4100 V while attaching capacitors to switch gear.

30. [E] A worker was electrocuted while cleaning insulators near a 44 kV line.

31. [B] A worker connected a hot wire to the ground lead and was electrocuted when inserting plug into outlet.

32. [E] A worker was electrocuted while cleaning insulators on a power line transformer.

Table 2.1 (continued)

33. [E] A welder was electrocuted when the welding rod apparently touched his face when he was welding.

34. [E] A worker was electrocuted when he put his hands into a 4160 V disconnect box and contacted energized parts.

35. [D] A worker was electrocuted while holding a wire rope cable on a crane when it contacted a high voltage line.

36. [C] A worker was electrocuted while connecting an electric motor.

37. [B] A worker was electrocuted when he touched a conveyor frame which was energized by a phase to frame fault in the motor.

38. [B] An employee was electrocuted while touching a filing cabinet that had been energized by a lightning stroke to a 220 V line.

39. [F] Victim found lying on ground near switch.

1974

40. [E] A worker was electrocuted when he contacted an energized 440 V line while connecting motor leads.

41. [B] A worker was electrocuted when he touched a pipe which had become energized through contact with a defective splice.

42. [B] A worker was electrocuted when he touched equipment with a faulty ground connection.

43. [B] A worker was electrocuted when he bridged from a poorly grounded control box to the frame of a crusher.

44. [C] A worker was electrocuted when he attempted to move a 440 V trailing cable with a cut in the insulation.

45. [D] A worker was electrocuted when a geophysical survey wire he was moving contacted a 230 kV line.

46. [D] A worker was electrocuted when the boom of a dragline he was touching contacted a high-voltage line.

1975

47. [F] A worker was electrocuted when he contacted an energized grid frame while building resistance grids.

48, and
49. [D] Two persons were electrocuted when a dump truck was raised into a power line.

50. [B] A worker was electrocuted when he touched an ungrounded crusher motor.

Table 2.1 (continued)

51. [E] A worker was electrocuted when he contacted the filament of a broken light bulb.

52. [E] A worker was electrocuted when he touched a bare energized conductor while wiring a 200 A breaker box.

53. [D] An experienced miner was electrocuted when he contacted a 7200 V line with an aluminum bar.

54. [F] A 48 year old plant manager was found dead under trailer from undetermined causes.

<u>1976</u>

55. [B] A worker was electrocuted when he dismounted a track loader after running over trailing cable.

56. [D] A worker was electrocuted when he contacted a low-hanging high voltage line with a steel bar.

57. [C] A worker was electrocuted when he contacted a poorly insulated splice.

<u>1977</u>

58. [C] A maintenance foreman was electrocuted when he grasped a 2300 volt power cable which had a tiny hole in the jacket and insulation of the cable.

59. [C] An electrician was electrocuted when he attempted to repair a switch on a circuit which was either not deenergized or deenergized but not locked out.

60. [B] An electrical leadman was electrocuted when he attempted to raise a neutral ground wire which had become energized over the front-end loader he was operating. The ground connection to this wire had been broken at some earlier time.

61. [C] A crusher operator was electrocuted when he touched a 500 volt cable on which the insulation was defective. The circuit was supposedly deenergized, but the handle was missing from the breaker, so it could not be locked out.

62. [B] An apprentice machinist was electrocuted while mating in-line power connectors, one of which was abused and severly damaged so that the ground prong entered the hot receptacle.

63. [E] A worker contacted an electrical terminal while attempting to reset a breaker with the electrical panel open.

64. [E] An electrician was electrocuted when he brushed against a 17 kV conductor while removing a conduit from a pole about 9 feet above ground. He was also touching the substation fence.

Table 2.1 (continued)

65. [B] A company president was electrocuted/drowned when he contacted a pump with a phase-to-frame fault for which no ground wire had been provided.

66. [B] Bull-dozer operator was electrocuted when he stepped directly from his equipment to an electric shovel with a phase-to-frame short and an open ground wire.

67. [D] A worker was electrocuted when a pipe on a crane he was guiding by a wire cable contacted a 7200 V power line.

68. [E] A dredge oiler with 3 days experience on the job was electrocuted when he contacted an electrode in a brine tank which was used to provide resistance for motor speed control. He was adding water to the tank.

69. [C] An electrician with 30 days mining experience was electrocuted when he cut into an energized circuit subsequent to having locked out and worked on an adjacent circuit.

70. [E] A plant foreman was electrocuted when he contacted one hot phase of a corner-grounded delta within a control box as he attempted to reset a tripped relay within the box.

71. [B] Miner was apparently electrocuted while servicing a continuous miner from an electrically powered lubrication truck to which the power had been temporarily disrupted by a loose cable connector that was subsequently "kicked" back in place.

72. [E] A crusher operator was electrocuted when he contacted a bare power conductor within a junction box on which the cover was open.

73. [E] A maintenance man with 660 hours training at an electronics institute was electrocuted when he attempted to replace a defective lighting socket on a crane boom without removing power from the circuit.

<u>1978</u>

74. [E] A dry-cement truck driver was electrocuted when he climbed to the top of his truck parked under high voltage lines and contacted one line with his outstretched hand.

75. [D] A truck driver was electrocuted when wind gusts caused 4160 V line to sway into raised dump bed.

76. [C] A worker was electrocuted when he picked up an energized 480 V ac trailing cable with a cut in the insulation.

77. [D] A drill operator was electrocuted when he raised the drill mast into a 12 kV line.

Table 2.1 (continued)

78. [D] Truck driver with one year experience was electrocuted when he dismounted from truck with raised dump body in contact with a high-voltage power line.

79. [B] A laborer with 8 days mining experience was electrocuted when he touched the frame of equipment with a 480 V phase-to-frame fault and an open ground wire.

80. [B] A foreman was electrocuted when he touched a conveyor with a phase-to-frame short circuit and an unconnected ground wire.

81. [D] A laborer was electrocuted when the boom of a crane carrying a pipe contacted a 25 kV line while he was touching the pipe.

<u>1979</u>

82. [D] A truck driver was electrocuted when he dismounted subsequent to having raised his bed into a 7200 V line.

83. [E] An electrician helper was electrocuted when he came into contact with an energized 440 V relay while replacing a cover panel.

84. [E] Painter with 23 days experience electrocuted when he contacted a nearby high-voltage power line while painting an elevated storage bin.

85. [B] An electricians helper was killed in a fall after being shocked by an improperly wired extension cord.

86. [A] A manager was electrocuted while standing in water near a trailing cable when it was pulled loose from its connector, causing two phase wires and ground to come in contact with the dredge frame in the water.

87. [C] A superintendent was electrocuted when he attempted to connect power to a 460 V pump from an energized line.

88. [E] A victim on a transmission line support tower contacted a power line and was killed.

89. [D] A truck driver was electrocuted when he stepped to the ground after raising the dump body into a transmission line.

90. [B] A wash plant operator was electrocuted when he bridged between two ungrounded pieces of equipment having phase-to-frame faults on different phases.

91. [E] A victim contacted an energized collector ring when installing a shovel transmission.

92. [C] A worker was electrocuted when disconnecting 4160 V motor leads that were unexpectedly still energized from another source.

Table 2.1 (continued)

93. [C] A worker was replacing center pin of shovel using extension cord light, contacted still-energized 2300 V conductor.

94. [D] A welder was electrocuted as he walked along guiding a metal structure that was being transported by a crane which touched an overhead high voltage line.

95. [C] An electrician was electrocuted when he cut into a 440 V cable after he had locked out the breaker but did not disconnect the cable from the power center.

96. [C] A skip tender with 4 days mining experience was electrocuted when he contacted an exposed conductor in a power cable.

2.2 IDENTIFICATION OF HAZARDS

Based on what was known about electrical accidents at the beginning of the study, it was assumed that many accidents occurred when persons interacted with equipment which was unexpectedly dangerous. The condition of the equipment was such that it was very likely to cause injury under circumstances where the typical miner would assume he was safe, and that he either did not recognize that he was in danger or at least did not appreciate the extent of any increased danger.

Careful evaluation of the various fatal accidents studied and the event trees which had been constructed revealed that there were only five distinct electrical hazards involved in most accidents. Mining has some level of risk associated with it that is assumed to be normal. Particular jobs, such as electrician also have inherent risks which are assumed to be normal for that job. We defined a "hazard" as an abnormal (and therefore unrecognized or unappreciated) risk not usually assumed to be inherent in a job. Every accident could therefore be described in part by some abnormal dangerous situation which lead up to it. Since we knew, however, that many accidents were attributable to "sheer stupidity", we also included the category "none", indicating that the equipment or environment was no more dangerous than the average miner believed it to be.

A decision was made that the identification of the hazard was to apply only "at the time of the accident" and only "to the environment of the individual that was injured". These categories along with the inevitable catch-alls ("unknown" and "other") are shown in Table 2.3.

2.3 IDENTIFICATION OF NEGLIGENCES

Many accidents, if not most, are directly related to the injured doing something incorrectly that he should have known how to do correctly. Persons performing jobs have a certain error level which is considered "normal" or "typical" for the situation. The normal acceptable error level depends on the degree of training of the individual. We defined a "negligence" as an error which is judged to be abnormal for a person with a particular job title or level of training. For instance, negligent behavior for an electrician may not be abnormal for a laborer.

As might be expected, there appear to be more distinct ways to be negligent than there are distinct electrical hazards. Nine different negligent behaviors with respect to electrical equipment were identified. These are shown in the lower portion of Table 2.2. As was done with the hazard categories, the decision was made that the behavior described was to apply only at the time of the accident and only to the person who was injured. If a person was injured because of the negligent behavior of someone else, that behavior was translated into a "hazard" experienced by the injured party, not his or her negligence. This appears to be the most useful way of identifying the accident.

It should be noted that to attempt to perform work for which one is not trained or certified to perform is a special category of negligent behavior, and has been given a completely separate branch in the tree of Figure 2.3.

TABLE 2.2. - Explanation of codes in accident event tree in Figure 2.3.

HAZARDS

H1 - Energized ground or frame - A potential appearing on a ground wire, pilot wire, or any normally noncurrent-carrying part of electrical equipment.
H2 - Energized power conductor thought to be safe by reason of being disconnected.
H3 - Improperly insulated or guarded power conductor so that contact occurs under conditions where it was assumed to be prevented.
H4 - Abnormal arcs or sparks generated by a short circuit, fault, defective switch, or other defect in the power system. Also include short circuits which cause excessive heating without arcs or sparks.
H5 - Defective tool or protective gear, not including defective circuit breakers or other power system protective devices.
H6 - Unknown
H7 - None - no hazard other than normally accepted in the situation.
H8 - Other electrical hazard not classifiable above.

NEGLIGENCES

N1 - Not attempting to remove power to circuit under repair.
N2 - Not tagging, locking out, grounding, or otherwise ensuring that circuit cannot become energized or equipment started while under inspection or repair.
N3 - Failure to test for voltage on conductor.
N4 - Incorrect tool or equipment or improper use of acceptable equipment.
N5 - Failure to maintain clearance with boom, truck bed, pipe (non-electrical tool) while working in the vicinity of energized conductors with normal clearances.
N6 - Failure to maintain clearance with body or hand tool (not working on involved circuit).
N7 - Not wearing or using protective gear.
N8 - Abusing equipment.
N9 - Horseplay.
NA - Unknown.
NB - No errors other than those usually considered to be normal.
NC - Other negligence or error not classifiable above.

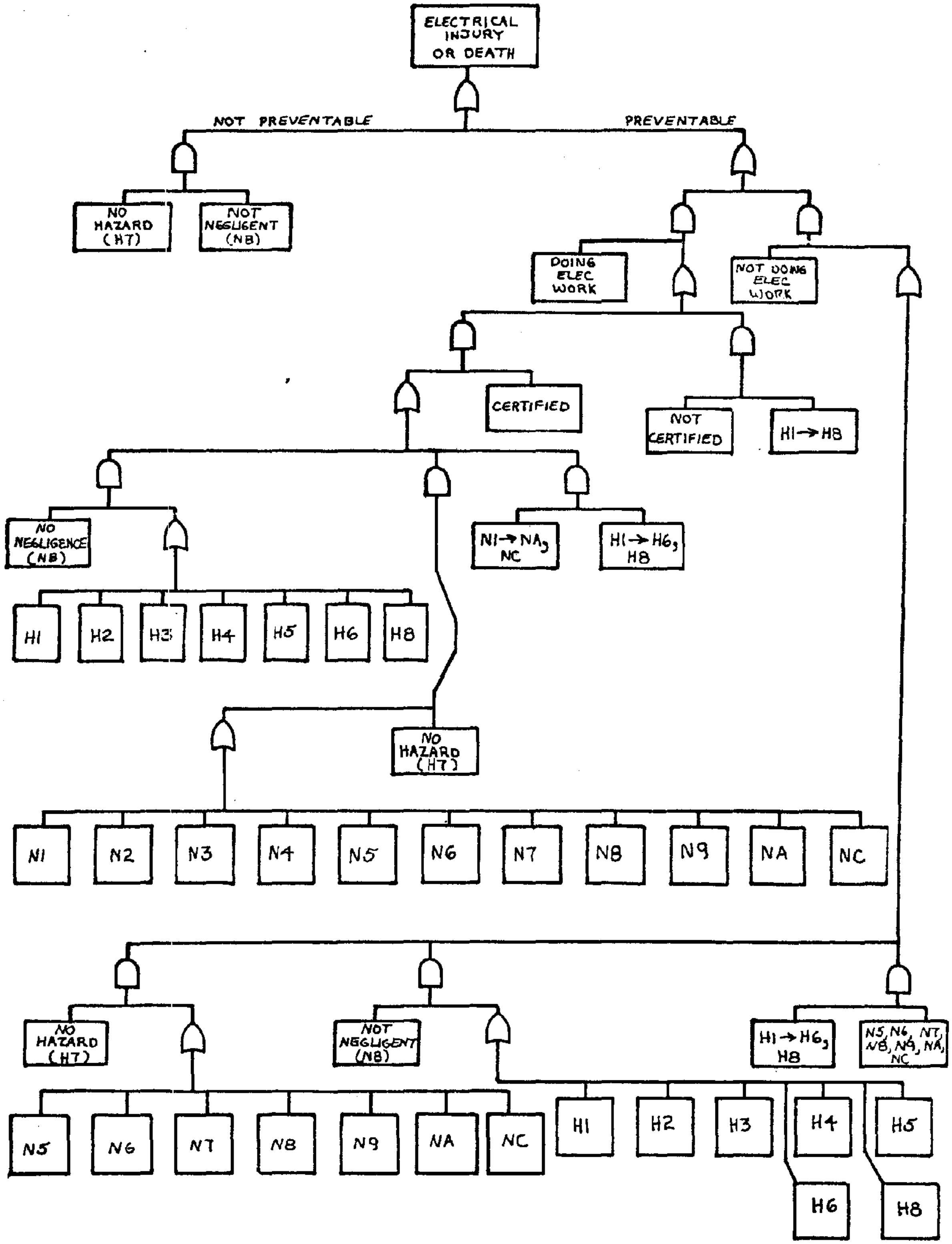


FIGURE 2.3. - Detailed electrical accident event tree.

2.4 USE OF HAZARDS AND NEGLIGENCES IN ACCIDENT ANALYSIS

Once the hazards and negligences had been identified and precisely defined, mine electrical accidents were studied and categorized. It was assumed that for each accident which occurred there was some specific identifiable (but not recognized by the injured) hazard, or some negligent (stupid) behavior on the part of the injured person, or both. Theoretically one could categorize an accident as "no hazard" and "no negligence", but this is equivalent to assuming that some accidents "just happen" and are totally unpreventable. We did not expect to find any of these.

Identification of negligences and hazards related to accidents was a difficult task. Fatal accident reports contained considerable detail, but the one-page non-fatal reports often contained little or no description of the accident, making the assessment rather subjective in many cases. Identification of negligence was particularly difficult, since it seems to be a human characteristic not to admit to any mistake. Statements like "he was working on it and it shorted out" were usually assumed to be cover-ups, and negligent behavior was assigned (i.e., not attempting to remove power to circuit under repair). Persons engaged in the task of assigning the hazard and negligence categories required considerable training in order to achieve an acceptable level of consistency. It is clear that accident reporting procedures must be changed if a more accurate assessment of accidents is desired.

2.5 IDENTIFICATION OF COUNTERMEASURES

The identification of the several types of electrical hazards and negligent behavior discussed in sections 2.3 and 2.4 provided a means by which each accident could be placed in one of about 100 different categories, given that one lists a single hazard and a single negligence for it. These two indices quite clearly identify the type of accident which has occurred. Each of these "generic" accidents was then considered by the research team. The team discussed accidents and listed possible engineering changes in the system or safety devices or procedures which might have prevented them. A long list of these "countermeasures" was generated, but it was easily trimmed to 25 items, shown in Table 2.3. Most of the items relate to ways to reduce or eliminate hazards, but many others relate to reducing the consequences of negligent behavior. Although negligent behavior itself can probably be reduced through effective training programs, most countermeasures assumed that there would be no change in the level of competence in the mine employees. Requiring that certain safety procedures be followed may be aided greatly by improved training, but was not considered training as such except for countermeasure #19.

2.5.1 Countermeasure Implementation

In terms of their implementation, the countermeasures fall into several categories. A few of them are already in general use (and may even be required by law) in the metal/non-metal mining industry, and an accident would occur only if the countermeasure was not being utilized at the time of the accident. Others are not in general use, but are in use by some operators or by similar industries. Still others are not now available for technical reasons, and

TABLE 2.3. - Detailed definitions of electrical accident countermeasures.

1. Use of a ground fault interrupter (GFI) on all branch circuits limited to 500 Vac or less; set at tripping level about 10 mA.

2. Use of existing protective gear, i.e. rubber blankets, gloves, hats, boots, hot sticks, tongs, safety glasses, etc., used in appropriate situations.

3. Use of an electrical interlock device which will remove power from a circuit whenever its protective enclosures or covers are removed, thereby exposing live conductors - includes power centers, distribution boxes, and mining machinery.

4. Use of a self-indicating device which would indicate visually: (1) whether a cable or circuit is energized or de-energized, or (2) whether a circuit breaker has tripped because of ground fault or phase overcurrent or short circuit.

5. A routine, scheduled, 100% effective physical examination or electrical test on a circuit element or device, which is then removed from service or disconnected until repairs are made.

6. A deliberate connection of the transformer secondary to earth via a controlled-impedance path; this earth connection is carried to the frame of each piece of equipment; ground fault protection is assumed.

7. Use of a proximity warning device which indicates a piece of equipment is approaching a high voltage line.

8. Use of a ground check monitor device to indicate the status of the frame grounding conductor where used.

9. Use of shielded cable or conduit so that all power conductors are completely enclosed by a grounded metal conductor, except at junction boxes and the like.

10. Elimination of all uninsulated or bare conductors on any overhead transmission and distribution line EXCEPT trolley wires.

11. Use of switchgear or a cable connector so constructed that it may be visually determined whether or not the circuit is connected.

12. Use of a fusible lightning arrestor. This is to be grounded separate from the safety ground bed if the safety ground is used.

13. The outer jacket of each cable is color-coded or provided with distinguishing markings to allow reliable differentation between cables.

14. A voltage test must be made on any circuit which is presumed to be de-energized before any further work is attempted.

15. No cable may be repaired until it is disconnected at both ends.

Table 2.3 (continued)

16. Use of a circuit to prevent sustained arcs at the trolley shoe.

17. Switchgear, fuses, and enclosures are designed to retain their physical integrity and not eject sparks or flames under all conditions, including short circuits.

18. Redesign mine electrical test equipment to eliminate the possibility of using that electrical test equipment (VOM's) on incorrect function and range scales.

19. No work may be performed on live circuits unless full protective gear and procedures are used.

20. If a power system has no intentional grounds on the transformer, to add frame grounding of all equipment and ground-indicating lights on each phase.

21. Circuits equipped with power-factor-correction capacitors must also include bleeder resistors.

22. A tool must always be used for the specific job for which it was intended; tools used for electrical work must be adequately insulated.

23. Bare wires are properly placed and/or guarded to prevent accidental contact; this specifically includes trolley wires.

24. Insulate or ground truck beds, drill masts, crane booms, ladders, etc. Place mats at operating handles.

25. All splices must be vulcanized or better, to prevent exposed conductors or leakage.

more research and development is needed before these could be implemented effectively. At this stage of the analysis no distinction was made between countermeasures in terms of their ease of implementation.

2.5.2 Countermeasure Compliance

A very important issue related to accident countermeasures is compliance. Most of the countermeasures listed could essentially eliminate a particular type of accident if each worker and each operator diligently implemented it. That is, the device or procedure was used everywhere appropriate and at all times, and that safety devices were properly maintained and calibrated. Even a cursory glance at accident records shows that total compliance is not an achieveable goal. As pointed out in the previous section, some of the listed countermeasures are already required under federal regulations and yet the accident data shows that they were not in use. If fines and other penalties cannot assure total compliance in these cases, it is unlikely that any countermeasure will be fully complied with. The end result is that no countermeasure will be totally effective in eliminating a particular type of accident.

If no countermeasure can be totally effective, it becomes a major effort to estimate its impact on the accident rate. This was not done in this study, and remains as a topic for future research. We have assumed 100% compliance in our estimates of cost and effectiveness.

2.5.3 Countermeasure Cost

Chapter VI details countermeasure cost assessment. Some of the costs are zero. This figure indicates that the countermeasure is already part of the mine system, usually because it is required by law. Since the costs estimated are for the incremental expense of instituting a countermeasure, simply doing what one is supposed to be doing already has been assigned zero charge.

A few of the countermeasures have very high costs. The usual reason for this is that technology is not presently available to implement the countermeasure.

The remaining countermeasures can be implemented by changing the present system with currently available technology.

CHAPTER III

ACCIDENT STATISTICS

The primary purpose of this section is to provide, in detail, how a sample of information on past electrical accidents was collected and analyzed. It also describes how the accident data were coded and recorded for subsequent retreival. Each accident was categorized under the "hazards" and "negligence" as identified in Chapter II. The frequency distribution of hazards and negligence are presented. The injuries were classified with respect to injury type, degree of injury, job title, age and job experience.

Injury indices and incidence rates were computed to classify some mine type or industries with respect to their frequency of accidents. The purpose of this classification is to see if a specific mine type or industry is naturally more hazardous or not and to investigate its causes.

3.1 SAMPLE DESCRIPTION AND ITS SOURCE

A sample of 405 electrical accidents in metal/non-metal mines and mills were collected from original accident files located at the MSHA Health and Safety Analysis Center (HSAC) at Denver, Colorado. These data include almost all electrical accidents in metal/non-metal mines during 1975, 1976 and 1979. In the original data several particular mines were observed to have unusually high numbers of electrical accidents, and for those mines a special effort was made to look at 1977 and 1978 data as well. Otherwise, 1977 and 1978 data was not examined.

3.2 ACCIDENT DATA FILE

3.2.1 Sample Size

The data was obtained by reading microfilm images of the original accident report forms submitted by the mines. Only 1975 and 1976 were organized in a way that made it relatively easy to locate the desired reports scattered amoung thousands of reports of sprained ankles, and the like. The 1979 data was obtained by doing a manual search and correlation of a detailed accident printout available from HSAC. The 1977 and 1978 data were also improperly organized for our purposes, so that we were able to obtain accident reports from a few specific mines rather than the whole industry. Data earlier than 1975 was not available to us. The sample size was therefore determined primarily by the effort that could be expended to find the desired information. The final accident total was 405.

3.2.2 Data Collection

From the original data (form 6-1555) of MESA or of MSHA the relevant information is summarized and coded as shown in Figure 3.1, titled "Mine Electrical Accident Report". Each accident report form was examined by a group of trained individuals who were given special instructions and training to interpret these forms. This trained group visited Denver and extracted the information that was needed for this study and directly recorded on the coded form as shown in Figure 3.1. It seems apparent that the interpretation of form 6-1555 to our coded data sheet requires certain knowledge and appreciation of electrical engineering, especially to identify hazard type, negligence type and the accident descriptions.

3.2.3 Type of Information

As noted before, all information recorded in the form 6-1555 was not coded. The research team observed that the accident report form may be sufficient for injury investigation but insufficient to develop a set of countermeasures to prevent the occurrence of similar incidents. Primarily, a data set contains the basic information - for example, Mine ID no., data, type of operation, age of injured, etc. and identification of hazards and negligences (see Table 2.2) and a short description of the accidents. The degree of injury and job experience of the injured person were also recorded.

3.2.4 Coding and Retrieval of Information

The coded information is punched on cards. Each data set is stored on four cards. In Figure 3.1, for each information column, numbers indicate where that information is punched. For identification purposes, the first nine columns of each card contain the document number. The Figure 3.1 shows the information recorded in the first three cards. The fourth card was added later indicating the countermeasures that could prevent the accident and the number of days lost. For easy retrieval purpose the locations of coded information are summarized in Table 3.1.

3.2.5 Studies of Hazards and Negligence

The coded accident data was analyzed by digital computer after sorting out bad data and the coding errors. Some of the highlights of the statistics generated include much higher than average accident rates in limestone, copper, sand and gravel, cement, potash, and molybdenum mines, and much lower than average in soda ash, pumice, feldspar, leonardite, titanium, gypsum and graphite mines.

In analyzing hazards and negligence, it has been observed that almost 60% of the accidents caused by H1 (energized frame or ground wire) were non-disabling (days away from work, but total recovery), 17% were minor injuries and 20% were fatal. There was a total of 405 accidents studied, but in many cases there appeared to be more than one hazard present, or the injured were negligent in more than one way. Table 3.2 shows the frequency distribution of hazards and accidents.

A. Frequency distribution of hazards - Table 3.2 shows the detail distribution. H4 (abnormal arcs and sparks) seems to cause the most electrical injuries in metal/non-metal mines.

B. Frequency distribution of negligences - Table 3.2 shows the detailed distribution of negligences. Among the known negligences, N1 (not removing power) and N6 (failure to maintain clearance with body) seem significantly high.

Mine Electrical Accident Report

Document No. ___ ___ ___ ___ ___ ___ ___ ___ ___ (1-9) 1 (10) Year 197__ (11) By ___ ___ ___ (12-14)

Mine ID No. ___ ___ - ___ ___ ___ ___ ___ (15-16) (17-21)

Type of Operation

__ Underground (Contractor? (31) Unknown 0

__ Surface ___ ___ ___ ___ ___ ___ ___ ___ (23-30) Yes 1

__ Dredge (22) No 2

Injured Year of Birth 19 __ __ (32-33) or Age __ __ (34-35)

Degree of Injury (36) D 1 D 2 D 3 D 4 D 5

Type of Injury (37-38) I 1 I 2 I 3 I 4 I 5 I 6 I 7 I 8 ________________

Performing Electrical Work? (39) 0 Unknown, 1 Yes, 2 No

Qualified to Perform Electrical Work? (40) 0 Unknown, 1 Yes, 2 No

Injured Activity: (41-80) 41 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ 55

56 ___ 80

Dup. 1-9 Job Title 2 (10) 11 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ 30

Mining Experience __ __ (31-32) YRS __ __ (33-34) WKS Job Experience __ __ (35-36) YRS __ __ (37-38) WKS

Hazard (39-40) H 1 H 2 H 3 H 4 H 5 H 6 H 7 H 8 ____________________

Negligence (41-42) N 1 N 2 N 3 N 4 N 5 N 6 N 7 N 8 N 9 N A N B N C ____________

Description: (43-55) 43 ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ ___ 55

56 ___ 80

Dup. 1-9 3 (10) ___ 32

33 ___ 56

57 ___ 80

Comments.

FIGURE 3.1. - Mine electrical accident data recording form.

TABLE 3.2. - Total hazards: 424

H1:	Energized frame or ground wire:	9.43%
H2:	Energized power conductor:	5.90%
H3:	Improperly insulated or guarded power:	8.73%
H4:	Abnormal arcs or sparks:	23.58%
H5:	Defective tools or protective gear:	0.94%
H6:	Unknown:	8.02%
H7:	None - no hazard:	39.93%
H8:	Other not classified above:	3.77%

Total Negligence: 458

N1:	Not attempting to remove power:	18.78%
N2:	Not tagging, locking out:	2.18%
N3:	Failure to test voltage:	2.18%
N4:	Incorrect tool or equipment	4.37%
N5:	Failure to maintain clearance with boom:	6.55%
N6:	Failure to maintain clearance with body:	12.66%
N7:	Not wearing or using protective gear:	2.40%
N8:	Abusing equipment:	2.18%
N9:	Horseplay:	0.0%
NA:	Unknown:	10.26%
NB:	Normal - no unusual error:	34.93%
NC:	Other negligence not classified above:	3.49%

C. Joint frequency distributions - Several analyses were done to determine the relation between certain hazards and negligences. Table 3.3 shows the relation between hazard and negligence in actual numbers.

TABLE 3.3. - Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	1	3	0	3	0	4	74	2
N2	0	2	0	0	0	1	7	0
N3	0	9	0	0	0	0	0	0
N4	0	0	0	1	1	0	18	0
N5	1	1	3	0	0	0	28	0
N6	0	1	3	0	0	2	49	3
N7	0	1	2	2	0	1	5	0
N8	0	0	0	7	0	0	3	0
N9	0	0	0	0	0	0	0	0
NA	5	1	4	14	0	23	7	1
NB	34	11	23	81	3	7	9	7
NC	2	1	2	2	0	0	7	3

3.3 RELATIONS BETWEEN H1 AND INJURY TYPE

As indicated before, it has been observed that almost 60% of the accidents caused by hazard H1 were non-disabling and 20% were fatal. The details of the degree of injury and injury types are summarized in Table 3.4.

TABLE 3.4. - Relation between H1 and degree of injury, injury type

Degree of Injury	% of H1
D1: Fatal	20.83
D2: Total disability	0.0
D3: Permanent partial disability	4.17
D4: Non-disabling	58.33
D5: Minor	16.67
Injury Type	**% of H1**
I1: Shock	29.72
I2: Electrical burn	9.24
I3: Flash burn	13.65
I4: Heat burn	34.14
I5: Explosion	2.01
I6: Smoke inhalation	0.0
I7: Reaction to electrical	7.63
I8: Other	3.61

3.4 ANALYSIS OF INJURY TYPE AND DEGREE OF INJURY

Out of a total of 405 mine accidents, approximately 67% were non-disabling, and 7% were fatal. 24.2% of the accidents caused minor injuries without any lost time. Also, it is important to note that almost a third of electrical accidents were due to flash burn and about a fourth of the accidents were due to shock. Table 3.5 shows the frequency distribution.

TABLE 3.5. - Analysis of injury type and degree of injury

Degree of Injury	% of Accidents
D1: Fatal	7.16
D2: Total disability	0.49
D3: Permanent partial disability	0.99
D4: Non-disabling	67.16
D5: Minor	24.20
Injury Type	**% of Accidents**
I1: Shock	26.85
I2: Electrical burn	13.23
I3: Flash burn	31.13
I4: Heat burn	19.26
I5: Explosion	1.17
I6: Smoke inhalation	0.0
I7: Reaction to electrical	5.06
I8: Other	3.31

3.5 INJURY INDEX

In this section an index is developed to measure the degree of hazards in relation to mine type and industry type.

A. Development of indices - The injury index is defined as:

$$\text{Injury index} = \frac{\text{Number of accidents}}{\text{Total number of workers}} \times 10^3$$

It should be noted that the injury index is closely related to the incidence rate which had been defined as:

$$\text{Incidence rate} = \frac{\text{Number of injuries}}{\text{Number of employee hours}} \times 2 \times 10^5$$

Figure 3.2 shows the relationship of injury index and incidence rates with respect to industry types.

B. Relation of index to mine type - shown in Figure 3.2.

C. Relation of index to overall industry - Figure 3.3 shows the relationship of injury indices and incidence rates with respect to four major categories: metal, non-metal, stone and sand-gravel. The sand-gravel industry shows a high injury index value.

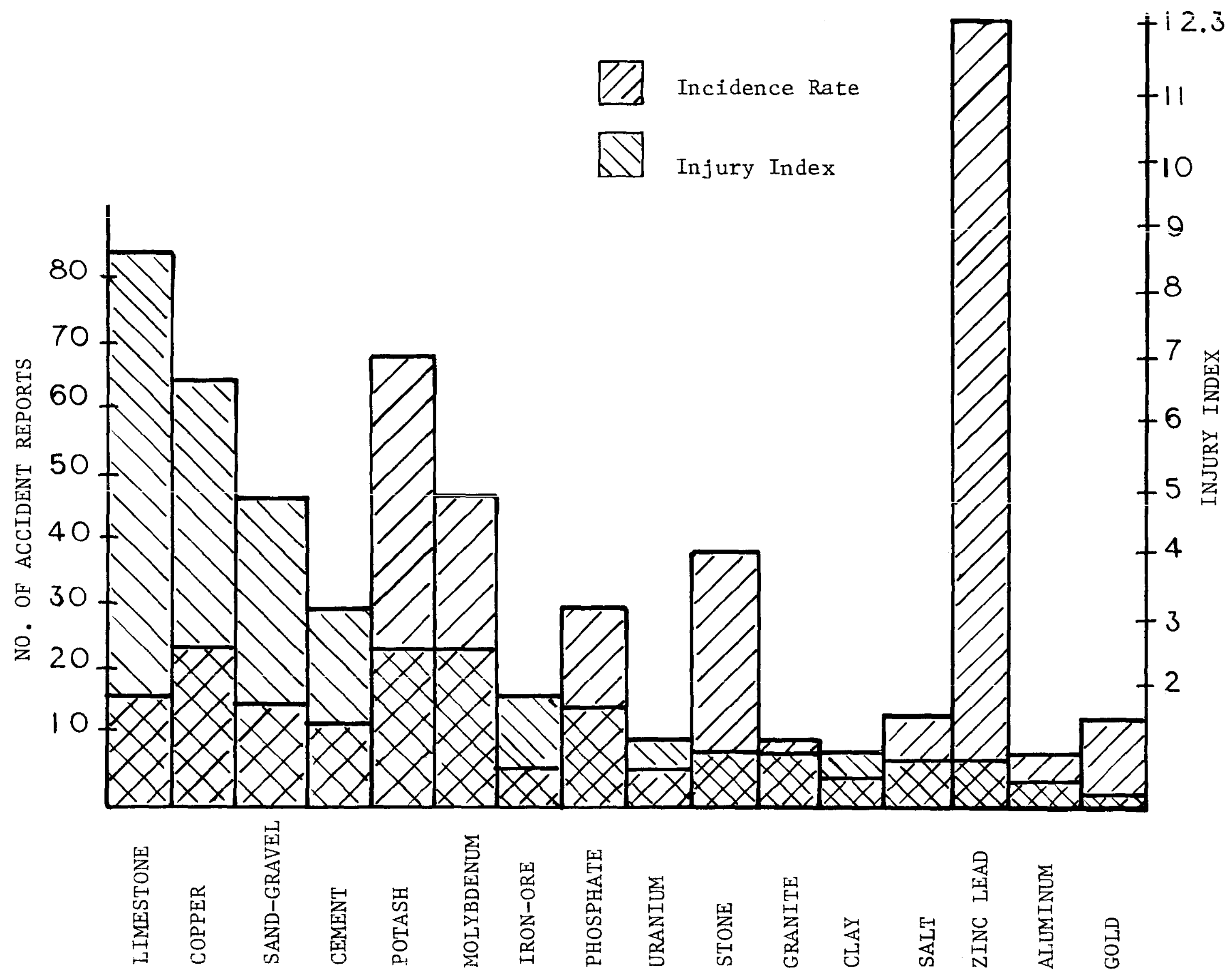
3.6 FATAL INJURIES

A separate detailed analysis was made of fatal electrical accidents. In the nine and one-half years covered by this survey, 85 people were killed in electrically-related accidents in metal and non-metal mines. The years 1973 and 1977 were the worst during the period, with 16 fatalities per year, while 14 men were killed in 1970. The best year was 1976, when the death toll was held to three. Fifteen men were killed in 1979, bringing the 10-year total to 96, but since the study was done in mid-1979, only 4 of these fatalities are included in the data.

Table 3.6 shows that most of the men killed were in the 20-29 age group (38.8%), followed by those who were 30-39 years old (21.2%). Young workers (18 and 19 years of age) made up 4.7% of the fatalities, a relatively high percentage when considering the small size of the age group. This statistical analysis is weakened by the fact that the actual nationwide age distribution of metal/non-metal mine workers is unknown.

Almost half of those killed had less than 2 years experience at their particular job task, as indicated by Table 3.7. Table 3.8 indicates that one-fifth of the men had less than 1 year of mining experience, and more than a third had worked in the mines for 2 years or less.

Table 3.9 gives a breakdown of fatalities by job title. Slightly under one-fifth of those killed by electricity were electricians or electrian helpers; presumably individuals who were familiar with the hazards of their job and the procedures which are necessary to carry out their work in a safe manner. Truck drivers were frequent victims, mostly dump truck



$$\frac{\text{No. of Injuries X } 2*10^5}{\text{No. of Employee-Hours}} = \text{Incidence Rate } \alpha \qquad \text{Injury Index} = \frac{\text{No. of Injuries X } 10^3}{\text{Total No. of Workers}}$$

FIGURE 3.2. - Injury index and number of accident reports vs industry type.

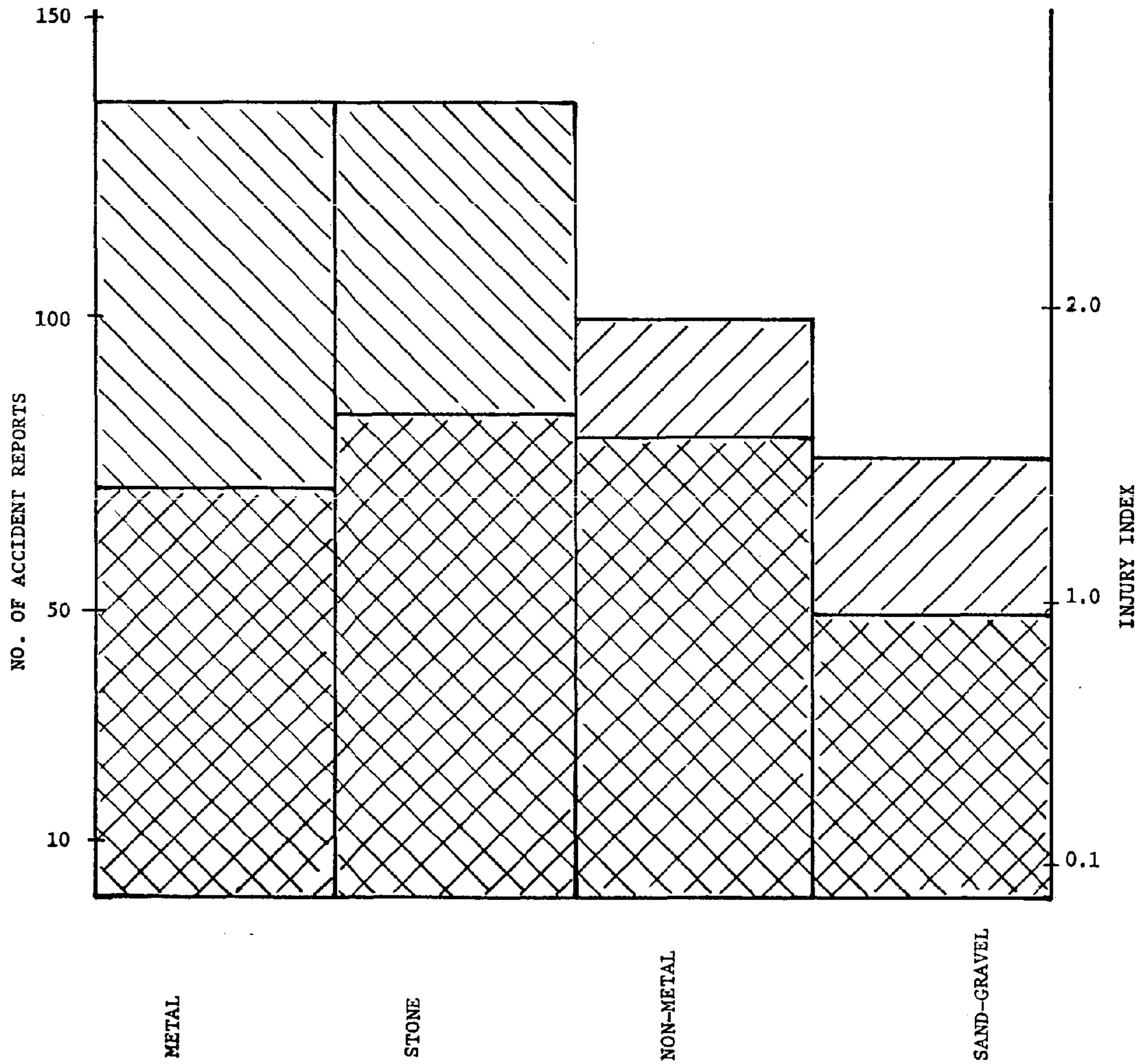


FIGURE 3.3. - Injury index and number of accident reports vs industry type.

TABLE 3.6. - Electrical fatalities by age of victim

Age	Number of Fatalities	Percent of Total Fatalities
18-19	4	4.7
20-29	33	38.8
30-39	18	21.2
40-49	16	18.8
50-59	9	10.6
60-69	2	2.4
Unknown	3	3.5
Total	85	Total 100.0

TABLE 3.7. - Electrical fatalities by job experience of victim

Job task experience years	Number of fatalities	Percent of total
less than 1	20	23.5
1-2	21	24.7
2-3	8	9.4
3-4	2	2.4
4-5	6	7.1
more than 5	16	18.8
Unknown	12	14.1
Total	85	100.0

TABLE 3.8. - Electrical fatalities by years of mining experience

Mining experience years	Number of fatalities	Percent of total
less than 1	17	20.0
1-2	14	16.5
2-3	6	7.1
3-4	3	3.5
4-5	1	1.2
more than 5	29	34.1
Unknown	15	17.6
Total	85	100.0

TABLE 3.9. - Electrical fatalities by job title

Job Title	Number of Fatalities	Percent of Total
Electrician	9	
Electrician helper	7	18.8
Truck driver	10	
Laborer	10	
Foreman or supervisor	9	
Mechanic or mech. helper	5	
Drill operator or helper	5	
Plant manager or owner	4	
Oiler	4	
Crusher operator	4	
Maintenance man	2	
Booster pump operator	1	
Continuous miner operator	1	
Truck expediter	1	
Loader operator	1	
Scoop operator	1	
Plant operator	1	
Track loader operator	1	
Apprentice machinist	1	
Dozer operator	1	
Tunnel operator	1	
Painter	1	
Miner	1	
Boring machine operator	1	
Car loader	1	
Desander operator	1	81.2
totals	85	100.0

operators who raised the dump beds of their equipment into contact with high-voltage lines. Drill operators suffered a similar fate, often raising the drill mast and then driving into overhead power conductors. Foremen, other supervisors, and laborers often attempted to perform electrical repairs for which they were unqualified, with fatal results. Mechanics usually came to grief while repairing equipment in confined spaces near exposed conductors.

Limestone operations (quarry and plant) claimed the most lives of any particular mining activity (22, or 26%), followed closely by sand and gravel installations (pits, plants, and dredges). As shown by Table 3.10, clay mines were third, followed by cement plants. Since all of these minerals are mined at many sites throughout the US, perhaps it should be expected that most fatalities would occur in those areas of the metal/non-metal industry which are numerically the most common. In addition, many of these facilities are small in size, possibly family-type operations employing one or two people, none of whom are familiar with electricity.

The cause of each electrical fatality is given in Table 3.11. Almost 39% of all deaths were caused by working or operating equipment near energized lines. Truck beds, drill masts, pipes, rods and other metal parts coming into contact with bare high-voltage conductors led to 33 fatal accidents during the period under review. Electrical work on or near energized conductors was the second most common cause of death, accounting for 22 lives, or 26% of the total. Inadequate or defective grounding procedures or equipment led to 13 fatalities (15%) over the course of 9 1/2 years, making this the third leading cause of death.

Most of the people killed in electrically-related metal/non-metal mine accidents were young and inexperienced, with less than 3 years job experience and less than 3 years of mine-related working time. The majority were not electricians and probably were not well-acquainted with electrical hazards nor with the safe working procedures which must be used when in the vicinity of energized conductors. It is possible that many of these deaths could have been prevented if the men had been given some training in hazard recognition and avoidance.

3.7 DISTRIBUTION OF HAZARDS AND NEGLIGENCE VS. MINE TYPE

An analysis has been carried out of the relationship between hazards and negligences for the most affected mine types. This analysis shows the following points:

A. LIMESTONE: H_4, H_6, H_1, N_1 and N_6 are the hazards and negligences which are likely to happen. Strong relationship between N_A & H_6.

B. COPPER: H_2, H_4, N_1 and N_5 are likely to happen. Strong relationship between N_3 and H_2.

C. SAND-GRAVEL: H_4, H_1, N_1, and N_5 are likely. Strong relationship between N_B and H_4.

TABLE 3.10. - Electrical fatalities by type of operation

Type of Operation	Year 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979*	TOTAL
Sand and gravel pit	1			1				2	1	1	6
Sand and gravel plant			1		2	1			1	1	6
Sand and gravel dredge		1	1		1	1		2			6
Limestone quarry	3	2		2	1	2	2	2	2		16
Limestone plant	1			3	1			1			6
Underground potash mine	1			1			1				3
Potash mill			1	1				1			3
Surface phosphate mine									1		1
Phosphate mill				2							2
Open pit copper mine	1										1
Cement plant				1				1	1	1	4
Underground copper mine	1	1			1						3
Copper mill									1		1
Underground iron mine	1										1
Underground lead/silver mine			1								1
Underground tungsten mine								1			1
Underground trona mine				1					1		2
Underground salt mine						1					1
Open pit clay mine	2			2		2		1			7
Open pit uranium mine	2							1			3
Open pit bauxite	1										1
Open pit silica mine			1					2			3
Granite quarry						1					1
Lead/zinc mill				1				1			2
Gold/silver mill								1			1
Taconite mill										1	1
Not on mine/mill site				1	1						2
Total	14	4	5	16	7	8	3	16	8	4	85

* = through May 31, 1979

TABLE 3.11. - Electrical fatalities by cause of accident

Cause	Year 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979*	Total
Electrical work on or near energized conductor	2	1	1	6	1	3		7		1	22
Operating equipment or working too near energized lines	12	1	1	2	2	3	1	4	5	2	33
Inadequate or improper grounding		2	2	2	2	1		2	2		13
Defective insulation or splice			1		2		1	2	1		7
Lightning				3							3
Improper repairs or equipment				1				1		1	3
Welding				1							1
Ran over cable							1				1
Not otherwise classified				1		1					2
Total	14	4	5	16	7	8	3	16	8	4	85

*Through May 31, 1979.

D. CEMENT: H_4 and N_1 are most likely to occur. Strong relationship between N_B and H_4.

E. POTASH: H_3 and N_1 are most likely to occur.

F. MOLYBDENUM: H_4 and N_1 are most likely to happen.

The detailed distributions of hazards and negligences are shown in Tables 3.12 to 3.17.

3.8 ACCIDENT VS. JOB TITLE

An investigation has been made to correlate mine electrical accidents and the occupation of the injured. Figure 3.4 shows the number of electrical accidents versus the occupation of the injured. Since the accidents are electrical in nature, it was expected that electricians and other electrical workers would suffer a large part of these accidents. From the figures one may conclude that some electrical training should be given to operators, mechanics and foreman because other non-electrical workers were frequently injured, although a portion of the injured mechanics were also qualified electricians. It seems, however, that more training might help in reducing electrical accidents among these job categories.

3.9 ACCIDENT VS. AGE

Figure 3.5 shows the frequency bar chart of electrical accidents with respect to the age of the victims. It is observed that among the 405 victims in our study 106 victims were between the age of 20 and 28. Table 3.18 shows the details.

TABLE 3.18. - Accident frequency versus age.

Age group	Frequency	Percentage
Less than 20	16	4.0
20-28	106	26.2
28-36	88	21.7
36-44	78	19.3
44-52	52	12.8
52-60	34	8.4
60-68	10	2.5
above 68	8	2
Missing age information	13	3.1
Total	405	100.0

3.10 ACCIDENT VS. EXPERIENCE

Two frequency distributions were studied.

1. Accidents vs. mine experience.

2. Accidents vs. job experience.

TABLE 3.12. - Limestone: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	1	1	0	1	0	0	13	0
N2	0	0	0	0	0	0	1	0
N3	0	0	0	0	0	0	0	0
N4	0	0	0	0	0	0	2	0
N5	0	0	0	0	0	0	3	0
N6	0	1	0	0	0	0	10	0
N7	0	0	0	0	0	0	3	0
N8	0	0	0	0	0	0	0	0
N9	0	0	0	0	0	0	0	0
NA	1	1	0	1	0	10	0	0
NB	5	2	2	19	1	1	1	2
NC	1	0	0	1	0	0	2	0

TABLE 3.13. - Copper: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	0	1	0	0	0	3	14	0
N2	0	0	0	0	0	1	1	0
N3	0	4	0	0	0	0	0	0
N4	0	0	0	0	1	0	1	0
N5	0	1	3	0	0	0	8	0
N6	0	0	0	0	0	1	8	0
N7	0	0	0	0	0	1	1	0
N8	0	0	0	0	0	0	0	0
N9	0	0	0	0	0	0	0	0
NA	1	0	0	2	0	4	4	0
NB	7	4	4	7	0	0	2	0
NC	0	0	0	1	0	0	3	2

TABLE 3.14. - Sand and Gravel: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	0	0	0	0	0	0	6	0
N2	0	0	0	0	0	0	1	0
N3	0	0	0	0	0	0	0	0
N4	0	0	0	1	0	0	3	0
N5	0	0	0	0	0	0	6	0
N6	0	0	1	0	0	0	7	1
N7	0	0	0	0	0	0	0	0
N8	0	0	0	0	0	0	0	0
N9	0	0	0	0	0	0	0	0
NA	0	0	0	2	0	1	0	1
NB	6	1	1	9	0	1	1	0
NC	1	0	0	0	0	0	0	0

TABLE 3.15. - Cement: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	0	1	0	2	0	1	4	0
N2	0	0	0	0	0	0	0	0
N3	0	0	0	0	0	0	0	0
N4	0	0	0	0	0	0	0	0
N5	0	0	0	0	0	0	0	0
N6	0	0	0	0	0	0	2	0
N7	0	0	0	2	0	0	0	0
N8	0	0	0	0	0	0	0	0
N9	0	0	0	0	0	0	0	0
NA	0	0	1	1	0	2	1	0
NB	1	1	2	10	0	0	3	2
NC	0	0	1	0	0	0	1	0

TABLE 3.16. - Potash: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	0	0	0	0	0	0	7	0
N2	0	0	0	0	0	0	1	0
N3	0	2	0	0	0	0	0	0
N4	0	0	0	0	0	0	0	0
N5	0	0	0	0	0	0	0	0
N6	0	0	1	0	0	0	2	0
N7	0	0	0	0	0	0	0	0
N8	0	0	0	0	0	0	1	0
N9	0	0	0	0	0	0	0	0
NA	1	0	0	1	0	1	0	0
NB	3	0	6	2	0	1	0	0
NC	0	0	0	0	0	0	0	0

TABLE 3.17. - Molybdenum: Relation between hazard and negligence

	H1	H2	H3	H4	H5	H6	H7	H8
N1	0	0	0	0	0	0	5	0
N2	0	0	0	0	0	0	0	0
N3	0	1	0	0	0	0	0	0
N4	0	0	0	0	0	0	4	0
N5	0	0	0	0	0	0	1	0
N6	0	0	0	0	0	0	4	0
N7	0	0	1	0	0	0	1	0
N8	0	0	0	0	0	0	0	0
N9	0	0	0	0	0	0	0	0
NA	0	0	0	1	0	0	1	0
NB	2	0	1	5	0	0	0	0
NC	0	0	0	0	0	0	0	0

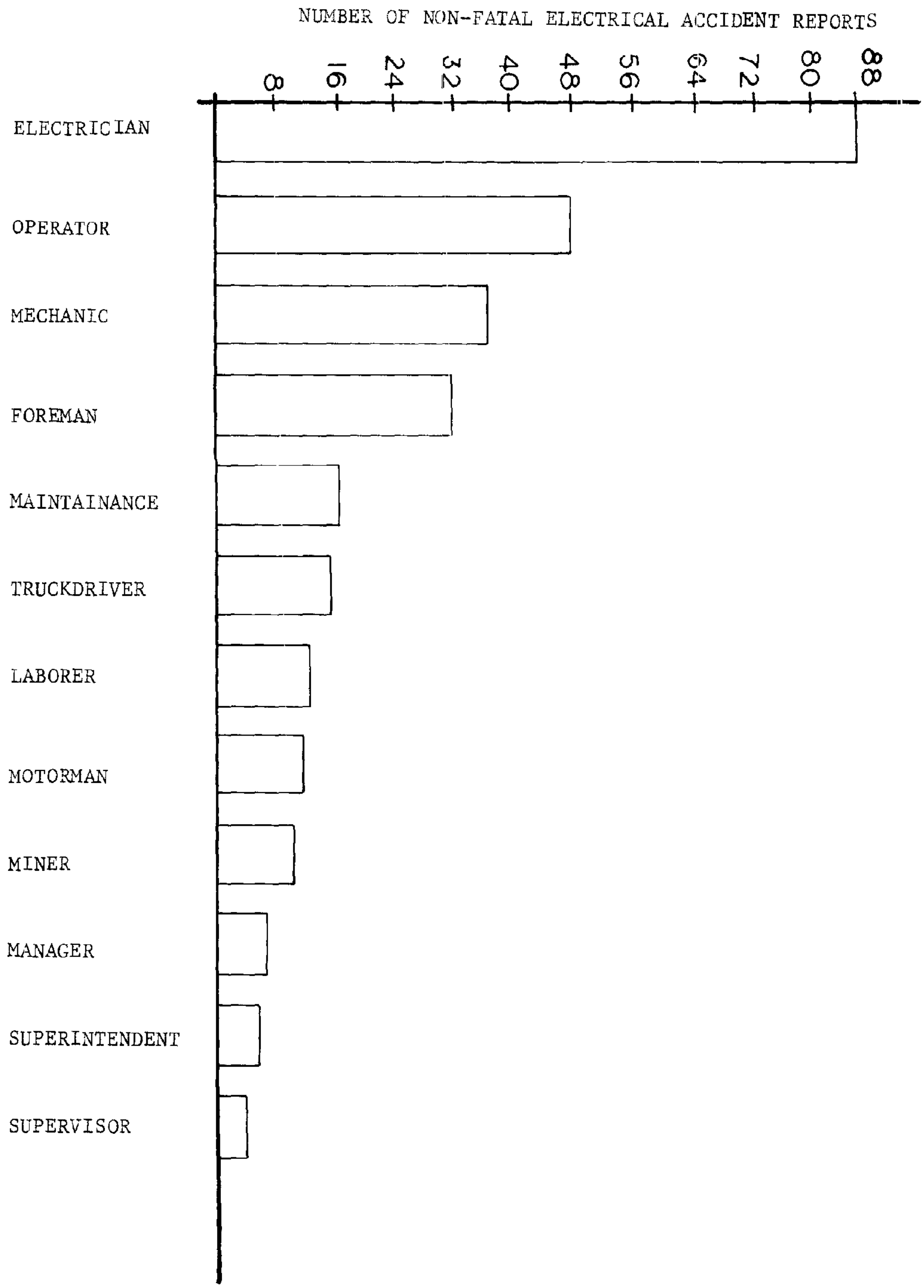


FIGURE 3.4. - Non-fatal electrical accidents for various job titles.

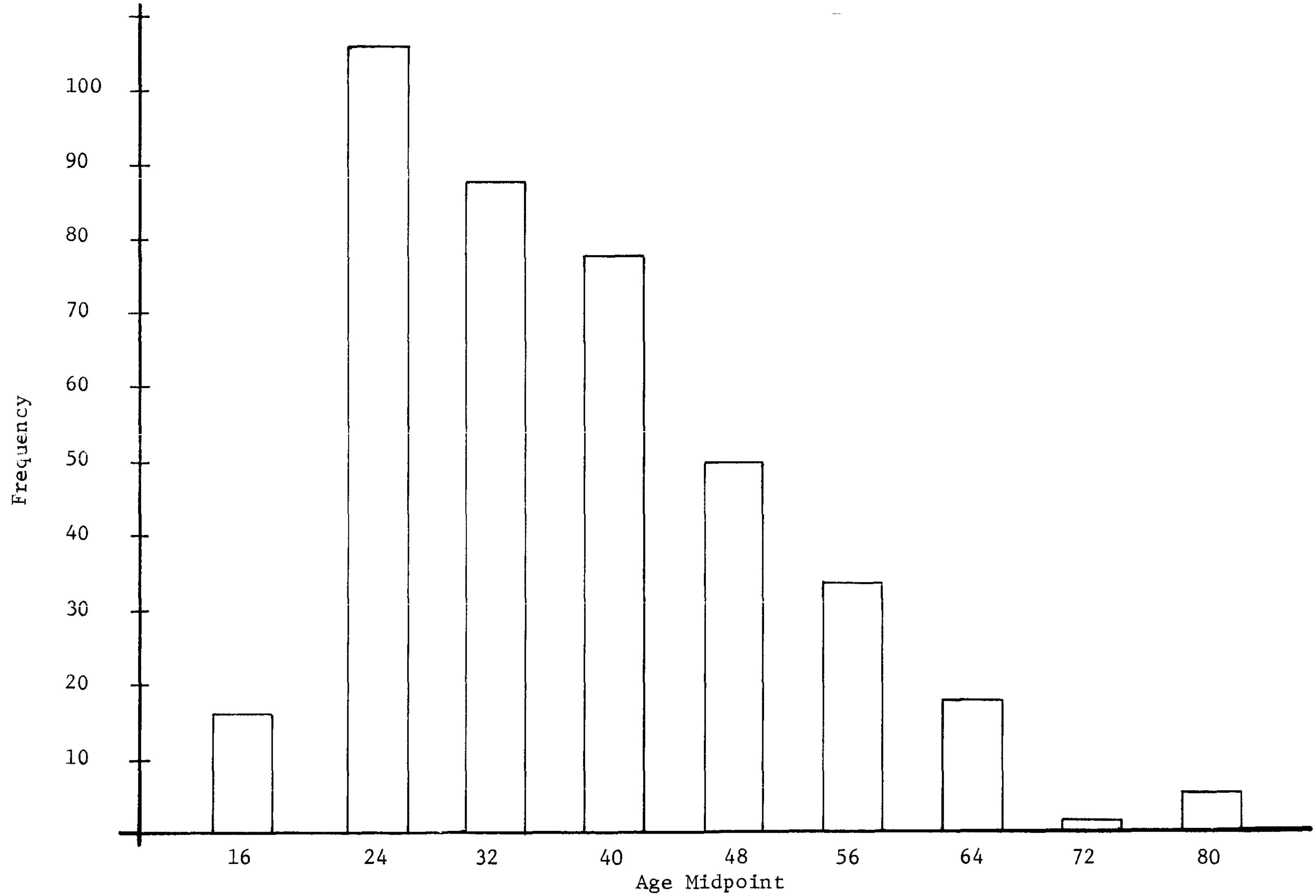


FIGURE 3.5. - Electrical accidents versus injured age.

Figures 3.6 and 3.7 show the detail. As expected in both cases, the higher the experience the lower the chances of an accident. Table 3.19 and 3.20 summarize the study.

TABLE 3.19. - Accident rate versus mine experience.

Mine Experience	Percentage of victims
Less than 5 years	44%
5 to 10 years	36%
10 to 25 years	12%
25 to 30 years	8%

TABLE 3.20. - Accident rate versus job experience.

Job Experience	Percentage of victims
Less than 2.5 years	48%
2.5 to 7.5 years	28%
7.5 to 12.5 years	14%
Above 12.5 years	10%

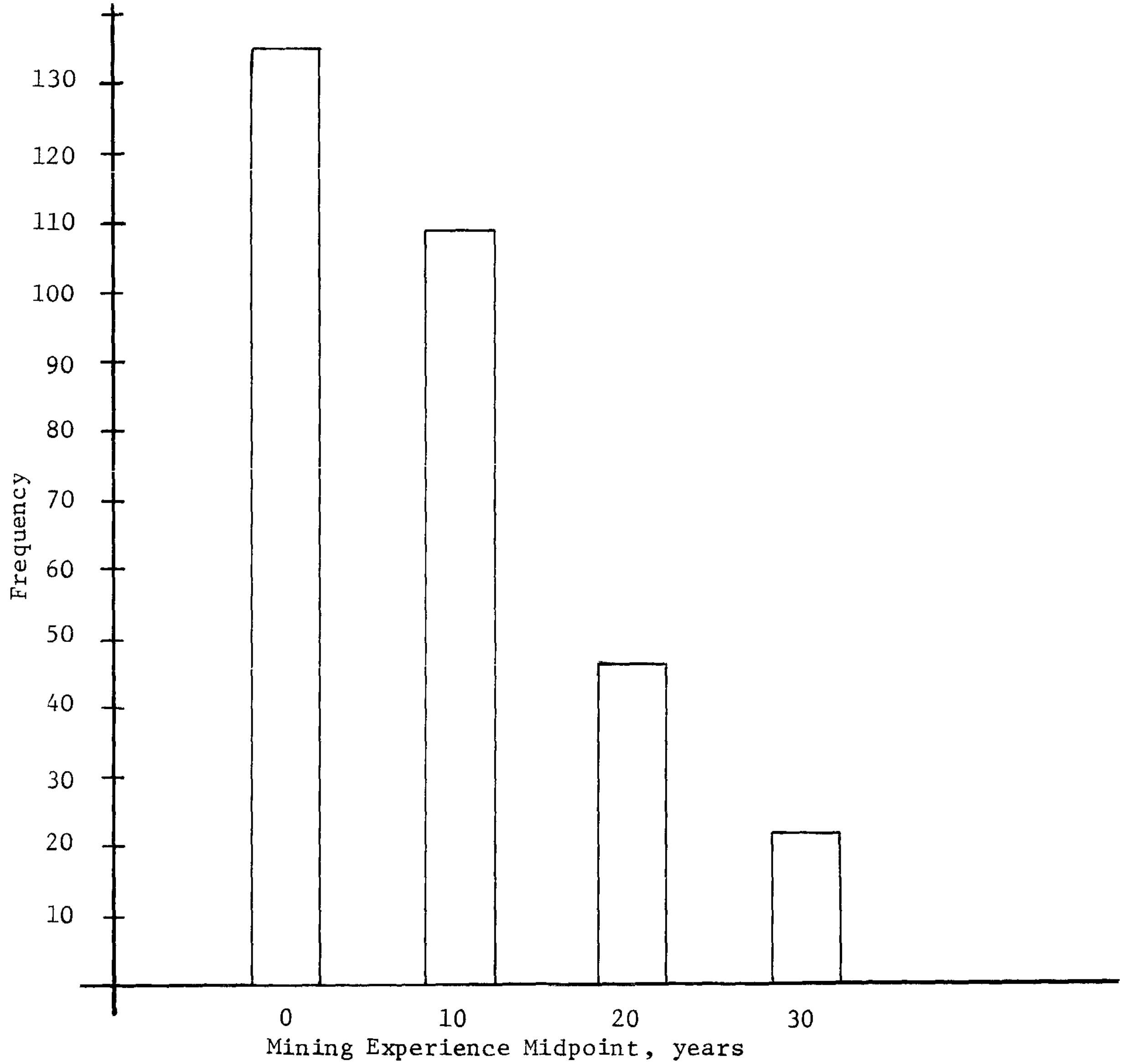


FIGURE 3.6. - Accident rate versus mining experience.

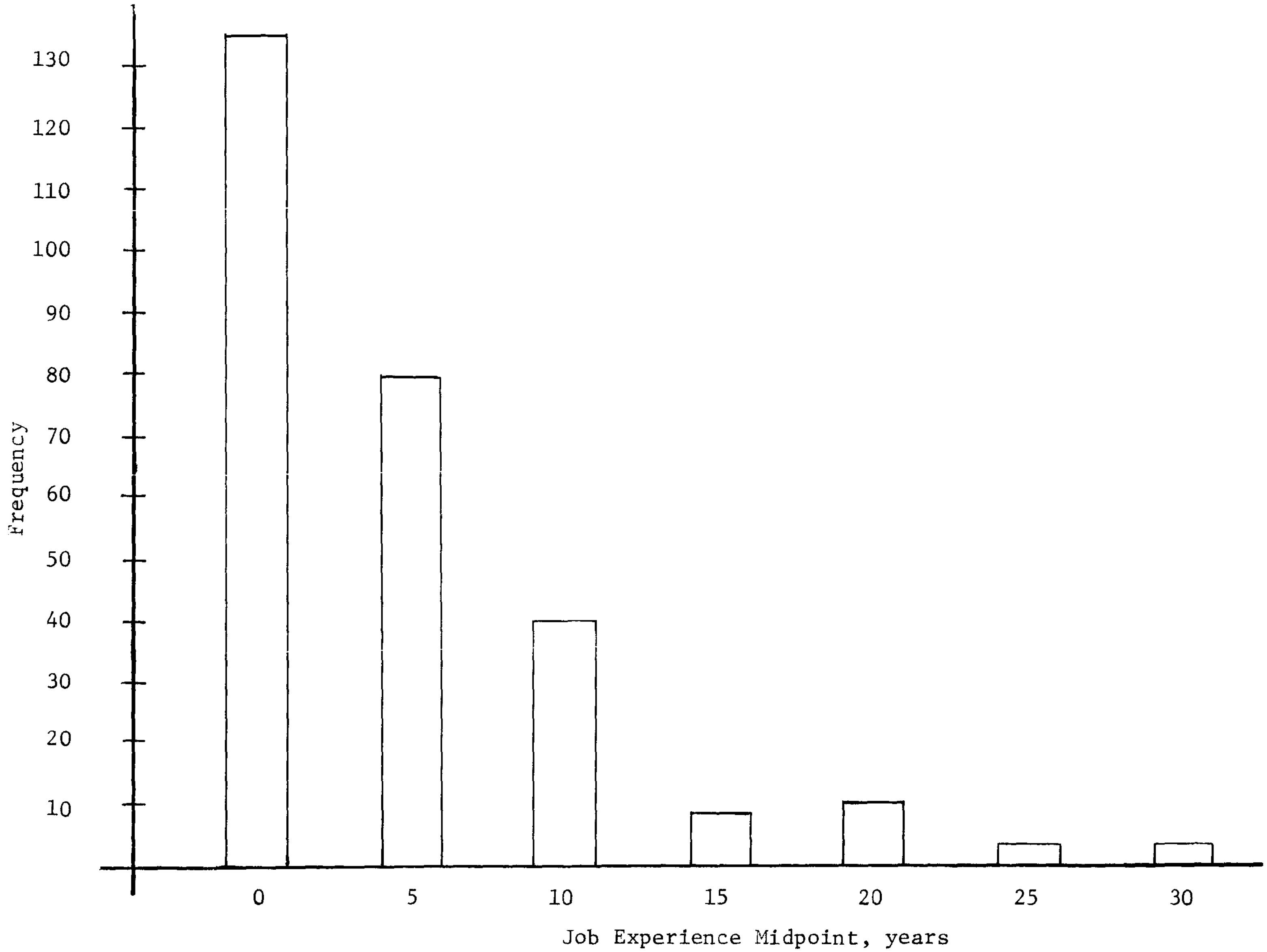


FIGURE 3.7. - Accident rate versus job experience.

CHAPTER IV

MINE VISITS AND MINE MODELS

4.1 INTRODUCTION

In order to determine current industry practices in the areas of electrical grounding and power distribution, the contract called for visits to at least twenty different mining operations throughout the country to gather data on these topics. Accordingly, phone calls were made and letters were written to gain permission to visit as many different types of facilities as possible. Thirty seven mines were visited, as well as 30 processing plants or mills. Specific emphasis was given to dredging operations and sand and gravel plants, as was required by the contract. Table 4.1 provides a listing of the number and types of facilities which were visited. The mines were located in thirteen different states, ranging from New England to the desert Southwest, and from the Dakotas to the Gulf coast.

TABLE 4.1. - Metal/non-metal mining operations and plants which were visited during inspection trips

12 dredges and 12 dredge plants (sand and gravel)
5 quarries and 5 plants (limestone, dolomite, granite, diabase trap)
4 river-bed sand and gravel plants
4 underground uranium mines and 1 mill
2 underground molybdenum mines and 2 mills
1 surface molybdenum mine
2 underground potash mines and 2 mills
4 surface phosphate mines and 1 plant
2 underground gypsum mines
1 surface gypsum mine and plant
1 underground copper mine and mill
1 surface copper mine and mill
1 underground trona mine
1 underground gold mine

4.2 MINE DESCRIPTIONS

All of the underground mines utilized resistance-grounded neutrals on their transformer secondaries, with protective relaying set to trip the circuit breakers on ground fault current levels as low as five amperes. Face utilization voltage was generally 480 V, although one installation was using 4160 V with shielded trailing cable as shown in Figure 4.1. Another operator had his 480 V face equipment powered via shielded trailing cables. Many of the mills and processing plants use 480 V distribution, with 2300 V for very large motors driving rod mills, ball mills, and the like. The 480 V transformer secondaries are often delta-connected so that plant operations may continue even if one phase becomes grounded, but these systems are always equipped with ground-indicating lights as shown in Figure 4.2 and usually have special fault-tracing equipment so that phase-to-ground faults can be detected and isolated. Other plants use either a solidly-grounded or resistance-grounded wye secondary, with selective ground-fault tripping.

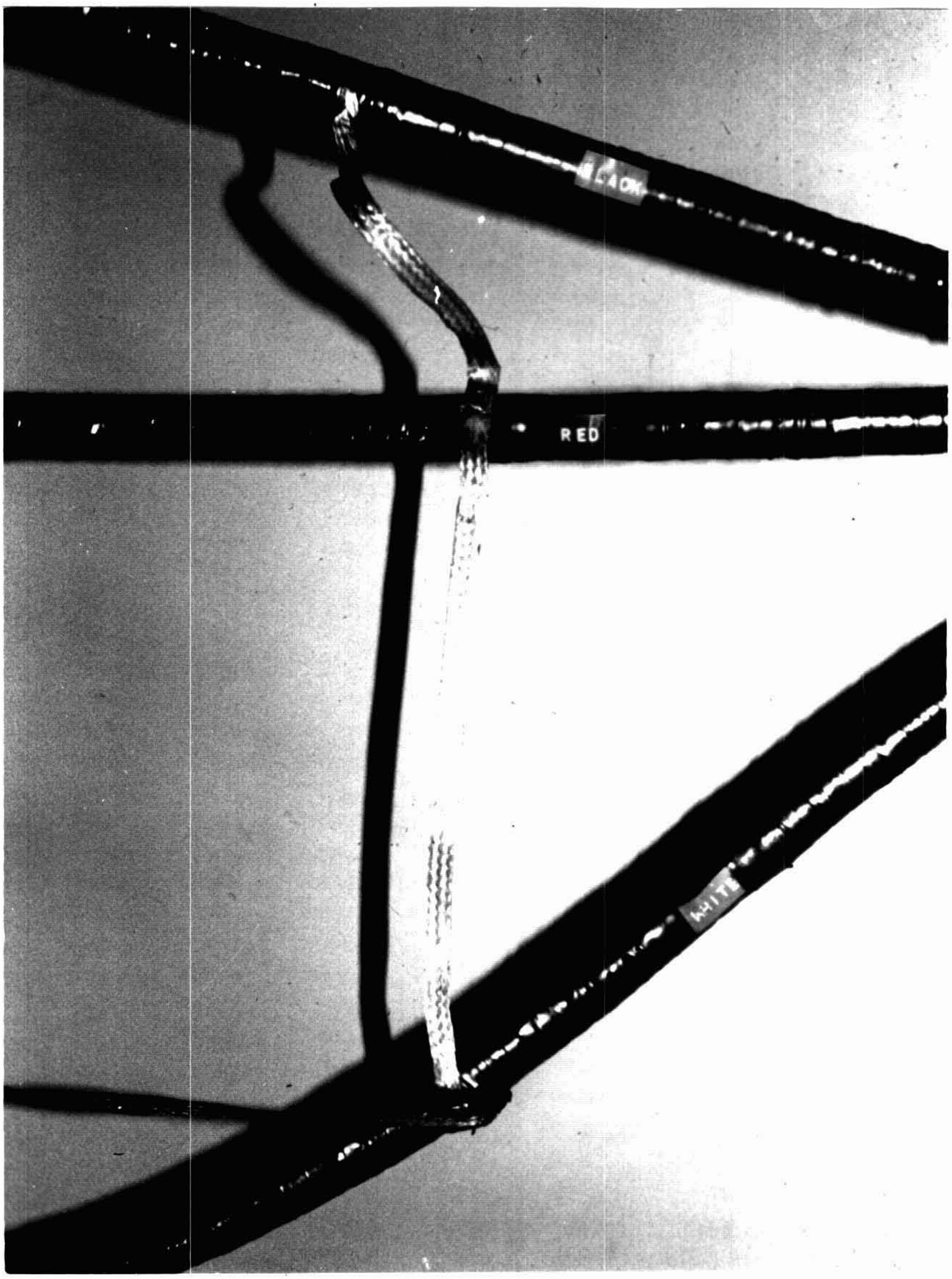


FIGURE 4.1. - 4160 V shielded trailing cable in underground phosphate mine.

FIGURE 4.2. - Ground indicating lights in granite quarry.

Heavy copper pigtails extend from the building steel to the frame of each motor to provide grounding in most plants as shown in Figure 4.3. In addition, the 480 V wiring is usually run in metal conduit which is often used as an additional ground conductor, and which is eventually bonded to the substation ground bed. Conduit ground conductors can be excellent, low-resistance paths if continuity is assured at each union and flex coupling, as shown in Figure 4.4, and if vibration is not a problem. However, in some installations which use shaking screens for size separation, particularly in sand and gravel or dredge plants, vibration may be so severe that conduit can literally be shaken to pieces. In these instances, conduit does not make an adequate frame-grounding conductor.

Most of the surface mines visited also utilized the resistance-grounded neutral system for circuits feeding portable and mobile equipment powered by trailing cables. However, at least one facility used a floating delta secondary with no grounding conductor whatsoever. In theory, ground fault current cannot flow in an ungrounded delta system, but in reality it does, because of stray circuit capacitance. Also, if two nearby pieces of equipment have phase-to-frame faults on different phases, a person who touches both machines simultaneously will be shocked with the full line-to-line voltage. Ungrounded systems pose a significant danger to personnel unless they are equipped with very sensitive GFI-type tripping, which is not available except on 120 V circuits. All of the dredges visited utilized shielded trailing cables as shown in Figure 4.5, and their power systems were equipped with resistance-grounded neutrals (some of which had been very recently installed). Many surface facilities did not use ground-check monitors to verify the continuity of the grounding conductor inside the trailing cables. The use of GC monitors is required by law in surface coal mines, and the metal/non-metal industry trend is in this direction. Because of the vital importance of the ground system, it is felt that monitoring is a necessity, and those in the industry who are using it on an experimental basis report good success, both with home-built and OEM units. An OEM unit is shown in Figure 4.6. Detailed descriptions of all mines, contractors and MSHA representatives visited are contained in Appendix A.

4.3 MINE ELECTRICAL MODELS

This section of this chapter reviews three models of electrical power systems for the metal/non-metal mining industry. The models are for:

A. underground hard-rock mine,

B. surface mine, and

C. dredge mine and plant.

The models were developed after observing actual industry practice and talking with mine electricians and electrical engineers about the advantages and disadvantages of various techniques. In addition, consultations were held with MSHA engineers and electrical inspectors to hear their viewpoints on electrical distribution and grounding. The models represent the combination of input from all these sources plus prior coal-mining experience, and are designed to provide both reliability and safety.

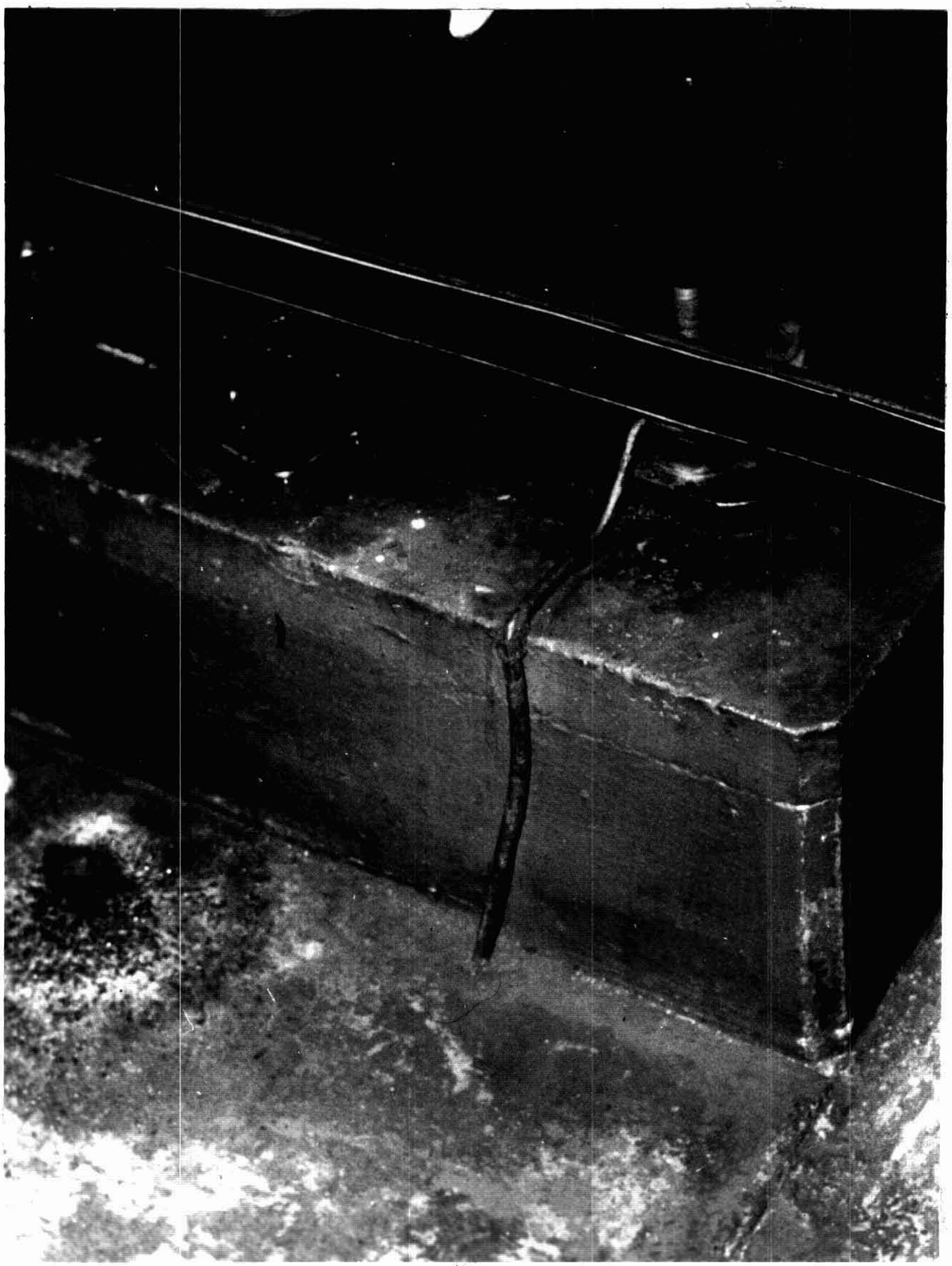


FIGURE 4.3. - Motor frame grounded to building steel in uranium mill.

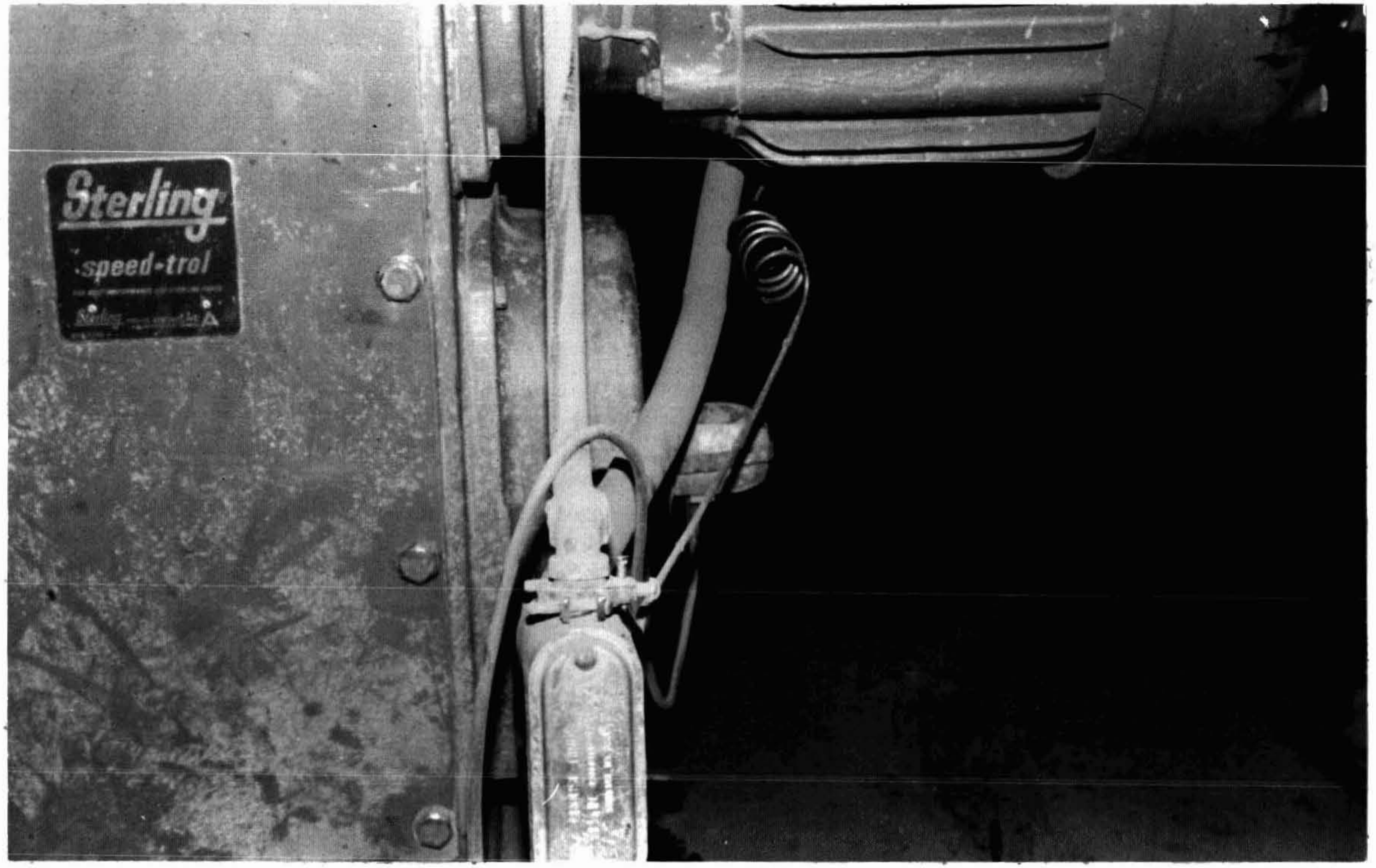


FIGURE 4.4. - Conduit and jumper used as ground in uranium mill.

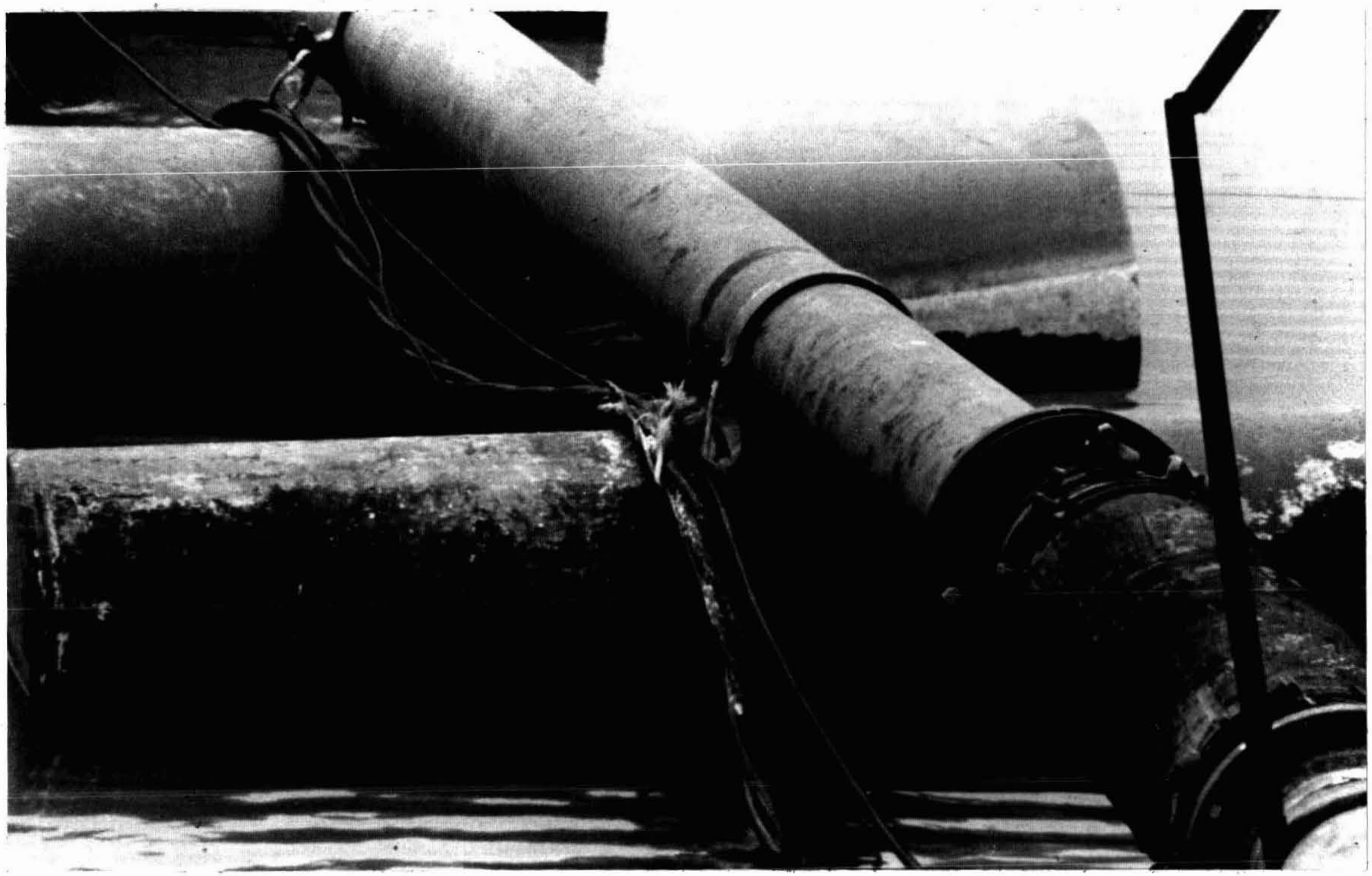


FIGURE 4.5. - Individually shielded cable on sand dredge.

FIGURE 4.6. - OEM ground fault on phosphate dragline.

4.3.1 Model of Power System for Underground Hard Rock Mine

The first model to be developed is that for the power system of an underground hard-rock mine, and includes distribution to surface support facilities, a mill or plant, and a subsidiary ventilation shaft, as well as two different underground mining levels. Figure 4.7 is a one-line diagram of the overall power system, and the subsequent figures show added detail for each of the units of interest.

The utility supply is shown at the 115 kV level, which is transformed to 13.8 kV by a utility-owned substation. From here, overhead lines are used to carry power to the mine site, mill, and ventilation shaft. All overhead distribution is via a 4-wire system composed of the 3 phase conductors and a static wire mounted above the phase conductors to provide lightning protection as shown in Figure 4.8.

The utility substation is shown in Figure 4.9. It includes a 10 MVA transformer with a solidly-grounded wye secondary and is equipped with metering to provide data on demand factor and the consumption of real and reactive power.

Figure 4.10 illustrates the configuration of the substation which feeds the surface mill or plant. One transformer is used to supply 3-phase 480-V power to the many small motors in the plant, as well as the 277-V lighting loads, which are connected line-to-neutral. Several small single-phase transformers are used to feed various 120 V and 240 V motors, and to power convenience outlets for hand tools. The other large transformer steps down from 13.8 kV to 2300 V for powering very large motors which are used to drive rod mills, ball mills, and the like. All distribution circuits in the mill include a ground conductor which is bonded to all machine frames, motor mounts, and building steel, as well as to the substation ground bed as shown in Figure 4.11. The circuit breakers shown in the drawing are equipped with protective relays to provide tripping for three separate occurrences:

A. short-circuit,

B. overload, and

C. ground fault.

Figure 4.12 shows the schematic diagram of the major mine substation, which feeds both surface and underground loads. A resistance-grounded neutral is installed on the transformer secondary, as shown in Figure 4.13, and fault current is limited to a maximum value of 50 A. Large loads such as the fan, hoist motors, and air compressor are powered directly at 4160 V, while step-down transformers are provided to supply 3-phase 480 V loads. An additional single phase transformer provides 120 and 240 V sources for lighting, convenience outlets, etc. A shielded mine power feeder cable extends from the substation approximately 700 feet down the shaft to transmit power to underground loads on the mine's upper production level.

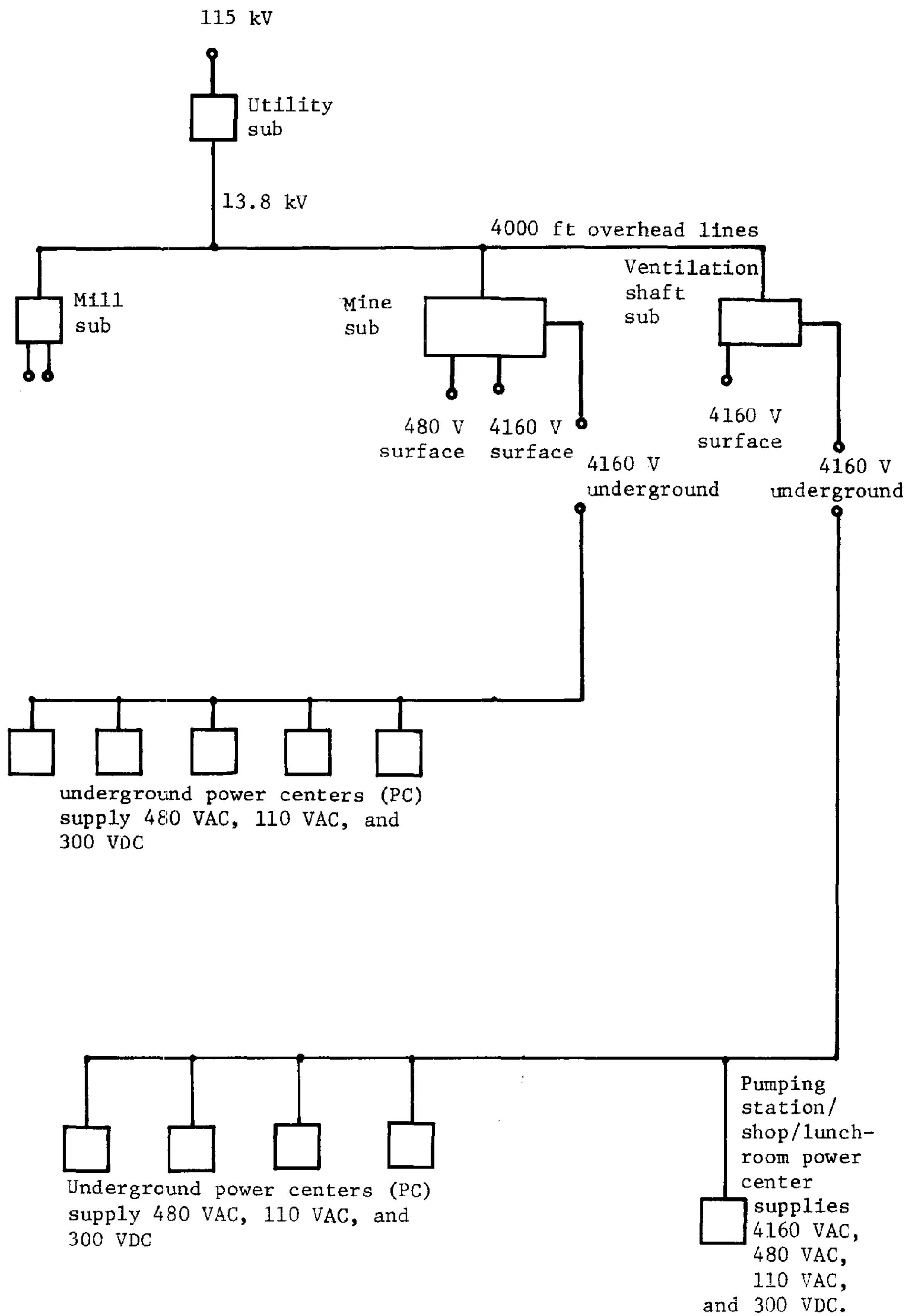


FIGURE 4.7. - Overall one-line of UG metal mine power system.

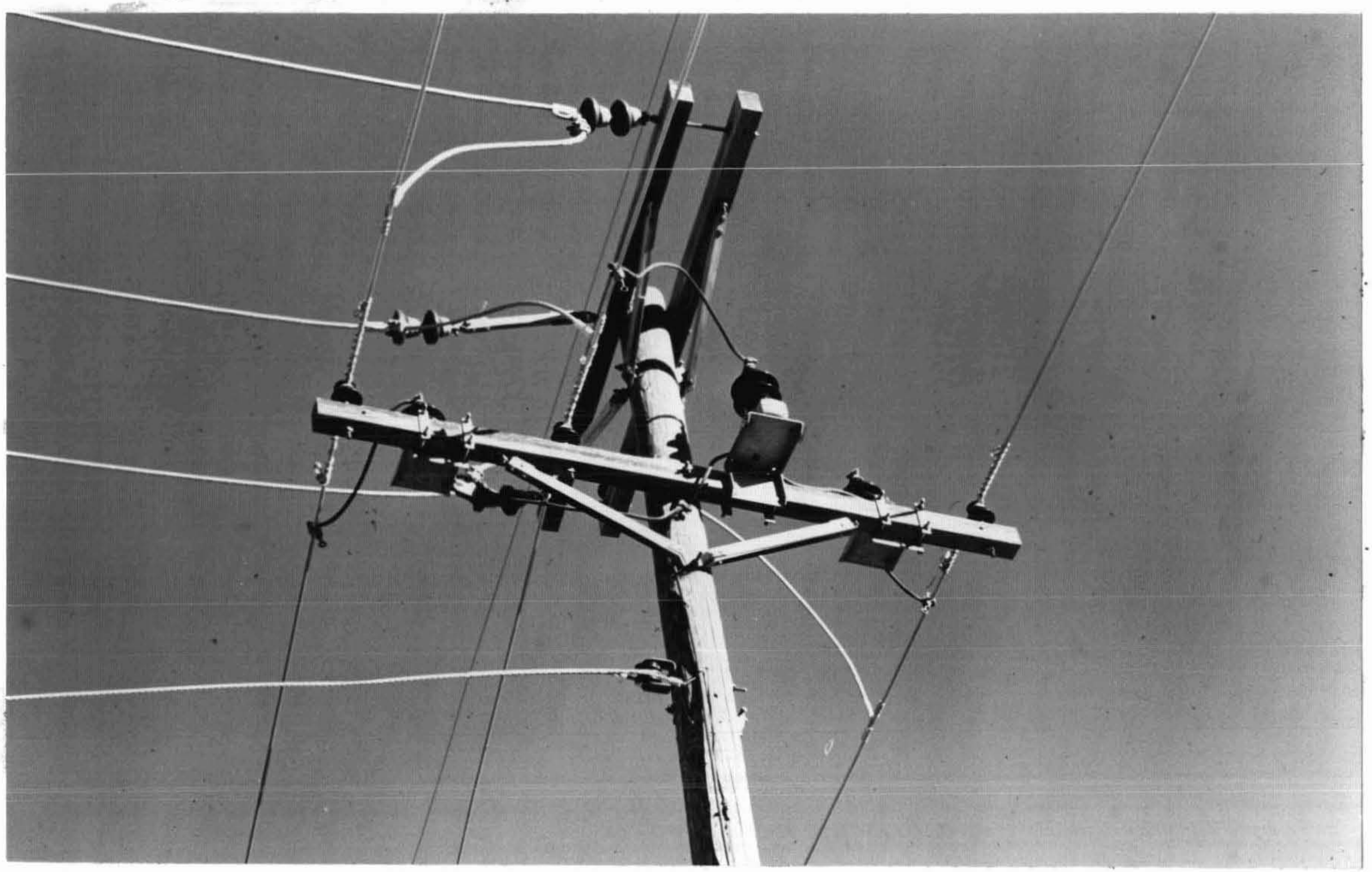


FIGURE 4.8. - Four wire overhead distribution at underground copper mine.

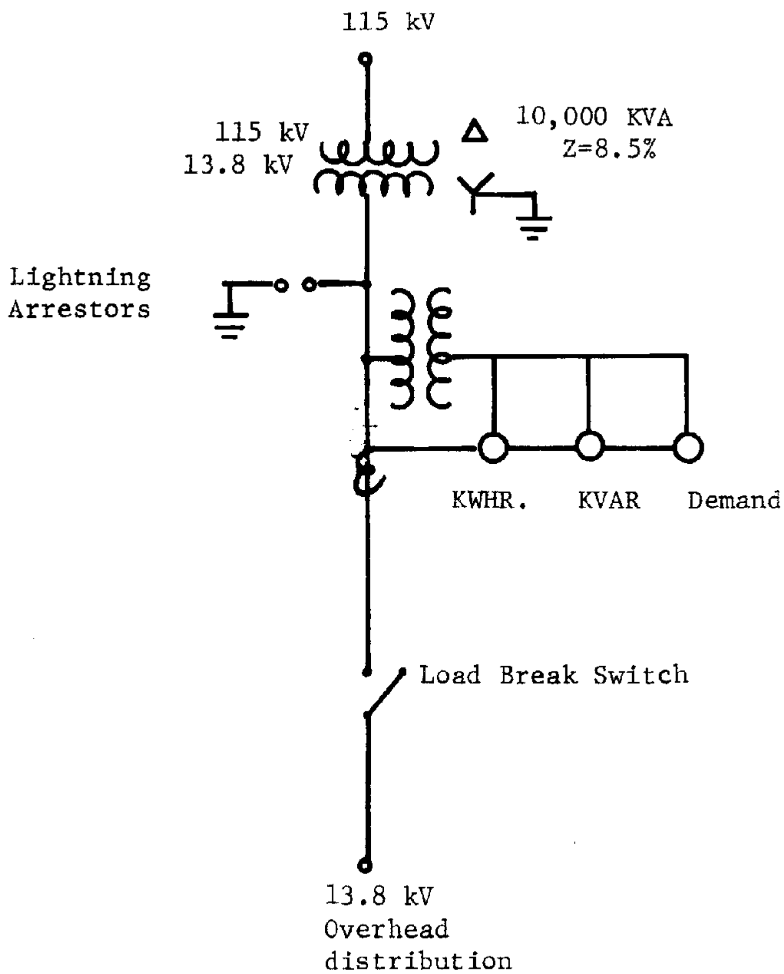


FIGURE 4.9. - Utility substation.

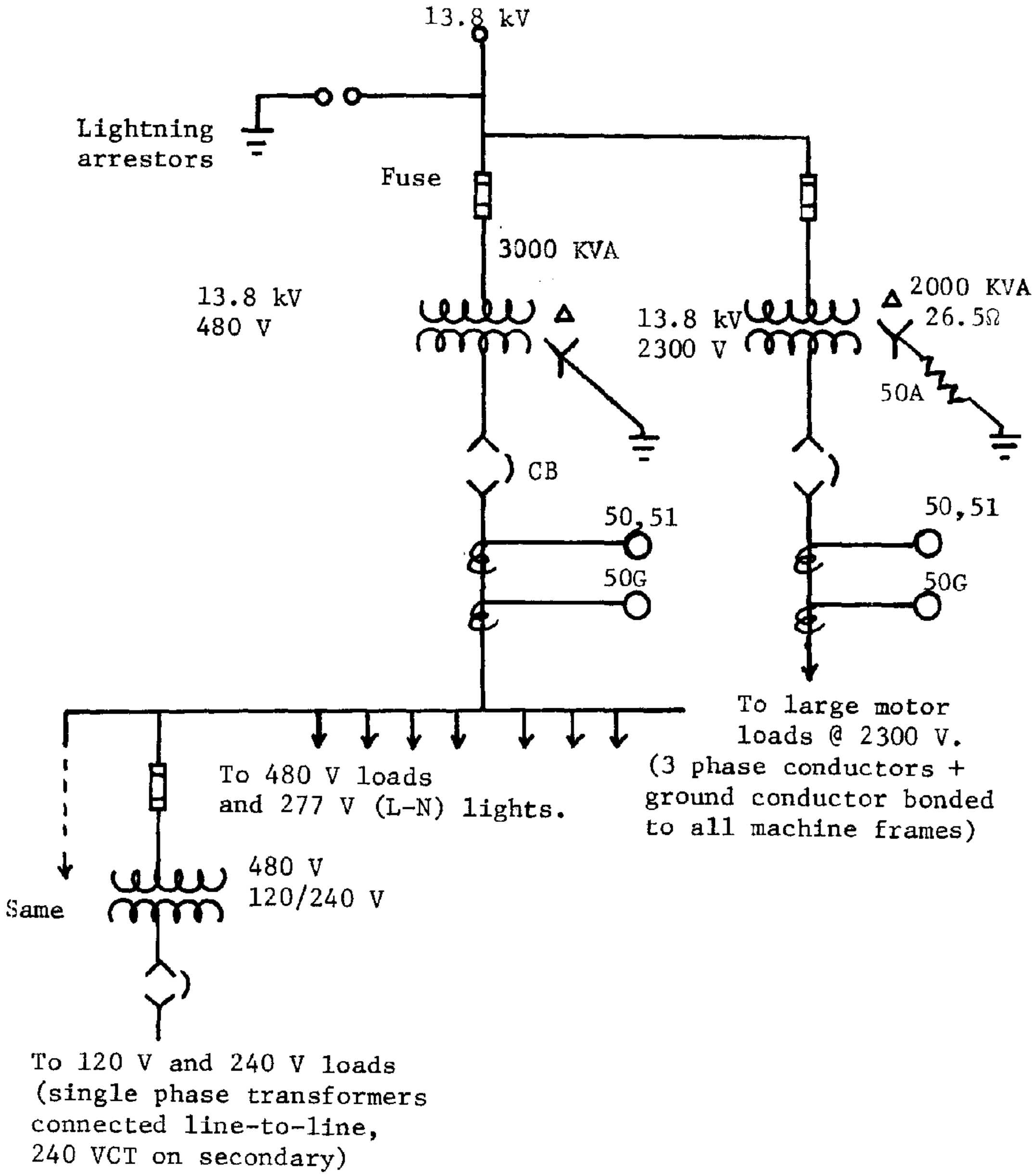


FIGURE 4.10. - Substation feeding surface mill or plant.

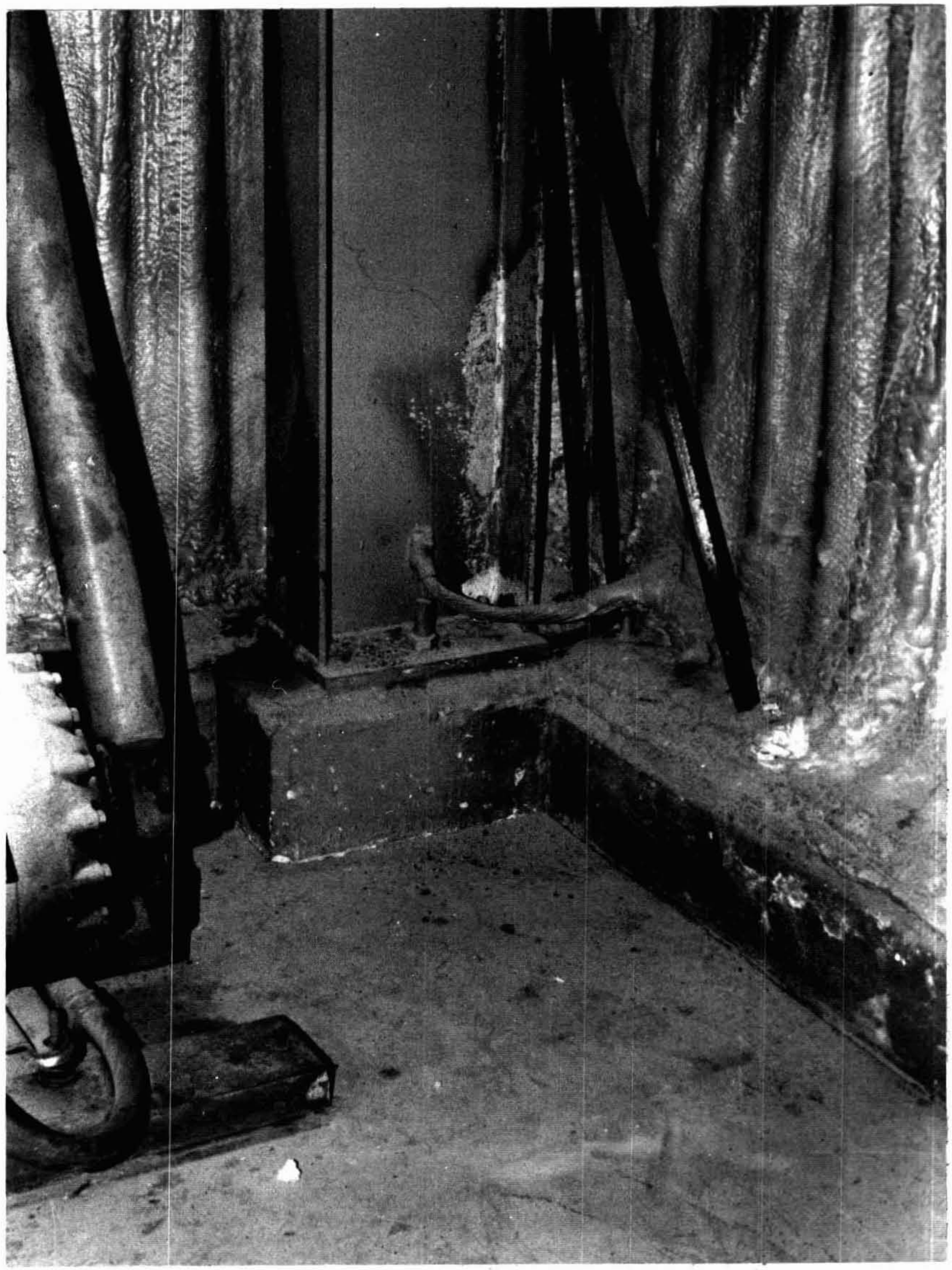


FIGURE 4.11. - Ground conductor bonded to building steel at underground uranium mine.

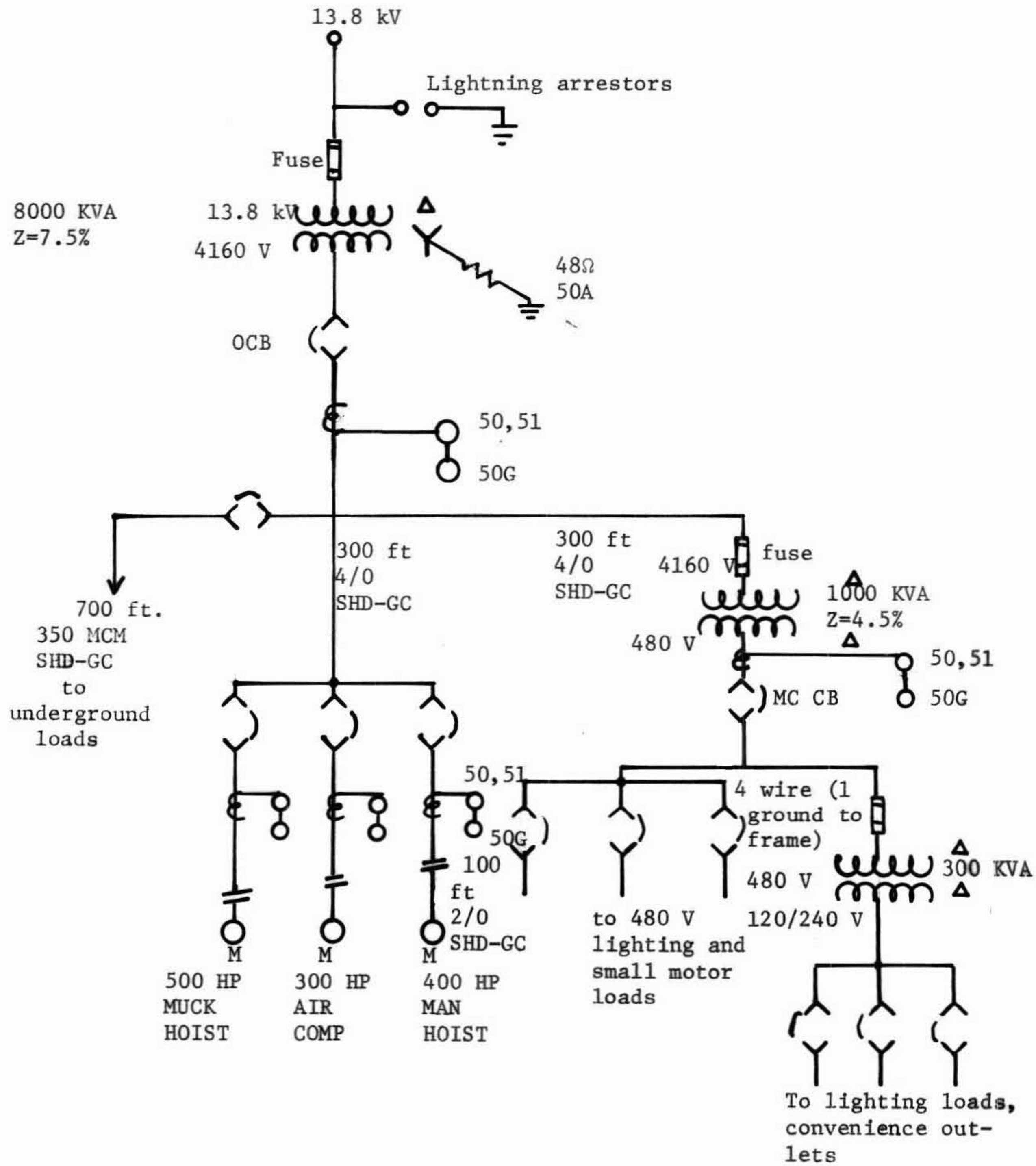


FIGURE 4.12. - Mine Substation feeding underground loads and surface support facilities.

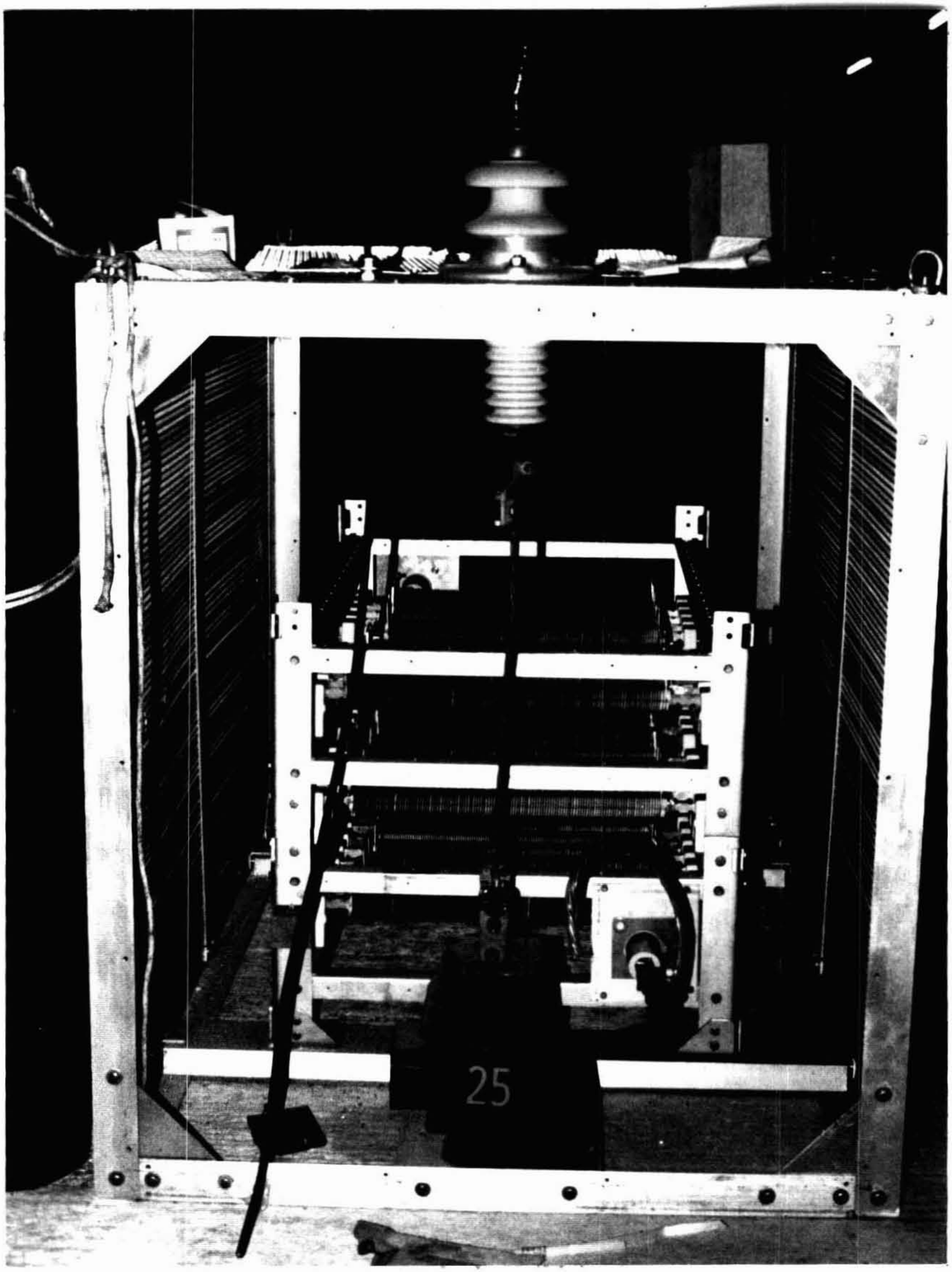


FIGURE 4.13. - Secondary neutral resistor in underground salt mine.

The ventilation shaft substation is shown on Figure 4.14. A mine of reasonable size will have at least one ventilation shaft in addition to the one containing the man and muck hoists. This ventilation shaft, which is generally several thousand feet away from the main shaft, will often have its own substation, shown in Figure 4.15, both for supplying power to the fan, and (in this case) to feed power to the second production level of the mine. This substation is somewhat similar to the substation shown in the Figure 4.12, but is simpler due to the absence of surface facilities. Again, a resistance-grounded neutral is used on the transformer secondary, with fault current limited to 50 A.

The typical underground power center, shown in Figure 4.16, is drawn in Figure 4.17, along with a simple diagram of the high-voltage distribution on one level of the mine. Five separate power centers are shown on this level, although the actual number may vary from two to ten depending upon the size of the mine and the number of production stopes. Each power center provides 480 Vac for slushers, pumps, and fans, as well as 300 Vdc for the underground rail haulage (locomotives powered from a trolley wire system). A delta-delta transformer is used to feed the 3-phase rectifier, as shown in Figure 4.18, in an effort to isolate the dc power supply from its ac counterpart. The 480 V transformer has a resistance-grounded neutral attached to the wye secondary. In this case the resistor is sized to limit fault current to 15 A, but this value may vary depending upon state regulations or company policy. A step-down transformer is used to derive single-phase power at 120 V for track lighting and signaling purposes, and back-to-back 480/120 V transformers are utilized to derive an isolated (non-grounded) 480 V feed for blasting circuits. No ground check monitors are shown on the three 480 V distribution cables leaving the power center. A single device can only monitor the continuity of the circuit until the cable reaches the first junction box. Although this practice is standard in some mines, no useful function is performed by the monitors in this application. If there is no mobile or portable equipment powered by trailing cables, then there is no pressing need for ground check monitors. Each power center is equipped with five 480 V outlets to supply underground distribution circuits, and each of these circuits will feed five to seven stopes.

Two examples of underground 480 V distribution circuits are shown in Figure 4.19. Several pumps or small fans along the haulageways may be powered from the 480 V line, as well as track lights, signals, and one or more production stopes. Each stope will include at least one slusher, lights, and a fan, and may possibly have a small pump and an additional fan.

The underground power center shown in Figure 4.20 is different from the others described previously, and performs several special functions. It supplies power at 4160 V directly to several large pumps, located in the mine sump, which transport water to the surface. In addition, an underground shop and lunch room are serviced by this power center, including 480 V heaters, a grinder and welder, as well as 120 V and 240 V single-phase circuits for power tools and lights. A small transformer feeding a rectifier is included for battery charging purposes.

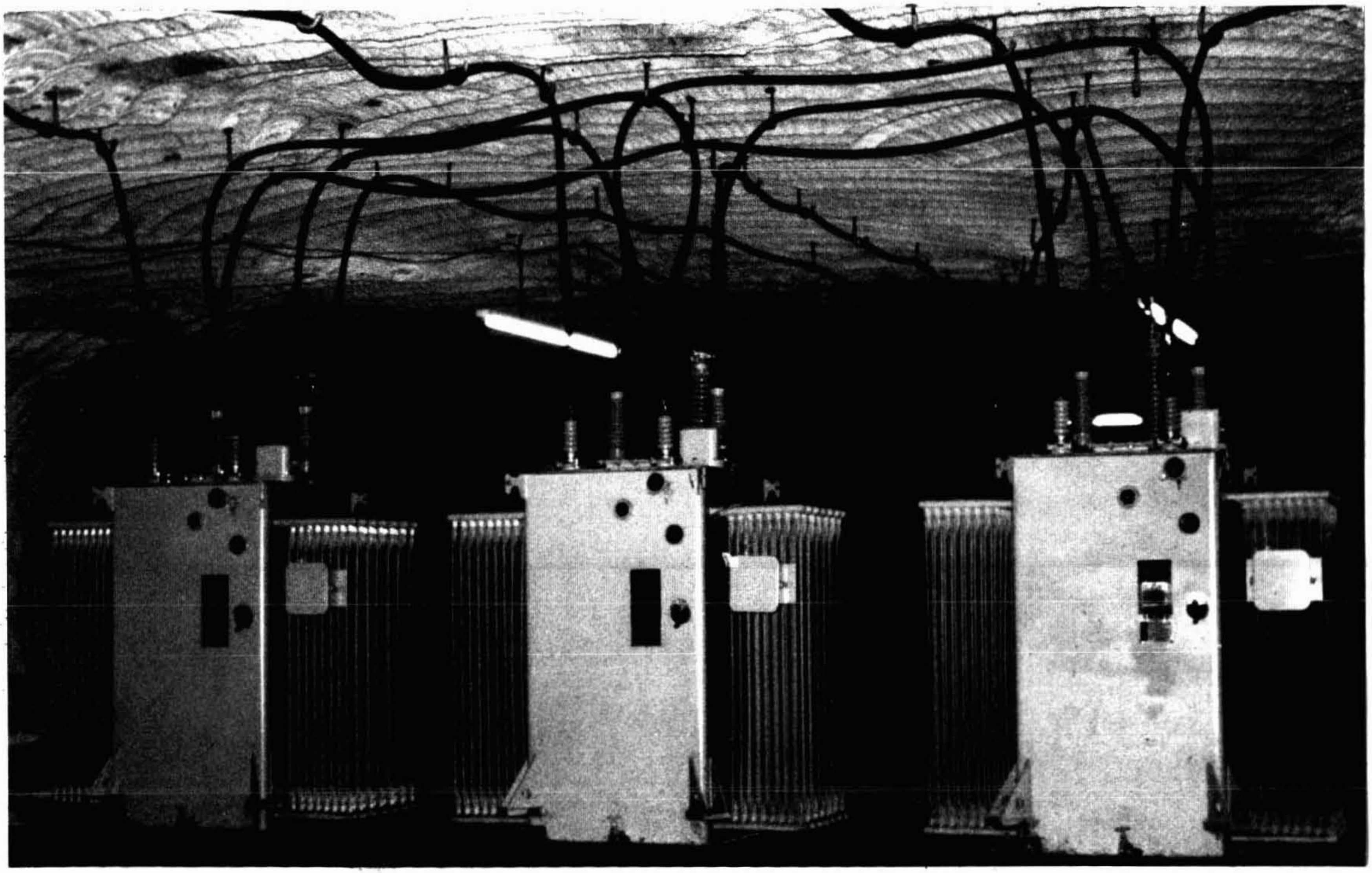


FIGURE 4.14. - Ventilation substation in underground salt mine.

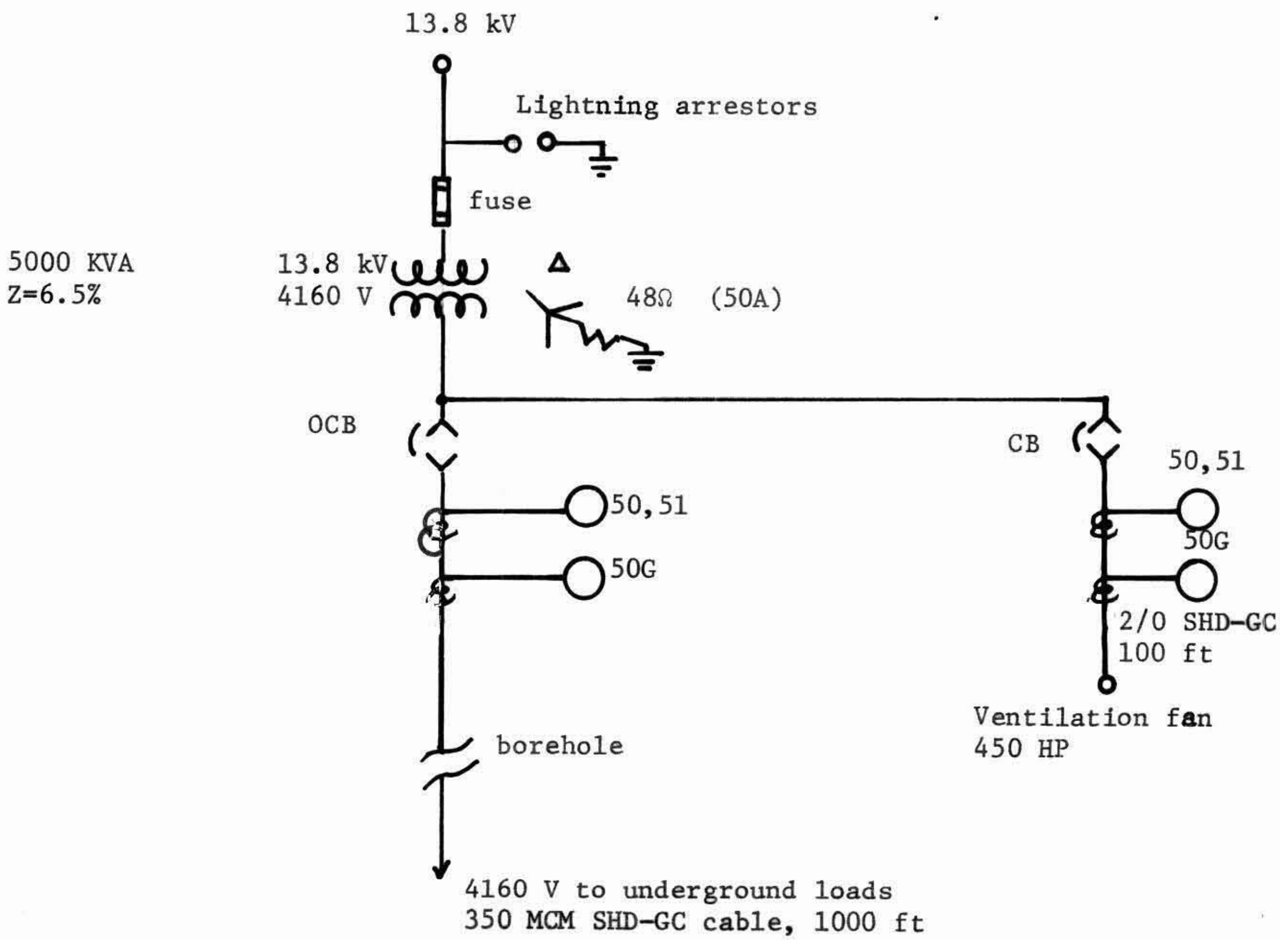


FIGURE 4.15. - Ventilation shaft substation feeding underground loads and fan on the surface.

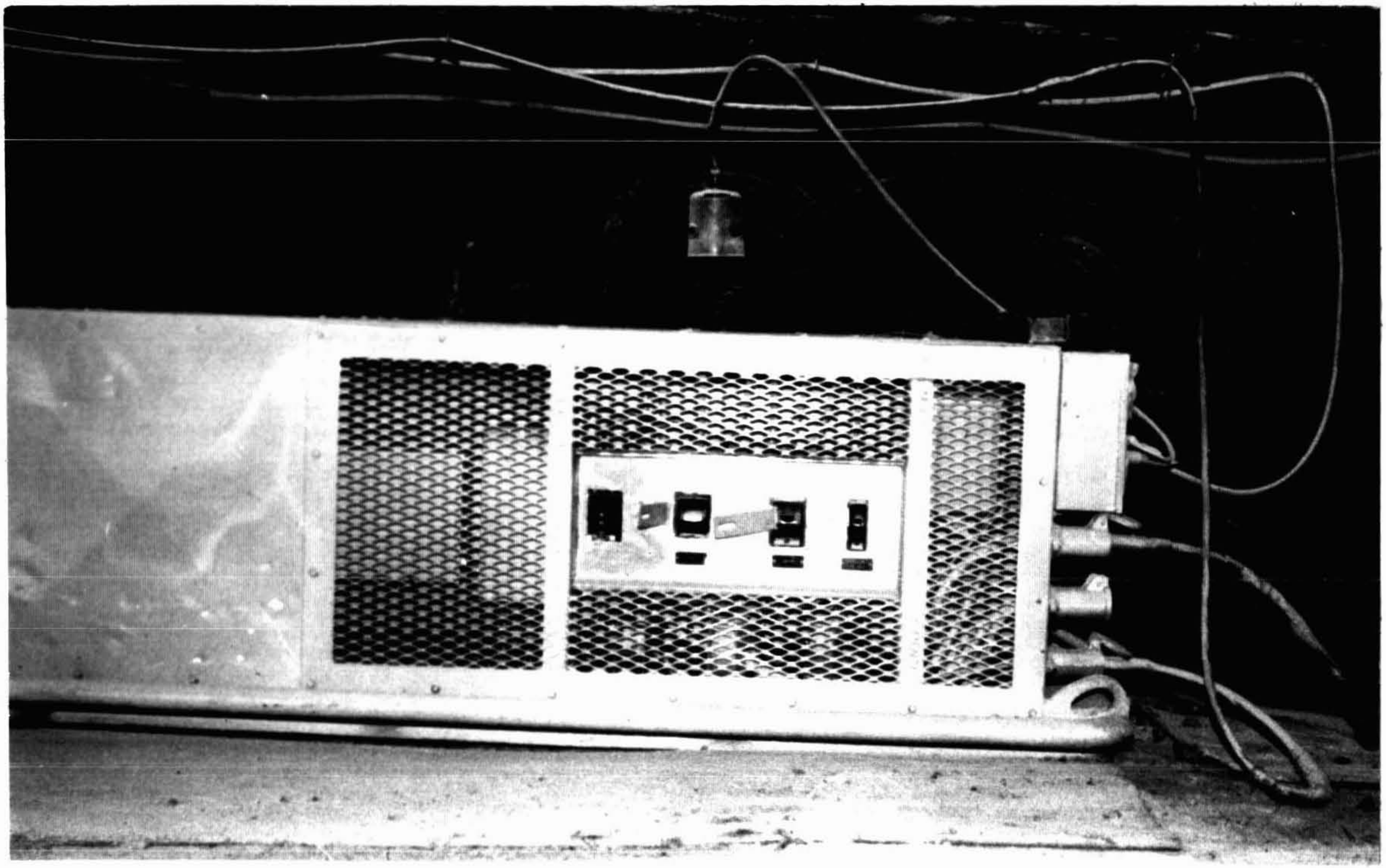


FIGURE 4.16. - Underground power center in phosphate mine.

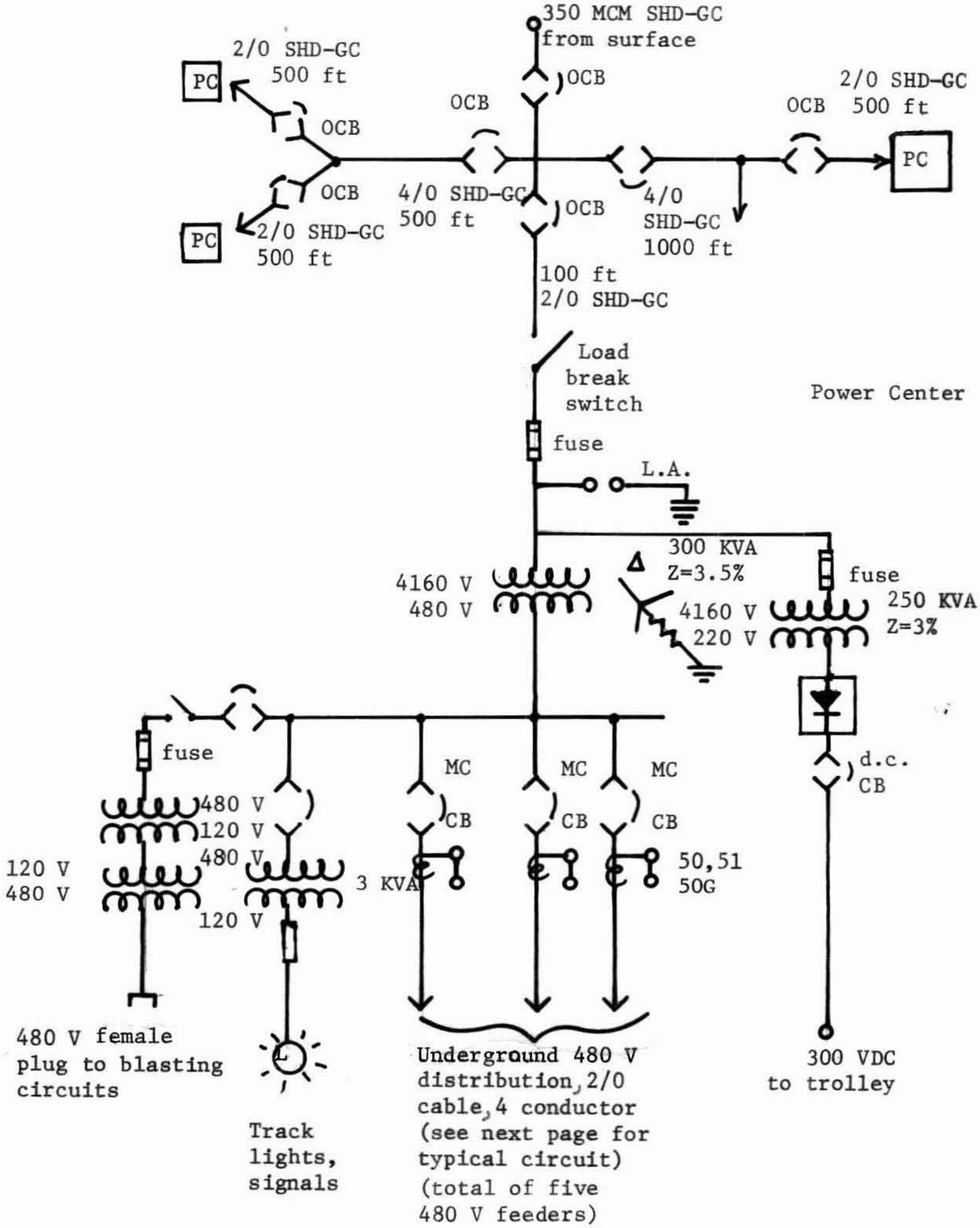


FIGURE 4.17. - Typical underground power center.

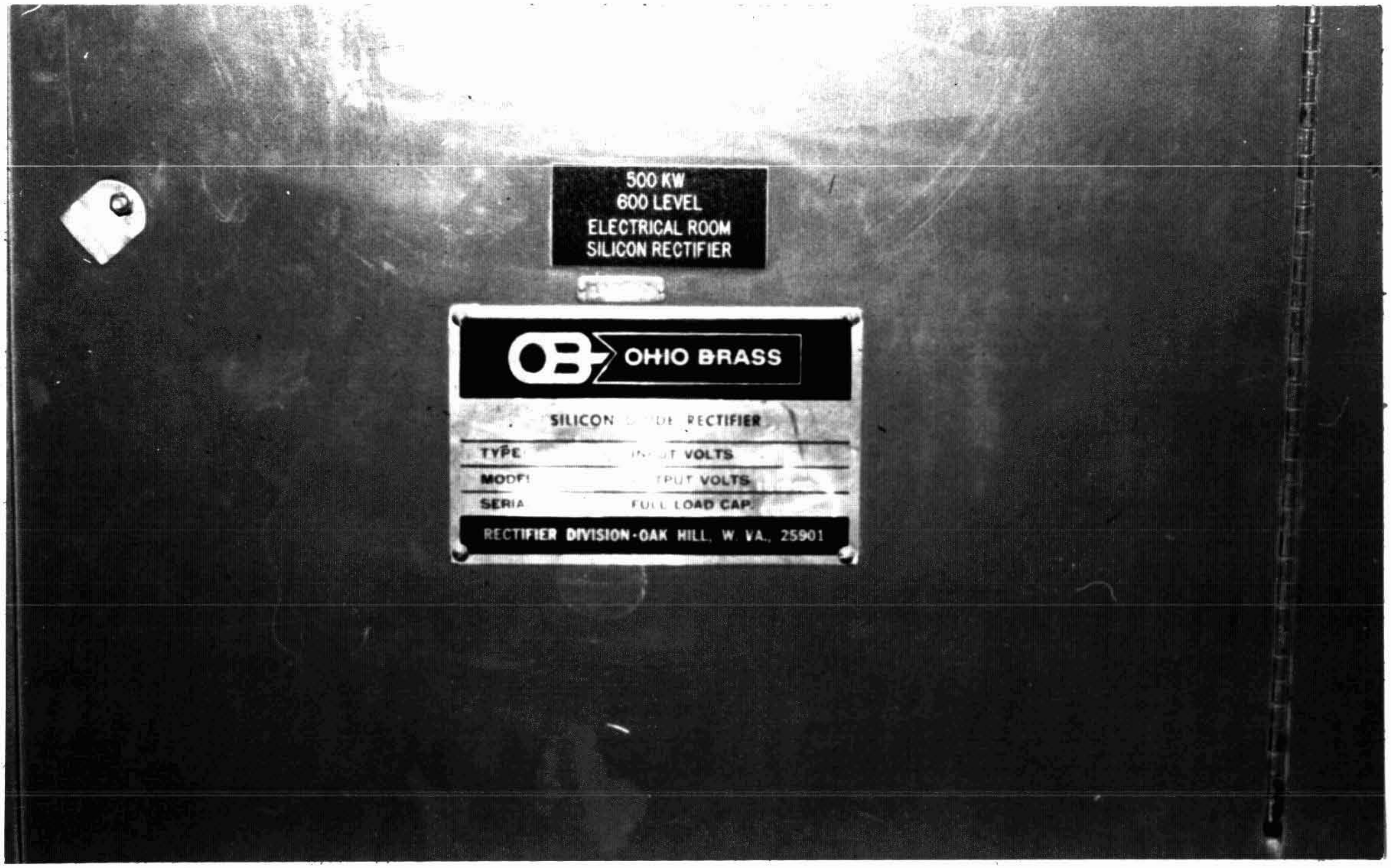


FIGURE 4.18. - 600 V rectifier underground molybdenum mine.

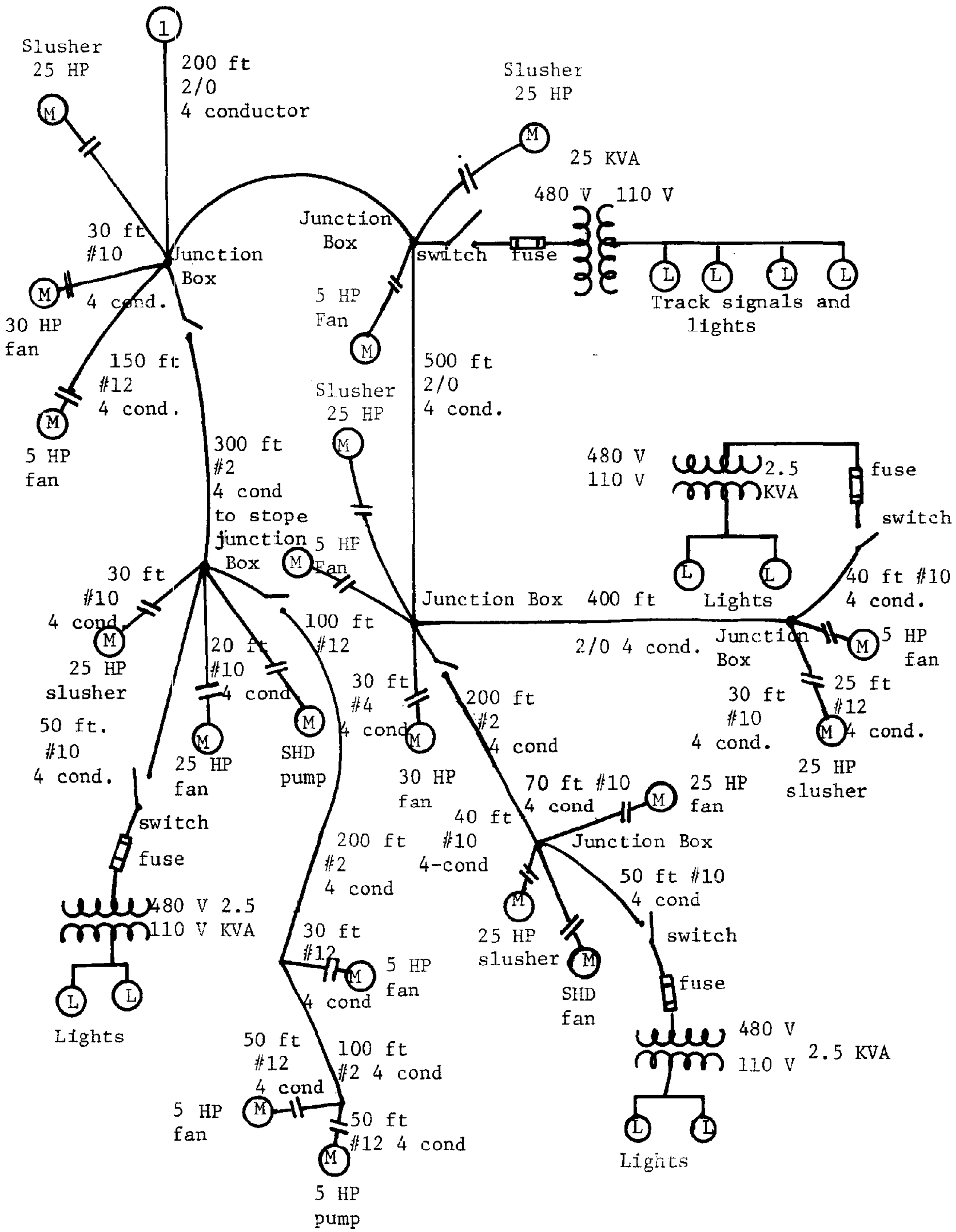


FIGURE 4.19. - Typical 480 V distribution circuits from power center.

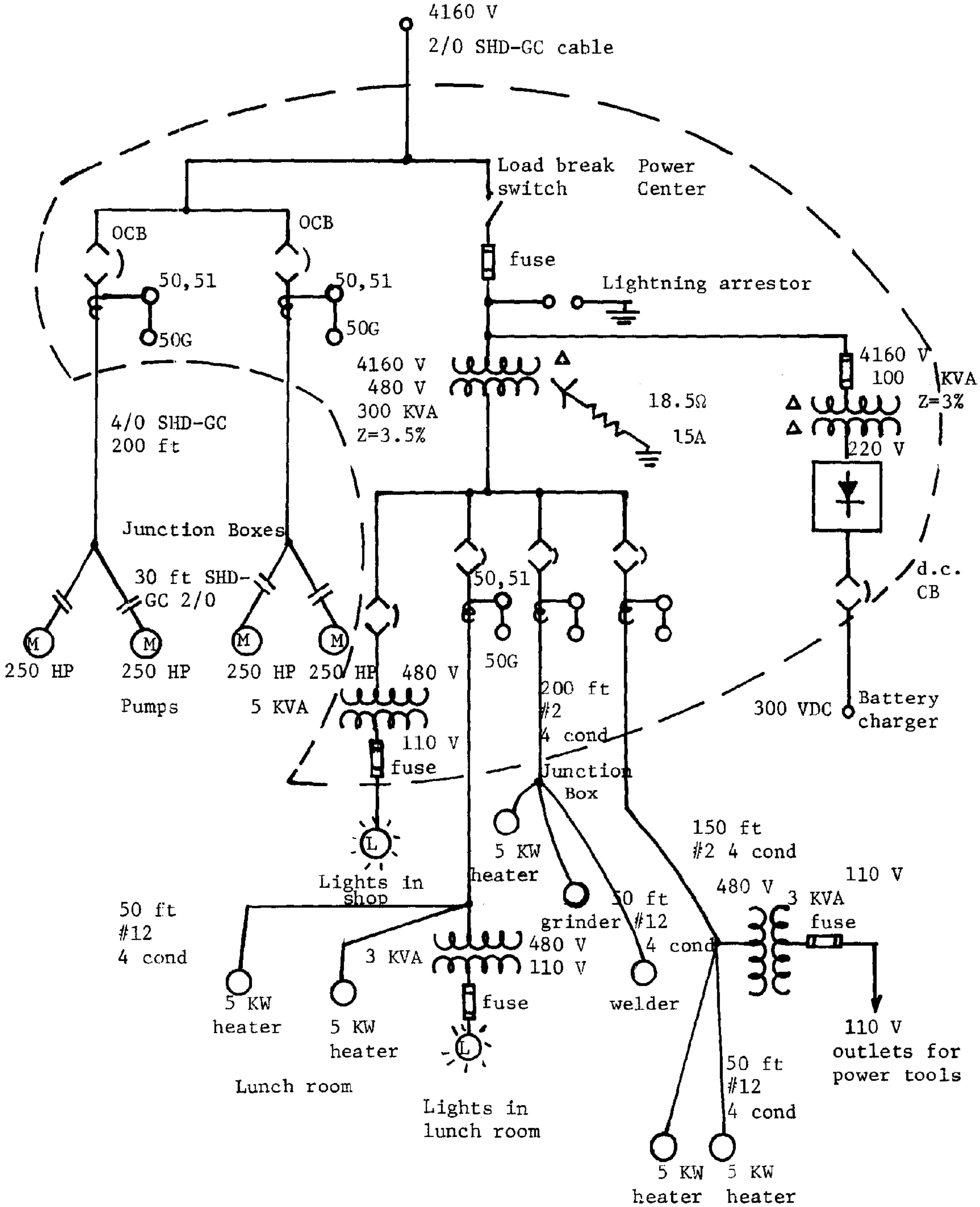


FIGURE 4.20. - Underground power center for pumping station/shop/lunch room.

4.3.2 Power System Model for Surface Mine

This model details a typical power system for a surface metal/non-metal mining operation. This could be an open-pit copper mine, a stripping-type phosphate mine, or a quarry-type limestone pit.

Power from the local utility enters the pit at 69 kV and feeds the main substation (see Figure 4.21), where the voltage is stepped down to 13.8 kV by a large transformer. This transformer is connected delta-wye, and the secondary neutral is grounded through a resistor to limit fault current to 50 A. The transformer primary side is protected by fuses and a load-break switch, and is equipped with lightning arrestors. The secondary has a main oil-circuit breaker (OCB) and feeds two branch circuits - one for the pit and one for the plant. Each branch circuit is supplied with an OCB, and includes protective relaying for short-circuit, overcurrent, and ground-fault conditions. From the main substation, power is carried at 13.8 kV to the mine workings and the plant on overhead lines. These lines are composed of 4 bare conductors, including an overhead ground wire or static wire, and the three phase conductors. The static wire is connected to earth by a ground rod driven at the base of each pole, as shown in Figure 4.22, and also is bonded to the ground bed at the main substation.

Figure 4.23 is a one-line diagram of the plant substation, which is fed from the main sub by an overhead line. The transformer is connected delta-wye with a solidly-grounded neutral on the 480 V secondary. The main 480 V molded-case circuit breaker (MCCB) and branch circuit MCCB's are all equipped with protective relaying for ground-fault, overcurrent, and short-circuit conditions. There are lightning arrestors, fuses, and a load-break switch on the high side of the transformer, and the station ground bed connects to the static wire on the 13.8 kV overhead line.

A 13.8 kV pole line runs along the perimeter of the mine workings, and is equipped with disconnects or cut-outs on every third pole. The static wire is grounded by a ground rod at the base of each pole, and is connected to the ground bed back at the main substation. Skid-mounted 13.8 kV/4160 V substations, as shown in Figure 4.24, may be connected at the cut-outs to feed mining equipment such as shovels, draglines, or large pumps. A typical one-line for the pit substations is shown in Figure 4.25. A disconnect switch, fuses, and lightning arrestors are mounted ahead of the 13.8 kV delta-connected transformer primary. The 4160 V secondary is wye-connected, and the neutral is resistance-grounded to limit fault current to 25 A. The two 4160 V cable couplers on the secondary are protected by oil circuit breakers with relaying for ground-fault, short-circuit, and over-current conditions. In addition, a ground check monitor is installed on each circuit to provide tripping if the continuity of the trailing-cable ground conductor is interrupted. Power is transmitted to mobile and portable loads via shielded 5 kV trailing cables which include a ground-check conductor. Maximum cable length is limited to about 2000 feet, and couplers are used to join cable sections together, as shown in Figure 4.26.

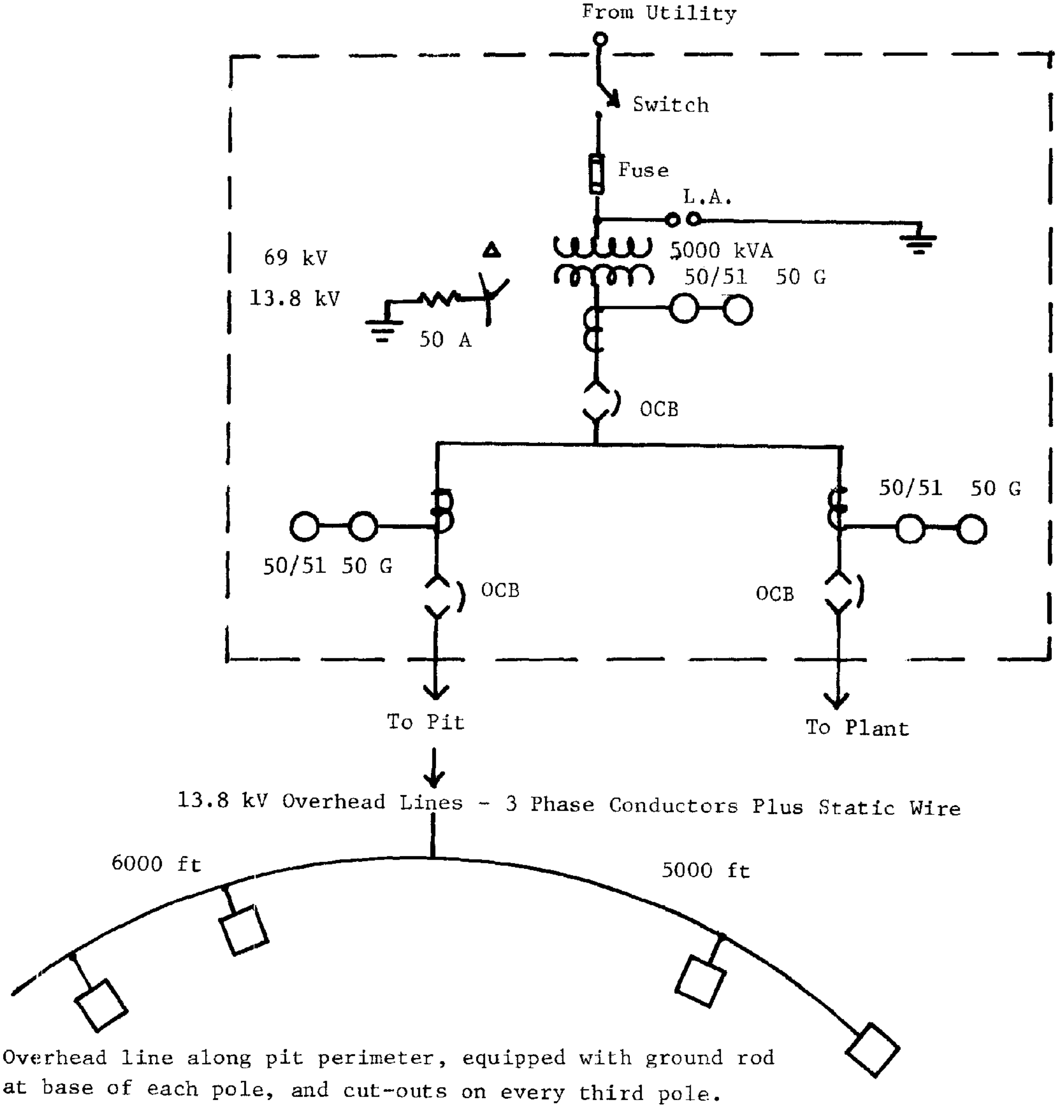
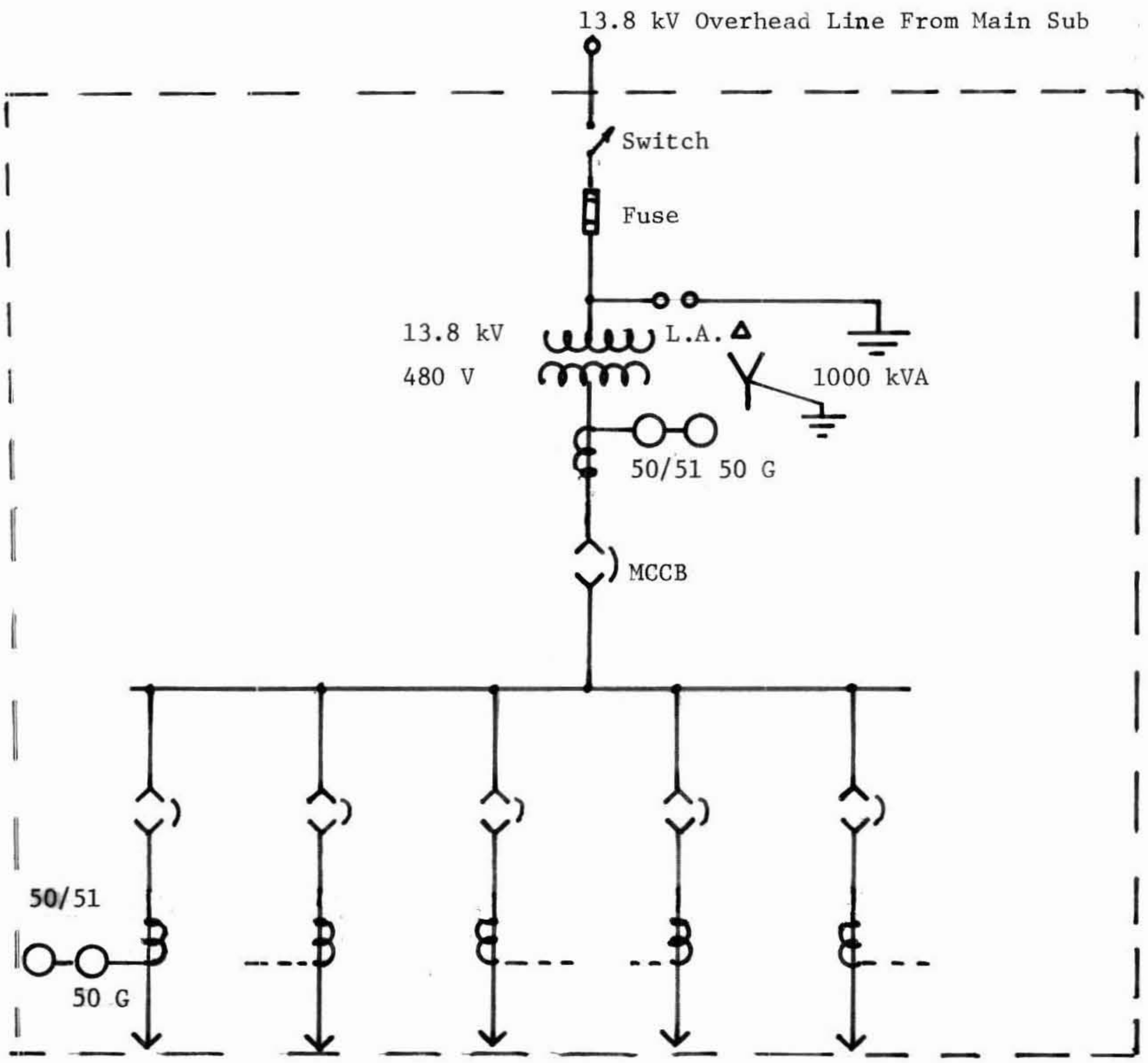


FIGURE 4.21.- Main substation.

FIGURE 4.22. - Static wire ground at pole base near sand dredge.



To 480 V Motor Control Centers
4/C Cables

FIGURE 4.23.- Plant substation.

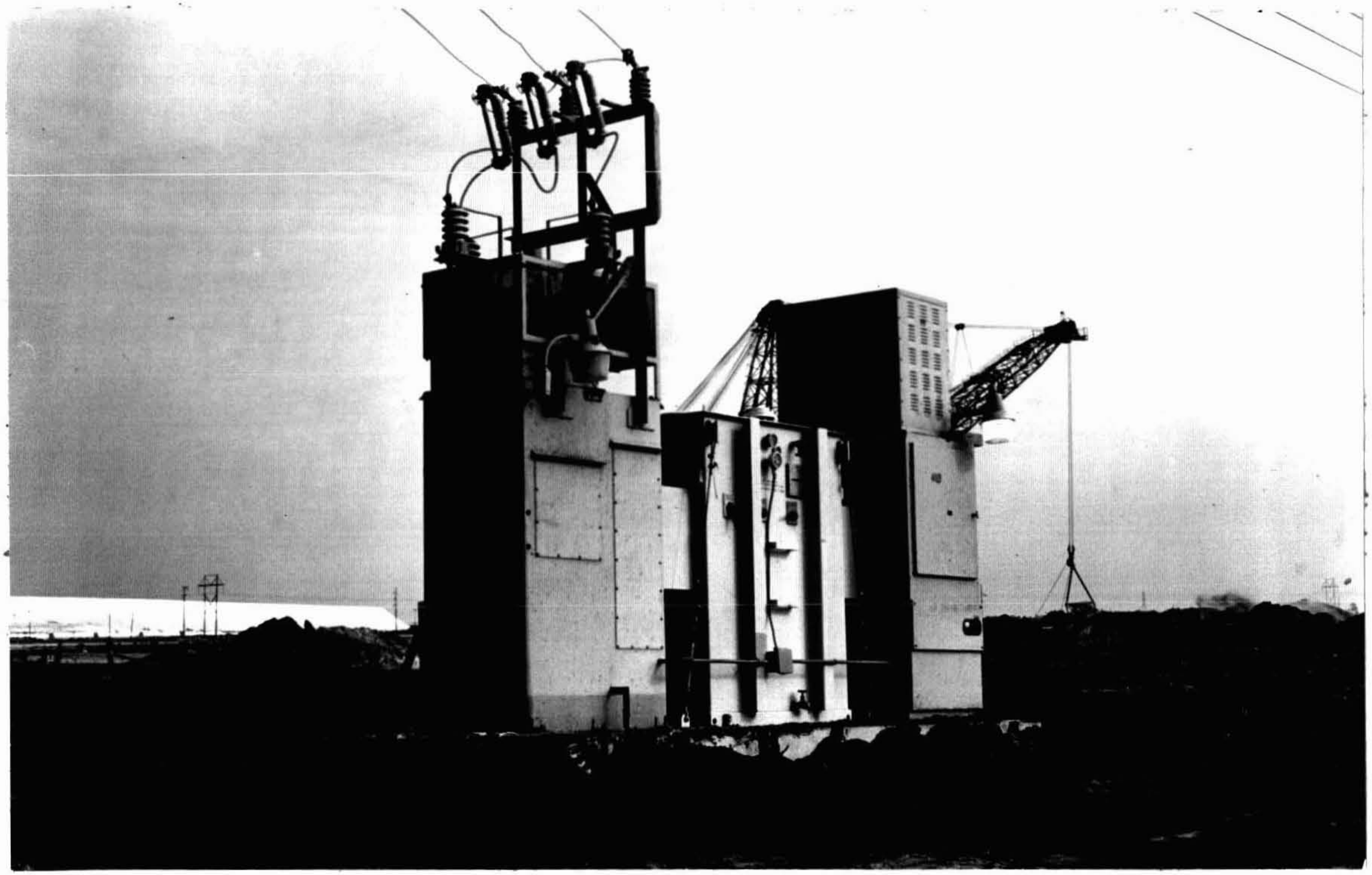


FIGURE 4.24. - Skid mounted substation at phosphate mine.

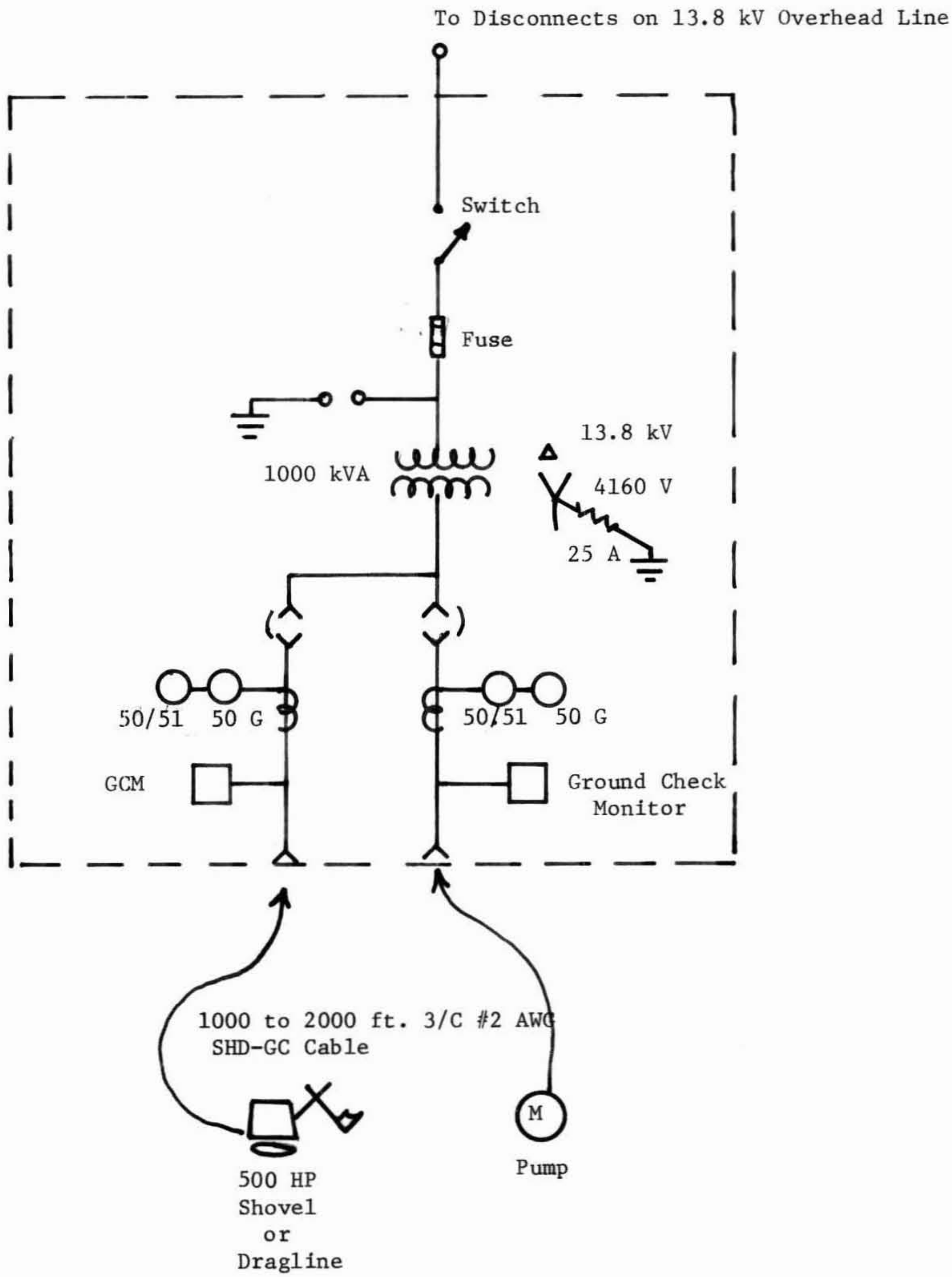


FIGURE 4.25. - Pit substation.

FIGURE 4.26. - 4160 cable coupler at surface phosphate mine.

4.3.3 Power System Model for Dredge Mine and Plant

Most dredging operations in the U. S. today utilize a single dredge, or at most two dredges, in conjunction with a processing plant to recover sand, gravel, or whatever valuable constituent is being mined. As a result, the power system diagram is fairly simple and relatively straightforward.

Figure 4.27 is an illustration of the main substation, owned by the electric utility company, which feeds the operation. The drawing shows a 33 kV primary feed which is stepped down to 2300 V via a delta-wye transformer with a resistance-grounded neutral. Some dredge mines operate from an ungrounded 2300 V system, and often power from the utility enters the property at the 2300 V level. In these cases, a zig-zag or grounding transformer can be used to derive a neutral point, as shown in Figure 4.28. Resistance grounding is recommended both to control transients and to limit fault current in the event of a phase-to-ground fault, especially one which occurs on the dredge, and is the configuration used in the model. A gang-operated switch, fuses, and lightning arrestors are installed on the primary side of the transformer for circuit protection.

A circuit breaker equipped with relays for tripping on ground fault and phase overcurrent (both time-delay and instantaneous) conditions is included on the outgoing 2300 V distribution, which extends to the processing plant and the shore of the dredge pond on 4-wire overhead lines. At the edge of the dredge pond, on the last utility pole, the overhead lines end at a pothead or other protected enclosure, where the marine trailing cable begins as shown in Figure 4.29. A ground check monitor is also included at this point to insure the integrity of the ground conductor which extends out to the dredge inside the cable. This cable is of the shielded type so that personnel will not be exposed to dangerous voltages if the cable insulation is damaged. Through the use of a 4-wire distribution system, both the dredge and the processing plant equipment are tied together by a metallic conductor and bonded to the substation ground mat.

A detailed diagram of the power system on the dredge is given in Figure 4.30. The suction dredge is equipped with a 350 hp motor driving a jet pump to produce a high-pressure water stream for breaking loose in-situ material beneath the surface of the dredge pond. This material is then drawn up by the suction pump through a large-diameter pipe and transported to shore via the pontoon-mounted pipeline. In this case the suction pump is driven by a 700 hp wound-rotor motor equipped with a "liquid controller" for speed adjustment. The "liquid-controller" is a tank filled with water and soda ash into which are placed three fixed and three movable grids, as shown in Figures 4.31 and 4.32. By varying the separation between the two sets of grids, the total resistance of the motor field circuit is adjusted to achieve speed control. Operators in hot humid climates have found that this method of control is much more compact and reliable than the more conventional system, which uses large banks of resistor grids switched into or out of the circuit by contactors. Both of these large motors are run at 2300 V, and include both phase overcurrent (instantaneous and time-delay) as well as ground-fault protective relaying. A small three-phase transformer mounted on the dredge steps down the 2300 V feed to 480 V for use by the remaining motors, which are fed through a motor control center (MCC). The transformer is connected delta-wye, and includes a resistance-grounded neutral to limit

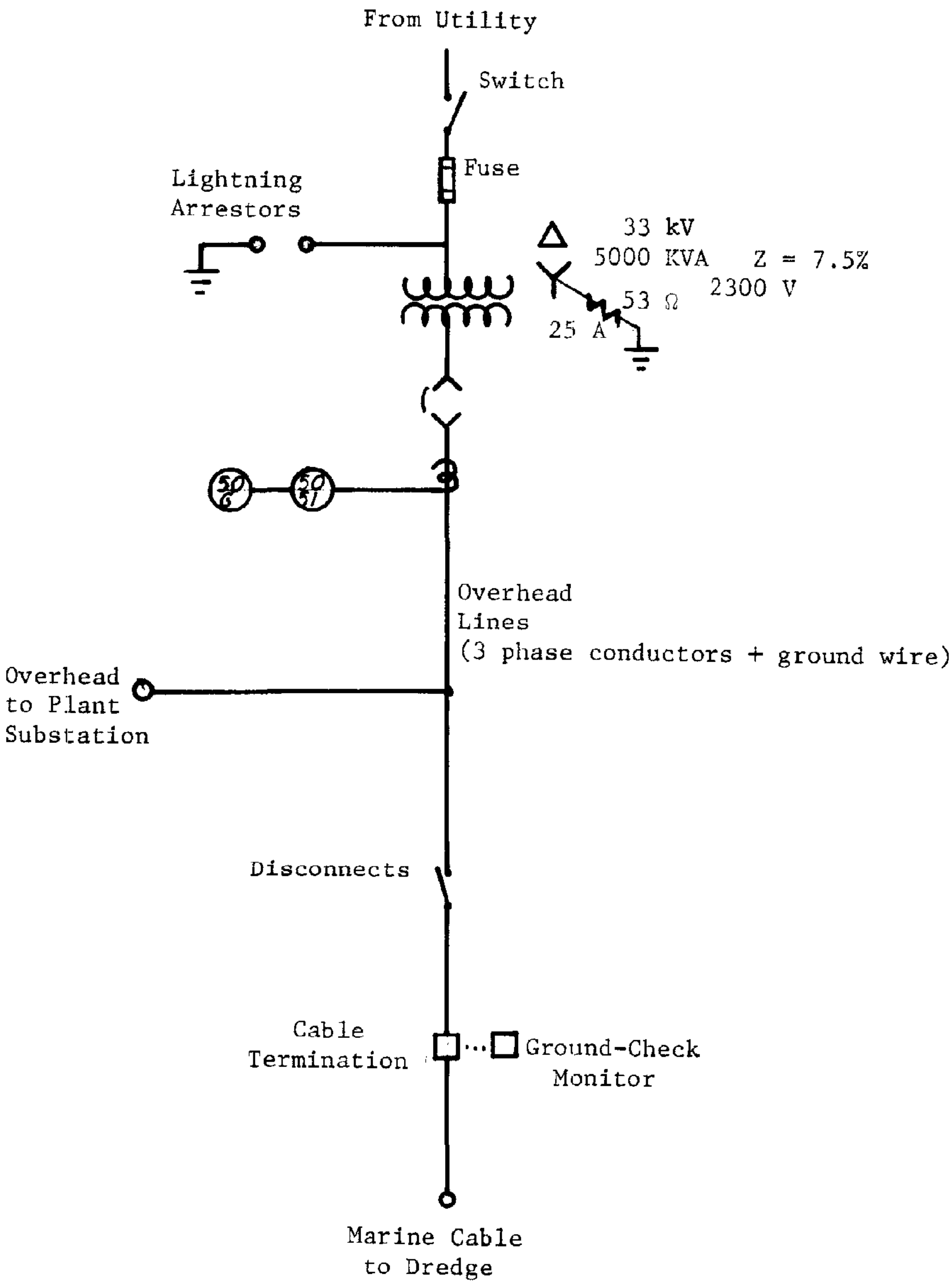


FIGURE 4.27. - One-line diagram of main substation.

FIGURE 4.28. - Zig-zag transformer at sand dredge.

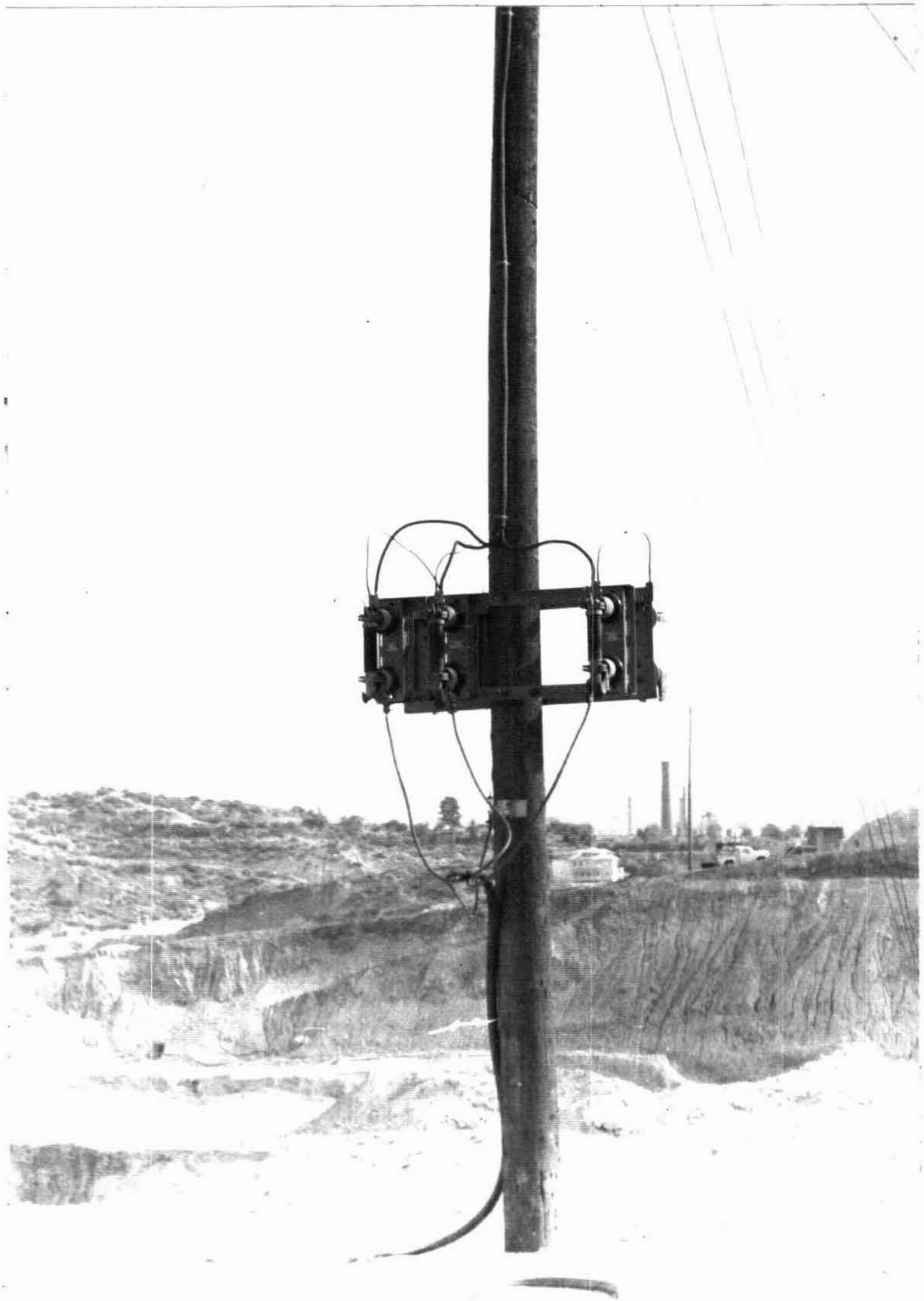


FIGURE 4.29. - Pothead at surface copper mine.

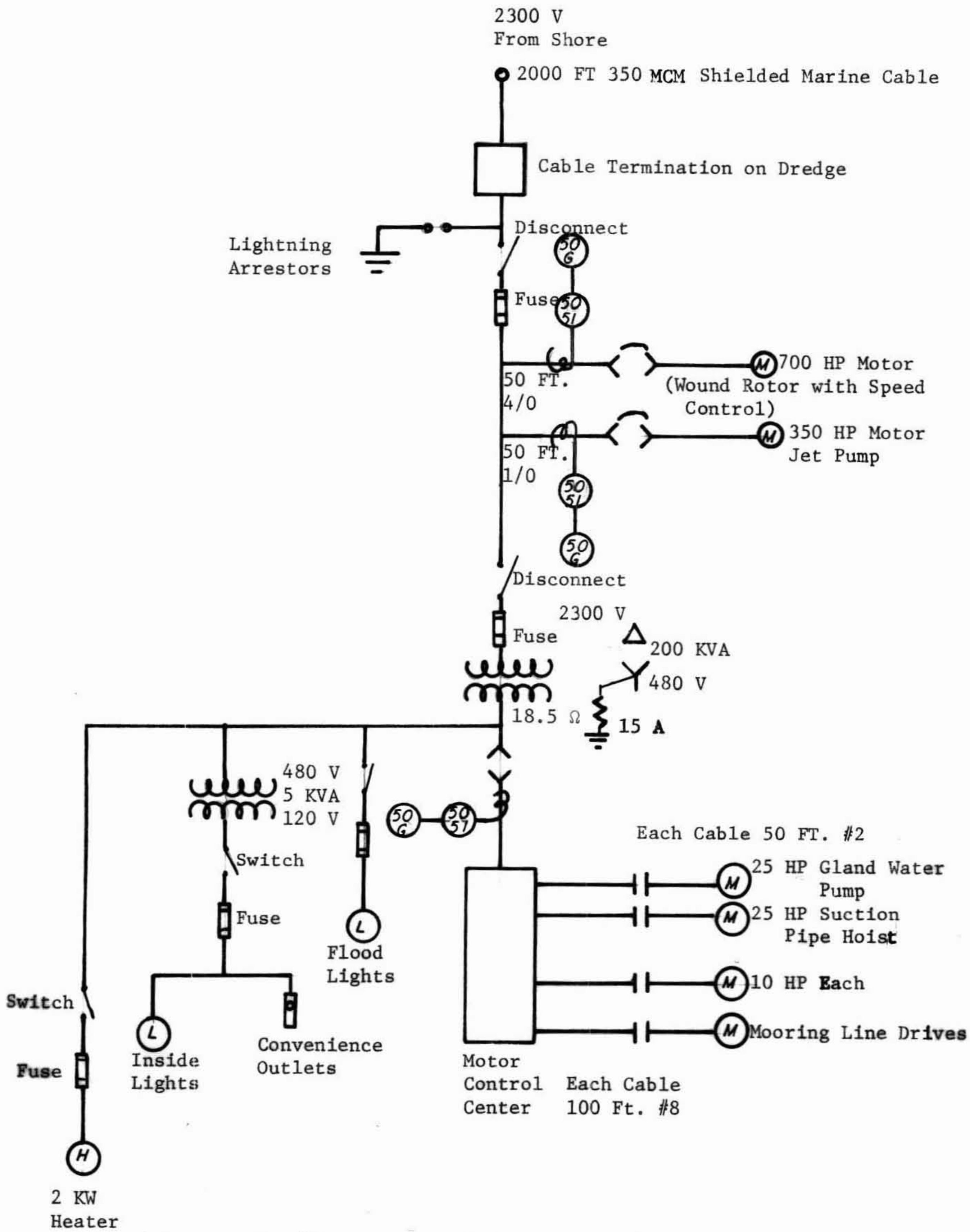


FIGURE 4.30. - One-line diagram of dredge power system.

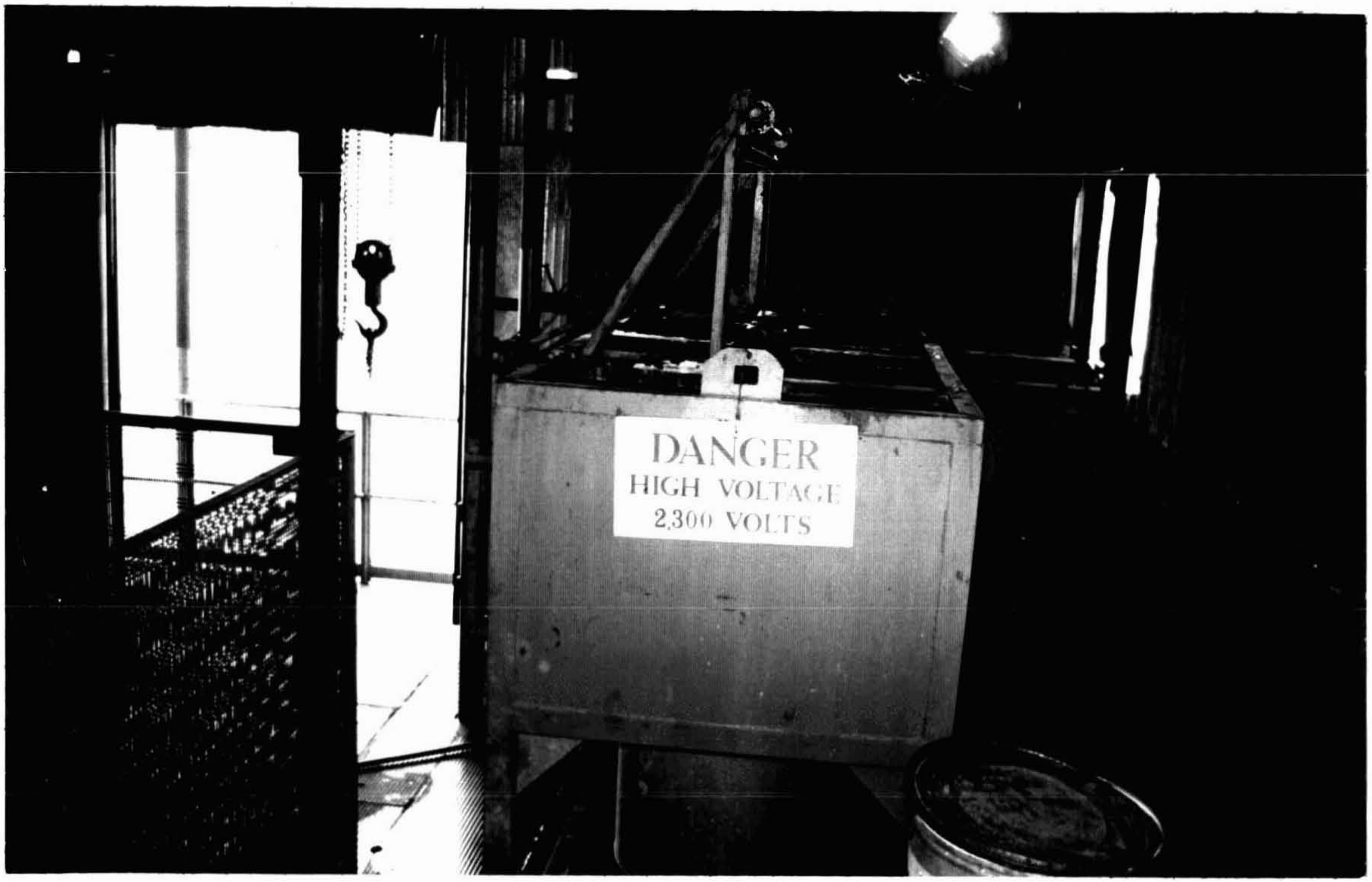


FIGURE 4.31. - "Liquid controller" at sand dredge.

FIGURE 4.32. - "Liquid controller" at sand dredge.

ground fault current to 15 A or less. Large flood-lights mounted on the exterior of the dredge for night-time operation are also powered at 480 V, and a small single-phase transformer provides several 120 V circuits for interior lighting and convenience outlets.

The processing plant wiring diagram is shown in Figure 4.33. The 4-wire overhead distribution at 2300 V is reduced to 480 V by a transformer connected delta-wye, with a solidly-grounded secondary. Several very large pump motors are fed by individual 480 V circuits, each of which is equipped with protective relaying, while the remaining motor loads are fed from a centrally-located motor control center. The main flood-lights are powered at 480 V, and a small transformer is included for convenience outlets and lighting loads. All 480 V motors are fed by a 4-wire distribution system (3 phase conductors plus a grounding conductor), with the ground bed at the plant substation connected to this grounding conductor and to the frames of all plant equipment. In turn, this ground mat is tied to the main substation ground bed (and therefore to the dredge) by the ground conductor (static wire) of the 2300 V overhead distribution.

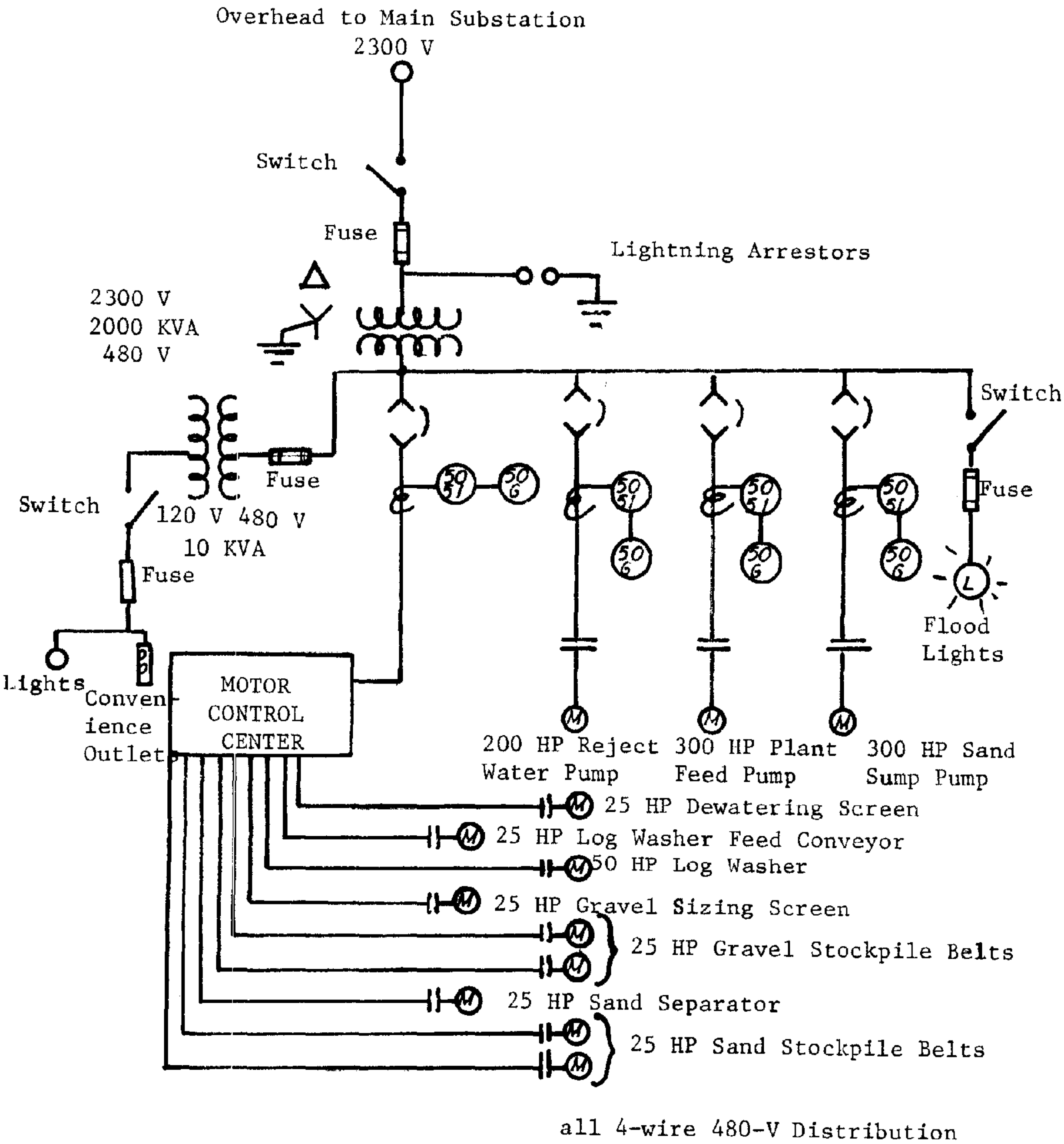


FIGURE 4.33. - One-Line diagram of Plant Power System.

CHAPTER V

COUNTERMEASURE BENEFIT ASSESSMENT

The principal objective of this section is to use the electrical accidents in metal/non-metal mines to develop a recommendation scheme to improve the safety of electrical power systems in those mines. All the electrical accident data for metal/non-metal mines as discussed in Chapter III were examined as to what could prevent or reduce the probability of occurrence. Since the principal objective of this study, as might be expected, is to reduce or eliminate the probability of occurrence of electrical accidents, a major effort was placed to develop a finite list of countermeasures which could conceivably prevent accidents due to the existence of electrical hazards or worker negligence.

5.1 COUNTERMEASURES OF EACH HAZARD AND NEGLIGENCE TYPE

All hazard and negligence categories were studied by several team members who independently prepared a list of countermeasures. Since there was significant overlapping of countermeasures, all lists were combined to a single set of 25 countermeasures. Table 5.1 shows the final list of 25 countermeasures which might eliminate or reduce the probability of occurrence of 405 electrical accidents studied.

5.2 ACCIDENTS AFFECTED BY THE COUNTERMEASURES

All 405 accidents which are classified under five major hazard types, and seven major negligence types were investigated by each member of the research team. Each member developed a matrix showing the number of accidents preventable by a high-effective implementation of the particular countermeasure specified. At initial attempt, some of the numbers varied between the members of the research team. Accidents were therefore discussed jointly to define the countermeasures more precisely. Table 5.1 shows the final description of 25 countermeasures. After repeated operations, each member of the research team came up with a number of accidents in each category that would be affected by each specified countermeasure with standard deviation within a comfortable range. Finally, these tables were averaged to a single table which was used to estimate the desired benefits of each countermeasure. Table 5.2 shows the average number of accidents under each hazard and negligence type that would be affected by each countermeasure. Table 5.3 shows the percentage of the number of accidents obtained by dividing the numbers in Table 5.2 by the sample size of 405 and multiplying by 100.

5.3 STUDY OF EACH ACCIDENT AND ITS POSSIBLE COUNTERMEASURES

In the second phase of the study of countermeasures, the hazard and negligence categories were ignored and all 405 electrical accidents in our sample were classified by all members of the research team as to what countermeasures could possibly prevent the accidents and their consequences. In this study major emphasis was placed on determining what caused the accidents rather than the severity of the consequences.

TABLE 5.1. - Detailed definitions of electrical accident countermeasures

1. GFI limited to 500 Vac or less; set at tripping level of 10 mA or less.
2. Use of existing protective gear, i.e. rubber blankets, gloves, hats, boots, hot sticks, tongs, safety glasses, etc., used in appropriate situations.
3. Implies a device which will remove power from the circuit whenever protective enclosures or covers are removed, thereby exposing live conductors; includes power centers, distribution boxes, and mining machinery.
4. Implies a device which would indicate: (1) whether a cable is energized or de-energized, or (2) whether a circuit breaker has tripped because of ground fault or phase overcurrent or short circuit.
5. Implies a routine, scheduled, 100% effective physical examination or electrical test on a circuit element or device, which is then removed from service or disconnected until repairs are made.
6. A deliberate connection of the transformer secondary to earth via a controlled-impedance path; this earth connection is carried to the frame of each piece of equipment; ground fault protection is assumed.
7. Indicates that a piece of equipment is approaching a high voltage line.
8. A device to monitor and indicate the status of the frame grounding conductor.
9. The power conductors are completely enclosed by a grounded metal conductor, except at junction boxes and the like.
10. Implies no bare conductors on any overhead transmission and distribution line EXCEPT trolley wire.
11. Indicates the use of switchgear or cable connector so constructed that it may be visually determined whether or not the circuit is connected.
12. Retrofit with fusible lightning arrestor.
13. Outer jacket of cable is color-coded or provided with distinguishing markings to allow differentation.
14. A voltage test must be made on any circuit which is presumed to be de-energized before any further work is attempted.
15. No cable may be repaired until it is disconnected at both ends.
16. Indicates the use of a circuit to prevent sustained arcs at the trolley shoe.

Table 5.1. - <u>Continued</u>

17. Switchgear, fuses, and enclosures are designed to retain their physical integrity under all conditions.

18. Eliminate the possibility of using electrical test equipment (VOM's) on incorrect function and range scales.

19. No work may be performed on live circuits unless full protective gear and procedures are used.

20. If a power system has no intentional grounds on the transformer, to add frame grounding of all equipment and ground-indicating lights on each phase.

21. Circuits equipped with power-factor-correction capacitors must also include bleeder resistors.

22. A tool must always be used for the specific job for which it was intended; tools used for electrical work must be adequately insulated.

23. Bare wires are properly placed and/or guarded to prevent accidental contact, this specifically includes trolley wires.

24. Insulate or ground truck beds, drill masts, crane booms, ladders, etc. Place mats at operating handles.

25. All splices must be vulcanized or better, to prevent exposed conductors or leakage.

5.4 BENEFIT MEASUREMENT PROCEDURE

How a countermeasure will benefit an industry is a difficult question to answer. An effort has been made to rank the countermeasures with respect to three criteria:

A. reduction in number of accidents.

B. reduction in number of days lost.

C. reduction in number of fatalities.

Obviously, in the first criterion we have ignored the severity of an accident, which is taken care of in the second criterion. In the third criterion, severity of an accident is heavily emphasized by ignoring non-fatal accidents. Which criterion should be used to make investment decisions on countermeasures will not be addressed in this report simply because there are several non-monetary intangibles that should be carefully looked at for selecting safety improvement countermeasures.

5.5 IMPACT OF NUMBER OF ACCIDENTS

Table 5.4 shows the detailed results of the impact of countermeasures on the accidents. The first major column represents the number of accidents that were classed as avoidable by a totally successful implementation of the proposed countermeasure. In order to be listed, an applicable countermeasure had to be identified by at least two members of the research team, independently. For example, out of 405 accidents, 117 accidents were identified by more than one member of the research team as ones that a ground fault interrupter (countermeasure 1) would have prevented.

The second column under the first major column represents the percentage of accidents that could have been avoided. The percentages were obtained by dividing by 405 and multiplying by 100. Notice that the sum of these percentages over the countermeasure is much higher than 100, primarily because many accidents could be avoided by more than one countermeasure. The third column of the first major column represents the relative rank which indicates that by fully implementing countermeasure 19 (no live circuit work) the largest number of accidents could have been avoided.

5.6 IMPACT OF NUMBER OF DAYS LOST

The second major column of Table 5.4 shows the number of work days lost for all 405 accidents. Notice that the days lost include all fatalities, each of which is equivalent of 6000 days lost. The second and third column of the second major column were obtained from the first column using similar approach as described to compute the first major column. The total number of days lost in the sample of 405 accidents were 176,801 days including 24 fatalities.

The rankings obtained out of days lost are different from the rankings obtained from the first criteria (number of accidents). For example, ground

TABLE 5.2. - Average number of accidents

Countermeasure	Hazards				
	H1	H2	H3	H4	H5
1. Ground Fault Interrupter (500 volts AC, 10 mA).	17.5	6.9	5	12.3	0.6
2. Use existing protective gear (gloves, nets, boots, glasses, hot sticks)	5.9	5.8	12.9	18.1	2.8
3. Interlocks	1.5	5.5	2.9	13.1	0
4. Self-indicating device, flags, monitors, etc.	1	16	1.8	10.8	0.5
5. Periodic testing or inspection	15.8	12	15.2	20	0.4
6. Resistance grounding	15.9	0.8	1.1	10.4	0
7. Proximity warning device	1	0.8	0.2	1.1	0
8. Ground check monitor	8.2	0	0	1	0
9. Shielded cable or conduit	3.8	0	10.8	7.1	0
10. No bare overhead transmission and distribution conductor except trolley wire	1.3	0	3	1.4	0
11. Visible disconnects, switchgear or cable connectors	0.2	8.2	0	1.1	0
12. Fused lightning arrester	2.2	0	0	0	0
13. Color-coded cables	0.6	3.1	0	0	0
14. Mandatory voltage test	1.6	14.9	1	2.9	0
15. Remove from service before cable repair	1.3	3.1	1.5	0.2	0
16. Trolley contact protection	0.4	0.6	0.4	2.5	0
17. Enclosure specification or switchgear interrupting capacity spec.	0.5	1.4	0	59.9	0
18. Improved VOM	0	1.4	0	4.4	1.8
19. No live circuit work	3.2	3.1	3.3	13.9	2.7
20. Ungrounded power supply with frame grounding	11.8	0.4	0.2	0	0
21. Bleed resistor	0	0.4	0	1.25	0
22. Correct tools, tool design, double insulated tools	1.5	0.1	1.9	2.7	1.7
23. Wire placement, guarding	5.8	1.4	11.7	4.4	0.5
24. Insulate or ground truck bed, ladders, rubber mats, wooden platform, etc.	2.1	0	0.8	0.8	0
25. Use of vulcanized splices	0	0	1.6	0.4	0

affected by the countermeasures.

Negligence									
N1	N2	N3	N4	N5	N6	N7	N8	N9	CM
30	4	2.2	6.1	2.5	20	4	1.4	0	1.
25.9	1.3	2.4	6	4	21	5.7	0	0	2.
52	5.4	2.6	1.2	1.4	20.3	2.4	0	0	3.
12.5	4.4	7.3	11	0	6.5	1.2	0	0	4.
1.8	0.2	0.4	0	0.5	0	0.8	0	0	5.
0	0	0	0	0.6	0.6	0	0	0	6.
0.8	0	0.4	0	9.5	0.8	0	0	0	7.
0.2	0	0	0	0.8	0.9	0	0	0	8.
2.7	0	0	0.3	5	1.6	1.4	0	0	9.
2	0.6	0	0	8	6.4	0.8	0	0	10.
1.4	1.3	2.6	0.5	0	0	0.2	0	0	11.
0	0	0	0	0	0	0	0	0	12.
0.6	0.6	1.6	0	0	0	0	0	0	13.
12.3	2.5	7.5	1	0	3.7	1.4	0	0	14.
3.1	2.6	1.8	0	0	0	0.2	0	0	15.
0	0	0	0	1.6	1.4	0.6	0	0	16.
4.3	0.6	0.2	0	0.4	0.6	1.1	5.4	0	17.
0	0	0	6.7	0	0	0	0	0	18.
58.1	4	0.4	5.1	1.5	31.4	4.6	0	0	19.
5.1	0.8	0	1	0.4	2.4	0	0	0	20.
0	0.2	0	0	0	0	0	0	0	21.
8.5	0.2	0.2	9.4	0.1	6.1	0.8	0	0	22.
3.8	0.4	0.8	0.2	10.5	9.8	1.4	0	0	23.
1	0.2	0.6	2	6	1.8	0.2	0	0	24.
0.8	0	0	0	0	0.4	0.4	0	0	25.

TABLE 5.3. - Percentages of accidents by

Countermeasure	Hazards				
	H1	H2	H3	H4	H5
1. Ground Fault Interrupter (500 volts AC, 10 mA).	4.3	1.7	1.2	3	0.2
2. Use existing protective gear (gloves, nets, boots, glasses, hot sticks)	1.5	2.1	3.2	4.5	0.7
3. Interlocks	0.4	1.4	0.7	3.2	0
4. Self-indicating device, flags, monitors, etc.	0.2	3.9	0.4	2.7	0.1
5. Periodic testing or inspection	3.9	2.9	3.7	4.9	0.1
6. Resistance grounding	3.9	0.2	0.3	2.7	0
7. Proximity warning device	0.2	0.2	0.1	0.3	0
8. Ground check monitor	2	0	0	0.2	0
9. Shielded cable or conduit	0.9	0	2.7	1.7	0
10. No bare overhead transmission and distribution conductor except trolley wire	0.3	0	0.7	0.3	0
11. Visible disconnects, switchgear or cable connectors	0.1	2	0	0.3	0
12. Fused lightning arrester	0.5	0	0	0	0
13. Color-coded cables	0.1	0.8	0	0	0
14. Mandatory voltage test	0.4	3.7	0.2	0.7	0
15. Remove from service before cable repair	0.3	0.8	0.4	0.1	0
16. Trolley contact protection	0.1	0.2	0.1	0	0
17. Enclosure specification or switchgear interrupting capacity spec.	0.1	0.4	0	14.7	0
18. Improved VOM	0	0.3	0	1.1	0.4
19. No live circuit work	0.8	0.8	0.8	3.4	0.7
20. Ungrounded power supply with frame grounding	2.9	0.1	0.1	0	0
21. Bleed resistor	0	0.1	0	0.3	0
22. Correct tools, tool design, double insulated tools	0.4	0.1	0.5	0.7	0.4
23. Wire placement, guarding	1.4	0.4	2.9	1.1	0.1
24. Insulate or ground truck bed, ladders, rubber mats, wooden platform, etc.	0.5	0	0.2	0.2	0
25. Use of vulcanized splices	0	0	0.4	0.1	0

countermeasures, hazards and negligences

Negligence									
N1	N2	N3	N4	N5	N6	N7	N8	N9	CM
7.4	1	0.5	1.5	0.6	4.9	1.0	0.3	0	1.
6.4	0.3	2.1	1.5	1	5.2	1.4	0	0	2.
12.8	1.3	0.6	0.3	0.3	5	0.6	0	0	3.
3.1	1.1	1.8	2.7	0	1.6	0.3	0	0	4.
0.4	0.1	0.1	0	0.1	0	0.2	0	0	5.
0	0	0	0	0.1	0.2	0	0	0	6.
0.2	0	0.1	0	2.3	0.2	0	0	0	7.
0.5	0	0	0	0.2	0.2	0	0	0	8.
0.7	0	0	0.1	1.2	0.4	0.3	0	0	9.
0.5	0.2	0	0	2	1.6	0.2	0	0	10.
0.3	0.3	0.6	0.1	0	0	0.1	0	0	11.
0	0	0	0	0	0	0	0	0	12.
0.1	0.1	0.4	0	0	0	0	0	0	13.
3	0.6	1.8	0.2	0	0.9	0.3	0	0	14.
0.7	0.6	0.4	0	0	0	0.1	0	0	15.
0	0	0	0	0.4	0.4	0.1	0	0	16.
1.1	0.1	0.1	0	0.1	0.2	0.3	1.3	0	17.
0	0	0	1.6	0	0	0	0	0	18.
14.3	1	0.1	1.3	0.4	7.7	1.1	0	0	19.
1.2	1.2	0	0.2	0.1	0.6	0	0	0	20.
0	0.1	0	0	0	0	0	0	0	21.
2.1	0.1	0.1	2.3	0	1.5	0.2	0	0	22.
0.9	0.1	0.2	0.1	2.6	2.2	0.3	0	0	23.
0.3	0.1	0.2	0.5	1.5	0.5	0.1	0	0	24.
0.2	0	0	0	0	0.1	0.1	0	0	25.

TABLE 5.4. - Impact of countermeasures on metal/non-metal mine accidents.

Countermeasures	Accidents that Might be Avoided			Days Lost that Might be Avoided			Lives that Might be Saved
	#	%	Rank	Days Lost	%	Rank	
1. Ground Fault Interrupter (500 volts AC, 10 mA).	117	29	2	66,909	38	1	10
2. Use existing protective gear (gloves, nets, boots, glasses, hot sticks)	89	22	3	32,009	18	7	3
3. Interlocks	89	22	3	36,237	20	6	5
4. Self-indicating device, flags, monitors, etc.	65	16	5	53,247	30	2	8
5. Periodic testing or inspection	50	12	7	11,146	6	16	1
6. Resistance grounding	23	6	13	18,928	11	9	3
7. Proximity warning device	14	3	15	24,375	14	8	4
8. Ground check monitor	11	3	17	12,503	7	13	2
9. Shielded cable or conduit	26	6	12	4,329	2	18	0
10. No bare overhead transmission and distribution conductor except trolley wire	32	8	11	53,180	30	2	8
11. Visible disconnects, switchgear or cable connectors	11	3	17	167	0	20	0
12. Fused lightning arrester	0	0	23	0	0	20	0
13. Color-coded cables	6	1	20	18,002	10	10	3
14. Mandatory voltage test	33	8	10	36,766	21	5	6
15. Remove from service before cable repair	6	1	20	12,056	7	13	2
16. Trolley contact protection	3	1	22	1	0	20	0
17. Enclosure specification or switchgear interrupting capacity spec.	56	14	6	929	1	19	0
18. Improved VOM	9	2	19	68	0	20	0
19. No live circuit work	122	30	1	47,622	27	4	6
20. Ungrounded power supply with frame grounding	17	4	14	12,268	7	13	2
21. Bleed resistor	0	0	23	0	0	20	0
22. Correct tools, tool design, double insulated tools	35	9	9	328	0	20	0
23. Wire placement, guarding	40	10	8	10,890	6	16	1
24. Insulate or ground truck bed, ladders, rubber mats, wooden platform, etc.	14	3	15	18,140	10	10	3
25. Use of vulcanized splices	0	0	23	0	10	10	0
Actual accident totals	405 accidents			176,801 days lost			24 fatalities

*Days lost includes fatalities and each fatality = 6000 days lost.

fault interrupter (countermeasure 1) was ranked no. 1 with respect to the number of days lost but it was ranked no. 2 with respect to the number of accidents.

5.7 IMPACT OF FATALITIES

The last major column in Table 5.4 represents the total number of lives that could be saved by the proposed countermeasures. Though the days lost column includes the lives lost (6000 days/life), it is important and interesting to look at the number of lives that could be saved by a proposed countermeasure. Note again, that the sum of the lives saved over the 25 countermeasures is not equal to the total number of fatalities (which is 24) because some fatal accidents could be avoided by more than one countermeasure.

CHAPTER VI

COUNTERMEASURE COST ASSESSMENT

The choice of which electrical accident countermeasures to implement depends at least partially on the cost to the industry of the countermeasure. A relative indication of costs has been generated by estimating the additional yearly cost to the mine operator to fully implement the countermeasure at his mine. This was done for each of the three model mines developed in Chapter IV. Each of the 25 countermeasures is taken in turn and its cost computed for each of the three model mines. It is assumed in these estimates that the mine is configured exactly as shown in the model of Chapter IV and that each countermeasure is the only one that is being implemented (i.e., no attempt has been made to estimate the cost of installing countermeasure A once countermeasure B has already been implemented on the power system).

6.1 COUNTERMEASURE #1 - GROUND FAULT INTERRUPTER

This countermeasure assumes that a sensitive GFI can be developed for all voltage levels less than 500 volts (ac), which will trip the controlling circuit breaker if a current imbalance of 10 mA or more is detected. Such a current imbalance would likely occur if a man were to contact an energized conductor, thereby diverting current through his body into the earth or into ground. On the underground hard-rock mine model, each 120 V and 480 V circuit would be equipped with a GFI mounted near the load. About 150 GFI units would be needed for the 120 V circuits and 975 480 V units would be required. Such units designed for use on 480 V circuits do not exist at present, and no attempt will be made to predict a development cost for such a unit. However, 120 V GFI units are available at about $50 each, and a purchase price of $250 will be assigned to the proposed 480 V GFI devices. Installation time for a 120 V GFI is estimated to be one hour, and two hours would be required for a 480 V GFI. Allowing a direct labor cost for an electrician of $12.50 per hour ($100/day), the total purchase and installation costs for the underground hard rock mine are:

A. Purchase cost for 120 V GFI = $50.00 each

B. Installation cost for 120 V GFI = $12.50 each

C. Total cost per 120 V GFI = $62.50

D. Purchase cost for 480 V GFI = $250.00 each

E. Installation cost for 480 V GFI = $25.00 each

F. Total cost per 480 V GFI = $275.00

G. Cost = $62.50 (150) + $275.00 (975) = $277,500.00.

Assuming that each GFI will last for 3 years, the annual cost of purchasing and installing these units is $\frac{\$277,500}{3} = \$92,500$. To this must be added a yearly maintenance cost, which will be zero for the 120 V GFI (defective units are simply replaced) and \$50.00 per year for each 480 V GFI. This amounts to \$50 (975) = \$48,750 per year in maintenance costs. Therefore,

H. Yearly cost of purchase and installation = \$92,500.00

I. Yearly maintenance cost = \$48,750.00

J. Annual cost at underground hard rock mine is: \$141,250.00

The dredge mine and plant would require 18 480 V, GFI units, at \$275.00 each for purchase and installation, and 10 120 V GFI units, at \$62.50 each for purchase and installation, or a total of 18 (\$275.00) + 10 (\$62.50 = \$5,575.00. Assuming a life of three years, this amounts to an annual cost of $\frac{\$5,575}{3}$ = \$1,858.33. Yearly maintenance is zero for the 120 V units and \$50.00 (18) = \$900.00 for the 480 V GFI's. So,

K. Annual cost at dredge mine and plant = \$1,858.33 + 900.00 = \$2,758.33

At the surface mine, most of the 480 V and 120 V circuits will be utilized in the plant, with very few being found in the mine, other than a few lighting circuits on shovels and draglines, and perhaps some small 480 V pumps for pit water removal. We will not consider the plant here. Estimated mine usage is 12 480 V units and 20 120 V units. Total cost for acquisition and installation is 12 (\$275.00) + 20 (\$62.50) = \$4,550.00 and with a projected life of three years this results in a cost of $\frac{\$4,550.00}{3}$ = \$1,516.67 per year. An additional cost for maintenance on the 480 V units amounts to 12 (\$50.00) = \$600.00 per year. Thus,

L. Annual cost at surface mine = \$600.00 + 1,516.67 = \$2,116.67

6.2 COUNTERMEASURE #2 - USE OF EXISTING PROTECTIVE GEAR

Proper use of existing protective gear is a countermeasure which should not cost the company anything. Apparently the main problem is getting mine personnel into the habit of actually utilizing the appropriate items of safety equipment when they are needed. With this in mind, it is possible for the company to actually make money on this countermeasure through the institution and enforcement of a system of fines. That is, if a worker is injured on the job, and an accident investigation reveals that one or more pieces of requisite safety gear were not used, then a monetary fine would be assessed and the amount deducted from the worker's next pay check. Some dredge operations which were visited enforced a policy whereby all workers either on the dredge or in a boat on the dredge pond had to wear a life jacket or face immediate dismissal. Obviously, the system of violations and fines would have to be carefully implemented, and all employees made aware of its implications. Cost = 0.00.

6.3 COUNTERMEASURE #3 - ELECTRICAL INTERLOCKS

An interlock system would consist, in its simplest form, of microswitches mounted inside each switchgear enclosure, wired so that they would trip any circuit breaker housed inside that enclosure. Of course, the line side of any circuit breakers inside the enclosure would still be energized, so that there would still be some live connections inside the box. A microswitch and the associated circuitry required to trip a circuit breaker could be purchased for about \$100.00. It should be noted that in some cases it may be necessary for a single microswitch to actuate a number of circuit breakers, which could add to circuit cost. For the underground hard rock model, about 1400 of these units would be required. Estimated installation time is one hour each, with actual time being shorter for enclosures containing a single circuit breaker, and longer than one hour for boxes with several breakers.

Total cost is:

A. Cost of purchase for microswitch unit = \$100.00 each

B. Cost of installation = <u>\$12.50 each</u>

C. Total per unit cost = \$112.50 each

D. Cost = \$112.50 (1,400) = \$157,500.00

Assuming that such a system would last for three years, the annual cost is

E. Annual cost for underground hard rock model mine = $\frac{\$157,500}{3}$ = $\underline{\underline{\$52,500.00}}$

Because the unit price is low, any defective unit would be replaced and no repairs or maintenance would be expected.

The dredge mine and plant would require about 25 of the microswitch interlock devices, at a total cost for purchase and installation of \$112.50 (25) = \$2,812.50. With a projected life of three years and no maintenance charges, the annual cost is:

F. Annual cost for dredge mine and plant = $\frac{\$2,812.50}{3}$ = $\underline{\underline{\$937.50}}$

The surface mine requires 25 of the interlock systems, which amounts to 25 (\$112.50) = \$2,812.50 for purchase and installation. Again, assuming no maintenance costs, and a life of three years:

G. Annual cost for surface mine = $\frac{\$2,812.50}{3}$ = $\underline{\underline{\$937.50}}$

6.4 COUNTERMEASURE #4 - SELF-INDICATING DEVICES

This countermeasure implies a device which would indicate 1) whether a cable is energized or deenergized by a change in its surface color, or 2) whether a circuit breaker has tripped because of ground fault, short circuit, or overcurrent.

At the present time it is impossible to buy cables which will change color when energized, and it is doubtful whether this could be done using presently available technology. Circuit breakers can be purchased which will indicate ground-fault tripping, although their cost is higher than that of a non-indicating unit. If it were possible to buy a 480 V molded-case circuit breaker which was equipped with lights or flags to indicate which tripping mode has been actuated (ground fault, short circuit, or over current), then it would probably cost about twice as much as the standard unit which is in use today. A 600 V circuit breaker rated at 225 A costs about $300 today, so we will assume a purchase price of $600 each for a self-indicating device. This represents a price differential of $300 per unit, or $60 per year per breaker if a five year lifetime is anticipated. No added installation costs are assessed because the new breakers will be installed on a replacement basis. For the high-voltage oil circuit breakers, the estimated cost of adding the self-indicating features is $2,000 per device, and a 10-year life will be assumed, making the annual cost about $200 per breaker.

The underground hard-rock mine requires 975 of the 480 V units and 5 of the high-voltage devices, for a total annual cost of:

975 ($60.00) + 5 ($200.00) = <u>$59,500.00</u>

The surface mine utilizes eleven high-voltage devices and 40 of the 480 V units (on board the dragline, shovels, and drills), for a total annual cost of:

40 ($60.00) + 11 ($200.00) = <u>$4,600.00</u>

Three high-voltage devices and 17 480 V units are required by the dredge mine and plant, for a total annual cost of:

3 ($200.00) + 17 ($60.00) = <u>$1,620.00</u>.

6.5 COUNTERMEASURE #5 - PERIODIC TESTING

Here is another example of a no-cost countermeasure. Electricians should perform this type of work routinely, while walking to and from the face area, and as a part of their preventive maintenance schedule. Quoting from Title 30, CFR:

" 55
56 12-29. Electric equipment and wiring should be inspected
57
by a competent person as often as necessary to assure safe operating conditions".

Mine electricians should be trained not to think that they "have nothing to do" simply because all the electrically-powered machinery on the section is running. Management must inculcate in these people an attitude of viligance and awareness, so that they become accustomed to performing the full range of tasks which should properly fall within their scope of work. As with item #3 (use of protective gear), perhaps a system of fines levied by the company could provide an incentive. That is, if an inspection by federal officials reveals that a circuit breaker on the section power center is not functioning, and the electrician had not indicated to his foreman that he was aware of this problem, then it could be assumed that, in fact, the electrician knew nothing about it because he hadn't checked. The electrician could then be fined for non-performance of his job. Annual cost = $0.00.

6.6 COUNTERMEASURE #6 - RESISTANCE GROUNDING

The costs for implementing this countermeasure were calculated by assuming that the initial system was ungrounded. The equipment which must be purchased and installed includes: A safety ground bed at each substation; a ground conductor which extends from the safety ground bed to the frame of each piece of powered apparatus (the ampacity of the ground conductor is equal to one half the ampacity of the phase conductor, and in no case smaller than #12 AWG); a zig-zag transformer which is used to derive a neutral point on systems using delta-connected secondaries; a neutral grounding resistor which connects between the safety ground bed and the neutral point; a potential transformer and relay which monitors the voltage across the neutral grounding resistor and trips a circuit breaker in the event of a ground fault.

Once the cable lengths and sizes are determined for the grounding conductors, it is assumed that one man can install 500 feet of cable in an eight hour shift, and is paid $100.00 per day, or $12.50 per hour. At the same wage rate it is assumed that two man days are required to install each combination of zig-zag transformer, grounding resistor, and potential transformer that is required for the power system. The cost of establishing a 5 ohm safety ground bed can vary widely because the physical size (and expense) of the bed is directly proportional to the soil resistivity. An average figure of $10,000 per ground bed, including all parts and labor, will be used. For the purposes of obtaining annual costs of resistance grounding for each of the three mine models, it will be assumed that the total grounding system has a useful life of twenty years with no additional maintenance or component replacement costs. Based on these assumptions the combined annual purchase and installation costs of resistance grounding for the three model mines are given below.

6.6.1 Underground Hard Rock Mine Resistance Ground - Added Cost Calculations

A. Grounding conductor = $\frac{1}{2}$ ampacity of a single phase conductor and in no case less than #12 AWG.

CABLE LENGTH AND SIZE	PRICE/FOOT		TOTAL PRICE
2000 ft. (350 MCM) → 2/0	$1.3935	ALL THW	$ 2,787.00
4000 ft. (4/0) → #1	$0.911	600 V	$ 3,644.00
94,000 ft. (2/0) → #4	$0.44175	Single	$41,524.50
35,500 ft. (#2) → #6	$0.29155	Conductor	$10,350.02
24,000 ft. (#10) → #12	$0.09185	Insulated	$ 2,204.40
25,500 ft. (#12) → #12	$0.09185		$ 2,342.18
185,000 ft.			$62,852.10

Installation Cost: $\frac{185,000}{500} \times \$100 = \$37,000.00$

B. Accessory equipment (for each power transformer secondary) zig-zag transformers:

13 - 480 V (500, 3000 kVA)	13 x $366.00 =	$4,758.00
1 - 2300 V (2000 kVA) 2 - 4160 V (5000, 8000 kVA)	3 x $2841.00 =	$8,523.00
		$13,281.00

Resistors:

13 - 480 V @ 15 A	13 x $95.00	$ 1,235.00
1 - 2300 V @ 25 A	$1,342.00	$ 1,342.00
2 - 4160 V @ 25 A	2 x $1342.00	$ 2,684.00
		$ 5,261.00

Potential transformers and relays:

13 - 480 V	13 x $168.00	$ 2,184.00
1 - 2300 V	1 x $322.00	$ 322.00
2 - 4160 V	2 x $438.00	$ 876.00
		$ 3,382.00

Installation for secondary equipment:

16 x 2 x $100 $ 3,200.00

C. Ground Beds

4 beds x $10,000 ea. = $40,000.00

Total annual cost of resistance grounding (20 year service life) $ 8,248.10

6.6.2 Dredge Mine and Plant Resistance Grounding - Added Cost Calculations

A.	CABLE LENGTH & SIZE	PRICE PER FOOT		TOTAL PRICE
Dredge	2500 ft. 2/0 → #4	$1.3935	ALL THW	$ 3,483.75
	100 ft. (#2) → #6	$0.29155	600 V	$ 29.16
	200 ft. (#8) →#10	$0.1384	Single	$ 27.68
	300 ft. (#12) → #12	$0.09185	Conductor Insulated	$ 27.56
Plant	700 ft. (#2) → #6	$0.29155		$ 204.09
	300 ft. (#8) → #10	$0.1384		$ 41.52
	800 ft. (#10) → #12	$0.09185		$ 73.48
	4900 ft.			$ 3,887.23

Installation: $\frac{4900}{500}$ x $100.00 = $ 980.00

B. Accessory equipment (for each power transformer secondary) zig-zag transformers:

1 - 2300 V		\$ 2,841.00
2 - 480 V	2 x \$366.00	\$ 732.00
		\$ 3,573.00

Resistors:

1 - 2300 V @ 25 A		\$ 1,342.00
2 - 480 V @ 15 A	2x \$95.00	\$ 190.00
		\$ 1,532.00

Potential transformers and relays:

1 - 2300 V		\$ 322.00
2 - 480 V	2 x \$168.00	\$ 334.00
		\$ 658.00

Installation costs: 3 x 2 x \$100 — \$ 600.00

C. Ground Beds

2 - beds @ \$10,000 each — \$20,000.00

Total annual cost of resistance grounding (20 year service life) — \$ 1,561.51

6.6.3 Surface Mine Resistance Grounding - Added Cost Calculations

A. CABLE LENGTH & SIZE	PRICE PER FOOT		TOTAL PRICE
		ALL THW	
13,500 ft. 2/0 → #4	\$1.3935	600 V	\$18,812.25
10,000 ft (#2) → #6	\$0.29155	Single	\$ 2,915.50
23,500 ft.		Conductor	\$21,727.75
		Insulated	

Installation: $\frac{23,500}{500}$ x \$100 — \$ 4,700.00

B. Accessory equipment (for each power transformer secondary) zig-zag transformers:

1 - 13.8 kV		\$ 3,500.00
4 - 4160 V	4 x 2841.00	\$11,364.00
		\$14,864.00

Resistors:

1 - 13.8 kV @ 50 A		\$ 1,342.00
4 - 4160 V @ 25 A	4 x 11342.00	\$ 5,368.00
		\$ 6,710.00

Potential Transforemrs and relays:

1 - 13.8 kV		\$ 560.00
4 - 4160 V	4 x \$438.00	\$ 1,752.00
		\$ 2,312.00

Installation: 5 x 2 x \$100 — \$ 1,000.00

C. Ground Beds

2 beds @ \$10,000.00 each — \$20,000.00

Total annual cost of resistance grounding (20 year service life) — \$ 3,565.69

6.7 COUNTERMEASURE #7 - PROXIMITY WARNING DEVICE

A proximity warning device would be placed on the boom of each dragline, shovel, and crane; on the mast of each drilling rig, and on the uppermost portion of the dump bed on every dump truck to give the operator of such equipment a warning that his machine is approaching a high voltage line (this is closely related to countermeasure #24). Several of these devices are either being designed or built, and Southwest Research Institute is presently studying them under a USBM Contract. It seems reasonable to assume that at least two of the devices should be installed on each piece of equipment to provide a significant degree of protection. The cost of each detector will be estimated at \$1200.00 (including installation) with a three year life and maintenance costs of \$100.00 per year, for battery replacement. Thus, the annual cost for a single unit is $\frac{\$1200.00}{3} + \$100.00 = \$500.00$, or \$1000.00 for each piece of equipment to be protected. (Two detectors per machine).

The underground hard rock model mine will have one crane and a front-end loader for supply handling and outside work, requiring 4 detectors.

A. Annual cost for underground hard rock mine = 4 (\$500.00) = \$2000.00

The dredge mine and plant will have the same two pieces of applicable equipment as the underground mine - a front-end loader and a crane, so the cost will be identical.

B. Annual cost for dredge mine and plant = \$2000.00

The surface mine model uses an extensive array of machines which must be protected: 4 loading shovels, 2 drills, 28 trucks, 2 cranes, and one front end loader, or a total of 37 units of equipment. Seventy-four detectors are required.

C. Annual cost for surface mine and plant = 74 (\$500.00) = \$37,000.00.

6.8 COUNTERMEASURE #8 - GROUND CHECK MONITOR

This countermeasure requires that each piece of portable or mobile equipment which is supplied with electric power via a "trailing cable" must have a ground-check monitor to continuously test the continuity of the ground conductor.

A home-made ground check monitor (designed and built by mine personnel) can be constructed and installed at a cost of $500.00 per unit. Commercially available units can be purchased and installed for about $1000.00 each, so the $1000.00 price will be used in the following cost figures.

The surface mine model uses four shovels, two drills, and is also equipped to handle two pumps, for a total of 8 pieces of portable and mobile machinery. This amounts to 8 ($1000.00) = $8000.00 initial cost. Assuming a life of three years and no salvage value:

A. Annual cost for model surface mine = $\frac{\$8000.00}{3} = \underline{\underline{\$2666.67}}$.

The dredge mine and plant will have a single dredge fed via marine cable, and perhaps a portable pump, so a total of two ground check-monitors, at $1000.00 each, will be required. If the components last for three years with no salvage value:

B. Annual cost for model dredge mine and plant = $\frac{\$2000.00}{3} = \underline{\underline{\$666.67}}$.

The underground hard rock mine has no mobile or portable equipment as such. The slushers are moved periodically, perhaps 6 times a year, and our grounding guidelines specify that, if a ground check monitor is not used, then the continuity of the grounding conductor must be checked both before and after the machine is moved, and at least once per year. If ground check monitors were installed on each slusher, the cost would be 55 ($1000.00) = $55,000.00 for initial purchase and installation. Assuming no salvage value and a useful life of three years:

C. Annual cost for underground hard-rock mine = $\frac{\$55,000}{3} = \underline{\underline{\$18,333.33}}$.

6.9 COUNTERMEASURE #9 - SHIELDED CABLE OR CONDUIT

In this case, all cables would have to be either enclosed in conduit or shielded. One shielding method, as in type SHD cable, utilizes a braided-wire shield around each individual phase conductor, while another approach is to use a single shield around all the other conductors, with the shield being physically adjacent to the outer jacket of the cable.

In essence, instituting this countermeasure would require the replacement of all medium-and low-voltage wiring in the mines, except that which is already routed through grounded conduit. It is here assumed that cable replacement would be done on the basis of attrition; i.e., a non-shielded cable would be replaced by a shielded cable only when the in-situ cable failed or wore out. A crash program would NOT be instituted to completely re-wire the mine and throw away tremendous amounts of non-shielded cable. Therefore, no additional installation costs are assessed since the cables are being installed only on an as-needed basis. The additional purchase cost is calculated by subtracting the price of a standard non-shielded cable from the equivalent-sized shielded cable price, except that #6 shielded cable was substituted for all sizes less than or equal to #6, since shielded cables in those smaller sizes could not be found. Many of the presently-available cables have a dual 600 V/2 kV rating, and these types are used here; cable life in each case is estimated at 20 years.

For the underground model mine, the total lengths and sizes of cable required are approximately 90,000 ft. of 2/0; 35,500 ft. of #2 AWG; 24,000 ft. of #10 AWG; and 25,500 ft. of #12 AWG. The total price differential for all of this cable, remembering that the #10 AWG and #12 AWG unshielded sizes are replaced by #6 AWG, is $221,781.60. With a life of 20 years, the annual cost for underground model mine = $\frac{\$221,781.60}{20} = \underline{\underline{\$11,089.08}}$.

For the dredge mine and plant, costs are rather low. The majority of dredges in this country are powered at 2300 V which is fed to the dredge via shielded high-voltage marine cable, so no changes are required there. In addition, most motor wiring on the dredge itself is carried in conduit, so the cost impact is again zero. Typical dredge plants are small and contain relatively few motors. The estimated cable lengths are: 700 ft. of #2 AWG; 300 ft. of #8 AWG; and 800 ft. of #10 AWG. The total price differential for replacing these cables with shielded types is $3246.20. Dividing this figure by an estimated cable life of 20 years, annual cost for dredge mine and plant = $\underline{\underline{\$162.31}}$.

The surface mine uses mostly 4160 V trailing cables, which are already shielded. In addition, just about all the 480 V and 120 V wiring on the draglines, shovels, and drills is carried in conduit, so this countermeasure has no cost impact here. Cost = $\underline{\underline{\$0.00}}$.

6.10 COUNTERMEASURE #10-INSULATE ALL OVERHEAD POWER CONDUCTORS

Since a number of metal/non-metal mine fatalities occur when metallic structures touch bare overhead power lines, insulating these conductors should help to reduce or eliminate these deaths. Our information shows that the cost to erect an insulated overhead line is about 4 times the cost of building an uninsulated system with wooden support structures. The cost differential, therefore, is about $39.00 per foot for a 13 kV line and $30.00 per foot for a 2300 V line. Assuming a life of 25 years for such structures, the additional annual costs are $1.56 per foot-year for 13 kV lines and $1.20 per foot-year for 2300 V lines.

Underground hard-rock mine: This facility utilizes 4000 feet of 13.8 kV overhead lines, so the extra yearly cost is 4000 ($1.56) = $\underline{\underline{\$6240.00}}$.

Dredge mine and plant: About 1500 feet of overhead 2300 V lines are used in this operation, for an added annual cost of 1500 ($1.20) = $\underline{\underline{\$1800.00}}$.

Surface mine: This operation requires 13,000 feet of overhead 13.8 kV line, which means an extra annual cost of 13,000 ($1.56) = $20,280.00.

6.11 COUNTERMEASURE #11 - VISIBLE DISCONNECTS

A subcommittee of the IEEE Mining Industry Committee is presently studying the portion of Title 30, Code of Federal Regulations, which deals with electricity. An issue which arouses considerable controversy surrounds the definition and use of "visible disconnects". The law states:

"55 }
56 } 12-6 Mandatory. Distribution boxes shall be provided with a
57 }
disconnecting device for each branch circuit. Such disconnecting devices shall be equipped or designed in such a manner that it can be determined by visual observation when such a device is open and that the circuit is deenergized, and the distribution box shall be labeled to show which circuit each device controls."

There are several points of contention. First, if the disconnecting device has clearly-labelled "ON" and "OFF" positions, is this sufficient, or must one be able to physically see that the contacts have opened? At present, "safety-view" circuit breakers are available on the market (480 V), but they are not UL-approved, and the viewing window clouds up after several tripping operations. Second, what is a "branch circuit"? If the cable leaving a junction box is the same size as that which enters the box, then it should be viewed as a continuation of the same cable. If several cables leave the junction box which are smaller than the incoming feeder, then these are definitely branch circuits. It appears that MSHA inspectors are presently allowing cable connectors to be interpreted as "visible disconnects". That is, if the power is turned off at the box (via a switch or circuit breaker) and the cable connector unplugged, this will meet the spirit of the law. To buy and install a 480 V receptable and plug costs about $500.00, or $50.00 per year assuming a 10 year life; a high-voltage unit will run about 4 times as much, or $200.00 per year.

The underground hard rock mine requires 975 of the 480 V couplers and 5 high-voltage couplers, for a total annual cost of 975 ($50.00) + 5 ($200.00) = $49,750.00.

The dredge mine and plant requires just six of the 480 V couplers, for a total annual cost of 6 ($50.00) = $300.00.

The surface mines will utilize 11 high-voltage couplers, costing a total of 11 ($200.00) = $2200.00 per year.

6.12 COUNTERMEASURE #12 - RETROFIT WITH FUSIBLE LIGHTNING ARRESTORS

The cheapest way to install "fusible" lightning arrestors is to add the fuse in series with an already-existing arrestor installation. Assuming that arrestors are mounted on every third pole of the overhead distribution lines, and that the poles are 100 feet apart, this means 1 set of three arrestors (one per phase) for every 300 feet of pole line. The added cost for buying and installing the fuses is about $120.00 per set of 3, and a life of 10 years will be postulated. This brings the resulting added annual cost to $12.00 per year per set of three fuses.

Underground mine: With 4,000 feet of overhead line, 14 sets of fuses are required, for an extra cost of 14 ($12.00) = $168.00.

Dredge mine and plant: In this case only 1500 feet of overhead line is used, necessitating 5 sets of fuses. This yields an added annual cost of 5 ($12.00) = $60.00.

Surface mine: For a total length of 13,000 feet of overhead line, 44 sets of fuses are needed, bringing the added yearly cost to 44 ($12.00) = $528.00.

6.13 COUNTERMEASURE #13 - COLOR CODED CABLES

At the present time it is not possible to buy electrical cables in a wide variety of colors. Certain manufacturers do produce a limited number of cables in a choice of colors, but they do not recommend them for mining use because dirt and abrasion quickly obliterate or wear off the colored portion of the insulating outer jacket, and differentation by color is then difficult or impossible. Furthermore, color coded cables are a special order item which must be purchased in minimum quantities of at least 5000 ft. with a four to six month delivery time. The insulating outer jacket is usually black, or occassionally white. The easiest way to achieve cable differentiation is to place tags on the outby end of each trailing cable where it connects to the power source. Before electrical work was started on a piece of equipment, or before cables splices were attempted, it would be required that the electrician trace the power cable back to the power source, ascertain from the tag that he had followed the correct cable, and the deenergize, disconnect, and "tag" the cable so that no one else would re-connect it in his absence. Inexpensive metal or plastic tags could be fabricated in the shop, or purchased locally, and installed by the electricians as a part of their normal maintenance routine until all pertinent cables were so equipped. The cost would be nominal, and essentially zero. Cost = $0.00.

6.14 COUNTERMEASURE #14 - MANDATORY VOLTAGE TEST

Once more, this countermeasure doesn't cost a dime. Whenever electrical work is done, the electrician should, if possible, first deenergize the circuit by opening a switch or tripping a circuit breaker. The circuit should then be locked out and tagged so nobody can reenergize it while work is being performed. Then, before commencing with the trouble-shooting procedure, the electrician should take out his meter and use it to verify that power has in fact been removed from the circuitry in question, as proven by a reading of zero volts on his meter. This technique can easily be learned and its application is straight-forward. It is without price, but of much value. Cost = $0.00.

6.15 COUNTERMEASURE #15 - REMOVE CABLE FROM SERVICE TO REPAIR

This countermeasure implies that a cable be disconnected at both ends before any attempts are made to splice or repair it, although it would appear to be perfectly adequate to only require that the cable be disconnected at the line end. There is at present no legal requirement for mine personnel to physically disconnect trailing cables from their power source before repairs are attempted, although this practice is standard operating procedure in some mines. The cost of instituting such a procedure is negligible, and has considerable merit. Cost = $0.00.

6.16 COUNTERMEASURE #16 - TROLLEY CONTACT PROTECTION

The goal of this countermeasure is to prevent sustained arcs at the trolley shoe. If the shoe or harp does bounce off the trolley wire while current is being drawn by the load, then an arc will result. The magnitude and severity of the arc will be proportional to the current demand of the load and the trolley voltage. Proper installation of the trolley wire, proper track installation, and prudent "driving" habits by operators of trolley-powered equipment will minimize the instances of trolley shoes bouncing off the trolley wire. Arcs which occur when the trolley harp or shoe initially is placed into contact with the trolley wire can be eliminated by placing the machine's operating handle in the "off" or center "neutral" position. This can be assured by wiring a microswitch and dc relay into the control circuit so that any loss of power will necessitate a return of the controller to the neutral position. Total purchase and installation cost will be about $50.00, and an extended lifetime of 20 years can be expected. This results in an added annual cost of $2.50 per year per installation. For the model underground mine, approximately 40 trolley-powered vehicles are used, making the total yearly cost of this countermeasure $2.50 (40) = $100.00. The dredge mine and surface mine have no trolley.

6.17 COUNTERMEASURE #17 - ENCLOSURE SPECIFICATIONS

This is not really an area where a precise dollar figure can be assigned to the countermeasure. If an engineering analysis is done by competent personnel, switchgear with appropriate interruption capacity and enclosures of adequate robustness will be specified as a matter of routine. Problems arise in several areas:

A. components of inadequate ratings are installed because of ignorance on the part of the installer.

B. inadequate components are knowingly installed on a "temporary" basis because of expedience, i.e. the correct part is unavailable or is so far away that production would be delayed excessively while waiting for it.

C. components such as circuit breakers or switches are deliberately or repeatedly closed-in on short circuits or other high-stress conditions.

If closing-in on a fault is thought to be a part of normal operating practice, then perhaps circuit breakers should be derated by some additional factor to account for this abuse. This would require a major change in component rating specifications, at a marked increase in cost.

However, it is felt that proper specification of component ratings by a qualified individual (perhaps an electrical engineer) in conjunction with an understanding and respect for equipment usage on the part of mine personnel, will obviate the need for more robust design criteria. Cost = $0.00.

6.18 COUNTERMEASURE #18 - IMPROVED VOM

Many electrical accidents occur when electricians are trouble-shooting defective equipment with their meters. Sometimes the meters are connected improperly or mistakenly set on the wrong range or function (i.e., "ohms" instead of "volts"). If this is done, the meter may explode, arc, or burn, and injuries to personnel often result. A solution to this problem would be to replace existing meters (typically a Simpson 260 VOM or the like) with a more rugged and expensive instrument equipped with auto-ranging and auto-function capabilites. Such an instrument can be purchased for about $190.00, while a Simpson 260 goes for around $130.00. Thus, a price differential of $60.00 per instrument is seen. In the hazardous environments found in most mines, the life of such a piece of precision electronic apparatus can be estimated at 3 years, with zero salvage value. Therefore, the added yearly cost per electrician (one meter to each electrician) is $\frac{\$190.00-\$160.00}{3}$ = $10.00.

The underground hard rock model mine employs 21 electricians, so annual cost at underground hard rock model mine = 21 ($10.00) = $210.00.

The dredge mine and plant, which employs only a single electrician, must pay a total annual cost of $10.00.

The model surface mine and plant employs 4 electricians, so this annual cost is 4 ($10.00) = $40.00.

6.19 COUNTERMEASURE #19 - NO LIVE CIRCUIT WORK

This countermeasure was cited more often than any other. In many cases, an electrician was shocked when his hand or test probes slipped while he was working on an energized circuit. It appears that there are instances when the power was presumed to be off, but was actually on, due to pulling the wrong circuit breaker or cable coupler. At times the deenergizing devices were activated but did not respond properly. However, human error was the primary cause for most of these accidents.

A lot of electrical trouble-shooting and maintenance work can be done with the circuitry deenergized, if properly trained personnel are available. An outside contractor can put on a good training course which will teach proper procedures to mine electricians, and will charge about $1000 per week per individual. The classes should last about 4 weeks, bringing the cost to

$4000 per electrician. In addition, the company must continue to pay the miner his wages, amounting to about $500 per week, or $2000 for the duration of the 4-week course.

The model hard rock mine will employ 21 electricians - 12 on day shift, 6 on afternoon shift, and 3 on midnight shift, since the facility operates around the clock. The costs of this countermeasure can then be summarized as follows:

A. cost of training course = $ 4,000 per miner
B. cost of wages = $ 2,000 per miner
C. total cost $ 6,000 per individual
D. for work force on 21 electricians at the model hard rock mine, cost = $126,000.

Since this training is not required every year, assume that because of employee turnover, this cost can be spread over 5 years. Then,

E. annual cost at model underground hard rock mine

$$\frac{\$126,000}{5} = \underline{\underline{\$25,200.00}}$$

The dredge mine and plant will have one electrician per shift of operation, or a total of one (the facility only runs during daylight). Thus the total cost would be $6,000 per individual in terms of wages and price of the training course, or $6000.00 for the single electrician. Again assuming a 5 year turnover or retraining period,

F. annual cost at model dredge mine and plant

$$\frac{\$6,000}{5} = \underline{\underline{\$1200.00}}$$

The model surface mine will employ four electricians, two for each of the two working shifts. Difficult or complex tasks such as erection of overhead lines can be handled by the two men working together. Total cost for the training course and wages is $6,000 per electrician or $24,000 for the whole crew. Annual cost, assuming a five-year turnover period, is

G. annual cost at model surface mine

$$\frac{\$24,000}{5} = \underline{\underline{\$4800.00}}$$

It should be noted, in conjunction with this discussion of "live circuit work", that Federal laws exist which require equipment to be deenergized before mechanical work is performed: or, if live work is performed, hot-line tools must be used.

"55 }
56 } 12-16. Mandatory. Electrically-powered equipment shall be
57 }

denenergized before mechanical work is done on such equipment. Power switches shall be locked out or other measures taken which shall prevent the equipment from being energized without the knowledge of the individuals working on it. Suitable warning notices shall be posted at the power switch and signed by the individuals who are to do the work. Such locks or preventive devices shall be removed only by the persons who installed them or by authorized personnel."

"55 }
56 } 12-17. Mandatory. Power circuits shall be deenergized before
57 }
work is done on such circuits unless hot-line tools are used. Suitable warning signs shall be posted by the individuals who are to do the work. Switches shall be locked out or other measures taken which shall prevent the power circuits from being energized without the knowledge of the individuals working on them. Such locks, signs, or preventative devices shall be removed only by the person who installed them or by authorized personnel."

Therefore, electricians should already know that "hot-line tools" and protective equipment are required when working on energized equipment. They should, as a matter of routine, deenergize, lock out, and tag any electrically-powered equipment upon which they plan to work, unless they intend to work on it "hot".

6.20 COUNTERMEASURE #20 - FRAME GROUNDING WITH UNGROUNDED POWER SUPPLY

Costs for this countermeasure can be easily derived by considering the costs of the resistance-grounded system calculated previously. The costs of zig-zag transformers, potential transformers, relays, and neutral grounding resistors are omitted, but the price for purchase and installation of ground-indicating lights on each phase must be added. It is estimated that it would cost $500.00 to buy and install a single (three-phase) set of ground-indicating lights with their associated circuitry for a 480 V installation, and $1500.00 to apply the same type of devices to a high-voltage 3-phase line. If the life of such equipment is 5 years, then the annual cost is $100.00 for a low voltage installation and $300.00 for a high-voltage installation. A ground bed will cost $10,000 to install (on the average) and should last for 20 years before the buried metal is destroyed by corrosion. Its annual cost is therefore $500.00. The added cable costs are taken directly from the section on resistance grounding, and a life of 15 years is postulated for all cables.

For the underground hard rock mine, the annual costs are

$\frac{\$62,852.10}{15}$ for cables, 4 ($500.00) for ground beds, and 4 ($300.00) for ground-indicating lights, or a total annual cost of $7390.14.

The surface mine utilizes 2 ground beds @ $500.00, 2 sets of ground-indicating lights @ $300.00; the cable costs amount to $\frac{\$21,727.75}{15}$, for a total annual cost of $3048.52.

The dredge mine and plant requires cable costing $\frac{\$3887.22}{15}$, 2 ground beds at \$500.00 per year, and one set each of high-voltage and low-voltage ground-indicating lights, or \$400.00 per year, yielding a total annual cost of \$1659.15.

6.21 COUNTERMEASURE #21 - INSTALL BLEEDER RESISTORS

The use of bleeder resistors will be limited to installations where power-factor-correction capacitors are used, i.e., in substations. The resistors will serve to bleed off any charge which might remain in the capacitors when power demand is low or nil. The cost to buy and install appropriate resistors is about \$300.00 per unit; with an approximate life of 15 years, the extra yearly cost per set is \$20.00.

Underground mine: There are 3 major surface substations at this mine, so the added annual cost is 3 (\$20.00) = \$60.00.

Dredge mine and plant: This operation utilizes 2 substations, thereby requiring an additional outlay of funds amounting to 2 (\$20.00) = \$40.00.

Surface mine: This facility also has 2 surface substations, so the cost per year of this countermeasure will be 2 (\$20.00) = \$40.00.

6.22 COUNTERMEASURE #22 - CORRECT TOOLS

Some miners attempt to perform their tasks with tools which are totally inadequate or appropriate for the job. Electricians most often come to grief when using tools with un-insulated handles. While putting some piece of apparatus back together, the tool may slip from its working position and contact an energized conductor, shocking the electrician. Assuming that proper training will convince the miner to use the correct tool for each specific job, then the remainder of the countermeasure boils down to the cost of providing each electrician with insulated tools. For the underground hard rock model mine, 21 electricians are employed, and the approximate price differential between normal tools and a set of specially-insulated tools is \$30.00. Therefore the costs are:

A. price differential per set of specially-insulated tools = \$30.00

B. for work force of 21 electricians,

total cost = \$30.00 (21) = \$630.00

Realistically, it should be remembered that tools are routinely lost, stolen, or broken in a mining environment, and the company management can expect to replace the entire set of tools within a two-year period. Therefore, the yearly cost of implementing this countermeasure is:

C. annual cost for underground hard rock model mine = $\frac{\$630.00}{2}$ = \$315.00

For the dredge mine and plant which employs a single electrician, the annual cost will be 1/2 the price differential between a typical set of tools and the specially-insulated variety, or

D. annual cost for dredge mine and plant = $\frac{\$30.00}{2}$ = $\underline{\underline{\$15.00}}$.

For the surface mine and plant, four tool sets are needed, one for each electrician, and replacement every second year is assumed. Therefore,

E. annual cost for surface mine and plant = $\frac{4(\$30.00)}{2}$ = $\underline{\underline{\$60.00}}$.

6.23 COUNTERMEASURE #23 - WIRE PLACEMENT OR GUARDING

This countermeasure can be implemented at essentially zero cost. Wire placement is important to electricians working on electrical equipment, who may accidentally come into contact with energized conductors, either directly (with some part of their body) or indirectly (using a tool or test equipment lead). Such energized-equipment work should be undertaken only via the use of "hot line tools"; otherwise, the power should be turned off. Switchgear could easily be coded, by color or otherwise, so that the "hot" side of all switches, fuses, circuit breakers, etc., was clearly identified. When miners are working near live bare conductors, trolley wires, and the like, "hot line tools" or guarding should be utilized, as is made clear in the applicable Federal regulations:

"55, 56, 57 } 12-66 Mandatory. Where metallic tools or equipment can come in contact with trolley wires or bare powerlines, the lines shall be guarded or deenergized."

"57.12-80 Mandatory. Trolley wires and bare power conductors shall be guarded at man-trip loading and unloading points, and at shaft stations. Where such trolley wires and bare power conductors are less than 7 feet above the rail, they shall be guarded at all points where men work or pass regularly beneath."

The only added cost of implementing this countermeasure, e.g., by spray-painting in a red color the hot or line side of all switchgear, can be easily performed by electricians during service and maintenance work, and is estimated to be $100 for several cases of red spray paint. Cost = $\underline{\underline{\$100.00}}$.

6.24 COUNTERMEASURE #24 - INSULATED EQUIPMENT

Implementing this countermeasure involves two items. First, insulating the boarding ladders, steps, hand rails, and door handles of all surface equipment such as draglines, shovels, drills, cranes, front-end loaders, and dump trucks, so that an operator does not contact the metal frame of the machine and the earth (ground) simultaneously. Second, all rubber-tired equipment listed above should be equipped with a heavy chain bonded to the frame which drags on the ground and can serve as a low-resistance path for electric current. The cost to buy and install the insuating material and grounding chains is about $300.00 per machine for parts and labor. These items would have to be replaced yearly because of heavy wear. Equipment not using rubber tires requires no grounding chain, and total cost is $225.00 each.

The underground mine model uses a front-end loader and a crane, so

A. annual cost for underground mine = 2 ($300.00) = $600.00.

The dredge mine and plant utilizes the identical two pieces of equipment, and the cost is the same.

B. annual cost for dredge mine and plant = 2 ($300.00) = $600.00.

The surface mine uses 31 pieces of rubber-tired equipment, and 6 machines whose metal frames rest directly on the earth.

C. annual cost for surface mine and plant = 31 ($300.00) + 6 ($225.00) = $10,650.00.

6.25 COUNTERMEASURE #25 - USE VULCANIZED SPLICES

Most surface mines today make use of vulcanized splices exclusively for the repair of trailing cables. In general, a damaged cable is removed from service and taken to a central shop or repair facility for splicing, while a replacement cable is substituted in its place. Underground mines use a variety of splice kits (available commercially) to repair damaged cables underground. These splice kits are rated as yielding "permanent splices" and are therefore equivalent (legally) to a vulcanized splice. Thus it is felt that there is no need to institute this particular countermeasure, and its cost is $0.00.

6.26 SUMMARY OF COUNTERMEASURE COSTS

A graphical summary of costs for the 25 countermeasures is presented in figures 6.1, 6.2, and 6.3. These bar graphs for each model mine operation are drawn to illustrate the annual cost per thousand tons of ore mined that will result from implementation of each countermeasure. The data plotted are derived from the annual cost figures presented in the preceding paragraphs and the following estimated annual production figures for the three model mines.

TABLE 6.1. - Estimated production of model mines

Type of mine	Estimated Annual Production
Underground Hard Rock	6 million tons
Dredge Mine	4 million tons
Surface Mine	4.5 million tons

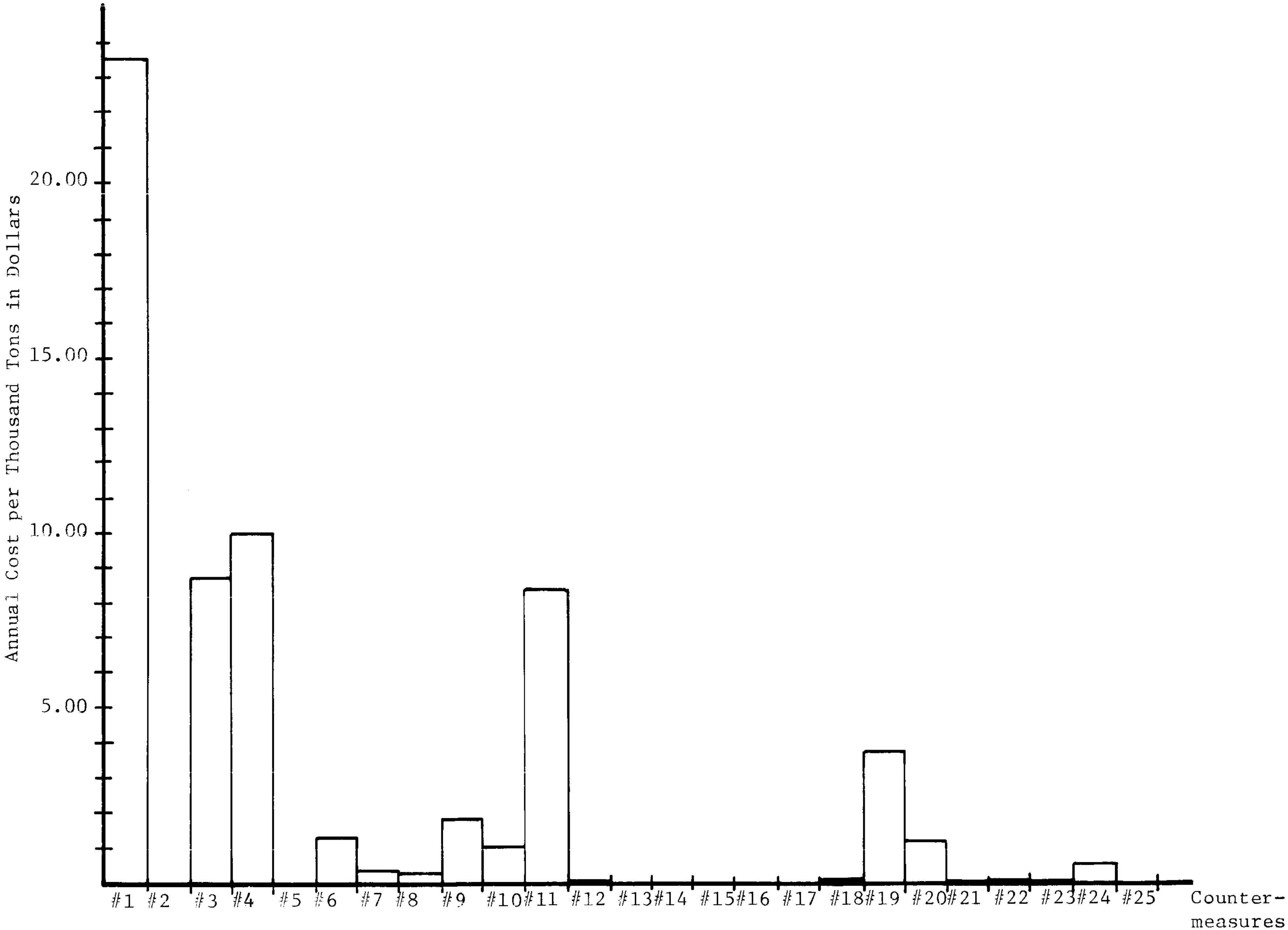


FIGURE 6.1. - Underground hard rock mine.

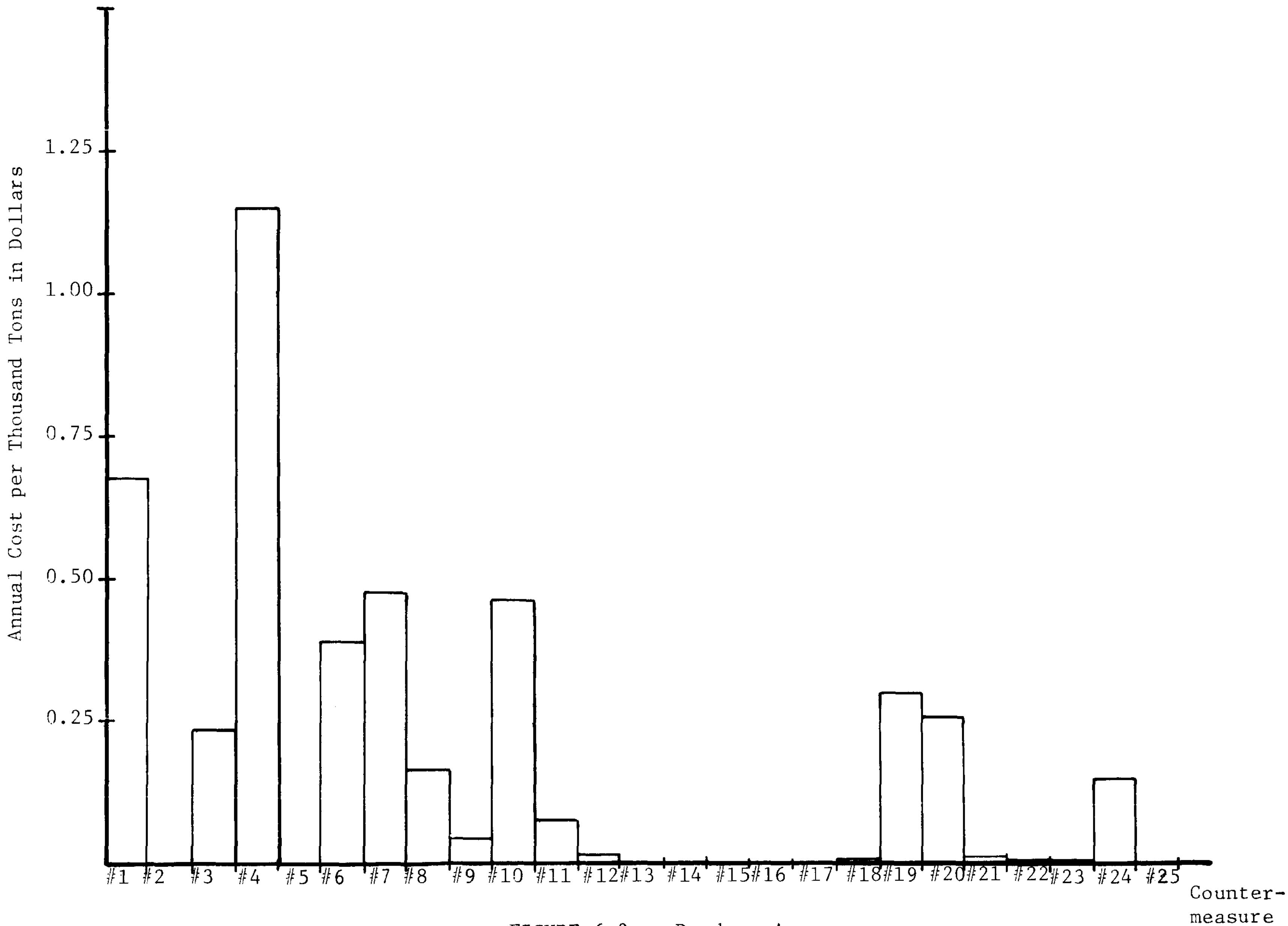


FIGURE 6.2. - Dredge mine.

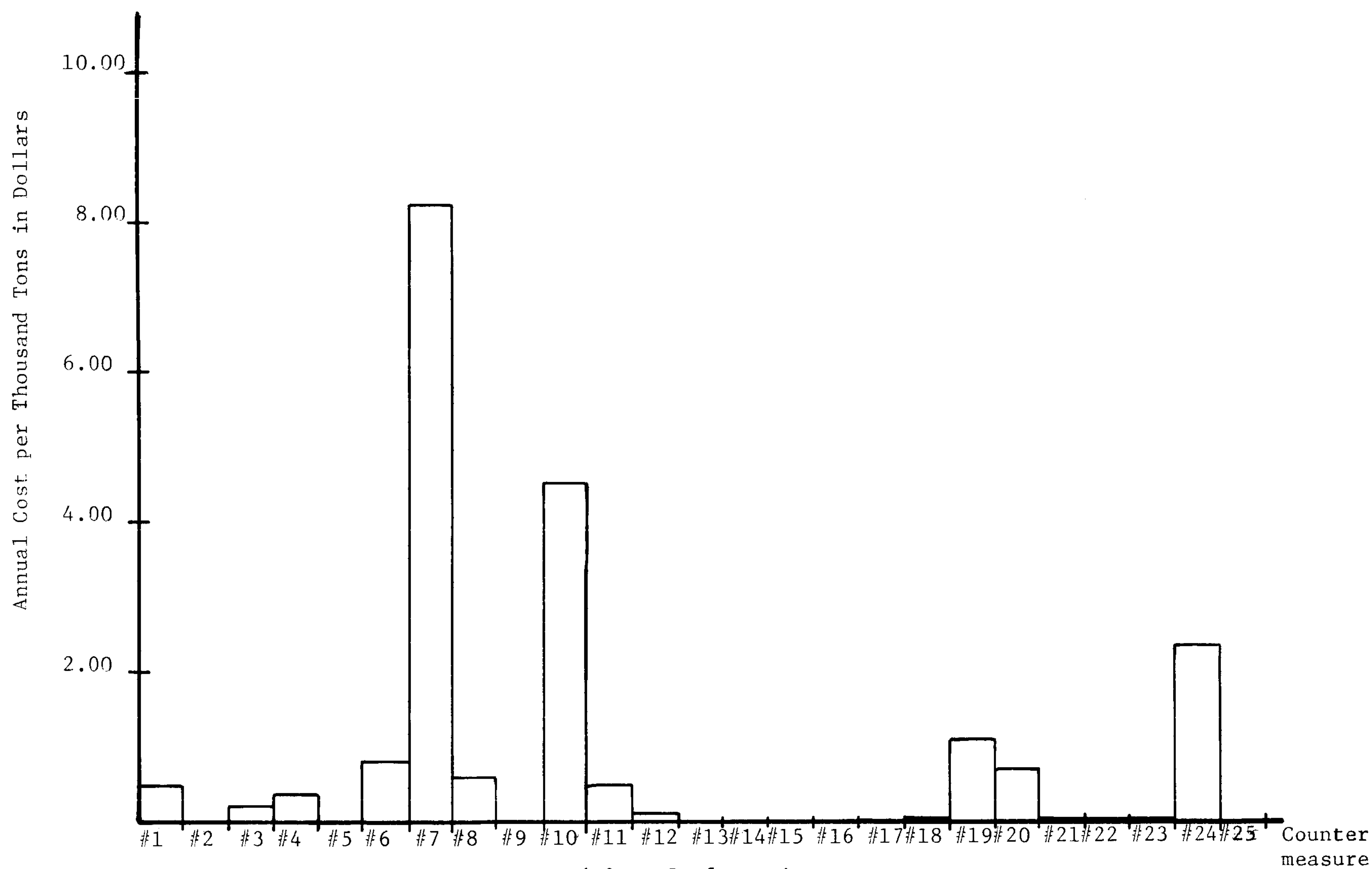


FIGURE 6.3. - Surface mine.

The primary value of these three bar graphs is in providing a rapid visual comparison of the relative costs of the various countermeasures for a given type of mining operation (i.e. deep mine, dredge, surface mine). The cost information for any particular countermeasure of interest can be quickly identified and then used in conjunction with corresponding information in chapter V to make careful cost-benefit comparisons.

CHAPTER VII

BENEFIT-COST FIGURES

As part of the process of estimating the safety and economic impacts of various electrical accident countermeasures, data has been obtained and processed to provide the background information contained in Chapters V and VI. Chapter V discusses in considerable detail the expected safety benefits of 100% compliance with the intent of the 25 countermeasures identified. Chapter VI provides even more detail on the methods used to estimate the average annual cost of each countermeasure to the operators of the three "model" mines developed as part of the study.

7.1 ACCURACY OF BENEFIT FIGURES

As discussed in Chapter V, the method used to determine the expected benefits of certain accident countermeasures was derived from actual mine accident data. This approach is probably the most accurate of several possible methods, but two particualr aspects of the analysis lead to some uncertainty in the results. One serious problem was the lack of complete and accurate data concerning accidents. MSHA requires that the mine operator report each accident on a one-page form, which is the only information available on the accident unless it is serious enough to be investigated by MSHA. Persons filling out these forms have apparently received no training for this task, and the results leave much to be desired. The data is very often incomplete, and MSHA apparently makes no attempt to see that missing data is obtained. In addition, the open-ended accident description that is called for is nearly useless. It is almost always used by those who fill out the form as a way to disassociate the company or the injured persons from any responsibility in the accident, rather than to try to give a clear picture of what actually happened. Not once did we ever see information indicating that the company was not in 100% compliance with MSHA regulations.

Besides this serious bias in the accident reporting procedure, estimating benefits requires some assumption about the effectiveness of various counter-measures. It is unlikely that a particular countermeasure will eliminate all accidents of a certain type. In fact, some of the countermeasures (c.f., #19, no live circuit work) are already required by law. If this countermeasure were truly 100% effective, then our data would show no accidents related to it. Such is not the case-in fact, it ranks first as a correlate of electrical accidents. Despite this complicating factor, it was assumed that all countermeasures could be implemented with total effectiveness, thus over-estimating their benefit by an unknown amount.

Because of these weaknesses in the analysis any absolute benefit estimate has questionable validity. Since the data bias and implementation problems probably occur to roughly equal degrees for all countermeasures, the relative benefits are likely to be much more meaningful.

7.2 ACCURACY OF COST FIGURES

As discussed in Chapter VI, mine size and configuration varies greatly within the metal/non-metal industry, covering everything from a 2-man sand pit to a gold mine or other large underground metal mine employing thousands of people. The task of estimating costs for a particular mine is not nearly as difficult as that of extrapolating the cost to the industry as a whole. The approach used was to define three "model" mines to represent the three major facets of the metal/non-metal mining industry. The costs were then estimated for these three mines.

The choice was made to not extrapolate costs to the industry for two reasons. First, this action adds an additional source of error to the data in that it would be necessary to assume an average yearly production figure for the model mines in order to compute the multiplication factors necessary to extrapolate. Second, while the total industry cost might be of interest to a government economist, the average mine operator is most interested in what compliance will cost him. Utility and accuracy both dictate that the cost data should be restricted to the model mines. Because it is so restricted, this data should also be used in a relative sense rather than as an absolute indication of compliance costs.

7.3 ESTIMATED RELATIVE COSTS AND BENEFITS

Subject to the constraints mentioned earlier, Table 7.1 displays both countermeasure costs and benefits. Benefit data is shown as percent of total accidents avoided, percent of total lost work days avoided, and percent of lives saved. Cost data is shown as yearly cost for the underground hard rock mine model, the dredge mine model, and the surface mine model.

TABLE 7.1

Estimated relative costs and benefits.

Countermeasure	% Accidents Avoided	% Lost Days Avoided	% Deaths Avoided	Cost for Model Mine, K$ Hard Rock	Dredge	Surface
1. Ground Fault Interrupter (500 volts AC, 10 mA).	29	38	42	140	3	2
2. Use existing protective gear (gloves, nets, boots, glasses, hot sticks)	22	18	12	0	0	0
3. Interlocks	22	20	21	52	1	1
4. Self-indicating device, flags, monitors, etc.	16	30	33	60	5	2
5. Periodic testing or inspection	12	6	4	0	0	0
6. Resistance grounding	6	11	12	8	2	4
7. Proximity warning device	3	14	17	2	2	37
8. Ground check monitor	3	7	8	18	1	3
9. Shielded cable or conduit	6	2	0	11	0	0
10. No bare overhead transmission and distribution conductor except trolley wire	8	30	33	6	2	20
11. Visible disconnects, switchgear or cable connectors	3	0	0	50	0	2
12. Fused lightning arrester	0	0	0	0	0	1
13. Color-coded cables	1	10	12	0	0	0
14. Mandatory voltage test	8	21	25	0	0	0
15. Remove from service before cable repair	1	7	8	0	0	0
16. Trolley contact protection	1	0	0	0	0	0
17. Enclosure specification or switchgear interrupting capacity spec.	14	1	0	0	0	0
18. Improved VOM	2	0	0	0	0	0
19. No live circuit work	30	27	25	25	1	5
20. Ungrounded power supply with frame grounding	4	7	8	7	2	3
21. Bleed resistor	0	0	0	0	0	0
22. Correct tools, tool design, double insulated tools	9	0	0	0	0	0
23. Wire placement, guarding	10	6	4	0	0	0
24. Insulate or ground truck bed, ladders, rubber mats, wooden platform, etc.	3	10	12	1	1	11
25. Use of vulcanized splices	0	0	0	0	0	0

CHAPTER VIII

RECOMMENDED GROUNDING GUIDELINES

The accident analysis carried out and the estimated benefits and costs of various safety practices has led to a series of recommended grounding guidelines. As can be seen from the data presented, good grounding practice can achieve significant benefits at moderate cost. What follows is our best engineering estimate of what can reasonably be expected of the mine operator in order to improve employee safety with respect to a certain class of electrical hazards (H1). This does not address other hazards which might exist or any of the various types of negligent behavior. In each case the recommended guideline is followed by a short justification.

8.1 GUIDELINES WHICH ARE STRONGLY RECOMMENDED

8.1.1 Ground All Equipment Frames

8.1.1.1 Recommendation - The frame of each piece of electrically-powered equipment must be connected by a ground wire to a competent ground bed. In other words, a 3-phase motor will receive power via three phase conductors and a ground conductor, which will be routed in close proximity to the phase conductors and which will be bonded to the motor frame.

8.1.1.2 Justification - If two adjacent pieces of equipment are powered from an ungrounded system, and a phase-A to frame fault occurs on one machine while there is a phase-B to frame fault on the other, then a person who simultaneously touches both machines would receive full line-to-line voltage. This has occurred more than once in the non-metal mining industry, with fatal results. If a grounded system was used, the above situation would lead to a phase-to-phase fault, and the circuit breakers would deenergize both machines.

8.1.2 Ground All Equipment to Same Bed

8.1.2.1 Recommendation - All electrical equipment fed from a particular substation or power center will be grounded to the same ground bed.

8.1.2.2 Justification - This is to prevent the possibility that the frame of one machine could rise in potential relative to the frame of another nearby machine if the two were connected to different ground beds.

8.1.3 Acceptable Grounding Conductors

8.1.3.1 Recommendation - The ground conductor leading from a machine or motor back to the ground bed must be an insulated copper wire, with an ampacity equal to one-half that of a single phase conductor, and in no case smaller than AWG 12. Metal pipes, conduits, conveyor belt structures, frameworks, etc., MAY NOT BE USED as a substitute for the ground wire.

However, in processing plants, wash plants, or mills, where conduit is used as the grounding conductor, this shall be acceptable provided that a competent, low-resistance path is maintained from the motor frame back to the ground bed. The continuity and resistance of this path will be checked at least once a year to verify the integrity of the conduit.

8.1.3.2 Justification - Joints, unions, weldments, etc., can break loose when subjected to mechanical stress and vibration, and these were not designed specifically to carry electric current. Therefore, they shall not be used for this purpose.

However, conduit is often used as the grounding conductor in many industrial plants, and it performs well provided that:

A. mechanical stress and vibration are kept to a minimum, so that the conduit remains intact, and

B. all junction boxes, unions, flexible connections, etc., are adequately bonded or bridged with wire so that a single, low-resistance path is maintained.

8.1.4 Transformer Connections, Plants or Mills

8.1.4.1 Recommendation - In processing plants, wash plants, or mills, the secondary of the transformer(s) feeding electrical loads must be connected in one of the following three configurations:

A. ungrounded delta,
B. solidly-grounded wye, or
C. resistance-grounded wye,

and the circuit must be equipped with protective devices which will trip the applicable circuit breaker(s) in the event of ground faults, short circuits, or overcurrent conditions.

Associated with the transformer secondary, whether delta or wye, there must be a ground bed to which the frames of all the electrical equipment powered from that transformer are tied.

8.1.4.2 Justification - Other grounding systems, such as corner-of-the-delta grounding and mid-phase grounding, are not allowed because they are obsolete and have a number of safety disadvantages when compared with the three systems listed above.

An operation which is "non-interruptable" would probably prefer the ungrounded-delta system since a single fault does not necessitate a shutdown, while other plants which can tolerate outages would utilize one of the two allowable grounded systems.

8.1.5 Transformer Connections, Underground Loads

8.1.5.1 Recommendation - In circuits which are located underground or which feed underground, the secondary of the transformer(s) must be connected in the resistance-grounded wye configuration, and each circuit must be equipped with protective devices which will trip the applicable circuit breaker in the event of ground faults, short circuits, or overcurrent conditions. A grounding conductor shall extend from the frames of all electrically-powered equipment to the grounded end of the neutral resistor, which shall be tied to a competent ground bed, located either on the surface or underground.

8.1.5.2 Justification - The resistance-grounded neutral provides current-limiting in the event of phase-to-ground faults, which is of vital importance in underground environments where a high-current, high-energy fault could cause an explosion in a dusty or gassy atmosphere.

8.1.6 Use Shielded Cable

8.1.6.1 Recommendation - All high-voltage equipment must receive electrical power via shielded cables. That is, there must be a grounded braid, armor, or sheathing around the phase conductor(s).

8.1.6.2 Justification - This will serve to protect personnel from exposure to lethal voltages if the trailing cable's insulating outer jacket were to become cut or abraded.

8.1.7 Verification of Ground Continuity, Portable and Mobile Equipment

8.1.7.1 Recommendation - All dredges and all other portable or mobile electrical equipment supplied power by trailing cables must be equipped with a ground-check monitor which verifies the continuity of the grounding conductor from the machine back to the location where the stationary part of the system begins. HOWEVER, ground-check monitors will NOT be required IF the continuity of the grounding conductor is tested each time the machine or piece of equipment is relocated or repaired (both before and after) and at intervals not less than once a year if the equipment is moved less frequently than once a year.

8.1.7.2 Justification - The integrity of the grounding system depends upon the existence of a continuous, low-resistance path from each equipment frame back to the ground bed. Portable or mobile equipment, and dredges, are supplied power via trailing cables, which are subject to rugged usage and abuse far beyond that to which a fixed, stationary piece of cable is exposed. Therefore, it is necessary to utilize some method of checking and verifying the continuity of the ground conductors in trailing cables.

8.1.8 Verification of Grounding Continuity, Stationary Equipment

8.1.8.1 Recommendation - The continuity of the grounding connection to each stationary electric motor or electrically-powered piece of stationary machinery must be checked at least once a year, and each time repairs are made (both before and after repairs).

8.1.8.2 Justification - The electrical grounding connections to stationary machinery are not subjected to the degree of abuse found in portable and mobile installations, but a yearly examination should be made to verify the continuity of the grounding conductor due to possible physical deterioration and vibration damage.

8.2 GROUNDING GUIDELINES WHICH ARE RECOMMENDED

8.2.1 Transformer Connections, Surface Mines and Dredges

8.2.1.1 Recommendation - The secondary of the transformer feeding portable or mobile surface electrical equipment such as dredges, shovels, draglines, and drills, shall be connected in the resistance-grounded neutral configuration. A grounding conductor shall extend from the frame of each piece of electrically-powered equipment to the grounded end of the neutral resistor, which shall be connected to a competent ground bed. Each circuit must be equipped with protective devices which will trip the applicable circuit breaker in the event of ground fault, short circuit, or overcurrent conditions.

8.2.1.2 Justification - Surface equipment which is powered by trailing cables almost always has a human operator aboard, and a system which limits fault current serves to protect personnel as well as equipment. The resistance-grounded neutral system is legally mandated for coal-mine usage, and has an excellent safety record.

8.2.2 Use of Safety Ground Bed

8.2.2.1 Recommendation - The ground bed which serves as the earth connection for electrically-powered equipment shall be a "safety ground bed" which is distinct from the "substation ground bed", provided this is physically and economically feasible. If an existing installation does not utilize a separate safety ground bed and one cannot be established without drastic alteration of the power system, then the "unified" ground system may be permitted until the substation is rebuilt or moved.

8.2.2.2 Justification - If a single, unified ground bed is installed, then any potential rise on the ground bed, such as those due to primary faults or lightning surges, is transferred directly to the frames of all equipment tied to the bed, posing a shock hazard. If the equipment is tied to a "safety ground bed" which is physically separated from the substation ground bed, then the shock hazard caused by currents flowing in the substation bed is reduced, because the potential transferred from one bed to the other is attenuated across the intervening soil. A bed separation distance of 25 feet, as is required by coal mining law, will provide about an order-of-magnitude decrease in the transferred potential. This separation may be sufficient to reduce the transferred potential under some primary fault conditions (where ground bed current can vary from about 100 A to 3000 A) to a safe level, but will probably not provide adequate isolation during lightning strikes (whose current amplitude averages between 10 kA and 20 kA) or low impedance faults.

If the "primary" or "substation ground bed" is physically very large and extensive, it may be impossible to construct a separate "safety ground bed" which is large enough to achieve a low value of earth resistance and yet simultaneously maintain an adequate separation distance from the primary bed. This is especially true in areas of very high soil resistivity, and at locations where all the buried metal such as pipelines, conduits, building foundations, etc. has been tied together to form the primary ground bed. In cases like this it is better to use a single, unified ground bed.

CHAPTER IX

GROUND CHECK MONITOR APPLICATIONS AND RECOMMENDATIONS

9.1 INTRODUCTION

It has been recommended that portable electrical equipment be connected to earth with a ground wire. Furthermore, it is recommended that this ground wire be monitored continuously or tested periodically and when the equipment is moved or repaired. (See Chapter VIII).

All ground check monitors are not created equal as there are significant differences in function between the different types. A monitor is defined as a device which will check the grounding circuit and will immediately trip the power to the equipment if a failure is detected in the grounding circuit.

A test of the grounding circuit is intended to mean a manual test with an indication of a good or bad grounding circuit. This test will not trip out the power to the equipment if a bad ground is detected. Remedial action is left up to the mine personnel.

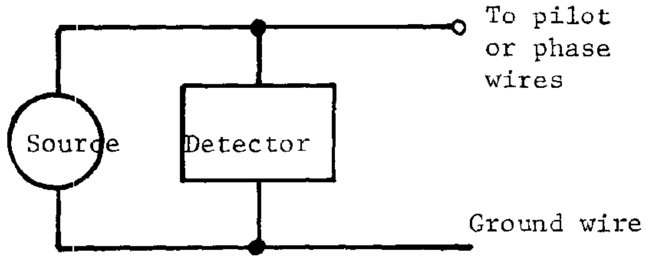
On the following pages, the relative merits of different monitor types and methods of testing will be discussed. Recommendations will be made as to the types of monitors that should be used and the applications of these monitors. In addition, methods of testing will be discussed along with grounding practices.

9.2 APPLICATIONS

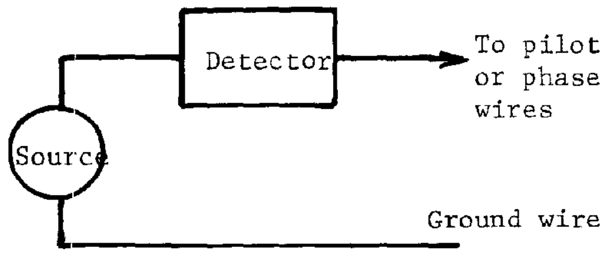
The applications of monitors and types of monitors must be considered simultaneously. Basically there are two separate applications: electrically powered mobile or portable equipment on land and floating equipment powered by electricity from the shore. For the land based case, safety considerations demand that the machine frame voltage be prevented from rising more than a few volts above earth potential under fault conditions. To do this, it is necessary to maintain a low impedance connection of the machine frame to ground. This result may or may not require a ground wire. The situation for the dredge is complicated by the possibility of having personnel in the water. Under these circumstances, it is desirable that no fault current flow in the water in addition to keeping the frame voltage low. Thus, in this case, a ground wire is necessary, and it must be a low impedance.

9.2.1 Monitor Types

There are three monitor configurations of interest. For the Thevenin equivalent circuit type (Type I) the monitoring signal source is between the pilot and ground wires and the detector either measures the voltage between the pilot and ground or the current in the pilot wire. This type is shown in Figure 9.1. The Thevenin equivalent circuit type measures the impedance between the pilot wire and the ground wire connections. In as much as a parallel path shunts the ground wire, a low impedance parallel path may mask a break in the ground wire. This problem may be overcome by



a. Potential detector measures voltage between pilot (or phase) and ground wire.



b. Current detector measures monitor current in pilot or phase wires.

FIGURE 9.1. - Type I monitors.

the use of a ground wire isolator as shown in Figure 9.2.

The second type (Type II) is the pilot wire source-ground wire detector monitor. The placement of the detector guarantees that the ground wire is good if current is detected in the ground wire. Unfortunately, a low impedance parallel path may shunt most of the monitor current away from the ground wire and false trips may result. This problem may also be overcome with a ground wire isolator. The circuit is shown in Figure 9.3.

A Type III monitor has both the source and detector in the ground wire as shown in Figure 9.4. This type monitor can guarantee the integrity of the ground wire and is unaffected by parallel paths. Since a ground wire isolator is not used to achieve these characteristics, the Type III monitor is superior to the other two. Typically, a current transformer would be used as the source and detector in the ground wire.

The ground wire isolator that is commonly used in coal mine situations is simply an arc suppressor. This may be a saturable reactor or a diode bridge. While the isolator must be large enough to carry fault current, it does add another component which is vulnerable to failure or tampering and is not monitored. Unless otherwise required, the ground wire isolators should be avoided.

On water based systems however, the ground wire isolators have a serious drawback. The isolator is placed in series with the ground wire, in effect raising the impedance of the ground wire to ground faults. Fault current may therefore flow in the earth return rather than the ground wire. While this situation is not serious on land where body contact resistance of personnel is usually high, in water it is serious because body contact resistance is very low. Thus, ground wire isolators in these circuits must be considered unsafe.

In terms of function, two functions can be performed. A Type I monitor without the ground wire isolator will measure the ground connection impedance (including parallel paths). All other configurations discussed will measure the impedance of the ground wire. In most cases, the Type II monitor without the ground wire isolator would be unacceptable due to false trips (see Table 9.1).

TABLE 9.1. - Measurement function of the monitor types.

Type I without ground wire	measures ground impedance
Type I with isolator Type II with isolator Type II without isolator Type III without isolator	measure ground wire impedance

9.2.2 Impedance Levels

The sensitivity of the monitors is also of importance. The object of the monitor is to guarantee a low impedance path for fault current. The ground wire is sized to ensure that it can carry the fault current. Thus as long as the ground wire is continuous, one would assume that it could carry the necessary current. If the ground wire is damaged however, it may not

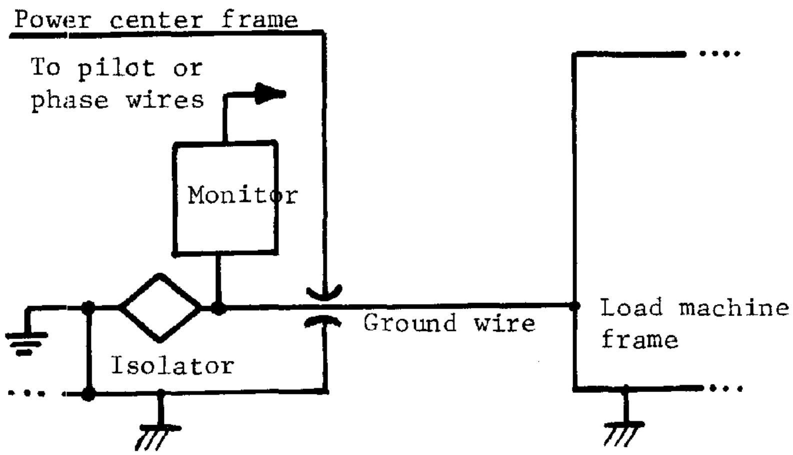


FIGURE 9.2. - An isolator may be used to isolate the ground wire from the earth at the power center.

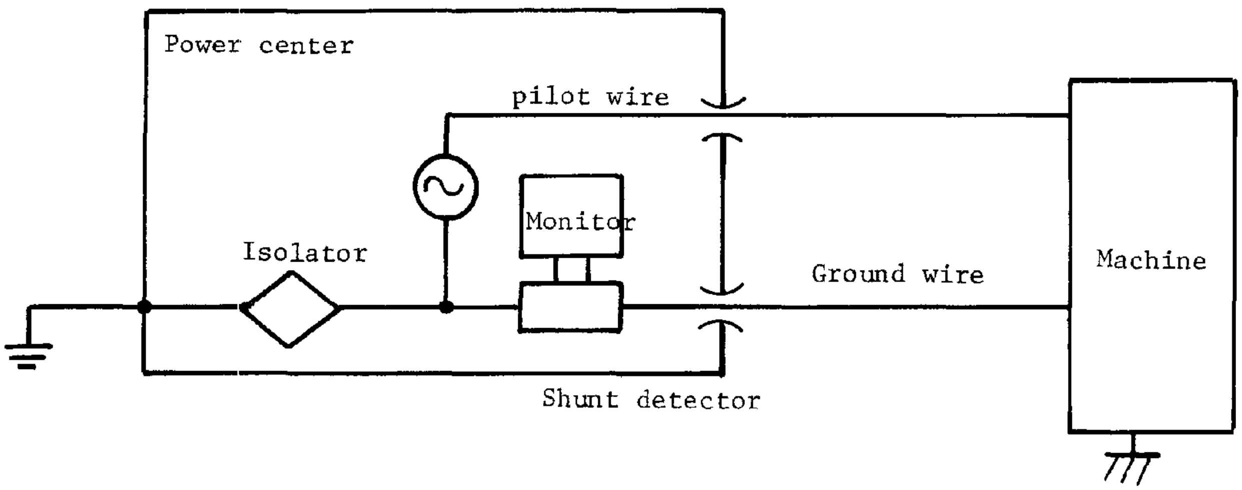


FIGURE 9.3. - A type II monitor with an isolator.

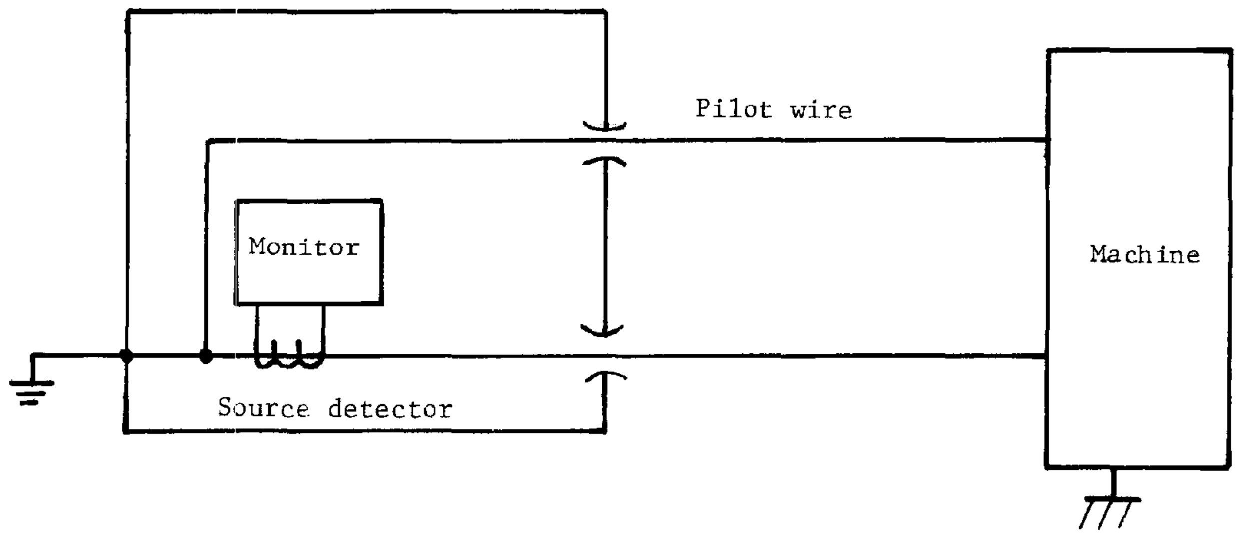


FIGURE 9.4. - A type III monitor.

be able to carry the current. Thus it is desirable that all monitors be able to detect a very low value of impedance or small changes in impedance. The impedance levels are a function of the system fault current as determined by the safety ground resistor.

If the standard is relaxed to allow less sensitive monitors, the minimum possible relaxation should be used. In the case of the Type I monitor without the ground wire isolator, the ground impedance measurement should be as low as possible. In this case, one is depending on chance grounding paths, perhaps without benefit of a ground wire, and there is no guarantee of current carrying capacity.

9.3 MONITOR RECOMMENDATIONS

9.3.1 Land Based Mobile Equipment

For land based mobile equipment, the monitor configurations are listed in order of decreasing acceptability.

1. Type III
2. Type I or Type II both with a ground wire isolator
3. Type I without a ground wire isolator.

In all cases, sensitivity to low values of impedance is desirable and is imperative in the third case.

9.3.2 Water Based Mobile Equipment

Because of the more stringent requirements for water based systems, most of the acceptable methods for land based systems are not acceptable on water. The primary purposes are to ensure that the machine frame potential does not rise more than a few volts above earth potential and that all the current flows in the ground wire rather than through the earth or water. For this reason, ground wire isolators are not acceptable along with systems that do not actually test the ground wire impedance. Thus only one type of monitor is acceptable:

1. Type III

Sensitivity to a low value of impedance is also required.

9.4 MULTIPLE FRAMES

If multiple frames are connected to the ground wire as shown in Figure 9.5, partial parallel paths from one frame to another can mask a break in the ground wire which cannot be detected by any of the monitoring methods. Cable couplers or other intentional or accidental contacts of the ground wire to earth or other equipment will also provide partial parallel paths.

The accidental contacts can be eliminated by using an insulated ground wire, and extraneous equipment connected to the ground wire should be eliminated. However, any piece of equipment which, because of its proximity to phase conductors might become energized due to a fault, must be considered

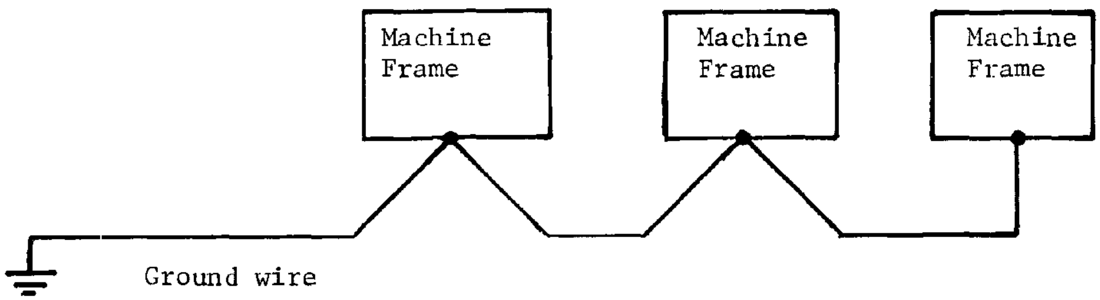


FIGURE 9.5. - Multiple machine frames connected to a ground wire.

separately. Failure to ground this equipment leaves personnel vulnerable in the case of a fault, while grounding this equipment will nullify certain aspects of the ground check monitor. Under consideration here is any piece of equipment in intimate contact with a power cable including cable hangers and floats for dredge cables.

There are three ways in which this problem can be approached. First the cables can be removed from the equipment or additional insulation provided. Second, in some cases such as for floats, the equipment can be made of insulating materials. Third, the monitoring method can be modified to eliminate the problem.

One method of monitoring is to use a multi-path monitor [1] in which connections to the ground wire are monitored individually. This method uses tuned filters from the pilot wire and ground wire connection as shown in Figure 9.6. This method can be used to guarantee that the frame is grounded but cannot verify the integrity of the ground wire, in as much as this method can only be used with a Type I monitor.

A second monitoring method is to use isolators to isolate each piece of equipment, except one, from the ground wire so that no partial parallel paths exist for the monitor signals. This method is shown in Figure 9.7 and is being used in some high voltage monitoring schemes [2,3]. This method suffers the inherent disadvantage of not being able to monitor the connection of the frame to the ground wire. The isolators should be tested periodically; probably on a yearly basis, whenever a ground fault occurs, or whenever the circuit is disturbed.

The third approach is to provide a separate ground wire for each piece of equipment and to monitor each ground wire individually. Each piece of equipment and its ground wire is to be treated individually and tested or monitored as required.

It would be expected that multiple frame systems would be handled using a combination of the methods outlined. When possible, insulating materials would be used, and otherwise an applicable method of monitoring would be used.

Water based systems present a special challenge in order to prevent as much as possible fault current from flowing in the water. A typical system diagram is shown in Figure 9.8. There is only one main piece of machinery, the dredge. Since the floats are in intimate contact with the cable, they must be considered as potential ground fault locations. If the cable follows the pipeline, similar arguments must be followed.

The object is to prevent current from flowing in the water. To this end, the ground wire to the dredge must be continuous. Therefore the grounding system to the floats must be considered. There are basically three alternatives. The first is to make the floats of insulating material or otherwise eliminate any possible ground fault to the float. It will be shown that this method is really the best in the long run.

A second solution is to use isolators from the float to the ground wire. This will allow monitoring of the ground wire and will also prevent current

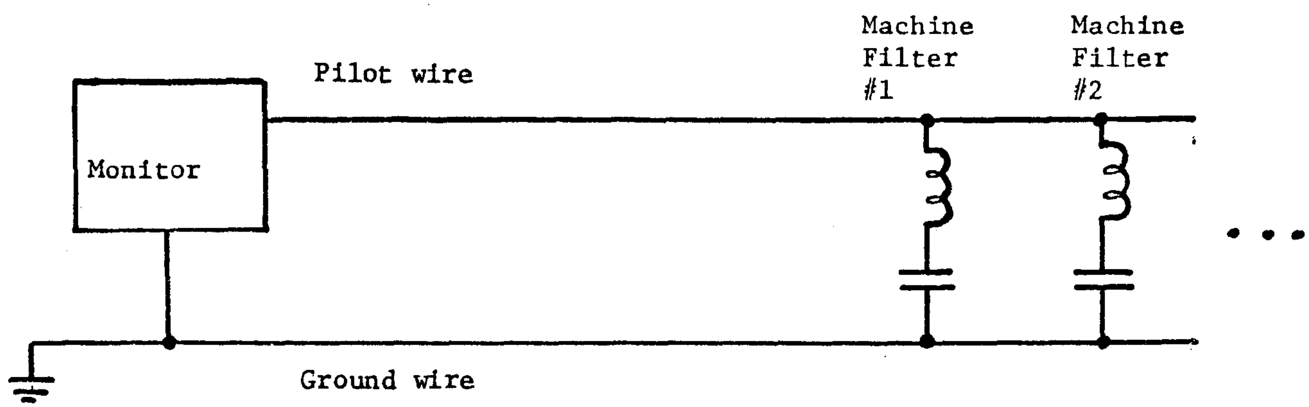


FIGURE 9.6. - A multipath monitor for monitoring multiple machine frames.

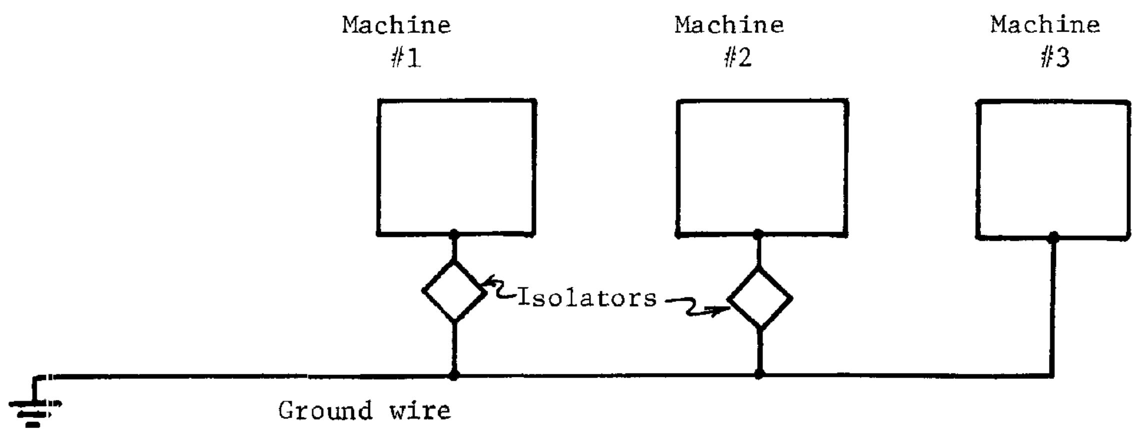


FIGURE 9.7. - Multiple frames grounded through isolators.

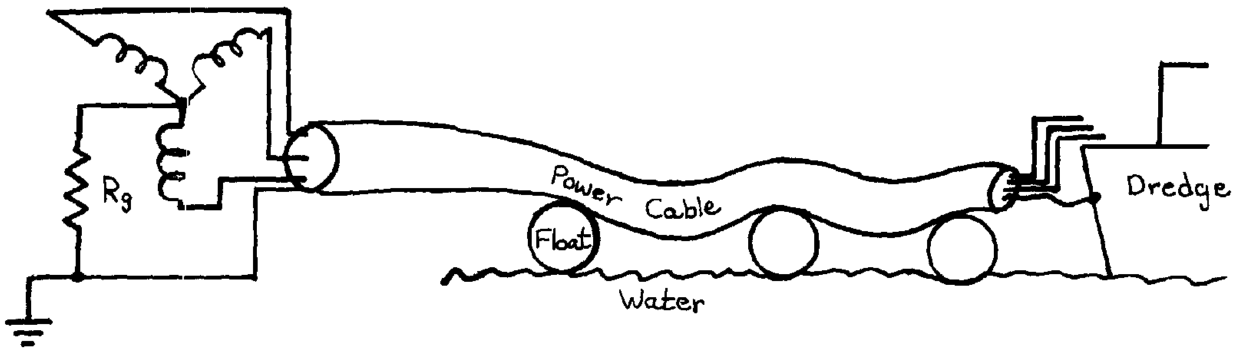


FIGURE 9.8. - A typical power system for a dredge.

flow in the water to the float in the event of a ground fault on the dredge. However, a ground fault to the float places the float at phase potential. The impedance to the ground connection on the shore may very well be lower through the water than through the isolator and ground wire. This reason along with the inability to monitor the isolators is enough to eliminate any further consideration of this method for water based systems.

The third method of handling the cable floats is to run individual ground wires to each float and to the dredge. Each wire can be monitored separately as described in the monitor section. This method will be satisfactory but fault current in the water between different pieces grounded equipment is possible. Thus, the first method (insulating the floats) is preferable.

9.5 RECOMMENDATIONS FOR MULTIPLE FRAME GROUNDING

In cases where ground faults may occur to disconnected metallic objects, the following recommendations are made.

9.5.1 Land Based Systems

For land based systems the following recommendations are made in order of decreasing safety.

1. Separate ground wires to each machine.

2. Each frame monitored separately (multi-path monitor)

3. Isolators between frames and ground wire.

9.5.2 Water Based Systems

For water based systems, the object is to prevent fault current from flowing in the water. Thus, only one system is acceptable:

1. Individual ground wires for each uninsulated frame.

9.6 MANUAL TESTING

The recommendations in Chapter VIII allow testing to be done on portable equipment in lieu of monitoring, providing the testing is done before and after moving and before and after repairs are made. While monitoring implies continuous checking and automatic power removal if a failure is detected in the ground wire, testing implies only a manual reading of the condition of the ground wire.

Testing would be logically reserved for those pieces of portable equipment which are moved infrequently and are moved with the power disconnected, whereas self-powered mobile equipment are the logical candidates for monitoring. It is also recommended that the ground connections on stationary equipment be tested periodically. Thus the following discussion on testing methods and procedures applies both to stationary equipment and portable equipment, but not to mobile equipment.

The three types of monitoring circuits are adaptable to testing equipment with the same characteristics as before. However, those methods which require current transformers in the ground wire must use permanently installed or clamp-on type instruments. Similarly, any isolators must be permanently installed. The reason for this requirement is that the ground wire should not be removed for testing. Not only are some mistakes likely in this procedure, but a high impedance fault on the machine would place phase potential on the ground wire when lifted. Economics indicates that permanently installed isolators and current transformers will not be used. Also parallel paths will probably prevent testing with a Type II circuit without isolators. In addition, the Type I monitor will probably not be satisfactory because of its inability to verify the continuity of the ground wire in the presence of parallel paths and because in many installations, the addition of pilot wires is prohibitive. Therefore, a Type III circuit with a clamp-on current transformer appears to be the most feasible.

Unfortunately, neither the Type III monitor nor testing circuit exists at this point. Thus, a development effort along these lines is recommended.

9.6.1 Grounding Requirements for Testing

It is assumed in the previous discussion, that one of the primary goals is to verify the integrity of the ground wire and the connection of the frame in question to the ground wire. Since the Type III circuit is the only feasible method of making this test, some discussion of the testing requirements and ground wire connections is in order.

A diagram of a simple system is shown in Figure 9.9. A Type III test circuit with a clamp-on current transformer is shown. The impedance looking into the current transformer is tested to determine if the ground wire has a low impedance. It should be noted that a parallel path is required for this test. In many applications, where many machines are interconnected mechanically or electrically, or are in good contact with the earth, parallel paths are assured. In some cases, however, where no reliable parallel path exists, an additional wire may be installed either temporarily or permanently. In cases where a temporary jumper is difficult due to length or other reasons, a good solution would be to install a second ground wire. This additional ground wire would improve the reliability of the grounding system and improve the safety. Note that the ground wire can be tested at any point between the source and load where the ground wire is accessible.

If power is delivered to the machine in a cable with ground wires, there are often multiple ground wires. If these ground wires are carried individually to the machine frame and connected at separate points, then testing of each individual ground wire and connection can be carried out with the return path via one of the other wires. At the power center, each ground wire should be connected to the safety ground in such a way that the test can be made with ease. Certain modifications could be made to power centers and switch boxes so that these ground wires could be easily accessible. In most cases then, testing could be carried out without interrupting service or operation.

In cases where multiple machine frames are to be grounded, the connections are to be made in a tree or fan type arrangement as shown in Figure 9.10. Each branch of the tree is to be measured individually. This method is a

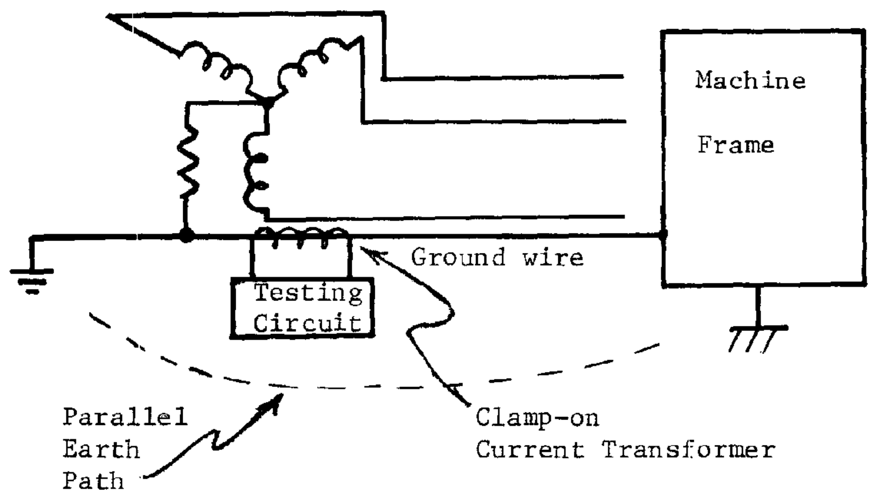


FIGURE 9.9. - A simple system to be tested for ground wire continuity.

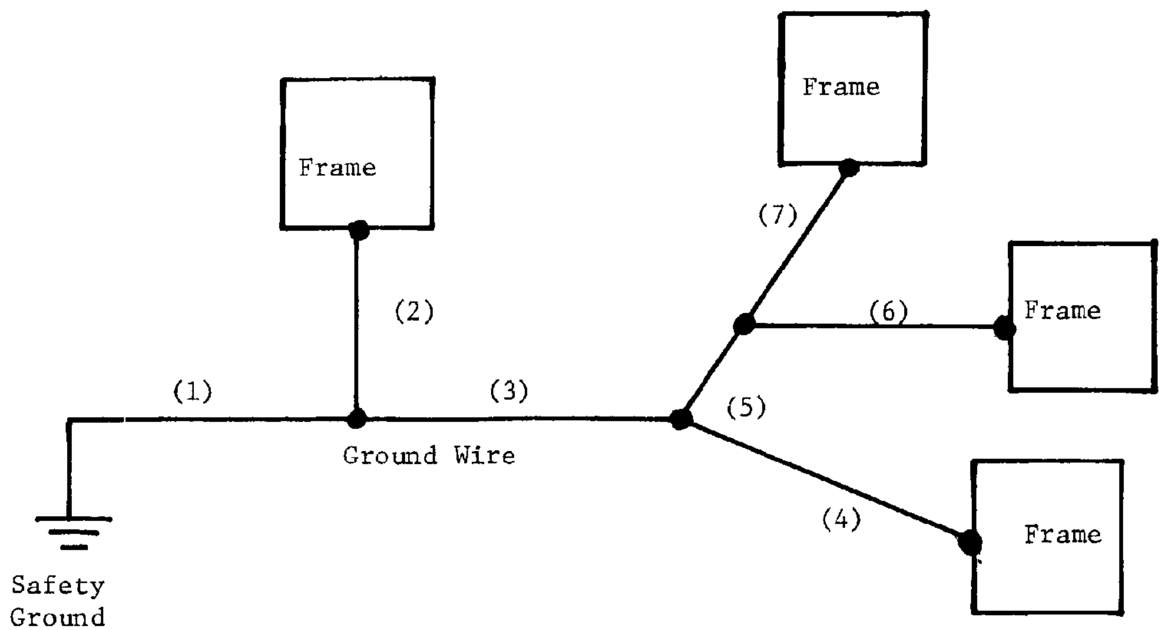


FIGURE 9.10. - Tree arrangement for grounding multiple frames. In this case, seven branches must be tested.

modification of the separate ground wire for each machine method. The results are identical.

9.7 REFERENCES

1. Cooley, W. L., McConnell, R. L., Mine Grounding Systems Final Report USBM Grant # G0144138, 1979, pp. 51-55.

2. Ritter, D. T., Dushac, H. M., Design of a High Voltage Ground Monitor System., IAS Annual Meeting, Conference Record, 1980, pp. 146-151.

3. DiPalma, G. A., Ground Check Monitor - A Practical Approach., IAS Annual Meeting, Conference Record, 1980, pp. 152-157.

APPENDIX A

Details of Interviews with MSHA Enforcement and Technical Support Personnel and Mine Visitation Reports.

Appendix A - Field Visits

TABLE OF CONTENTS

A.1 PHOENIX MSHA OFFICE

During the research field trip to Arizona in November 1979, a visit was made to the Phoenix office of the Mine Safety and Health Administration, (MSHA). While there, we talked with Bill Boult, who is an electrical inspector, and Garry Day, his supervisor.

Bill stated that sand and gravel operations were his biggest problem. These facilities are often small one- or two-man outfits, and the personnel usually have no electrical expertise. The wiring of these plants is done by outside contractors, and if changes or repairs are needed, plant personnel often attempt to do the work themselves, sometimes with disastrous consequences.

Many of these sand and gravel operations utilize portable gasoline or diesel generators as sources of electric power, and the generators are often poorly grounded, if they are grounded at all. The electrical standards don't require frame grounding for motor-driven equipment, so the power distribution may be entirely via 3-conductor cable. In some cases a fourth (ground) conductor may be used, or structural steel such as conveyors and equipment frames may be relied upon to act as a ground conductor. Bill feels that there should be a ground rod at each motor location, and that all equipment should be tied together by a ground wire. He says that structural steel should not be used in lieu of a metallic conductor, because there are often high-resistance joints or bonds in the steel framework. In addition, corrosion can attack these structures and cause poor electrical conductivity. Bill also stated that he would like to see all motors equipped with magnetic starters and provided with both short-circuit and overload protection. Certified electricians should be required to do or at least inspect all wiring of electrical equipment before it is put into service. Bill agrees with the MSHA Technical Support people in Denver that there are two major grounding requirements which should be made mandatory:

A. tie all equipment frames together with a ground conductor.

B. connect this ground conductor to a competent earth ground whose resistance is 10 Ω or less.

A.2 MSHA TECHNICAL SUPPORT CENTER, DENVER

In early November a visit was made to the Technical Support Center of MSHA located in Denver, Colorado. The purpose of this trip was to meet with MSHA electrical engineers and inspectors to get their input on grounding practice in the metal/non-metal mining industry of the mountain West. The people with whom we talked are: Merle Venters, Larry Filek, Roy Rutherford, Craig Miller, and Terry Dinkel. Most are electrical engineers, although Roy Rutherford is a former mine electrical inspector.

The consensus was that there are two main concerns with grounding systems in metal and non-metal mines:

A. that the frames of all equipment be tied together via a low-impedance metallic conductor, which is carried in close physical proximity to the phase conductors, and

B. that this ground conductor in turn should be bonded to a competent earth ground.

Even if the secondary of the mine power distribution is ungrounded (delta-connected), a common ground conductor attached to all machine frames is desirable so that fault current will not flow through the earth. In the event of a phase "A" -to-frame fault on one machine and a phase "B" -to-frame fault on another nearby machine, current can flow through the earth between the two pieces of equipment, and the frames of both can be elevated to lethal potentials. A frame grounding system would eliminate this hazard, and MSHA would like to see this practice become a legal requirement. However, they do not demand a derived neutral on the secondary, although some of the engineers did ask if resistance grounding might not be a necessity in gassy M/NM mines.

In discussing the need for a competent ground bed, the National Electrical Code (NEC) only requires that a check be made on the ground bed resistance, and that an additional rod be driven if the resistance measurement is over 25 Ω. After this additional rod is driven, presumably everything is fine, as the NEC does not even ask for a second resistance check. MSHA feels that this is inadequate, and that some sort of standard should be met-for instance, a law requiring that any ground bed must measure less than 25 Ω. It was stated that grounding is largely ignored by the industry - "They drive one rod no matter how big the substation is". Also, the Denver offices do not get industry requests for help in locating good spots for ground beds, or requests to measure ground bed resistance.

For portable equipment, MSHA has been recommending separate ground beds if possible (separate safety ground bed and substation ground bed), as the NEC requires that the ground bed on systems supplying portable high-voltage equipment shall be separated from other ground beds by 20 feet.

In reference to CFR Standard 57.12-28, which requires that equipment ground conductors and ground beds be checked at least once a year, the following method for testing ground conductor continuity is recommended:

A. Disconnect the power conductors at the load end of the line and at the source.

B. Tie the 3 phase conductors to the ground conductor at the load end.

C. At the source end, insert a variable autotransformer between ground and phase A, impress a low test voltage and measure the current; let $Z_A = V/I$.

D. Repeat with phases B and C to find Z_B and Z_C.

E. Insert the autotransformer between phases A and B, impress a low test voltage, and measure the current; let $Z_{AB} = V/I$.

F. Repeat between phases B and C and again between phases C and A to find Z_{BC} and Z_{CA}.

G. If the ground conductor is satisfactory, then the phase-to-ground impedances should be equal to each other and also should be the same as the phase-to-phase impedances.

Also in reference to CFR Standard 57.12-28, MSHA pointed out that, when measuring the earth resistance of ground beds, it is important to disconnect any parallel ground paths which may exist.

There seems to be some variety of opinion as to what sort of protective relaying should be required in M/NM mine power systems. Craig Miller stated that he would like to see short-circuit, over-current. ground fault, and ground-check monitoring on both HV and LV power systems, and a resistance-grounded neutral on all underground installations.

At the present time, MSHA has very few regulations which they can really use to enforce M/NM mine electrical safety, and when questions arise, they try to follow the NEC or common industry practice. However, some of the practices which are widespread in today's industry leave a lot to be desired from the standpoint of safety. The MSHA personnel with whom we talked would like to see a set of clear, well-defined regulations written specifically for the M/NM mining industry. Then both the mine operators and the Federal inspectors would know exactly what was required by law, avoiding many protracted legal battles and hopefully making the mines safer places in which to work.

A.3 ALBANY MSHA OFFICE

The MSHA subdistrict office in Albany, New York covers all of New England, New York and New Jersey with a staff of 47 inspectors. The inspectors interviewed stated that their own lack of electrical training is sometimes a handicap. They also feel a need for someone to refine and re-evaluate the regulations. The subdistrict manager stated that this district is considered the most enforcement-minded and wrote more citations than any other subdistrict in the nation.

The consensus of the MSHA office is that they would like to see a continuous metallic connection joining the system to a low-impedance earth electrode. Also ground check monitors on portable equipment and at least grounding lights on floating deltas would be desirable. Only one accident in their district last year was attributed to bad grounding. Most of the operators usually want assistance in interpreting and complying with the grounding regulations. One problem is that the inspectors refuse to ask any operator to disconnect his grounds. They have disagreed with Denver Technical Support on this point. Anytime they do have a tough electrical problem they use people in Pittsburgh Technical Support. The inspectors say that many times they get different interpretations of the same regulation from Denver and Pittsburgh.

A.4 MSHA OFFICE IN SOUTHEASTERN U. S.

On Tuesday, December 4, 1979, a visit was made to an MSHA office in the southeastern U. S. We talked with Russell Morris, who is the only electrical inspector in the area, about his philosophy on electrical practices in mines, especially electrical grounding practices.

Russ is from southern West Virginia, and before his transfer he worked as an MSHA electrical inspector in the coal mines of that region as well as eastern Kentucky. As a result, he is extremely familiar with coal-mining law (CFR Parts 75 and 77) and would like to see the electrical laws of part 77 transferred essentially intact to Metal/Non-Metal (CFR Parts 55, 56 & 57). He feels that the present Metal/Non-Metal electrical regulations are vague and incomplete, giving him very little in the way of guidelines and almost nothing in the way of enforcement tools. He sees many hazardous situations which are clearly spelled out as violations in Part 77, but for which there is no corresponding regulation in Parts 55, 56, or 57.

In particular, Russ wants every substation feeding portable or mobile equipment to have a resistance-grounded neutral on the secondary, with a separate safety ground bed and ground conductors leading to the frames of all equipment. The minimum separation distance between ground beds should be 25 feet, and the ground bed resistance should be under 10 Ω, although 5 Ω or less is preferable. He also feels that ground-check monitors should be required on all trailing cables, and that ground fault relays should be set to trip on the minimum possible amount of current and in the shortest possible time (time dial set at no more than 0.5).

Part 12-28 of the Metal/Non-Metal regulations is a particular problem for Russell. This rule requires that companies periodically check the resistance of ground beds and maintain records of their measurements. It also requires that the continuity of all grounding conductors be verified. In a processing plant (or underground mine) this could mean checking the continuity of the ground circuit from each motor frame all the way to the ground bed. How is this to be accomplished? Russ feels that ground bed resistance measurements should be performed in the presence of the inspector - it's easy for people to keep record books full of made-up numbers. He says that the law should simply require that any ground bed must measure less than 10 Ω and leave it at that. Also, a law governing the design and construction of trailing cable junction boxes is needed.

Specific problems which Russ has seen in the field include:

A. bad connections at cable connectors,
B. bad connections at the cable termination inside the dragline tub,
C. open grounding resistors,
D. ground conductor connected to wrong side of grounding resistor,
E. ground bed missing (not installed at all), and
F. trailing cable splices where the shields around the phase conductors were not continuous across the splice.

A.5 ELECTRICAL CONTRACTOR

While in the southeast, a visit was made to the offices of a local electrical contractor. The owner of this small firm is reputed to be the best industrial electrician in the area, and has done a considerable amount of contract work for the dredge operators in this part of the state. He feels that few of the mines presently have two separate ground beds at their substations, but that this trend is just starting and will continue (perhaps spurred by the local MSHA electrical inspector). The protection he recommends for loads supplied by trailing cables includes instantaneous, time-overcurrent, and ground-fault relaying as well as ground-check monitors. It was stated that most ground beds are made up of rods driven in a triangular pattern, with the objective of achieving an earth resistance of 25 Ω or less.

A.6 SIX SOUTHEASTERN SAND AND GRAVEL DREDGES

A visit was made to a large and growing sand and gravel supplier in the southeast. This company operates a number of dredges, which are used to recover sand for use as aggregate. The electrical cables supplying power to the dredge, and the pipe used to transport the sand/water slurry back to shore are both supported on the same pontoons. The pipe is in 40-foot sections, joined by flexible pipe joints, which are bridged with wire jumpers. Thus the pipeline forms a continuous metallic conductor extending from shore to the dredge. The trailing cable may extend for 2000 to 3000 feet, and may be either a single 3-phase SHD type cable, or three separate single-phase shielded cables wrapped into a bundle with a bare ground conductor. On shore, a safety ground bed is established which is isolated from the station ground bed and separated from it by at least 50 feet. A hand-cranked Biddle instrument is used to measure the earth resistance of the safety ground beds, using the fall-of-potential method. The goal is to achieve an earth resistance of less than 25 Ω, preferably less than 10 Ω. The ground conductor is equipped with a CT to provide ground fault protection, and the phase conductors are provided with both instantaneous and time-overcurrent tripping. Ground-check monitors are not presently in use, but the electrical supervisor may soon install a unit made by Compton Electric of Huntington, WV.

The first dredge which we visited was powered from a 12.47 kV:2400 V substation, with the transformer connected delta-delta. An overhead static wire is used on the 12.47 kV system, and it is tied to the main substation ground mat. The 2400 V secondary is carried overhead for 1 pole span, with no static wire. A zig-zag transformer is mounted in an enclosure at the first pole, along with the neutral resistor and a CT for sensing ground fault current. A separate safety ground bed composed of driven rods is installed near the zig-zag transformer. A fall-of-potential measurement was performed on this ground bed, and its earth resistance was found to be 7.41 Ω. Table A.1 shows the results of a resistivity survey performed in the vicinity of the ground bed. This data indicates that the soil conductivity is very low, even at considerable depth. Three 1/0 shielded cables and a bare ground wire extend from the dredge back to the zig-zag transformer and safety ground bed on the shore. The individual cable shields and ground conductor are all tied to this ground bed.

Dredge number two was powered from a similar substation, 12.47 kV:2300 V delta-delta, with a zig-zag transformer to derive the neutral, and a safety ground bed installed one pole-span away from the substation. The ground wire is used as a messenger wire to support the three separate insulated, unshielded phase wires over several pole spans from the safety ground bed to a metal box mounted on the last pole at the edge of the dredge pond. At this point, 3 individual shielded phase conductor cables and a bare ground conductor carry the 2300 V power out to the dredge. A resistivity survey performed in the vicinity of the safety ground bed yielded the figures shown in Table A.2, and again reveal that the soil in this area has very poor conductivity.

Recently a new sled-mounted portable substation has been purchased for use with another dredge. This unit is equipped with Toshiba vacuum contactors, a neutral grounding resistor, and protective relays for short-circuit, over-current, and ground-fault tripping. All overhead circuits, whether 12.47 kV or 2300 V, are provided with lightning arrestors. Unfortunately, it was reported that there are very few arrestor failures -- equipment gets destroyed instead.

TABLE A.1. - Soil resistivity survey near dredge #1 safety ground bed

Electrode spacing (ft)	Resistivity (Ω-ft)
3	5260
9	7460
27	4580

TABLE A.2. - Soil resistivity survey near dredge #2 safety ground bed

Electrode spacing (ft)	Resistivity (Ω-ft)
3	4150
9	7010
27	4930

A third southeastern dredging operation produces 1 million tons per year of cement and asphalt sand. A single large suction dredge supplies all the raw feed to a modern processing plant located adjacent to the dredge pond. The facility employs 8 people and one supervisor, and operates only 1 shift per day. There are no electricians on the payroll, as all electrical work is done by an outside contractor.

A single substation converts the utility supply to 4160 V which feeds the dredge via an overhead pole line. The pole line carries 5 wires, and we were told that the neutral was the bottom wire, while the top conductor was a static wire. An examination of the substation (from outside the fence) failed to reveal what type of grounding was used, or whether two separate ground beds were included. The overhead line terminates at a metal box mounted on the last pole at the edge of the dredge pond. From there, a trailing cable mounted on small floats transmits power to the dredge. This particular dredge is the largest we have yet seen, and floats on two 9-foot by 60-foot pontoons. The dredge has a 2000 hp MG set which generates direct current to drive a submarine pump mounted on the dredge tube. The water/sand slurry is transported to the plant through an 18" steel pipe which is mounted on large floats, separate from those which support the trailing cable. The manager told us that lightning has struck the trailing cable and barrels (floats) in the water, and the operation is completely shut down if lightning gets too close.

Two resistivity surveys were performed on the sand near the dredge pond. Table A.3 gives the data from the first series of tests, where the Wenner array electrodes were run on a line parallel to the edge of the pond. The figures in Table A.4 are for a similar survey done perpendicular to the water's edge. The results for each orientation are quite similar, with the conductivity being poorest near the earth's surface, but increasing gradually with depth. This is the first time the resistivity measured in both directions was the same. Perhaps this sand is so porous that water from the pond can seep for a considerable distance into the outlying soil. Whatever the reason, the values of resistivity gotten on a line normal to the pond bank are much lower than those obtained elsewhere in the area. Tests on a sample of the water from the pond yielded a resistivity of 233 Ω-ft.

TABLE A.3. - Resistivity survey parallel to edge of dredge pond

Electrode spacing (ft)	Resistivity (Ω-ft)
3	960
9	770
27	490

TABLE A.4. - Resistivity survey perpendicular to edge of dredge pond

Electrode spacing (ft)	Resistivity (Ω-ft)
3	940
9	790
27	490

On January 8, 1980, a visit was made to a fourth southeastern dredging operation. This mine utilizes a suction dredge to recover silica for use in cement plants, road aggregate, grouting, and mortar sand. Annual production is about 1.25 million tons, and 70 workers are employed on a 5-day-a-week operating schedule.

The single electric dredge is powered by trailing cable at 2300 V. A contractor does all the electrical work, and there are no electricians on the work force. The plant manager does some electrical maintenance, but only very minor jobs.

Two resistivity surveys were performed in the sand at the edge of the dredge pond, using the 4-probe Wenner array. Table A.5 shows the results of the first survey, which was performed on a line perpendicular to the water's edge. The soil resistivity at the surface is very high, but decreases with depth, becoming lower by an order of magnitude at a depth of 67 feet. The second survey was run on a line parallel to the edge of the dredge pond, and these results are given in Table A.6. The resistivity was even higher in this case, and the value measured at an electrode spacing of three feet (47,100 Ω-feet) was the highest ever seen by this researcher. Again, the resistivity decreased with increasing depth, although the conductivity in each instance was lower than those measured perpendicular to the pond bank.

Several samples of the pond water were taken in order to determine its electrical properties. Results indicated that the resistivity of the water was 675 Ω-ft., which was ascertained by filling a specially constructed cell with pond water and then measuring the resistance of the cell using the Biddle earth tester.

TABLE A.5. - Soil resistivity along a line perpendicular to the edge of the dredge pond

Electrode spacing (ft)	Resistivity (Ω-ft)
3	17,100
9	10.100
27	3,240
67	1,260

TABLE A.6. - Soil resistivity survey along a line parallel to the edge of the dredge pond

Electrode spacing (ft)	Resistivity (Ω-ft)
3	47,100
9	19,800
27	8,480

A visit was made on January 9, 1980 to a fifth dredging operation in the southeastern U. S. An idle diesel-powered dredge was examined in an effort to measure its earth resistance, and to determine the applicability and accuracy of the several available resistance-measuring techniques. The dredge was situated about 50 feet from the bank of the dredge pond, and oriented so that its long axis was essentially perpendicular to the pond bank. The bank of the pond in this area closely resembled the high wall of a surface coal mine, and rose steeply for about 30 feet to the level of the surrounding countryside, which is almost flat.

An attempt was made to measure the earth resistance of the dredge utilizing the 29° method. Wires to connect to the auxiliary current and potential electrodes were run from the dredge up the bank onto the level ground, and readings were taken at distances ranging from 75 to 300 feet. It was assumed that the indicated values would start out low, increase gradually, and eventually level off when the auxiliary electrodes were far enough from the dredge to be outside its area of influence. The actual results, shown in Table A.7 seem to be somewhat erratic, and the values did not follow the expected trend.

Another attempt was made to measure the dredge's earth resistance, this time using the classic fall-of-potential method. The remote current electrode was placed at a location 415 feet away from the dredge, and readings were taken at various potential electrode spacings. The outcome of this test, shown in Table A.8, reveals a behavior which, as before, is different than what one might anticipate. Normally the values would increase, level off, and then increase again as the potential electrode was moved from the vicinity of the dredge outward toward the auxiliary current electrode.

One additional resistance measurement was made, using very large electrode spacings. The remote current electrode was placed 672 feet from the dredge, which involved crossing a fence onto an adjacent property. Then the auxiliary potential electrode was driven at 415 feet, which is 61.8% of the distance to the current electrode. The resistance measured in this case was 10.4 Ω.

A series of resistivity profiles were made on the soil between the dredge pond and the remote current electrode. Table A.9 shows the data for a test run at the top of the bank (highwall), parallel to the edge of the bank and immediately adjacent to it. Table A.10 is for measurements made in the same area but along a line perpendicular to the water's edge. In each case the surface resistivity is high, but climbs to even higher values at greater soil depth, virtually doubling in magnitude as the electrode spacing is increased from 3 feet to 9 feet. Tables A.11 and A.12 show the results of two more resistivity profiles, one parallel to and one normal to the water's edge, with the center of the Wenner array about 75 feet back from the top of the bank. This data shows a high surface resistivity, with an underlying layer of soil whose resistivity is higher still. Even deeper in the earth, the conductivity of the soil increases to such a degree that the resistivity figures obtained at an electrode spacing of 27 feet are lower than those gotten either at a 3-foot or a 9-foot spacing. The final group of resistivity measurements are given in Tables A.13 and A.14. As in the previous instances, surveys were run both parallel and perpendicular to the edge of the dredge pond, and on this occasion the center of the Wenner array was positioned about 150 feet away from the highwall. Both of the readings taken at 9 foot spacings were very high, with the 3-foot readings being the lowest, and the 27-foot figures falling in between. All of the above data shows that the soil in this region is a very poor conductor of electricity, and that a band or layer of earth having unusually high resistivity seems to exist between 3 and 9 feet below the surface of the ground.

TABLE A.7. - Measurement of dredge resistance using 29° method

Distance to auxiliary electrodes (ft)	Resistance (Ω)
75	45.4
100	25
150	17.2
175	9.15
200	13
300	18

TABLE A.8. - Measurement of dredge resistance using fall-of-potential method

Distance to potential electrode (ft)	Resistance (Ω)
75	5.84
100	10.7
150	20.1
200	14.8
250	8.87
300	10.9
350	20.4

TABLE A.9. - Resistivity survey parallel and adjacent to highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	12,400
9	26,000

TABLE A.10. - Resistivity survey perpendicular and adjacent to highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	13,700
9	25,100

TABLE A.11. - Resistivity survey parallel to highwall, 75 feet from edge of highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	40,100
9	43,300
27	29,700

TABLE A.12. - Resistivity survey perpendicular to highwall, 75 feet from edge of highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	36,400
9	44,700
27	22,200

TABLE A.13. - Resistivity survey parallel to highwall, 150 feet from edge of highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	27,900
9	35,800
27	30,200

TABLE A.14. - Resistivity survey perpendicular to highwall, 150 feet from edge of highwall

Electrode spacing (ft)	Resistivity (Ω-ft)
3	25,100
9	34,800
27	25,800

On January 10, 1980, a visit was made to a sixth sand dredging facility in the southeast. This operation uses a single jet dredge to produce 1.3 million tons per year of silica sand, and employs a total of 12 people.

The mine substation transforms the utility feed to 2300 V, using a delta-delta transformer with an external zig-zag transformer to derive the neutral point on the secondary. The grounding circuit includes a 25 A current-limiting resistor and a separate safety ground bed which is isolated from the main substation bed. The 2300 V distribution system is equipped with fused disconnects, instantaneous and time-overcurrent relays, and a ground fault relay. The dredge is powered via shielded trailing cable with internal ground conductors. Steel pipe is used to carry the sand/water slurry to shore, while plastic pipe is utilized to span the distance between the shore line and the processing plant. Some problems with lightning have been experienced, mostly involving the deep-well pumps which supply process water to the plant. Mine personnel stated that they have had no problems with people getting shocked.

Two resistivity surveys were performed on the soil (sand) at the edge of the dredge pond. The first set of data, shown in Table A.15, is for a Wenner array oriented parallel to the bank of the pond, while Table A.16 gives the figures obtained when the electrode array was positioned normal to the water's edge. The sand near the shore conducts electricity much better than that located farther from the water, which may indicate that water from the dredge pond has permeated into the soil strata located adjacent to the pond. This hypothesis is reinforced by the variations in resistivity with soil depth, which are identical in trend for both array orientations. A sample of the pond water was measured, and its resistivity was found to be 340 Ω-ft.

TABLE A.15. - Resistivity survey along shore of dredge pond

Electrode separation (ft)	Resistivity (Ω-ft)
3	980
9	1,270
27	845

TABLE A.16. - Resistivity survey perpendicular to the shore of dredge pond

Electrode separation (ft)	Resistivity (Ω-ft)
3	11,300
9	16,800
27	8,900

A.7 SIX GULF COAST DREDGES

This is the first dredge operation visited in the Gulf Coast region; the plant runs 8 hours a day, 5 days a week, and produces about 600 TPD of gravel utilizing a work force of 11 people.

All gravel is mined using a 12" suction dredge. Fresh water is pumped at high pressure into a small-diameter spray jet mounted above the main intake pipe. This high-pressure spray breaks up and loosens the in-situ material beneath the water's surface, where it is then swept up and brought to the surface by the main suction pump. This centrifugal pump, driven by a 500 hp wound-rotor motor, propels the sand/water mixture to the shore-based processing plant. Both the 500 main suction drive and the 150 hp high-pressure pump motor are operated at 2300 volts. Power is brought onto the dredge via an insulated marine-duty cable with 3 phase conductors and several ground conductors. Back on shore, the ground conductors in the marine power cable are tied to a driven-rod ground bed.

Flow rate in the pipeline from dredge to shore is regulated by varying the resistance in the field circuit of the wound-rotor motor. This is accomplished, not by switching fixed values of resistance into and out of the circuit, but by using a continuously-variable "liquid controller". The speed controller is a steel tank filled with a mixture of soda-ash and water. Inside the tank are 3 fixed metal grids (one for each phase) and three movable grids, which are moved up and down (further away or closer to the fixed grids) to vary the total field resistance and hence the motor speed. This type of speed control is preferred by Gulf Coast dredge operators because of its physical compactness and low maintenance requirements.

The raw material pumped from the dredge to the processing plant is a mixture of sand and gravel immersed in a far greater volume of water. It is first sent to a desanding screen where the water and sand flow through the screen openings, while the coarser (gravel) fractions are taken off the end of the screen for further separation. The sand and water are presently pumped directly back into the dredge pond as fill, but soon an additional facility will be added to recover this sand and separate it into two salable products. Meanwhile, the screen oversize is transported by belt to a log washer, a device resembling a trough containing two paddle-studded shafts, which breaks up large mud-balls picked up by the dredge. The gravel is then separated into 3 size fractions by a double-deck vibrating screen, and delivered to stockpiles by conveyor belt.

Two resistivity surveys were performed near the dredge pond, one along a line parallel to the pond's edge, and the second perpendicular to the shore. The results are shown in Table A.17 and Table A.18 respectively. In both cases, soil conductivity increased with depth. Also, the resistivity of the soil near the water was lower than that further on-shore, indicating that perhaps the pond water had infiltrated the soil near the pond, thereby increasing its conductivity. Measurement of a water sample seems to confirm this hypothesis, for a test showed that the resistivity of the water is about 279 ohm-feet.

TABLE A.17. - Resistivity survey of soil near dredge pond, taken on a line parallel to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	9990
9	5220
27	4720

TABLE A.18. - Resistivity survey of soil near dredge pond, taken on a line perpendicular to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	44,100
9	14,900
27	2,780

The second dredge operation which was visited during the Gulf Coast trip is located about 70 miles from the first one. A total of 500 tons per day of gravel is mined and processed by a labor force of 14 employees, with operations continuing around the clock, 7 days a week.

This particular dredge is powered by two Caterpillar diesel engines, but the remainder of the plant is electrically-driven. All motors in the plant are operated at 480 V, which is obtained from a company-owned substation. The primary windings of the 3 single-phase pole-mounted transformers are delta-connected, and the secondary is a grounded wye, connected to driven rods at the base of the poles. The 480-V distribution system is all grounded, using a grounded steel messenger wire to support the insulated phase conductors for overhead spans.

Resistivity surveys were conducted on the soil near the dredge pond, both parallel and perpendicular to the water's edge. The results, shown in Tables A.19 and A.20, indicate that the soil conductivity is quite low, and that the soil nearer the edge of the pond has a somewhat lower resistivity, possibly due to water infiltration. The water itself is a relatively poor conductor, with a measured resistivity of 2740 Ω-ft.

TABLE A.19. - Resistivity survey of soil near dredge pond, taken on a line parallel to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	11,900
9	2,110
27	7,680

TABLE A.20. - Resistivity survey of soil near dredge pond, taken on a line perpendicular to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	14,200
9	3,130
27	ground too soft

The third dredge operation which was visited on the Gulf Coast trip was located only a few miles from the second. The plant runs 24 hours a day, 5 days a week, and 13 employees produce an average output of 1000 TPD of gravel.

This facility is unique in that it utilizes a German-built clamshell dredge in lieu of the more common suction dredge. This machine is equipped with an 8 cubic yard clamshell bucket which is raised and lowered through a well in the center of the dredge, and which scoops material from the bottom of the dredge pond. A dredge-mounted vibrating screen provides a gravel product, a sand/water underflow, and a very coarse oversize which is returned immediately to the pond. The gravel-sized rocks are transported to shore via a series of float-mounted articulated belt conveyors, while the sand/water screen underflow is pumped ashore via pipeline. A sand processing plant will soon be installed to handle this size fraction, but it is presently being flumed into an adjacent pond. The dredge has a capability of operating to depths of 160 feet, and can be set up for fully automatic operation. The machine is electrically complex, large in size, and appears to be quite costly.

A marine cable feeds power to the dredge at 2300 V. This cable includes a ground conductor which is tied to driven ground rods at the base of the utility poles supplying power to the dredge via overhead lines. These overhead lines terminate in cut-out switches to which the cable is connected. The resistance of this ground bed was measured using the fall-of-potential method, and a figure of 4.85 Ω was obtained. This value is lower than the actual resistance because we were unable to disconnect the bed from the remainder of the system. The dredge itself was therefore also acting as a ground rod, leading to an optimistically low value of earth resistance. A resistivity survey near the ground bed yielded values of 594 ohm-feet and 661 ohm-feet at electrode spacings of 10 feet and 20 feet respectively. This soil had the highest conductivity by far of any measured in this region.

The gravel deposit at this site is broken up by drilling and blasting before the dredge moves in, so that the banks of the dredge pond are very steep. For this reason, no water sample was obtained.

The processing plant itself is conventional, powered by a 4-wire 480 V system. The 480 V supply is obtained from the 2300 V dredge feeders, via a bank of three transformers connected delta-wye with the neutral point of the secondary solidly grounded.

A fourth dredging operation was also visited on the Gulf Coast trip. The single piece of mining equipment is a large suction dredge, equipped with an 18" suction line and 16" discharge. The suction pump is powered by a 1000 hp 2300-V wound-rotor motor using a soda-ash-and-water "liquid controller" for speed control. The jet pump is driven by a 400 hp motor which also operates at 2300 V. The plant functions 24 hours a day, 5 days a week, and the 30 employees produce an average of 1500 TPD of sand and gravel.

The processing plant is set up to yield 2 size fractions of sand and two of gravel. There are three 400 hp and five 25 hp motors in the facility, all operating at 480 V. The plant power is derived from a set of three single phase transformers connected delta-delta to the 2300 V overhead lines from the utility. All the motors are frame-grounded to driven ground rods located at various points throughout the plant. It appears that each motor frame is grounded to the earth, but it is possible that these motor frames are not all tied to each other unless it is through the metallic structure of the plant. The dredge is powered via a shielded marine cable, with the cable shields connected to a ground bed. This ground bed is located at the base of the last utility pole on shore, where the overhead 2300 V line terminates at cut-out switches to which the cable is connected.

MSHA inspectors visit the facility about 4 times each year, and look at "everything". The parent company also has its own safety personnel who make periodic visits and who are "tougher than MSHA". The plant superintendent was very helpful and wanted to know if there was a possibility for plant operators to provide additional direct input to MSHA when the time comes for Federal rule-making.

Two resistivity surveys were performed on the soil near the edge of the dredge pond, one parallel to the pond bank and another perpendicular to the bank. The results, shown in Tables A.21 and A.22, indicate that the soil conductivity is quite poor, and that the resistivity increases as one goes further away from the water. A sample of the pond water showed its resistivity to be 2010 ohm-feet.

TABLE A.21. - Resistivity survey of soil near dredge pond, taken on a line parallel to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	3660
9	3460

TABLE A.22. - Resistivity survey of soil near dredge pond, taken on a line perpendicular to water's edge

Electrode spacing (ft)	Resistivity (Ω-ft)
3	7690
9	4250

While in the area, a telephone interview was conducted with a local electrical contractor. He did not know the primary voltages furnished to the various dredge operations by the utilities, but stated that he prefers a 2300 V wye secondary, with the neutral point solidly grounded (although sometimes he is faced with 2300 V delta secondaries). He has a Biddle Megger, and always installs and checks his own ground beds, increasing the amount of buried metal until the resistance reading is 10 ohms or less. On one occasion he had to drive a rod to a depth of 85 feet to achieve a satisfactory ground bed, but he sometimes utilizes an array of 10-foot rods in a diamond- or star-shaped pattern.

For marine-cable (dredge) 2300 circuits, he usually installs 200 A fuses on shore, with disconnects mounted at both ends of cable (at the dredge and on shore). The large motors on the dredge, which propel the jet pump and the main suction pump, are operated at 2300 V directly. Smaller motors on board the dredge are powered by a 480 V supply derived from the 2300 V feed via a delta-wye transformer bank mounted inside the dredge. The neutral point on the secondary is solidly grounded to the machine frame and 4-wire distribution is used. There will also be a small 480:110 V single phase transformer to feed lighting loads, with fuses installed on the high side of each transformer.

The shore-based processing plants are generally 2300:480 V with delta primary and either delta or wye secondary. If the secondary is wye-connected, then the neutral point is solidly grounded at the substation and a 4-wire 480 V distribution is used. The 480 V system often is supported from poles, using messenger wires which are grounded at each pole, and which may form the 4th wire (ground conductor) of the 480 V system when it is carried overhead. This usually terminates in a small building or trailer which houses the 480 V switchgear. From this point, 4 conductor type STO insulated cable is used to supply individual motor loads. Poles supporting the overhead lines are grounded both with a ground rod at the base of each pole and by butt-wrapping each pole. If the 480 V secondary is delta-connected, then the grounding configuration is the same as for a wye secondary, except of course that the transformer secondary floats. A derived neutral (zig-zag transformer) is not used. He again strives for an earth resistance reading of 10 ohms or less for the ground beds on the 480 V system.

In general, conduit is not used for the 480 V distribution because of extreme vibration conditions encountered at the sand and gravel plants. Most size-separation operations are performed by shaking screens which set up very strong oscillations in the conduit. This causes the conduit to come apart at the joints, or to weaken and break. Then the sharp edges of the broken conduit abrade the insulated electrical cable, leading to short-circuits and plant down-time. It is for this reason that he avoids using conduit for 480 V circuits.

He seemed extremely glad to help us, and offered to provide additional assistance if we had a need to ask further questions.

The fifth dredge to be visited on the Gulf Coast trip is equipped with a 200 hp motor driving the suction pump, which has a 10" intake and 8" discharge line. Small wooden supports with insulators are mounted on the floats supporting the discharge line, and these insulators support 3 separate insulated phase conductors plus an insulated ground conductor, through which power is transmitted from the shore to the dredge (at 2300 V). As was the case with all the operations we visited, the discharge pipeline which is used to transport the rock/water slurry to shore is composed of sections of metal pipe coupled together with flexible sections of rubber.

The local utility supplies the facility with power via an overhead ungrounded 2300 V feed. The dredge cables terminate on shore at pole-mounted disconnect switches, and a ground bed is installed at the base of the pole. The cables feeding the dredge appeared to have many splices, but all were well-taped.

The processing plant is fed via a 2300:240 V delta-delta transformer bank, with a ground bed installed at the substation and a ground conductor extending along with the phase conductors to all motor loads. The 240 V cables also seem to be full of splices, but they appear to be well-insulated.

Resistivity surveys were performed on the soil near the dredge pond, and the data is shown in Tables A.23 and A.24. The surface soil is much more conductive than than which was found in other localities, with several resistivity figures below 400 ohm-feet. However, it appears that the conductivity decreases markedly with increasing soil depth. Measurements on a water sample yielded a resistivity of 1890 ohm-feet for the pond water.

This facility employs 4 people who work 10 hours a day, 5 1/2 to 6 days a week, to produce a daily output of about 2600 tons of gravel. The plant foreman told us that MSHA inspectors appear about 4 times per year to check out the entire operation. He also stated that the safety inspector who works for the insurance company whose policy covers this plant is more difficult to satisfy than are the MSHA inspectors.

TABLE A.23. - Resistivity survey of soil near dredge pond, taken on a line parallel to water's edge

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	339
9	362
27	2380

TABLE A.24. - Resistivity survey of soil near dredge pond, taken on a line perpendicular to water's edge

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	294
9	395

The sixth stop on our trip to the Gulf Coast was also a dredge plant. This facility employs 25 workers, and operates around the clock 7 days a week to produce 1300 TPD of gravel and 700 TPD of sand.

Some electrical maintenance is performed by plant employees, but there are no electricians as such, and all complex jobs are done by an electrical contractor. MSHA inspectors visit the plant fairly often, but the company's own safety people are more rigid in their requirements than MSHA.

The operation utilizes a single dredge equipped with a 700 hp wound rotor motor, using the soda ash liquid controller for speed adjustment. The dredge has a 14" suction and 12" discharge, with a 150 hp motor-driven jet pump. A marine cable suspended by short lengths of sealed plastic pipe transmits power to the dredge at 2300 V. A ground conductor included inside the cable is tied to a ground rod at the base of an on-shore utility pole where the cable terminates. This ground wire extends along with the phase conductors, via overhead lines, back to the substation feeding the dredge. The substation, whose transformers are connected wye primary and delta secondary, has a ground bed, but the bed was not connected to the overhead ground wire, which appeared to be cut off part way down the pole at the substation.

The sand plant and the gravel plant were powered by separate 2300:440 V substations, with the transformer windings connected delta-delta. A ground bed at each substation is connected to a ground conductor which then becomes an integral part of the 440 V distribution. The 440 V lines extend to small buildings which contain motor control centers, and neoprene-jacketed 4-conductor type SO cable is used for the runs from the motor-control centers to the motors.

Two surveys were performed on the soil near the dredge pond to determine its resistivity, and the results are given in Tables A.25 and A.26. The soil near the water had a higher conductivity than that located farther from the bank, indicating water infiltration of the ground immediately adjacent to the pond. The overall resistivity of the soil was quite high, and a test of the pond water revealed that its resistivity was 1400 ohm-feet, also a high value.

TABLE A.25. - Resistivity survey of soil near dredge pond, taken on a line parallel to the water's edge, 20 feet from the water

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	9420
9	3900

TABLE A.26. - Resistivity survey of soil near dredge pond, taken on a line perpendicular to the water's edge

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	1090
9	1680
27	1440

The last visit made in the Gulf Coast region was a dredge mine and plant. The facility operates 24 hours a day 7 days a week, and 21 employees produce about 1350 TPD of sand and gravel combined.

Two suction-type dredges are located on-site, with one feeding material to the other. The larger has a 14" intake and discharge, and is equipped with a 400 hp suction-pump drive while the smaller has a 10" suction and discharge, with the suction pump driven by a 200 hp motor. Both of the suction pump drives are 2300 V wound-rotor motors; the larger one uses a "liquid controller" and the smaller uses a conventional grid system for speed adjustment.

Power for the dredge is supplied by the local utility using a 4-wire overhead feed at 33 kV. This is stepped down to 2300 V by 2 parallel-connected transformer banks in a wye primary-delta secondary configuration. The 2300 V overhead lines do not have a ground conductor, but a ground bed is installed at the base of the last utility pole where the lines and the marine cable join at cutout switches. The marine cable contains a ground conductor which is tied to all motor frames on the dredge.

The sand and gravel plant is fed from a delta-delta 2300:440 V substation, and a ground bed at the substation extends along with the phase conductors to all motors. A resistivity survey was performed on an area of undisturbed soil supporting the utility pole at the end of the marine cable feeding the smaller dredge. The results, shown in Table A.27 indicate that the soil conductivity is quite low, as is usually found in these areas. The measured resistivity of a sample of pond water was 1390 ohm-feet. This figure is rather high, and is almost identical to that previously measured at another dredge operation about 40 miles away.

TABLE A.27. - Resistivity survey of soil at base of utility pole at terminus of marine cable

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	5470
9	1190
27	1410

It is important to note that, with a delta-connected secondary, there is no path for fault current during a phase-to-frame fault on a motor, except for a minor amount of leakage back to the source. This fault will therefore go undetected. A second phase-to-frame fault on another machine can result in a dangerous condition. If the faults involve different phases, then a person touching both faulted pieces of equipment is exposed to full line-to-line voltage. This can be prevented if all machine frames and motor mounts are tied together by a ground conductor. This ground conductor should be connected to a competent ground bed. In addition, if the system does have a delta-connected secondary, a zig-zag transformer should be used to derive a neutral point. This neutral point is then tied to the system ground conductor and ground bed. This arrangement will allow for the detection and interruption of phase-to-frame faults, and will protect both men and equipment.

A.8 THREE MOUNTAIN-WEST METAL MINES

The first leg of trip number three brought us to an underground gold mine. The mine has been in continuous operation since April 1876, and daily output averages about 5000 tons of gold ore, with some silver as a by-product. The mill operates 24 hours a day, 7 days a week, while the mine runs just 2 shifts a day, 5 days a week. The labor force numbers some 1500 employees, including 55 electricians and 20 supervisory electrical personnel. The mine workings extend for miles, with horizontal entries extending outward from the two main shafts at 150-foot intervals. The present development work is being carried out at depths in excess of 8000 feet, with plans to reach down eventually to 12,000 feet beneath the earth's surface.

Primary power is derived both from the local utility and from several company-owned hydro-electric plants. The utility, which has nearby major substations and generation, supplies electricity to the processing plant and main mine-shafts via overhead lines to the company's integrated system at 2400, 12,000, and 69,000 V. The overhead lines have ground conductors (static wires) extending from ground beds at the substations and generation plants to each utilization site. The static wire is connected to earth via pole grounds at every second or third pole. The 2400 V and some of the 12 kV circuits are delta, and all the delta systems contain ground fault indicating lights. Protection at the substation includes lightning arrestors, oil circuit breakers with overcurrent tripping, and disconnect switches. The hydro-electric stations owned by the company are located in the mountains, where power is generated by water-driven turbines at 2400 V. This is stepped up to 33 kV via delta-delta transformers for transmission to the mine site via overhead lines equipped with static wires. In town, another set of delta-delta transformers steps the voltage back down to 12 kV for system tie.

Electricity enters the mine via 12 kV and 2400 V bore-hole type cables ranging in size from 1/0 to 500 MCM. Shielding is used on 12 kV cables, but the 2400 V cables are unshielded. Numerous switches and circuit breakers are installed to isolate and provide for parallel operation of circuits. At various underground levels, the 12 kV cables feed 12 kV/2400 V substations, which are again connected delta-delta. Each of these substations is equipped with an air circuit breaker, fused disconnect switches, and protective relaying. Those units above the 4850 foot level are also provided with lightning arrestors.

Power at the 2400 V level is distributed throughout the mine via miles of 350 MCM or 500 MCM shielded cable. Small 300 kVA power centers, situated at intervals along the haulage drifts, are used to step the voltage down to 480 V. Each 2400 V branch circuit feeding a power center is equipped with a fused disconnect switch. The three-phase transformers are connected delta-delta, with a fused safety switch installed in the secondary circuit. A neutral point is derived via a zig-zag transformer, and the neutral is then grounded through a 51 ohm resistor, which limits fault current to 6 A or less. A current transformer and relay monitoring the ground conductor are set up to activate instantaneously in the presence of a 6 A ground fault.

From the 480 V safety switch, power is transmitted to the production stopes via 2/0 cable rated at 2000 V, although some cables have the newer 600/2000 V rating. This cable is constructed with the three insulated phase conductors surrounded by a "concentric shield" or very heavy braid which serves as the ground conductor. The concentric ground in the 480 V cables has 100% of the conductivity of the power conductors and consists of a number of relatively short lay, usually smaller than #12 AWG, tinned copper conductors. The researchers from WVU had not seen this type of cable before, but it is used throughout this particular mine and is common in Europe according to mine personnel. The 480 V cable may extend for hundreds of feet down a drift, and serve several mining areas. Each branch circuit connects to the cable at a junction box, and is equipped with a safety switch or fused disconnects. Cables from the junction boxes are used to power either small ventilation fans (1-15 HP) or slusher control units.

A typical slusher control box is connected to a junction box via 50 or 100 feet of #2 AWG cable. The control box contains a (fused) safety switch and a magnetic starter (with overload protection) for the slusher motor, which is usually rated at 15 to 30 HP. A balanced-flux CT is also included, set up to trip the motor contactors at a level of 2 A. A single-phase 277/120 V transformer provides power for lights and control circuits. From the slusher control box, a 7-conductor cable up to 150 feet in length extends to the slusher itself. This cable contains three #6 AWG conductors for the slusher motor, three #12 AWG conductors for the 120 V lighting and control circuits, and an equipment grounding conductor. A single 3-wire 120 V receptacle is installed on the slusher for lighting circuits. None of the 120 V underground circuits are equipped with GFI protection, but a 6 A circuit breaker is installed in the 120 V wiring inside the slusher control box.

Large underground motor loads are operated directly at 2400 V. These include many large pumps (six @ 700 HP, five @ 500 HP, two @ 350 HP, and five @ 250 HP), three 400 HP fans, and several hoists for men and ore, rated from 300 HP to 600 HP. The huge pumps and hoists mounted on the surface are also powered at 2400 V. The ore hoist at the top of one shaft is driven by dc motors powered from a big MG set using modified Ilgner-Ward-Leonard control. The prime mover of the MG set is a 2000 HP wound-rotor motor which turns two 1250 kW dc generators and uses a soda ash and water "liquid controller" for percent slip adjustment. This is the first time we have seen the "liquid controller" in use other than on dredges in hot humid climates, although mine personnel stated that it is widespread.

Even though the three-phase power distribution is "floating" at all levels except 480 V, all pieces of electrical equipment, even the light bulb housings, are tied together via an equipment grounding conductor which extends to a ground bed on the surface. Because all substation ground beds were also tied together, via the static wires, we were unable to isolate any particular ground bed. Measurements were made on one bed while it was connected, using the battery Biddle, and an earth resistance of 19.35 ohms was obtained. The WVU CERTS machine was then connected and a reading of 19.6 ohms was observed. Unfortunately, when attempts were made to achieve higher current drive levels from the CERTS, the instrument failed. A soil resistivity survey, the results of which are shown in Table A.28, indicates that the soil in the vicinity of the substation is not a good conductor, but a ground bed resistance of almost 20 ohms still seems rather high. We were told that, if a new ground bed is installed, its resistance is measured before interconnecting it with the rest of the system, but all readings thereafter are taken with the ground bed connected. Standard construction practice for substation ground beds includes 4 foot by 8 foot copper plates at the base of concrete pads, plus a horizontal copper mesh with 8-foot ground rods installed at intervals along the mesh. Newer beds are established in some instances by driven rods and connection to foundation and slab rebar.

TABLE A.28. - Soil resistivity near outdoor substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	2090
9	1790
27	4090

Underground ore haulage is via a 275 VDC trolley system. All rail joints are welded, with cross-bonds every 200 feet. In addition, a bare parallel return feeder is used. Trolley power is obtained from rectifiers operating from the 480 V underground distribution system.

Mine personnel stated that they occasionally have problems with lightning on their surface 2300 V compressor motors, but there is rarely any trouble underground.

Inspectors from MSHA visit four times each year, but a single visit may last three to four weeks because the facility is so big. These inspectors are not electrical specialists, but look at everything. If a specific electrical problem arises, electrical experts from Technical Support in Denver will come and make an examination. It is felt that there are three problems existing presently with MSHA:

A. Interpretation of the rules and regulations by inspectors-MSHA should print and distribute an official list of the rules and their correct interpretation so that everybody is playing the same ball game,

B. MSHA is poorly managed and very inefficient,

C. Why hasn't MSHA published reports showing how their rules and regulations have been effective in reducing accidents? Is it because MSHA hasn't done anything that makes a difference in safety?

The electrical personnel at the mine feel that they have an "average" amount of problems with MSHA - and "average" in this case means "considerable".

The second stop on this trip was at a molybdenum mining complex. This facility is composed of an underground mine, open pit mine, and a processing plant or mill. Both mines and the mill operate around the clock seven days a week, except for two three-day vacation periods, one during the July Fourth holiday and the other at Christmas. Daily production is about 50,000 tons of ore, averaging 0.1 to 0.3% molybdenum, which means that each ton of ore contains about 2 to 6 pounds of metal. Last year the mine produced about 57 million pounds of molybdenum. The work force numbers around 3,100 employees, including about 200 in the electrical department, of whom about 24 to 30 are in management positions.

Electricity enters the property at 115 kV via several overhead lines. Two separate transformer banks step the voltage down from 115 kV to 13.8 kV. Both banks are connected delta-wye with a solidly-grounded neutral. The 13.8 kV distribution travels via overhead lines to several portals where it enters the mine. These overhead lines utilize a static wire, grounded at every pole and tied into the substation ground mat, for lightning protection. The overhead lines feed other substations or terminate in pot-heads for distribution via cable. Four separate 500 MCM cable circuits (two in each of two shafts) are protected by a disconnect switch and a circuit breaker, and supply power to the underground mine workings.

The underground mine has two major production levels. In addition, there is an IVL (intake ventilation lateral) level located 29 feet below each of the production levels. The two IVL levels are used to supply fresh air to the mine. All the 13.8 kV feeder cables extend down from the surface, in two different shafts, and extend horizontally through the mine from a central distribution point on the lower level.

These feeders branch upward or downward at intervals to supply various substations installed on the two production levels. The 13.8 kV cables are armored, and each phase conductor is individually shielded; the cable contains ground conductors as well.

There are three permanent substations on the upper level, each of which is mounted on a concrete pad and physically resembles an outdoor substation. The 13.8 kV feed passes through an air-break switch and a circuit breaker before reaching the step-down transformers, which are usually connected delta-delta. Two of the substations have both 13.8 kV/2400 V and 13.8 kV/480 V transformers, while the third has only 13.8 kV/480 V transformers. The ungrounded secondaries are equipped with ground-indicating lights to warn of phase-to-ground faults. Each 480 V circuit leaving the substation is equipped with a circuit breaker and protective relaying to provide tripping in the event of a short-circuit, overload, or ground fault. A typical 480 V feeder is composed of three single-conductor 500 MCM insulated cables, and may be 2000 to 3000 feet in length. This circuit is tapped at intervals to feed "switch vaults" or slusher motor control centers. Each switch vault contains two molded-case circuit breakers and two #5 magnetic starters equipped with overload protection. A small 277/120 V single-phase transformer is included to provide control power for the switch gear and an on-off switch for the slusher motor. From the switch vault, a 2/0 type G cable, containing three #6 ground conductors, extends to the slusher, a distance of about 25 to 50 feet. A two-conductor #12 cable also is used to feed the on-off switch on the machine. A bare #4 ground wire connects the slusher frame to the switch vault and also to the "drift ground" conductor.

The "drift ground" is an insulated 500 MCM cable which extends from the ground beds at the surface substations to every part of the mine. It is connected to the #4 ground conductors at all switch vaults, to all substation switchgear and metal housings, to the rail haulage tracks, the negative return at the trolley rectifiers, and to all air lines and water pipes. Almost everything inside the mine which is metallic, and anything which is electrically powered, is tied to the "drift ground" and hence to a ground bed on the surface.

The underground 2300 V lines are used for supplying power to large 500 and 1000 HP ventilation fans, and for operating the 60" gyratory crusher drive motor.

A series of resistivity measurements were performed underground, usually adjacent to a substation, or in the track entry on the side opposite from the substation. The standard Wenner array was used in each case, and the electrode spacing was held constant at three feet. Measured values of resistivity varied considerably, ranging from 128 ohm-feet to 809 ohm-feet, with an average of 408 ohm-feet. The mean value was obtained from a total of 8 different measurements, and indicates that the conductivity of the country rock underground is fairly high. The data is shown in Table A.29.

TABLE A.29. - Results of underground resistivity measurements, using Wenner Arrary and 3-foot electrode spacing

Location	Resistivity (Ω-feet)
Adjacent to 319 sub	138
Across drift from 319 sub	334
Adjacent to 311 sub	809
Across drift from 311 sub	337
Adjacent to 3110 sub	675
Across drift from 3110 sub	458
Adjacent to 629 C-raise sub	128
Adjacent to 629 2400 V sub	383

The open-pit section of the mine is supplied with electricity by two 13.8 kV/4160 V substations located outside the perimeter of the pit. Both transformers are connected delta-wye, and each has a load capacity of 5000 kVA. The neutral point on each transformer secondary is grounded through a resistor which is sized at 96 ohms to limit ground fault current to 25 A. Each secondary circuit is equipped with a circuit breaker which will trip under conditions of overload, short-circuit, or ground fault. Power enters and leaves these substations via overhead 4-wire circuits; the overhead ground conductors (static wires) on both the low side and high side are bonded to the substation ground mat and to pole grounds at each pole.

The overhead 4160 V distribution enters the pit and terminates at pole-mounted disconnects, where it joins a 1000-foot section of 8 kV shielded mine power feeder cable. This cable also terminates at pole-mounted disconnects, where it feeds one or two "skid breakers". A "skid breaker" is a rubber-tired or skid-mounted switch-house which is used to supply a loading shovel or blast-hole drill via a 1000 to 4000-foot length of SHD-GC cable. This switch-house contains disconnects, a circuit breaker (with ground fault, short-circuit, and overload protection), and an Ensign ground-check monitor. The trailing cables and all cable couplers are supported by saw horses. Mining equipment serving the pit includes four P & H 15 yd^3 model 2100 loading shovels, several Bucyrus-Erie model 48 R and 61 R drills, and 35 trucks, both 120-and 170-ton models. Resistivity surveys were performed at two different locations in the pit. The results, shown in Tables A.30 and A.31 indicate that the rock is a very poor conductor, with average resistivity values of 1350 ohm-feet and 7000 ohm-feet for the two locations.

TABLE A.30. - Resistivity survey in pit

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	1710
9	1300
27	1020

TABLE A.31. - Resistivity survey on an upper bench

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	7030
9	7010
27	6970

The molybdenum mill complex is quite large and is fed by five or more small 13.8 kV/480 V substations. Tables A.32 and A.33 give the outcome of resistivity surveys performed adjacent to two of these substations, and the data reveals excellent soil conductivity at these locales.

TABLE A.32. - Resistivity survey near mill substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	303
9	264
27	102

TABLE A.33. - Resistivity survey near fishing pond

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	716
9	442
27	280

Mine electrical personnel have their own Biddle earth tester, and had just finished measuring the resistance of all ground beds prior to our visit. Typical readings ranged from 0.5 ohm to 4 ohms, with a few measurements as high as 10 ohms or so. In all cases the tests were made with the ground bed connected.

It was stated that the number of state mine inspectors had been greatly reduced because the legislature felt MSHA was doing their work for them. Mine personnel stated that they preferred MESA, which made recommendations, to MSHA, which writes citations. Apparently the American Mining Congress, in conjunction with IEEE, has recently completed a review of Federal Register electrical laws in an attempt to make the Federal regulations

(1) clear and easy to understand (interpret),

(2) enforceable.

The mine electrical people were co-operative and helpful to us, and they seem to be both competent and dedicated to their work.

The last visit on our third trip was another molybdenum mine. The operation is composed of an underground molybdenum mine with three production levels and a processing mill. The mine uses the block-caving method of ore extraction. Total employment at the facility is about 2050, of whom 1500 work at the mine. Both mill and mine operate around the clock seven days a week, and ore production averages 35,000 tons per day.

Power for this operation is supplied by the local utility, which owns and maintains three 115 kV/13.8 kV substations to service the facility. All the 13.8 kV secondaries have their neutral points solidly grounded; protective equipment at the substations includes fuses on the high side and circuit breakers on the 13 kV transformer secondaries. Power is fed from the substations to several switchgear buildings via armored underground cables. Each cable consists of three shielded 500 MCM phase conductors and three interstitial ground wires. In the switchgear buildings are 13.8 kV busbars, fed through the main oil circuit breaker, which is equipped with ground fault and time-overcurrent protection. Branch circuit OCB's have time-delay, instantaneous and ground fault relaying. At the mill, 13 kV circuits, in underground cables, feed power to eleven 13.8 kV/480 V "unit load centers". Each load center has two 1250 kVA transformer banks, equipped with switches and fuses on the high side, and circuit breakers for the main feeder and branch feeders on the secondary. The transformers are connected delta-wye, with the neutral solidly grounded. The circuit breakers include tripping for instantaneous, time-delay, and ground fault conditions. The 13.8 kV switchgear building feeds three 13.8 kV/480 V pumphouse substations and two 2400 V unit load centers, whose switchgear is similar to that of the 480 V unit load centers. All step-down transformers are connected delta-wye and have solidly-grounded neutrals. The 2400 V load centers supply power to several pebble mills which perform the secondary grinding of the ore after primary grinding in ball mills. The final 13.8 kV mill circuit feeds six 3500 HP ball mill drive motors directly, without any step-down in voltage.

Two substations and a switchgear building provide the 13.8 kV electric power for the underground mine and its surface support facilities. There are three 13.8 kV/480 V substations which supply such loads as hot-water boilers, electric heaters, humidifiers, shops, and motor control centers. Each transformer is delta-wye connected, with a solid ground on the neutral. The primary side of the transformer circuit includes a switch and fuses, while circuit breakers are used on the main and branch feeders of the 480 V secondary. Time-delay, instantaneous, and ground fault tripping are used on the branch feeder OCB's; the main breaker is similar except that instantaneous tripping is omitted.

There are two large 13.8 kV/4160 V surface substations which feed high-horsepower motors driving the air compressors, hoists, and ventilation fans for the mine. These transformers are connected delta-wye, and the neutrals are resistance-grounded to limit ground fault current. The motor circuits are all fused and include extensive protective relaying.

Mine personnel have not made any ground bed resistance measurements, although they have purchased a Bison instrument to make the tests. All ground beds, building steel, motor frames, and switchgear are tied together by cable ground conductors or external ground wires, and mine personnel stated that they will not disconnect any grounds to make resistance checks. WVU researchers asked for and received permission to attempt earth resistance measurements at several locations on the periphery of the all-in-one ground bed. Our battery-powered Biddle instrument and the mine's Bison were both used for the tests. The structure ground bed at the chlorinator building yielded an earth resistance value of 2.10 ohms (Biddle) and 1.78 ohms (Bison) with the remote current electrode spaced at 150 feet. A resistivity survey performed nearby showed that the soil in this area is a relatively poor conductor, (see Table A.34), averaging about 2000 ohm-feet resistivity. Resistance measurements near the flume house yielded values of 5.25 ohms (Biddle) and 5.3 ohms (Bison) for the structure ground, using a current-electrode spacing of 100 feet. Table A.35 contains the data from a resistivity survey taken nearby, and the figures here are somewhat lower than those found at the chlorinator building, being in the neighborhood of 650 to 1200 ohm-feet. A final earth resistance check, made from the fuel storage depot substation fence, produced the lowest values of earth resistance, 0.49 ohms (Biddle) and 0.47 ohms (Bison). The soil resistivity numbers, shown in Table A.36, were also the lowest found on the surface, ranging from 150 to 530 ohm-feet. Mine electrical engineers were interested in the resistivity of the country rock found in the vicinity of the surface facilities, so a resistivity test was made at the base of a steep, nearly-vertical rock face east of the batch plant. Because of space limitations and the danger of being injured by falling rocks, only a single measurement was taken. With the electrodes of the Wenner array spaced 10 feet apart, a figure of 1790 ohm-feet was obtained for the rock resistivity.

There are twelve substations located underground which supply power to the mine workings. Four are rectifier substations, equipped with delta-wye transformers whose neutrals are solidly grounded. The high-side protection

TABLE A.34. - Resistivity survey taken near chlorinator building

Electrode spacing (ft)	Soil resistivity (Ω-ft)	
	Biddle	Bison
3	2150	-
9	2000	-
27	1370	1160

TABLE A.35. - Resistivity survey taken near flume house

Electrode spacing (ft)	Soil resistivity (Ω-ft)	
	Biddle	Bison
3	654	660
9	939	945
27	1200	1200

TABLE A.36. - Resistivity survey taken near fuel storage depot substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)	
	Biddle	(Bison)
3	524	528
9	231	240
27	153	148

includes fused switches and 13.8 kV circuit breakers, while the trolley-wire output circuits are equipped with dc circuit breakers. Of the remaining eight underground substations, two have 13.8 kV/480 V and 13.8 kV/4160 V transformers, while the others have 13.8 kV/480 V exclusively. The 13.8 kV/480 V units are delta-wye connected with solidly-grounded neturals. Main 480 V feeders have circuit breakers set up for time-delay and ground fault tripping, while the OCB's on the branch feeders also have instantaneous tripping.

An individual 480 V branch circuit consists of a three-conductor cable plus the drift ground, which is a 500 MCM insulated (or bare) copper cable. All underground switch-gear, motor frames, and electrical equipment housings, as well as the negative trolley supply and haulage track, are connected to this drift ground. The 480 V cables are sized according to the current drain of their expected loads. Each branch circuit from the feeder is made through a fused switch; typical loads include pumps, fans, and lights. There are some 277 V/120 V transformers which power fluorescent lights, but most illumination is from 277 V mercury-vapor bulbs. The mine uses a tremendous amount of diesel-powered equipment, including trucks, tractors, load-haul-dump (LHD) units, road graders, etc. As a result there are only a few electrically-operated jumbo drills and mucking machines in use.

A few tests were made underground to determine soil resistivity and ground bed resistance, using the Bison instrument belonging to the mine electrical department. Only a limited number of measurements were taken due to cramped quarters in the underground workings and heavy traffic in the drifts. The substation ground bed at one substation on the 7500 level had an earth resistance of 26.4 ohms, which is a little high. The soil resistivity was 756 ohm-feet and 1660 ohm-feet respectively for electrode spacings of three and nine feet. The site of a new proposed substation on the 7700 level was visited; the heavy copper wire used for the substation ground mat was in place, lying on the floor of the drift, but the concrete had not yet been poured. An earth-resistance test was therefore not attempted, but the soil resistivity was measured at the ground-mat location. For electrode spacings of three feet and nine feet, the resistivity values were 213 ohm-feet and 365 ohm-feet respectively. The soil (rock) in this area is somewhat more conductive than that at the previous substation, as may be seen from an examination of the data. A relatively untraveled drift was found near a storage area on the 7500 level, and a resistivity survey was performed there. The value for a three-foot electrode spacing was 636 ohm-feet, while 780 ohm-feet was obtained with a nine-foot spacing. Note that the first substation is also on the 7500 level, but the soil there is not nearly as conductive (at depth) as it is adjacent to the storage area.

A.9 SEVEN URANIUM MINES

This visit was to a southwestern mining complex which includes 7 underground uranium mines and a large mill for the processing of uranium ore. The total work force is about 1600, including 65 electricians, who extract and process 140,000 tons of ore (uranium oxide) per month, or about 1.7 million tons per year. Energy consumption amounts to 132 million kilowatthours per year.

The utility provides power at 115 kV, which is transformed to 13.8 kV at two surface substations and routed to the mines and mill via overhead lines at this voltage level. Each mine then has its own individual substation (or several if the mine is large) where the power is again transformed down to utilization level. Typically, a delta-wye transformer is used to reduce the incoming 13.8 kV to 4160 V. The neutral point is connected to ground via a current-limiting resistor rated at 50 amperes. Instantaneous and time-overcurrent protection, as well as ground fault tripping is provided for the 4160 V feed, which enters the mine via a borehole cable.

Underground, smaller power centers are located in strategic areas which transform the 4160 V down to 480 V, again using a delta-primary and wye-secondary. The neutral grounding resistor is sized to limit fault current to 15 amperes. Instantaneous and time-overcurrent protection is again provided, as well as a balanced-flux CT set to trip at 5 A of ground current, which is a state law. The 480-V system feeds many 20 HP to 60 HP underground motor loads such as slushers, fans, and pumps, and is a 4-wire system, with 3 phase conductors, and a ground conductor bonded to each motor frame. The roof and ribs of the mine are covered with metallic mesh to provide ground control, i.e., to prevent loose or poorly-supported rocks from falling onto the mine personnel. The mesh is held in place by roof bolts, which are the primary means of roof support. This entire network of mesh and roof bolts is also tied to the ground system, and each underground power center and motor load is bonded to it. The ground conductors in the 4160 V mine feeder cable carry this ground to the surface where it joins the ground beds at the 13.8 kV/4160 V substations. The static wires and pole grounds on the overhead 13.8 kV distribution are connected to this ground, as are the ground beds at the 115 kV/13.8 kV substations with their associated pole grounds and static wires. It can be seen that, in effect, all ground connections are tied together to form one enormous "distributed ground bed", which even includes metallic borehole casings and shaft linings.

Lightning arrestors are used at the 115 kV, 13.8 kV, and 4160 V levels, with the 4160 V arrestors mounted inside the substation near the borehole where the 4160 V feeder cable goes underground. No problems with lightning have been experienced. New underground 480 V equipment is provided with pilot-wire, impedance-type ground check monitors, but only the length of cable back to the first junction box is monitored.

All seven mines have fairly similar power systems. The uranium mill is fed by a 13.8 kV/480 V substation, delta primary and wye secondary, with the neutral solidly grounded. The 480 V distribution is carried through the plant on a 3-wire system inside metal conduit. This conduit is joined by wire nuts or couplers, and wire jumpers are used if the conduit is discontinuous. In addition, each motor frame is bonded to the steel frame of the building, which is tied to a copper ground mesh underneath the plant. Two 450 HP synchronous motors driving rod mills are fed through a separate 13.8 kV/2300 V delta-delta transformer. These motors are equipped with a GE high-resistance ground and pulsing system to detect and locate ground faults. Thus, the mill ground system is also tied into that of all the underground mines. Ground bed resistances are checked at least once a year, using a Biddle instrument and the fall-of-potential technique. It was stated that the instrument readings seemed to be the same no matter where the electrodes were placed, which is probably due to the fact that the mine personnel were unable to escape from the area of influence surrounding such an enormous distributed ground bed.

The biggest difficulty experienced by mine electrical personnel is in the interpretation of CFR 57.12-28, in regard to the periodic testing of ground beds. With some 60,000 connected horsepower, most of it in 20 or 30 HP loads, should they treat each motor's connection to earth as a separate ground bed? If so, this would require a tremendous amount of man-hours, and would produce hundreds of redundant measurements in view of the single enormous "ground grid". Personnel at the mine would also like a single, coherent set of understandable regulations which they could read and follow, and which would not be subject to interpretation by various inspectors.

At mine #1, a "split bolt" was cut free of the wire mesh supporting the roof and thereby isolated from the remainder of the ground system. The bolt, which was 4 feet long, has an earth resistance of 21.6 ohms. A nearby bolt, which was connected (through the steel mesh) to the ground system, showed an earth resistance of 0.45 Ω. In contrast, an isolated 6 foot conventional (expansion shell) roof bolt measured about 214 Ω for its earth resistance. The soil resistivity in the area was 50.3 Ω-ft., as measured in a Wenner array at 10 foot spacing. In another area of the mine, an isolated 6' conventional roof bolt was tested, and a resistance of 70.6 Ω was found, while a similar bolt tied to the steel mesh system showed a resistance of 0.26 Ω. The resistivity of the soil in this part of the mine, measured at 10 foot spacing, was 14.4 Ω-ft, which is very low. Two-terminal resistance measurements between a grounded switchbox and the haulage track yielded a value of 1 Ω, while the resistance between the switchbox and a roof bolt was 0.5 Ω, and the resistance between the switchbox and a water pipe was 0.3 Ω. All of these results indicate that the various metallic structures and equipment in the mine are essentially tied together.

Also at mine #1, the ground bed at the substation feeding borehole #11 was tested, and its resistance was measured at 0.48 Ω. A Wenner resistivity survey was also performed, and the results showed a low soil resistivity with the conductivity increasing at greater soil depths. The data is given in Table A.37.

A similar set of tests were performed at the mine #2 substation, where the ground bed resistance was measured at 2.03 Ω. Resistivity data taken at this site, shown in Table A.38, reveals that the soil in this area is even more conductive than that found at mine #1, with the conductivity again increasing at greater soil depths.

A series of tests were made in the underground working stopes at mine #3. A 30 HP slusher measured 3.03 Ω earth resistance when isolated from the power system ground, and only 0.65 Ω when re-connected to the grounding system. The resistance of an isolated 6 foot split bolt was measured at 22 Ω, while another bolt connected to the wire mesh ground system showed a resistance of 0.7 Ω. A Wenner soil resistivity test, at 10 foot electrode spacing, yielded a value of 96 Ω-ft, indicating that the soil is highly conductive.

A resistance measurement was performed on the substation ground bed at a vent hole of mine #3. This vent hole has a metallic casing which is 48" in diameter and extends down 700 feet to the mine workings. The casing is interconnected to the remainder of the mine ground system, but tests with the casing both isolated from and tied into the mine ground system yielded identical earth resistance values of 0.19 Ω. A resistivity survey of soil in the vicinity of the substation yielded the data shown in Table A.39. As in the other locales investigated in this report, the soil resistivity is low, and decreases at increasing soil depths. The resistivity figures shown in the table were obtained from a four-probe Wenner array except for the 270-foot figure, which was derived from a modified (Hill) method.

It should be noted that many of the resistance measurements were made inside the "area of influence" of the single distributed ground bed, especially those tests which were made underground. However, in all cases, the data points seemed to follow the classic fall-of-potential curve, which was the method used to perform the tests.

TABLE A.37. - Soil resistivity near borehole at mine #1

Electrode spacing (ft)	Resistivity (Ω-ft)
10	104
30	224
90	147

TABLE A.38. - Soil resistivity near mine #2 substation

Electrode spacing (ft)	Resistivity (Ω-ft)
10	104
30	85
90	79

TABLE A.39. - Soil resistivity near vent hole substation, mine #3

Electrode spacing (ft)	Resistivity (Ω-ft)
10	298
30	170
90	124
270	51

A.10 SOUTHWESTERN COPPER MINE

On November 14 and 15, 1979, a visit was made to a large southwestern open-pit copper mine. Several open pits, located relatively near to each other, are under development, with production currently at 19,000 tons of ore per day. The mine employs about 230 workers, including 7 electricians and one apprentice electrician. All the electrical personnel work on day shift except a single electrician who is on second shift.

A single large substation transforms incoming power at 115 kV down to 22.9 kV. Power is distributed at this level to several secondary substations which step the voltage down to either 4160 V (60 Hz) or 2300 V (25 Hz). The 25 Hz power is used to feed several very old 25 Hz shovels which are still in use. Large "frequency changer" houses containing MG sets are fed by the primary substation to produce 25 Hz power which then supplies the 25 Hz substations. All the secondary substations use resistance-grounded neutrals on their secondaries; the 25 Hz (2300 V) subs are delta-delta with zig-zag transformers and the 60 Hz (4160 V) subs are delta-wye connected. These substations have separate safety and station ground beds, although in earlier years a single (common) ground bed was used. The 3 phase conductors and the ground wire are carried on wooden poles from the substations into the pit, where the pole lines terminate in small switch-houses. The ground conductor serves as the static wire for the overhead distribution, and most of the poles have 8 foot ground rods, driven at their bases, which are connected to the static wire. Each switch-house also has a ground bed consisting of a 30 to 35-foot borehole which contains a #4 copper cable. The borehole is then filled with copper sulfate, coke, and water. This borehole ground bed is connected to the ground conductor (static wire) coming from the substation, to the metal switch-house itself, and to the ground conductors in the trailing cable leading to the electric shovel. The safety ground bed at each substation is checked once a year, while the borehole grounds are examined every 6 months or whenever the switch-house is moved. An Associated Research "Vibroground" earth tester is used with the fall-of-potential technique to measure the earth resistance of ground beds, and each bed must measure 5 Ω or less to be judged satisfactory by mine personnel.

Each switch-house includes circuitry to protect against short-circuits and ground faults, while the substations are equipped to handle overcurrent, short-circuit, and ground fault tripping. The shovels themselves have under-voltage releases on-board, and the newest switch-house, which feeds 3 shovels, is equipped with ground-check monitors. The trailing cables which are monitored are type SHD-GC, while the remainder are SHD. Mine personnel stated that 5 additional ground-check monitors would be required to give complete protection for the company's 8 shovels, at an estimated cost of $1200 per unit.

Lightning arrestors are used at all levels of voltage distribution, and some troubles are experienced with lightning surges "blowing off insulators" during the summer months, especially July.

At this mine, the connections of the trailing cable ground conductors at the machine frame are inspected, both visually and mechanically, every 3 months. This is an excellent idea, and one that has not been generally practiced by the industry as a whole.

Mine officials felt that "a set of standards that everyone can go by" was badly needed in order to end the present confusion caused by a lack of coherent regulations. These men stated that they were willing to fulfill any reasonable request which would increase the safety and reliability.

Measurements

The most recent modification made to the mine electrical system was the installation of safety ground beds at each substation. In earlier years, the station ground, which consists of a mesh or grid beneath the substation, was also used as the safety ground bed. Present practice, however, is to install a separate safety ground bed, identical in construction to the switch-house ground bed (borehole) described earlier.

Measurement of ground bed resistance is also new to the mine personnel. One of the electricians remembered the Penn State team making resistance tests in the mid 1970's and remarked that "we didn't know what in the world they were doing, and now we do the same thing ourselves". The chief electrician allowed us to examine their records of ground bed resistance measurements, which dated from 1976 to 1979. These files contained 81 data entries, and all but 6 showed results of 5 Ω or less.

A.11 FIVE SOUTHEASTERN PHOSPHATE MINES

During the first week of December, 1979, a visit was made to the southeastern U. S. to visit a phosphate-mining complex composed of 3 surface mines, a central processing plant, and several smaller washing plants. The facilities are run 24 hours a day, 7 days a week, employing about 1600 people to produce an output of 40,000 tons per day. The work force includes 62 electricians, 20 instrument men, and several electrical engineers who fill staff and supervisory positions. Only one electrician works on second shift, and none work on third shift or weekends, unless called out for emergencies. The utility bill for the entire operation is about $2.5 million per month, indicating a considerable usage of electric power.

A substation transforms the utility feed from 69 kV to 2300 V for use in the main processing plant. The transformer is connected delta-delta, and a ground conductor originating at the substation ground bed is carried with the 2300 V phase conductors. Balanced-flux or "donut" current transformers monitor the 2300 V circuits, which are carried underground from the substation to the plant by shielded cables. Each building in the plant has a steel framework which is tied to the substation ground bed via the shielded cables. Inside the plant, several smaller power centers transform the 2300 V supply down to 480 V for use by hundreds of low-horsepower motor loads. The power centers are again delta-delta connected, and a ground conductor is carried along with the phase wires to facilitate motor grounding. In addition, each motor frame is tied to the steel frame of the building, providing an alternate path back to the substation ground bed. Donut current transformers are used to provide protection for the 480 V feeders.

Each mine has a substation which steps the 69 kV utility supply down to 12 kV for distribution to the pit. The high side is always delta-connected, but the secondary may be either a delta or wye connection depending upon the individual mine. The secondary is left ungrounded in either case, although a ground wire is tied to the substation ground bed and then carried as a static wire with the 12 kV phase conductors. The 4-wire 12 kV system is carried on wooden poles and used to feed sled-mounted portable substations located throughout the mine area. These 12 kV lines are equipped with protective circuitry for short-circuit, over-current, and ground fault tripping. Every pole has a butt-ground which is tied to the static wire, and lightning arrestors are mounted at intervals of 1000 feet or less. This geographical region is the "lightning capital of the world", leading to lots of power outages and blown arrestors, but equipment damage is said to be minor.

All of the sled-mounted portable substations are 12 kV delta primary and 4160 V wye secondary. The neutral point of the secondary is grounded through a 96Ω resistor to limit the maximum available fault current to 25 A. An 8-foot ground rod is driven at each corner of the sled and connected to the overhead static wire to form the primary or "station" ground bed. A separate safety ground bed is established at a point 50 feet from the sled, and is used as the earth connection for the neutral resistor and all secondary loads. The 4160 V loads are all fed via shielded trailing cable, and may include

A. draglines varying in payload size from 21 to 50 cubic yards

B. pit cars, which are high-pressure hydraulic monitors and pumps

C. 1500 HP booster pumps which are used to propel the ore/water slurry from the pit car to the processing plant

Protective circuitry at the 4160 V level includes both instantaneous and time-overcurrent tripping on the phase conductors, and a CT on the ground wire set to trip instantaneously at 2.5 A of ground current. All relays are checked for correct operation at least once a year. Most trailing cables are 1000 feet in length (SHD-GC) and 2 or sometimes 3 sections of cable may be used to span the distance from the substation to the load. Metal junction boxes are used in lieu of cable couplers, because couplers are disliked both by the electricians and the electrical engineers. No ground check monitors are in use yet, but the company holds a patent on a ground check monitor design which they will use if GC monitoring becomes mandatory.

The company has an earth tester, and they have been making ground bed resistance measurements since mid-1979 or earlier. They use the fall-of-potential method, with the potential electrode at 62 feet and the current electrode at 100 feet from the ground bed under test. They strive to achieve a resistance of 5 Ω or less for substation ground beds, and 20 or less for safety ground beds.

There are no State electrical inspectors, and company personnel get along well with the Federal inspector. However, they feel that some of the Federal regulations, especially those on the continuity of motor ground conductors are unclear. In addition, it is felt that some Federal inspectors are not electrically oriented, and that only electrical inspectors should be used to evaluate electrical power systems.

Measurements

Two unused sleds (which formerly carried portable substations) were examined to determine their earth resistance "in situ" sitting on the earth. The base of each sled is approximately 10 feet by 17.5 feet, and a four-probe Wenner resistivity array, at 3-foot spacing, showed the soil to have a resistivity of 2680 Ω-feet, which is quite high. One sled had an earth resistance of 47.5 Ω while the other had a resistance of 91.2 Ω. Apparently the difference in these two values was due to the formation of rust on the bottom of the sleds, allowing one sled to make better contact with the soil than the other sled.

We then moved to an active mining area and measured the earth resistance of a Bucyrus-Erie 1250-B dragline which was undergoing repairs to the bucket. This dragline has a 35 cubic yard bucket, weighs about 7 million pounds, and rests upon a tub or base which is 53 ft. in diameter. Its earth resistance was only 1.28 Ω, an extremely low value. A soil resistivity survey was performed in the vicinity of the machine, as shown in Table A.40, and the soil proved to be highly conductive.

Another resistivity survey performed only a short distance away (2500 ft) on undisturbed soil yielded values of soil resistivity which were higher by an order of magnitude, as shown in Table A.41. A third survey was run on some very fine-grained sand tailings from the froth flotation cells at the processing plant. This material looked much like sand found at the beach, and its resistivity was quite high, which was as expected. This sand was located adjacent to a lake used for water storage, and the resistivity values measured at 9 and 27-foot spacings (see Table A.42) are probably due to the effects of water infiltration into the sand.

A visit to another mine yielded some additional resistivity data. Table A.43 shows the results of a resistivity survey performed near a portable substation feeding 3 booster pumps. In this area, the soil conductivity was quite high and rather uniform with depth. Only half a mile away, however, at the substation feeding the dragline, very high soil resistivities were measured, as shown by Table A.44. It is obvious that soil conductivity in this area is highly variable, and ranges from about 100 Ω-feet all the way up to 15,000 Ω-feet or more. Thus, care in the selection of locations for substations can lead to greatly reduced effort in achieving a satisfactory (low-resistance) ground bed.

On Friday, December 7, a visit was made to another southeastern phosphate mining operation.

This company has several mining and processing facilities, employing about 1000 employees to produce a total of 6 million tons per year of wet and dry phosphate rocks. The work force includes 35 electricians, of whom 34 are employed on day shift and one on second shift. It was stated that finding and retaining good electricians was a very difficult task in this part of the country.

The operation includes 6 mining sections, each of which utilizes 5 to 7 portable substations. Overhead lines carry power to these substations at 34 kV, using a static wire connected to driven-rod pole grounds for lightning protection. The 4160 V transformer secondaries are wye-connected with resistance-grounded neutrals, and each sled-mounted substation has a safety ground bed which is physically separated from the station ground bed by at least 50 feet. A Biddle instrument is used to measure the earth resistance of each ground bed, with 5 Ω being the upper limit for any bed. The 4160 V system is equipped with both instantaneous and time-overcurrent protection, and a balanced-flux ("window") CT is used to detect ground fault current. The neutral resistor is sized to limit ground fault current to a maximum of 50 A, and the donut CT is set to trip at 5 to 7 amperes. A typical ground bed consists of 12 rods driven in 4 sets, with each set composed of 3 rods spaced 6 to 10 feet apart in a triangular array.

In a few cases the 4160 V distribution is carried on overhead lines, and in these instances the ground conductor is carried overhead as a static wire while the ground-check conductor is carried beneath the three phase conductors. The majority of the 4160 V system is composed of 5 kV SHD trailing cables, some of which contain a ground-check conductor while others (pre-1971) do not. The total length of trailing cable used to feed a particular load is usually from 3000 to 4500 feet, and never more than 5000 feet. As was found in most phosphate mines, junction boxes are used in lieu of cable couplers.

The company presently has two ground check monitors in operation - one on a pump and another on a dragline. These monitors were made on-site by company personnel, at an approximate cost of $500 each, including installation. The monitor was designed with no solid-state components whatsoever, to avoid problems with lightning damage, and incorporates a 2-to-10 cycle time delay to preclude transient-induced nuisance tripping.

Mine personnel stated that MSHA often had non-electrical inspectors looking at electrical problems, and that in effect the MSHA people sometimes did not know what they were doing. Also, each inspector seems to have a different interpretation of the rules and regulations, because they are so poorly written, and as a result compliance is sometimes very difficult.

TABLE A.40. - Soil resistivity survey near B-E 1250-B dragline

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	135
9	116

TABLE A.41. - Soil resistivity survey near pumping station

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	4240
9	2540

TABLE A.42. - Soil resistivity on sand tailings

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	15400
9	7520
27	2600

TABLE A.43. - Soil resistivity survey near pumping station

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	116
9	76
27	100

TABLE A.44. - Soil resistivity survey near B-E 1260-W dragline

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	15500
9	16200
27	2540

A.12 EASTERN PHOSPHATE MINE

This east coast phosphate operation employes 1500 people, three shifts a day, seven days a week to produce phosphoric acid and fertilizer. The top 37 feet of overburden is dredged away and then draglines are used to remove 60 more feet of overburden and the phosphate ore.

The local utility supplies the plant with 105 kV which is transformed to 23 kV and distributed by a four wire pole line to the plant and to sled mounted portable substations. These substations power two 4160 V draglines, two 7200 draglines, the 4160 V dredge and other portable pumps. These portable substations are tied to ground rods around the sled perimeter, the substation fence and the pole line static wire (which is butt grounded at each pole and tied to the utility company ground at the main substation). The 7200 V equipment is fed by an 8 kV 300 MCM SHD-GC neoprene cable. The 4160 V machines are fed by a 5 kV 2-0 SHD-GC neoprene cable. The cables all have ground check equipment (usually G.E.) installed, although not all of it is currently operational. There are thirty electricians employed.

The CERTS was field tested at a portable substation feeding a 4160 V dragline. There was a large amount of 60 Hz ground current present which made unassisted Bison resistance measurements and low current level CERTS tests hard to null. The high level CERTS tests were much more stable. The unassisted Bison resistance measurements are given in Table A.45. The CERTS assisted measurements are given in Table A.46. The Bison was hard to null at the two lowest current levels because of stray currents. This gives the first two low level sets of results quationable validity. Resistance of the connected ground bed is .68 Ω.

TABLE A.45. - Unassisted Bison resistance measurements.

P_1 (ft)	2Π (V/I)	R(Ω)
10	2.50	.40
20	3.50	.56
30	5.00	.80
32	5.50	.87
40	9.70	1.55

TABLE A.46. - CERTS assisted resistance measurements.

Current Gain	Total Current (A)	Bed Current (A)	Bed Current / Total Current	Total Resistance	Connected Resistance
9.55	.275	.210	.817	.7453	.9122
18.64	.410	.331	.8073	.6137	.7602
26.36	.580	.465	.8017	.5301	.6862
36.36	.800	.660	.8250	.5474	.6635
45.45	1.00	.810	.8100	.5534	.6832

A.13 SOUTHWEST POTASH AND SAND MINES

The first facility visited during this trip to the Southwest was a large potash operation. The plant is composed of an underground mine and a surface mill which together employ about 400 people to produce approximately 9000 TPD of ore. The mine operates 24 hours a day, 7 days a week.

Electric power is provided by the utility at 69.5 kV, and this is stepped down to 4160 V in a large substation located at the edge of the property. The transformer is connected delta-wye with a resistance-grounded neutral on the secondary. This resistor has a value of 50 ohms, and serves to limit ground fault current to about 48 A. From the main substation, power is transmitted to the mine, the plant, and other surface facilities via buried cables carried in conduit.

The total surface motor load is about 10,000 kVA, mostly composed of small 480 V motors. The drive motor for the muck (ore) hoist and a large crusher motor in the plant are powered directly at 4160 V. A number of outdoor substations located adjacent to the plant are used to derive 480 V power from the buried 4160 V feeder cables. These subs are transformers connected delta-wye, with the neutral point on the secondary solidly grounded. From the substation, a 1600 A bus transmits power at 480 V to various motor control centers in the plant, and thence to each individual motor. All of these 480 V circuits consist of three phase conductors carried inside metal conduit. All motor frames and electrical conduit in the plant are tied to copper pig-tails which extend throughout the facility, and which are in turn connected to a ground mat buried beneath and within the building's foundation. This ground bed is also connected to the ground beds which are established at the 4160/480 V substations as well as to the ground grid at the 69 kV/4160 V substation.

A resistivity survey was performed on the soil near the main substation, and the results are shown in Table A.47. This data reveals that the desert soil is highly conductive, and measurements of the ground bed's earth resistance (by mine personnel) show readings of 0.5 ohm or less. State mine inspectors now require that annual checks be made of the earth resistance of all ground beds at the site, and mine personnel are now using equipment recently purchased for this purpose.

The area around the plant is subjected to a lot of lightning, but the damages each year are relatively minor. Solid-state controls at the deep-well water pumping stations are the most frequent casualties, along with an occasional blown arrestor. The 4160 V distribution circuits are not equipped with lightning arrestors at all.

From the main substation, power is carried underground via two parallel-connected 600 MCM MPC feeder cables. At the bottom of the shaft, 1600 feet below the surface, these cables enter a distribution station. This unit contains circuit breakers and protective relaying for the three main 4160 V cables (600 MCM) which leave the distribution box and carry power throughout the mine. Each of the three mine feeders is equipped with a watthour meter and ammeter, and is protected by instantaneous and time-overcurrent relays as well as a ground fault relay. The 4160 V cables in the mine are either

TABLE A.47. - Soil resistivity survey performed near main substation.

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	136
9	137
27	117

shielded or metal-clad for personnel safety. In years past, some difficulty was experienced with the 4160 V cables before the mine workers learned to properly stress-relieve the high-voltage cable at connectors and splice points. This is done either by hand-making the stress-relief or by using stress cones.

The underground mine workings extend for 9 miles; ore thickness is 4 1/2 feet, and its depth below the surface ranges from 1600 to 1900 feet. There are 8 working sections in the mine, but only 5 are active on any particular shift. Each section crew is composed of a face boss, continuous mine operator, and two shuttle car operators. The shuttle cars are 11-ton capacity diesel-powered units, and transport ore from the continuous miner to a feeder located at the tail piece on the panel belt. The continuous miner operates at 4160 V, and is connected to the section power center via a shielded trailing cable (SHD-GC) about 700 feet in length. There is no regular roof-bolting plan, but spot-bolting is performed if necessary, and is done by the maintenance crew during the down-shift. All other equipment on the section (roof bolter, pumps, fans, etc.) is powered at 480 V via trailing cables which are unshielded but include a ground conductor. All electrically-powered face equipment (both 4160 V and 480 V) is protected by ground-check monitors, and the plant manager is considering the use of shielded 480 V trailing cables in an effort to increase personnel safety.

Each underground working section is served by a power center fed from the 4160 V feeder cables. The power center has a primary circuit breaker which will trip in the event of ground fault or phase overcurrent (time and instantaneous) conditions. A 300 kVA transformer connected wye-delta feeds the 480 V loads. A neutral is derived by using a zig-zag transformer, and the neutral point is grounded through a 50 ohm resistor to provide current limiting during ground faults. The power center is able to feed five different 480 V circuits simultaneously, and also includes a 480/120 V transformer to supply lighting loads. Each 120 V outlet is equipped with very sensitive ground fault protection (GFI) and is set up to trip at 7.5 mA.

The mine has extensive shop and service facilities located underground. These are supplied by 4160/480 V transformers connected wye-delta with a zig-zag on the secondary. All lighting is provided by 277 V fluorescent bulbs, and 120 V convenience outlets (GFI protected) are also provided. The electrical shop is set up to test and adjust almost any type of electrical equipment, including circuit breakers and relays. All ground-circuit protective devices are checked once each month. The 4160 V trailing cables on the continuous miners are never handled while energized, except by using a "hot stick".

In summary, the electrical system at this facility seems very good in every respect, and mine management does whatever possible to promote safety.

The second stop on the trip to the Southwest was at another potash facility, composed of an underground mine and processing plant. This operation runs around the clock, 7 days a week, and about 650 employees produce a daily output of 15,000 tons.

Power is supplied to the facility at 69 kV, and is stepped down to 12.47 kV at the main substation. Several 12.47 circuits then feed smaller substations supplying the processing plant, surface facilities, hoist, and underground workings. The muck hoist and several 150-300 HP motors in the plant are fed at 2300 V derived from a 12.47 kV/2300 V transformer connected wye-delta. The 2300 V circuits feed these loads via a 3-wire distribution inside metal conduit. These circuits are protected by instantaneous and time-overcurrent relays, with grounding lights mounted at the motor control center to warn of a ground fault. Several substations around the plant are used to transform the 12.47 kV feed to 480 V for distribution to motor control centers. These substations have wye-delta transformers, and the 480 V distribution is via 3-wire circuits inside conduit or armored sheathing. All of these circuits also have grounding lights to indicate fault conditions. Plant lighting is provided by 480/120 V transformers, and consists mostly of fluorescent and sodium vapor units. The plant structure and all motor frames are connected to a copper ground mesh which runs under and around the buildings, and this mat in turn is bonded to a vertical cable which runs down a bore-hole to the water table. The underground portion of the electrical system is also bonded to this grid via the ground conductors inside the feeder cables. A survey of the soil outside the plant yielded the resistivity data shown in Table A.48. As can be seen from this chart, the soil in this area is highly conductive, and a ground bed established in this type of material should provide an excellent earth connection.

Power is fed to the underground workings via two 4/0 feeder cables connected in parallel. These extend 800 feet down from the surface to a 4160 V distribution center at the shaft bottom. The distribution center is equipped with a circuit breaker and disconnects, and supplies four 2/0 4160 V branch feeders, each of which can be isolated via fused disconnects. Power-factor-correction capacitors are also mounted at the distribution center. The branch feeder cables are rather old, and consist of 3 insulated phase conductors covered by a lead sheath (the ground conductor) wrapped in jute. However, these cables appear to be perfectly adequate in spite of their age. Each working section is equipped with a power center where the 4160 V feed is stepped down to 480 V for utilization by the face equipment. The 300 kVA transformer is connected wye-delta, and uses a zig-zag transformer to derive a neutral. The neutral point is grounded via a resistor which is sized to limit ground fault current to 10 A. From the power center, several 480 V circuits are available for feeding safety circuit centers (distribution boxes) located near the face. A length of cable mounted on a wooden cable reel is used to supply power from the power center to the distribution box, and the cable reel makes it easy to move up the distribution box as mining advances. Each 480 V feeder at the power center is equipped with a circuit breaker and a balanced-flux (donut) CT which is set up to trip instantaneously at a current level of 3 to 5 A.

Each distribution box is built with circuit breakers to handle one 300 A load (cutting machine or loading machine), one 150 A load (drill), and two or three 30 A loads (fans or utility circuit). All the face equipment is set up with special cable connectors, as are the distribution boxes, so that, for example, both a cutting machine and a loading machine cannot be powered simultaneously from the same distribution box. It is therefore necessary, in the course of normal mining operations, to have at least two distribution boxes on the section to supply all of the equipment. Trailing cables from the distribution box to the machine are only 225 feet long, and each machine is equipped with a company-built pilotless ground-check monitor.

The underground mine workings extend for approximately 10 miles, and encompass three levels of operation, located 800, 850, and 900 feet below the surface of the earth. Mining is done by the room and pillar method, with the rooms about 32 feet in width. The "conventional" method of mining is used, and face equipment includes a Joy loader, cutting machine, and dual-boom jumbo drill, as well as two Elmac diesel-powered ram cars for face haulage to the panel belt. Blast holes are loaded with ANFO (ammonium nitrate and fuel oil) and shot using detonating cord and electric caps.

Electrical practice at the mine appears to be quite good. Once each day a staged phase-to-ground fault is initiated at the distribution box, and the amount of current required to trip the circuit breaker at the power center is measured to make sure that it will open at 3 to 5 A. In addition to the power factor connection capacitors, lightning arrestors and surge suppression devices will soon be added to the main underground 4160 V feeders.

Mine management feels that the main MSHA thrust is on enforcement, whereas most accidents are directly related to worker carelessness. Thus MSHA should redirect its efforts toward training programs rather than constant inspections.

TABLE A.48. - Soil resistivity survey near administration building

Electrode separation (ft)	Soil resistivity (Ω-ft)
3	16.6
9	22.1
27	40.7

After leaving the potash mines, our next stop was at the offices of MSHA in Phoenix, Arizona to meet Special Investigator Clarence Ellis, who is a mine inspector for MSHA. He arranged for visits to four different sand and gravel operations in Maricopa County, and accompanied the field investigators to each locale. All of these facilities use diesel-powered shovels or front-end loaders to extract sand and gravel directly from the normally-dry river beds which traverse the Phoenix area. The plants consist of a series of crushers, conveyor belts, shaking screens, and mobile stacker-conveyors which are utilized to liberate, size, separate, and stockpile the various sand and (mostly) gravel products. These raw materials are used in the construction of roads, sidewalks, and buildings of all types.

The first facility visited was owned by a large concrete-manufacturing firm. About 145 employees produce 350 TPH from a plant which operates around the clock, seven days a week.

Power is purchased from the local utility which supplies everything down to the motor control centers. A local electrical contractor installed the motor control centers and their associated circuitry, and as a result we were able to acquire most of our data only from direct observation. Electricity enters the property via a 4-wire overhead system, which feeds three single-phase pole-mounted transformers via a set of disconnects. These transformers are connected delta-wye, with a solidly-grounded neutral on the secondary. The overhead static wire and a ground bed at the base of the utility pole are connected to this neutral point, and power is distributed to various small substations via a 4-wire underground conduit system.

Located at various points throughout the plant are several transformers (pad-mounted and totally sealed) which step down the supply voltage from the main substation to 220 V for the motor control centers, one of which is situated immediately adjacent to each transformer. The motor control centers are equipped with protective circuitry and switch-gear for each motor load, as well as ground-indicator lights for each phase, leading one to suspect that the power supply transformer is ungrounded on the secondary. All motor-circuit distribution is via a 4-wire system carried in conduit or cable. All motor frames and metal structures are tied solidly together to a ground grid installed beneath each concrete transformer pad and building foundation. Each 120 V convenience outlet is of the three-wire (grounded) type, but these circuits are not equipped with GFI protection.

The results of a soil resistivity survey, taken near one of the small enclosed transformers, are shown in Table A.49. This data indicates that the soil here, composed entirely of fill material from the bed of the Salt River, is a very poor conductor.

TABLE A.49. - Soil resistivity survey near small enclosed substation

Electrode spacing (feet)	Soil resistivity (Ω-ft)
3	46,200
9	8,930
27	5,260

A plant owned by a large conglomerate was the second sand and gravel operation to be visited in the Phoenix area. An output of about 600 TPH is obtained from the plant, which operates 8 hours a day, 5 days a week, and employs 32 production workers.

The main substation is fed from a 4-wire 7200 V overhead system, and three old pad-mounted single-phase transformers are connected wye-delta to produce a 3-wire 480 V output which feeds several motor control centers via underground conduit. A ground bed beneath the substation is connected to the conduit, the high-side lightning arrestors and static wire, as well as to the equipment inside the substation. Ground-indicating lights for the outgoing 480 V feeders are mounted immediately adjacent to the substation fence. Table A.50 shows the results of a soil resistivity survey carried out near this substation, and reveals that the soil in this locality, adjacent to the river, is a very good conductor. This substation feeds a conventional motor control center (MCC), which is underlain by a ground bed and connected to it by an external ground wire. From the MCC, 4-wire circuits, either in insulated flexible cable or enclosed in conduit, carry power to the individual motor loads.

A second substation, similar to the first, supplies another motor control center which feeds the remainder of the plant. The transformers here, which step the 7200 V supply down to 480 V, are connected delta-wye, but the neutral point on the secondary is ungrounded. A three-wire circuit, equipped with ground-indicating lights, carries power to the MCC via underground conduit.

TABLE A.50. - Soil resistivity survey near substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	114
9	310
27	387

The third sand and gravel facility inspected was located adjacent to a river in west Phoenix. A total work force of 95 (which includes truck drivers and office personnel) is employed, and production averages 250 TPH from the 40 hours-per-week operation.

The three-wire overhead 12 kV feed terminates at three single-phase pole-mounted transformers, connected wye-delta, where it is stepped down to 480 V. Lightning arrestors on the high side are connected to a ground bed at the base of the utility pole, and this ground is carried with the three 480 V phase conductors to an adjacent motor control center (MCC) via conduit. From the MCC, various motor loads are fed through 4-wire cable enclosed in conduit. A second substation and MCC were examined. This one utilized a totally-enclosed transformer, with both primary and secondary feeders cased in buried conduit. The soil conductivity near this substation was fairly good, as can be confirmed by referring to the data given in Table A.51. As before, conduit-enclosed 4-conductor cables were utilized for power transfer from the MCC to all motor loads. All motor frames were tied together, and to an earth connection either at the motor control center or transformer (or both).

TABLE A.51. - Soil resistivity survey near substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	467
9	515

The final stop on the trip to the southwest was in northwest Phoenix. This plant was very small, employing only six workers, and production figures were unknown. Power enters the plant site through a 4-wire overhead system at 12 kV, and is stepped down to 480 V by a bank of three single-phase pole-mounted transformers connected wye-delta. The overhead static wire connects to a ground bed at the base of the utility pole, and a ground conductor extends from this point to the frame of all motors via the MCC. Resistivity measurements, given in Table A.52, indicate that the soil here is highly conductive, more so than at any other site which we visited while in Phoenix.

TABLE A.52. - Soil resistivity survey near ground bed

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	92.7
9	166
27	178

All of the sand and gravel operations visited appear to be essentially alike. The 480 V (or 220 V) motor-utilization system is ungrounded to assure continuous operation even in the presence of ground faults. Ground indicating lights are used to warn when a fault has occurred, and trained personnel will then isolate and repair the defective circuit. All motor frames are tied together and connected to a ground bed in order to prevent dangerous touch potentials. In general, these plants have excellent electrical systems, and we were impressed by the overall quality of the facilities.

A.14 TWO MIDWEST GYPSUM MINES

The first mine visited was an underground mine in the Midwest. The facility also includes a screen plant and a plant for making wallboard and bagged plaster. The visitation concentrated on the mine.

The mine produces approximately 1600 tons per day of gypsum rock from a seam approximately 12 feet thick. The mine is entered through a slope which is 2200 feet long, extending some 500 feet under the surface of the earth. Mining is carried out by the room and pillar method, using a conventional mining technique of drilling, blasting, and loading the material. There are 26 union employees and one foreman underground, working a single shift. The mine has one electrician and an electrician's helper underground.

The facility has a main substation at which it receives power at 34.4 kV via pole line from the utility company. This is transformed to 4160 volts for distribution to several substations at the facility. A pole line carries power to the board plant substation, a short cable carries power to a nearby mill substation, and a second pole line carries power to the mine portal substation and mine substation.

The main substation incorporates a 200 A neutral grounding resistor and a ground trip system using a current transformer around the neutral lead. Their one-line diagram shows a disconnect switch in the neutral conductor between the transformer neutral and the grounding resistor. Mine personnel said it was used for maintenance purposes and was opened only once when lightning damaged the resistor.

An interesting feature of the grounding arrangement is the construction of "grounding pits" at several of the substations. Each pit began with a hole seven feet deep and seven feet in diameter. The bottom two feet was then filled with crushed coke and charcoal. A heavy star-shaped copper structure was then fabricated and laid on the fill. This structure was bonded to the station ground structure through three or four separate paths. The pit was then filled to grade level with a mixture of salt and earth. Although the pits were carefully located outside the perimeter of the substation, in each case they were bonded to the substation mat. Resistivity readings taken near the main substation were very low, as shown in Table A.53, indicating that the ground mat resistance is probably extremely low.

Power is fed to the mine at 4160 volts via a large (250 MCM) lead-sheathed feeder cable hung in the slope. This circuit had ground fault protection. At the bottom this cable fed a mine substation. This incorporated several 480 V circuits via unshielded cable to the underground crusher and to the shop as well as a feed-through at 4160 V to the several load centers located near working areas. This distribution cable was also unshielded. Each load center was a moderately permanent 4160/480 V substation (one we looked at was enclosed in a fence and had not been moved for 10 years). The 480 V was then fed through two parallel fused switches to open insulated 480 V lines (3 phase + 1 ground lines) suspended from the roof. We were told that the parallel feed would eventually be converted to a loop feed system, but it had existed in this configuration for some time.

The open 480 V lines were carried for up to 1500 feet toward the working face from the load centers. In the face area, taps were made to this open line, and short pieces of cable run to fused switch boxes mounted on the rib. These boxes then connected to in-line cable couplers to which machine trailing cables could be attached. Electric face equipment consists of a jumbo drill and a roof-bolting machine at each working section. Loading and hauling was done with diesel equipment.

The mine had quite a few incandescent lighting circuits. These were each fed with a 3-wire 220 V center-grounded single phase circuit. Bulb sockets were spliced to alternate pairs of wires to produce a balanced load.

Material was removed from the mine on a sloping conveyor belt, powered from the surface. Men and supplies rode a cable car raised by a manually controlled slope hoist.

All electrical grounds were tied together throughout the mine and surface facility. Cable grounds are not monitored, but the grounds are checked for continuity any time a cable is spliced or disconnected for relocation. All circuits are solidly grounded with two exceptions: 1) The main substation secondary is resistance grounded, as mentioned earlier. 2) One of the three load centers was ungrounded. It utilized some rather old single-phase transformers which had been connected Δ-Δ to obtain 480 V on what had been a 277-volt circuit. No ground fault indicator lamps were provided. We we informed that at times during wet weather employees had complained of mild shocks, but they had never measured more than 30 V to earth from a machine frame, even during cable faults. The electrician indicated that he had placed metal drag-straps on equipment to provide contact with the earth, and that this had eliminated the shock problem.

The mine uses electric blasting based on a permanent blast distribution circuit. In order to keep people away from the blast area, the blasters tie their lead wires from the blasting caps to a 600 V insulated pair strung along an entry. They move away from the area and connect the firing unit to the pair at some remote point, thus completing the circuit. This blasting cable is kept well-separated from the power lines.

Discussion with mine personnel indicated that they had experienced no problems with electricity except for the shock problem mentioned earlier, and some occasional shorts in cable couplers.

Mine mangement indicated that they did not have much trouble with MSHA electrical regulations or inspectors, but later in the same discussion questioned the real value of many of the regulations they had to or might have to meet.

TABLE A.53. - Resistivity near main substation

Spacing	Resistivity
2 ft	71 Ohm-ft
5 ft	63 Ohm-ft
20 ft	68 Ohm-ft

The second mine visited was also in the Midwest. Their production is approximately 600,000 tons of gypsum rock per year from which they make 500 million square feet of wallboard per year. The mine is highly automated, requiring only 27 employees underground spread over two shifts. The same seam is being mined as at the first mine, but in this case it is about 350 ft below the surface, and is reached by a vertical shaft.

Mining is by the room and pillar method using conventional techniques. The mine used to use electrical face equipment and still has a considerable amount of power apparatus underground. All face activities now use diesel equipment however, primarily because of its increased mobility. Two of the underground substations/power centers are nearly unloaded, and feed only lighting circuits.

Power is delivered to the main substation at 34.5 kV. It is stepped down to 4160 V by three 1250 kVA transformers connected Δ-Y. The neutral point of the transformers is connected to the station ground mat through a 200 A grounding resistor. The circuit has ground fault protection set at 50 A. High voltage (4160 V) circuits extend in several directions from the main sub. A pole-line circuit extends approximately 5000' over land to power fans and a hoist at a remote ventilation and escape shaft. A second circuit extends a short distance in an aerial cable tray to the hoist house. A third circuit extends about 1000 feet as a three conductor aerial cable to a 4160/4160 isolation transformer substation. The secondary is resistance-grounded to a separate safety ground bed established 50' outside the substation. A borehole cable carries the safety-grounded 4160 V underground. Several other 4160 V circuits leave the main substation to carry power to the kettle mill and board plant.

The hoist house contains a 4160 V/480 V substation which provides power for the hoist drive and some other equipment. It also provides one 480 V circuit which is carried down the mine shaft. This supplies power primarily to belt drives near the shaft. Circuits on this system are grounded to the substation ground mat (lightning arrestor ground) on the surface by ground conductors in the cables or run in parallel with the cable.

The hoist is a double-skip arrangement with a man-cage incorporated as part of one of the skips. Hoisting is controlled manually by controlling the rotation and speed of an ac motor by switching series resistance. The hoist operator can control access to the man cage with remotely operated locks. He can also sense whether or not the cage access door has been properly closed.

The crusher, crusher discharge belt, and some other small loads are powered via the separate borehole feed mentioned earlier. This is a safety grounded system, with a 4160 V/4160 V 750 kVA isolation transformer used to allow the separate ground. The neutral of the secondary is connected to a 25 ampere resistor which is then grounded at a point 50 ft from the substation. The safety ground bed is constructed of approximately 10 ground rods driven on 10' centers and interconnected, plus two sections of large diameter pipe buried in trenches. The electrician said they were attempting to achieve a 2 ohm bed, and actually achieved about 1.5 ohms. We measured the earth resistivity near this site, and found it to be quite low. The results are shown in Table A.54.

TABLE A.54. - Resistivity near safety ground bed

Spacing	Resistivity
2 ft	104 ohm-ft
5 ft	76 ohm-ft
20 ft	104 ohm-ft

The substation contains a ground fault unit as well as a ground check monitor for the borehole cable. The monitor is a simple continuity unit which circulates about 3 A of ac. This monitor has failed twice when a capacitor failed, but it has not been damaged by lightning or other transients. The borehole casing is bonded to the substation ground at the top. The borehole cable contains both a bare ground wire and an insulated ground wire. The bare ground wire and the cable armor are bonded to the substation ground and to the borehole casing and a junction box on bottom. The insulated ground is connected to the safety ground bed and is kept isolated. The substation ground terminates in the junction box, whereas the safety ground is carried to the mining equipment.

Power is fed to high voltage switchgear near the borehole bottom, which provides three distribution circuits, one to the crusher sub and two to the two portable subs. The two portable sub circuits are ground check monitored with dc monitors. A battery with trickle charger has been installed to circulate dc during short power outages so that the breakers will not trip from loss of monitor power.

The crusher sub contains a 4160 V delta to 480 V wye 300 kVA transformer with a 15 A neutral grounding resistor. This serves primarily the crusher, crusher feeder, and the crusher discharge belt. Since the tail frame of the main belt was in electrical contact with a belt suppled by a 480 V station-grounded power via the mine shaft, it was necessary to take special measures to maintain the isolated safety ground. This they did by cutting the belt frame in two places about 10' apart and inserting short insulating timber sections to break the continuity of the belt frame. The frame was cut twice so that a significant touch potential could not exist.

The two portable subs provide 480 V for mining equipment, but are almost unused. They are both resistance-grounded with ground fault protection. The mine was in the process of converting to pilot cable so that ground-check monitors could be installed on the face equipment when the decision was made to convert to diesel. Monitors were not installed.

The mine uses power factor correction capacitors at several places. These are switched in and out automatically as the load varies.

The crusher control panel incorporates a bank of signal lights and automatic shutdown features. If belt slip or other problem causes the system to shut down, the appropriate signal light remains lit until it is reset by the electrician. The electrical system in general is so well thought out that the mine functions with no electrical people at all. If there is a problem, they call down an electrician, which occurs a couple of times a month. The entire facility has 9 electricians, 7 of which are qualified to work in the mine.

The electrical people at this mine were some of the most knowledgeable we have ever talked to with respect to grounding and electrical practice in general.

A.15 NORTH-CENTRAL AND WESTERN U.S. MINES

The first visit on the fourth trip of the summer was to a surface gypsum mine and plant in the north-central U. S. About 1.3 million cubic yards of overburden are stripped each year to uncover 800,000 tons of gypsum (calcium sulfate) rock. The gypsum deposit is composed of three seams, each separated from the other by approximately five feet of shale. The upper seam, which is located 60 to 80 feet beneath the earth's surface, is 20 feet thick, and the two lower seams range from five to six feet in thickness. The overlying dirt is scraped and removed by bull-dozers, which push the material into belt-feeders; conveyor belts then transport the dirt across the pit for deposition in mined-out areas. Each layer of gypsum is then drilled and shot, using crawler-mounted diesel-powered wagon drills and ANFO explosives. The shale partings between seams are also shot and removed. Rubber-tired front-end loaders dump the blasted rock into Stamler feeder-breakers, similar to those found in underground coal mines, and thence onto a series of belt conveyors which transport the rock 3/4 of a mile to a dumping point near the plant. Several large storage piles are maintained at the dumping point, which provide surge capacity and act as a buffer between pit and mill. Two electric shovels with 4 yd^3 buckets, situated at the dumping point, load the gypsum rock into 50-ton dump trucks for the short haul to the primary crusher at the mill. Inside the mill are several stages of crushing and a screening plant to provide a variety of product sizes. Both the mine and the mill operate two shifts a day; the pit works five days per week while the plant works seven days each week. A total of fifty workers are employed, including two electricians and one electrical foreman.

Electric power enters the facility at 43 kV, and is stepped down to 2400 V at a utility-owned substation located on company property. A four-wire overhead line runs a short distance from the substation to a 2400 V switch-room. The static wire, which is carried beneath the 2400 V phase conductors, is tied to the ground bed at the substation and to a ground rod at the switch room. Since the utility transformer is connected delta-delta, a zig-zag transformer and neutral grounding resistor are also mounted at the switch room, with the resistor tied to the ground bed. The incoming 2400 V circuit on the load side of the grounding transformer is equipped with fused cut-outs and an oil circuit breaker, while each of the three 2400 V branch circuits includes an OCB. Protective relaying on the breakers consists of instantaneous, time-overcurrent, and ground-fault tripping. Two of the three branch circuits feed the pit via 4-wire overhead lines, with an 8-foot ground rod connected to the static wire at every second or third pole. The third branch circuit is an underground (and underwater) cable, consisting of three phase conductors and an external grounded shield, which supplies power to the off-shore loading facilities.

Adjacent to the switch room is a 1000 kVA transformer bank, connected delta-delta, which drops the 2400 V feed down to 480 V for use in the mill. All motor frames, building steel, and conduits are tied together, but there is no intentional connection between this "ground" and the 2400 V ground system. All the 480 V circuits have molded-case circuit breakers and appropriate protection.

The pit is supplied by two overhead 2400 V 3-phase lines, one made of copper and the other of aluminum. There are 18 "drop-points", equipped with cut-outs, where loads may be connected to these lines. From the cut-outs, a very short cable run enters a skid-mounted switch-house, which contains a circuit breaker equipped with short-circuit, time-over-current, and ground fault protection. Trailing cables from the switch house to the load are type SHD, rated at 5 kV to 8 kV, and are not more than 1000 feet long. Most of the motor loads are 250 to 500 hp conveyor belt drives, and the loading shovels are rated at 250 hp. There are also several small skid-mounted 2400 V/480 V substations in the pit. These are connected delta-delta, and include an integral zig-zag transformer, neutral grounding resistor, and protective relaying. A few of these units are equipped with built-in ground-check monitors, but the monitors are not used because the SHD cables do not have a ground-check conductor.

Each "drop-point" is equipped with lightning arrestors and an 8-foot ground rod at the base of the utility pole. Lightning does cause some circuit-breaker tripping, but so far there has been no equipment damage. In addition, there have been no apparent problems with transients as yet. The electrical department has a Biddle "Megger" and personnel have been making measurements of ground-bed resistance since 1978. These readings, taken once each year, are made with the ground bed disconnected, and vary from 0 ohms to 90 ohms depending upon location and time of year. MSHA officials have not yet asked to look at these records.

Two soil resistivity surveys were performed at the facility. The first one was carried out in undisturbed soil overlying the three gypsum beds, and the data is given in Table A.55. The approximate depth of overburden at this point is 75 feet, and it appears that the conductivity of the ore may account for the decrease in resistivity as the electrode spacing was increased from 75 to 100 feet. In any event, all three resistivity figures are quite low, indicating that the soil is an excellent conductor. Table A.56 shows the results of the second survey, which was taken near the main 43 kV/2400 V substation. Smaller electrode spacings were used because of space limitations, but in general the soil conductivity here was not as good as was found in the mine, although the numbers are not excessively high.

TABLE A.55. - Resistivty survey in undisturbed land overlying ore body

Electrode spacing (ft)	Soil resistivity (Ω-ft)
25	81.7
75	217
100	176

TABLE A.56. - Resistivity survey near main utility 43 kV/2400 V substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	692
9	628
27	251

Mine personnel stated that MSHA inspectors seemed to be knowledgeable, especially when compared with their OSHA counterparts. The MSHA people inspect twice each year; an inspection may include a team of specialists or a single general-purpose man. Three main points were expressed by mine management:

(1) MSHA and OSHA haven't reduced accidents at all.

(2) Safety is an attitude - it cannot be regulated or legislated into existence.

(3) Miner training is the only good thing to come from MSHA - 95% of all accidents are caused by unsafe acts, not unsafe conditions.

To conclude, we were quite favorably impressed by the electrical system at this facility, and by the attitude of the people in charge. Some good points were made in regard to the training of employees, and especially in the area of safety as a "state of mind".

The second facility to be visited on this trip was an underground copper mine. The operation is composed of a mine, mill, smelter, and power plant. Some 1200 employees produce about 11,500 tons of ore per day, mostly copper sulfides but including some native copper, from the underground workings. There are 52 electricians in the labor force, 18 of whom are assigned to duties on the surface, while the remainder work underground. All facilities work around the clock, seven days a week.

The company generates its own electric power from 4 coal-fired steam-driven generators, which operate at 13.8 kV. Distribution on the surface is mostly at the 13.8 kV level, either through cables or via overhead 4-wire circuits. The 13.8 kV cables are made up of 3 shielded phase conductors, three ground conductors, and an external metal sheath, either a solid welded outer jacket or a heavy wire mesh. All overhead lines are protected by a static wire which is mounted above the phase conductors, and the static wire is connected to a 10-foot copperweld ground rod installed at the base of each utility pole. All surface substations are equipped with station-class lightning arrestors on the high side, as is some of the underground switchgear, especially at shaft-bottom substations. Very little damage has been experienced due to lightning, although the local utility, whose 69 kV overhead line is not protected by static wires, has had a fair amount of trouble.

There are 80 to 85 substations serving the facility, in addition to underground power centers. Most of the surface load is fed at 480 V via 13.8 kV/480 V transformers, connected delta-wye with the neutral solidly grounded. The primary side is equipped (generally) with fused disconnects, and the secondary normally has a main circuit breaker as well as an individual molded-case circuit breaker for each branch circuit. Each CB is equipped with short-circuit, over-current, and ground-fault protection. Some large motor loads on the surface are powered at 4160 V by 13.8 kV/4160 V substations. The protective gear is quite similar to that provided in the 480 V substations, except that the neutral point on the 4160 V secondary is resistance-grounded to limit fault current.

Most underground distribution is at 4160 V, fed to the mine through boreholes via cable from surface-mounted 13.8 kV/4160 V substations. In a few cases power enters the mine at 13.8 kV, but is immediately stepped down to 4160 V by substations at the shaft bottom. All the 4160 V transformer secondaries are wye-connected with resistance-grounded neutrals. Shielded cable transmits the 4160 V power throughout the underground workings to skid-mounted power centers located in the various active parts of the mine. Each power center has a fused switch on the high side and individual molded-case circuit breakers for each branch circuit on the low side. The transformer is 4160 V/480 V, connected delta-wye with a resistance-grounded neutral. The 480 V breakers are equipped with over-current and short-circuit protection, and a balanced-flux CT which is set up to trip at 2 A of ground fault current. The ground-fault relays are checked once every 6 months by applying a phase-to-ground short at the load end of each circuit. Most underground 480 V loads consist of pumps, fans, conveyor belts, air compressors, and a few roof bolters. The face drills are air-powered, and haulage is performed by diesel-powered scoops. There is no dc trolley system. The 480 V cables are type G or GC, mostly #2 or #4 AWG, depending upon the current drain of the load. No ground check monitors are used. Each power center contains a small 480 V/110-220 V transformer for supplying lighting loads or hand tools, although these circuits do not have GFI protection.

All the surface substations have ground beds, and all grounds are deliberately tied together. This includes fences, building steel, motor frames, static wire pole-grounds, and substation beds. All underground electrically-powered machinery and switchgear is also connected to this unified ground system via the ground conductors in the power cables. A fall-of-potential measurement was made on the unified ground bed at the #3 Shaft substation; an earth resistance of 0.72 ohms was obtained with the current-electrode placed 200 feet from the bed, which was not disconnected for the test. A resistivity survey performed at this locale yielded the figures shown in Table A.57, indicating a high soil conductivity. An isolated 10-foot copperweld ground rod, newly-installed and not totally in contact with the soil, was measured and found to have an earth resistance of 12.4 ohms. A Wenner array with 10-foot electrode spacing showed that the soil resistivity in this area was only 94 ohm-feet, a very low value. Another soil resistivity survey was performed, this time adjacent to the tailings dam, and the results are given in Table A.58. Not only are the values here also quite low, but they are very similar to those found at the #3 Shaft substation (see Table A.57), indicating a remarkable uniformity of the soil strata over a wide area. Several attempts were made to measure soil resistivity underground. The first effort was a failure, as the mine floor was exceedingly hard and the WVU personnel were unable to drive electrodes into the floor. Two more attempts were successful, however, and the outcome of these tests is given in Tables A.59 and A.60. The values measured underground are not quite as low as those found on the surface, although in no case did the resistivity exceed 350 ohm-feet. This entire area seems to be an excellent conductor of electricity.

TABLE A.57. - Resistivity survey performed at #3 shaft substation

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	87.1
9	110
27	170

TABLE A.58. - Resistivity survey performed at tailings dam

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	124
9	131
27	170

TABLE A.59. - Resistivity survey performed underground

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	213
9	337

TABLE A.60. - Resistvity survey performed underground

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	115
9	252

Mine personnel stated that some MSHA inspectors seemed to be knowledgeable, while others were not. One or more Federal inspectors are on-site virtually all the time, and they often seem to dwell on nit-picky types of violations. When asked what value of ground-bed resistance was acceptable (in relation to 57.12-28), the MSHA officals said they didn't know, and as yet they are not enforcing 12-28. Problems exist in the wording of 12-69, regarding the separation of lightning-arrestor grounds from neutral ground beds. This seems to be saying that separate ground beds are required, and mine electrical personnel do not feel that this is a good idea. Considerable controversy exists pertaining to parts 12-82 and 12-83, which deal with "power lines" and "power cables". Other mine operators have voiced similar complaints when discussing this issue of power cables (or lines?) touching water pipes or air lines. As usual, the problem seems to rest upon the definition of specific terms, and the interpretation of certain phrases in the regulations.

The power system at this mine appears to be in excellent condition, and the electrical personnel are really "on top of the situation". They have even gone so far as to perform computer studies on their protective-relay coordination, while several mine operators have told us that they have no relay coordination. In summary, we were impressed by what we saw.

The third leg of our trip brought us to the offices of a large Western company. The company owns two dredges which are used in a gold-mining operation in the North. The dredges operate only during the warm part of the year, which is from four to six months in length. During this period of time the work force numbers around 250 people, including one electrician. During the cold months, one supervisor and five maintenance men perform repairs on the dredges and associated equipment, while the remainder of the labor force is laid off. Work proceeds around the clock seven days a week during the operating season, but only 40 hours per week during the winter. Average yearly production is between 5,000 and 10,000 ounces of gold.

Electric power is provided by five diesel-fired generators which operate at 2400 V. The electricity is transferred by cable to an adjacent substation, where the voltage is stepped up to 12 kV by several delta-delta transformer banks connected in parallel. The high-side switchgear includes oil circuit breakers equipped with short-circuit, overload, and ground-fault protection. Two pole lines, 18,000 feet and 19,000 feet long, transmit power at 12 kV from the substation to the two dredge ponds. Each pole line has a static wire (#2 AWG bare copper), which is mounted beneath the phase conductors and grounded at each pole via a 10-foot ground rod. The pole lines are equipped with lightning arrestors only at the substation, and the lightning arrestor ground bed is isolated from that of the substation, being physically separated from it by at least twenty feet.

At the edge of each dredge pond, the overhead line terminates and connects to a "shore cable" which feeds power to the dredge. The #6 dredge, which was recently renovated and updated electrically, is fed via 1200 feet of 15 kV SHD-GC cable mounted on buoys. The cable terminates on board the dredge at a fused disconnect switch, and a ground-check monitor is used to verify continuity of the ground conductor. Two parallel-connected transformer banks, wired delta-delta, step the incoming voltage down to 480 V for utilization by the four wound-rotor motors (40 to 250 HP) mounted on the dredge. Each motor is equipped with complete protective relaying, and the main distribution panel includes grounding lights for each phase. The other dredge, #5, is different electrically from its recently-renovated brother. Power is carried from shore via 1000 feet of cable, composed of three individual shielded single-phase conductors and an added ground conductor. There is no ground-check conductor, and ground-circuit continuity is not monitored. Electricity feeds through an isolating switch and oil circuit-breakers to two parallel-connected 12 kV/480 V transformers which are again wired delta-delta. A distribution board and several motor-control centers are used to supply more than twenty motors, ranging from 3 to 300 hp, which are mounted on this dredge.

In addition to feeding a dredge, each of the overhead lines supplies power to a pumping station. Each pumping station includes several 12 kV/480 V delta-delta transformers which drive pump motors rated at 200 hp to 250 hp. These pumps circulate a brine solution through the soil located ahead of the dredge pond, so that the permafrost can be thawed out. This enables the material to be mined the following year by the dredge. The overhead line feeding dredge #5 also supplies power to the personnel-support facilities located near the two dredges.

With the exception of the lightning-arrestor ground bed, all other metal structures are solidly tied together with copper wire and bonded to the substation ground bed. The dredge hulls, motor frames, and switchgear are all connected to the "shore-cable" ground conductors, and hence to the substation ground bed via the overhead static line. All the switchgear in the power plant, as well as the generator frames, are wired together and tied to the substation ground bed by heavy copper conductors. The bed at the substation is made up of a buried horizontal mesh which includes twelve 10-foot ground rods spaced at intervals around the perimeter.

This entire installation works well, as no complaints have been heard from on-site personnel in over five years. It is uncertain whether MSHA officials have ever made an inspection, but no citations have been received. It is important to note that the soil around the power plant and substation does not freeze, because of heat given off by the generators, but permafrost conditions exist elsewhere in the area except for those locales where thawing is done in advance of mining.

The last stop on this trip was at a trona mine and processing plant located in the West. The total work force is about 1400, and average mine production is 15,000 tons per day. Both the mine and mill operate around the clock, seven days a week. The mine workings are about 1600 feet beneath the earth's surface, and cover an area of about 18 square miles. There are 18 mining sections-11 conventional, 4 using drum-type continuous miners, and 3 using boring-head continuous miners. All mining is presently done by the room-and-pillar method of extraction, although a longwall section is planned for early 1981.

The facility produces about 80% of its own power through the use of six coal-fired generators. Three operate at 13.8 kV, while the other three are 4160 V units whose output is transformed up to 13.8 kV. The remaining 20% of the plant's demand is supplied by the local utility through a 34.5 kV/13.8 kV substation. All these power sources are tied into three main 13.8 kV busses, each of which is equipped with a zig-zag transformer and a neutral resistor sized to limit fault current to either 400 A or 600 A.

A total of 18 feeders are supplied from the 13.8 kV busses, but only four supply power to the mine; the remainder are for surface facilities. In addition, there are 15 feeders which branch out to other surface loads from the 4160 V generator bus. Motor loads on the surface are powered either at 480 V or 4160 V depending upon the horsepower ratings. Motors for some fans, pulverizers, compressors, and pumps, which range from 200 to 1500 hp, are fed directly at 4160 V through 13.8 kV/4160 V substations. The transformers are connected delta-wye, and the neutral is resistance-grounded to limit fault current to 25 A. Each motor has its own starter and is equipped with comprehensive protective relaying. Some of the older 480 V circuits in the plant are fed by 13.8 kV/480 V transformers connected wye-delta. In these cases, each phase is equipped with a voltmeter (rather than lights) to indicate the presence of a ground fault. The newer 13.8 kV/480 V substations are connected delta-wye with solidly-grounded neutrals. All the plant motors are fed from motor control centers, with the usual protective circuitry. The 480 V system is all fed by 4-wire circuits, so that each motor frame is tied solidly to a copper ground conductor. A network of 4/0 copper conductors is buried beneath each building in the plant and interconnected to all metal structures such as tanks, conveyor frameworks, I-beams, etc. The motor-frame grounding conductors and all switch-gear are bonded to this network, as are eight "ground wells". Each ground well is composed of a 30 foot section of 2-inch copper tubing placed in a 6-inch borehole which is filled with coke breeze.

The four 13.8 kV underground feeders are made of 15 kV armored cable. The armor is used as a ground conductor, and each phase conductor is shielded as well. All of these feeders are equipped with lightning arrestors and a disconnect mounted on the surface. At the shaft bottom, each feeder enters a 13.8 kV distribution center. This unit is fitted with a disconnect switch and a vacuum circuit breaker with over-current and ground-fault protection. Four branch circuits, each with its own breaker, radiate out from this point to distribute power at 13.8 kV from the shaft-bottom distribution centers. The power is carried via 15 kV pre-assembled "aerial cable", which is made from three shielded 4/0 phase conductors and a single 4/0 copperweld ground conductor. This aerial cable feeds a number of "block transformers", which are skid-mounted 13.8 kV/4160 V substations. The transformer is connected delta-wye, and a neutral resistor is used to limit fault current to 25 A. There is a disconnect switch on the high side, and an amp-guard starter used as a circuit breaker on the transformer secondary, with ground-fault and overcurrent protection.

From the "block transformer", two or three 4160 V branch circuits radiate outward to feed power centers in active working sections. These branch circuits are composed of 5 kV, 2/0 mine feeder cable, similar in construction to type SHD. The section power centers vary somewhat, depending upon the type of mining equipment used in that section, and will be described individually.

A conventional mining section consists of nine parallel entries, and utilizes the following equipment:

face drill (one @ 50 HP)
cutting machine (one @ 285 HP)
loading machine (one @ 200 HP)
roof bolters (two @ 50 HP)
shuttle cars (two @ 40 HP)
feeder-breaker (one @ 200 HP)
belt conveyor (one or two @ 60 HP)
auxiliary ventilation fans (nine @ 15 HP)

The power center has a single 750 kVA transformer, 13.8 kV/480 V, connected delta-wye with a 15 A or 25 A grounding resistor. There is a fused disconnect on the high side, and the low side has six 480 V outputs, each of which has a molded-case circuit breaker with ground fault and over current protection. Each circuit also has a ground-check monitor of the pilot-wire, impedance type. A length of 480 V cable, 2/0 type SHD-GC, runs about 300 feet from each of the six 480 V connectors on the power center to a "circuit center". Each circuit center, in turn, contains five molded-case circuit breakers and cable couplers. Each breaker has protection for short-circuit and ground fault conditions, and each circuit is again equipped with a ground-check monitor. From the circuit center, shielded 480 V trailing cables approximately 500 feet in length supply the various motor loads on the section. The power center also has a separate 4160/480 transformer to feed the conveyor belt drives, and a 100 kW rectifier for the 250 Vdc shuttle cars.

The equipment on a drum-type continuous miner section includes the following:

Joy 12 HM continuous miner (two @ 600 HP)
roof bolter (one @ 50 HP)
shuttle cars (two @ 40 HP)
feeder-breaker (one @ 200 HP)
belt conveyor (one @ 60 HP)
auxiliary ventilation fans (two to six @ 15 HP)

A power center for this type of mining section uses two 1000 kVA transformers, each with a 4160 V delta-connected primary and dual 995 V/480 V wye-connected secondaries. The 995 V secondary is rated at 600 kVA, to power the 12 HM miner, while the 480 V secondary is 400 kVA; both are equipped with resistance-grounded neutrals. The 480-V output from the power center feeds from two to four cable couplers; each circuit has a ground-check monitor and a molded-case circuit-breaker with ground-fault and the time-overcurrent tripping. As with the conventional section's power centers, each circuit feeds a "circuit center" equipped with five additional ground-check monitors, circuit-breakers, and cable couplers. There is also a separate belt transformer and a 100 kW rectifier for the buggies, which are fed through 500 feet of type G two-conductor flat trailing cable.

A section utilizing the boring-head type of continuous miner comprises the following equipment:

boring-head continuous miner (one @ 750 HP)
roof bolter (one @ 50 HP)
shuttle cars (two @ 40 HP)
feeder-breaker (one @ 200 HP)
belt conveyor (one @ 60 HP)
auxiliary ventilation fans (two to six @ 15 HP)

The power center on these sections is slightly different, because the continuous miner operates directly at 4160 V, fed through a circuit breaker with protective relaying for short-circuit, overcurrent, and ground fault conditions. A 500 kVA 4160 V/480 V transformer is used to supply the remaining loads. It is connected delta-wye with a resistance-grounded neutral. The power center has from two to four 480 V outlets, each of which feeds a "circuit center" with five additional couplers. All protective relaying and ground-check monitors are as previously described. There is a 100 kW rectifier for the shuttle cars, and a separate belt transformer.

Mine personnel state that it is hard to splice the shielded 480 V trailing cables, but proper training has enabled them to do a good job, and the shielding provides an extra margin of safety for the men. The resistance of each ground well is checked once a year, using an Associated

Research "Vibroground" with the fall-of-potential method. The series resistance from each motor frame to earth is also measured once a year. All the protective relaying is coordinated, from the generators to the underground face equipment. The area is subjected to a lot of lightning, but there has been only minor damage. All substations and power centers, even those underground, have lightning arrestors on the high side, and motors rated 100 HP or more have surge-packs on them to provide transient protection. Power-factor correction capacitors are being incorporated into the system, although inductors have also been added in some cases to eliminate troublesome harmonics.

Several attempts were made to ascertain the resistivity of underground strata by driving electrodes into the mine floor, but in each case the readings exceeded the maximum range of the instrument. Two resistivity surveys were performed on the surface, and the results are shown in Tables A.61 and A.62. The first set of numbers indicates a very high soil conductivity, while the second group shows the presence of a very high-resistivity layer of soil somewhere between three and nine feet beneath the surface. It is uncertain whether this drastic a variation in resistivity is possible, and it may be that there was some sort of problem within the test instrument. The overall electrical system at the mine and plant is very good, and the personnel are committed to safety.

TABLE A.61. - Resistivity survey near #3 shaft

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	74.8
9	23.2
27	22.1

TABLE A.62. - Resistivity survey near #7 shaft

Electrode spacing (ft)	Soil resistivity (Ω-ft)
3	87.3
9	14,300 ?
27	3730

A.16 NORTHEAST STONE QUARRIES

On November 27, 1979, a visit was made to a large quarry located in the northeast U. S. This facility produces from 3.5 to 4 million tons per year of limestone and dolomite. About 250 workers are employed at the mine and mill, including 6 electricians (3 on day shift, 2 on afternoon shift, and 1 on midnight shift).

Incoming power is supplied at 13.8 kV, and the total connected load for the entire facility is about 8-9 MVA. The utility feed is carried to six pit substations via overhead pole lines, which are protected by a static wire. Each substation has a primary or station ground bed consisting of 32 copper-clad rods, 5/8" diameter by 8' long, spaced 6' apart in a 4 x 8 array, and tied together with 4/0 cable. Bonds are Cadweld or brazed connections. The substations are all connected delta primary and wye secondary, and supply 2400 V power to the electric shovels used in the pit.

Four of the substations have no grounding on the secondary, and the 3 phase conductors are carried to the working location on pole lines. Each pole is set in a block of concrete, which rests on the quarry floor. When the lines must be moved, a front-end loader lifts and carries the pole and its concrete base as a unit. Every third pole is equipped with a set of fused cut-outs for the purpose of connecting the shovel trailing cable, which is either SHD-GC or SHD+GC. In addition, an 8' ground rod is driven at the base of the pole (if it has cut-outs) to provide an earth connection for the ground conductors in the trailing cable. The resistance of these pole grounds is not checked by mine personnel, so a number of them were checked by the WVU researchers. The first rod measured 145 Ω, but a soil resistivity survey was not made in this area. The second rod, in a different locale, showed a resistance of 3530 Ω, which is extremely high. The soil resistivity, which was tested using a Wenner Array with 10 foot spacing, was 19,900 Ω-ft, also a very high value. The last rod had an indicated earth resistance of 2440 Ω and the soil resistivity was 12,800 Ω-ft. All of these rods were located within the quarry itself, where the rock strata are very hard. It was difficult to pound stakes into the ground for the purposes of taking data, and mine personnel indicated that it was equally hard for them to install the pole grounds. This entire series of measurements may be incorrect, because the Biddle earth testers give results which are uncertain if the probe resistances are above 1500 Ω, which was almost surely the case for the second and third rods. Nevertheless, it is probable that, in both instances, the soil resistivity and ground rod resistance are quite high.

The fifth substation was equipped with a neutral grounding resistor (25 A) on the transformer secondary, and a separate safety ground bed, identical in construction to the main substation bed, was installed at a distance of 50' from the substation. Power is carried via pole lines to two switch-houses which each feed a single shovel, and the ground conductor is carried below the phase conductors. In addition, each switch-house is equipped with phase overcurrent and ground fault protection for the cables leading to the loading shovels.

The sixth substation has a separate safety ground bed installed 50' from the substation bed, but both are presently tied together. A ground conductor is carried overhead, beneath the phase wires, to the switch-house, and thence to the shovel frame via the trailing cable. However, the Y-point (neutral) of the transformer secondary is ungrounded as is the case with the first four substations.

The resistance of each substation ground bed is tested at least once a year, in accordance with CFR 57.12-28. A Biddle battery tester is used in conjunction with the fall-of-potential method. Two substation ground beds were checked by company personnel during our visit, and we simultaneously performed resistivity surveys near each of the two substations. The ground bed at number 3 substation measured 18.8 Ω, while the indicated soil resistivity was rather low, as shown by Table A.63.

TABLE A.63. - Soil resistivity survey near #3 substation

Electrode spacing (ft)	Resistivity (Ω-ft)
3	163
9	156
27	176

This substation is located outside the pit limits, and may have been built partially on fill dirt. It is therefore conceivable that the soil in which the ground bed was driven is markedly different from the soil where the resistivity was measured. In any event, mine personnel stated that they try to get all ground bed resistances below 5 Ω, so the value of nearly 19 Ω is a surprise.

At #8 substation, the ground bed resistance was much lower, only 3.96 Ω, and the soil resistivity was somewhat higher, as shown in Table A.64.

TABLE A.64. - Soil resistivity survey near #8 substation

Electrode spacing (ft)	Resistivity (Ω-ft)
3	120
9	208
27	450

Each substation is equipped with lightning arrestors, and the overhead pole lines in the quarry have arrestors on each pole equipped with cut-outs. These lightning arrestors are grounded to the 8' rods at the base of the pole. It was stated that about 6 of these 2400-V arrestors are lost each year, but no other lightning-related problems have been encountered.

One switch-house, made by Westinghouse, is equipped with a ground check monitor, and apparently it has caused no difficulties. Each shovel trailing cable is checked twice a year (with a Megger) and the ground connections at the shovel frame are also examined at these times. All cables are roughly 1000 ft in length. There have been no problems experienced with transients, and no one has been shocked "in a long time".

The crushing and grinding plant (mill) is fed from a separate 13.2 kV to 480 V substation, connected delta-delta. All buildings have grounding grids in their concrete footers, and each motor frame is tied to the footers as well as to the electrical conduit protecting the 480-V feeder.

Wire jumpers are used on flexible joints where the conduit is not continuous. Several ball mills in the plant are driven by 2300 V motors which are fed from a separate transformer, also connected delta-delta, and these motors have their frames grounded to a conductor which returns to the substation ground grid. Ground indicator lights are used to detect phase-to-frame faults.

Mine personnel stated that they get along well with the Federal electrical inspectors. However, the State inspectors (Dept. of Environmental Resources) try to keep up with the Federal men. Each time the "Feds" come, a few weeks later the DER will also show up, and stay for exactly the same number of days as MSHA. Although the DER has no electrical regulations, they will write up "violations" on other regulations if their electrical "recommendations" are not carried out. These recommendations are often inconsistent and are subject to the personality or interpretation of the individual State inspector.

A visit was made to a small northeast quarry on November 27, 1979. The mineral mined here is diabase trap, a very hard rock which is crushed and used for railroad ballast. The labor force includes 24 workers and 5 supervisors, and annual production is about 500,000 tons. Only one employee could be classed as an electrician, and his knowledge of the subject is limited. Almost all electrical work is performed by outside contractors.

Very little data on the power system was obtained, other than that which could be obtained by observation. The crushing plant is powered by an extremely old-looking substation, apparently 13.8 kV delta to 480 V delta to feed motor loads. Another substation feeds the single Marion M-111 shovel in the pit. This is a 13.8 kV delta to 2300 V delta system. The 2300 V feed is carried via a 3-wire overhead line to a small switch-house ("dog box") located on a hill overlooking the pit. Lightning arrestors on the last pole, adjacent to the switch-house, are connected to a ground rod at the base of the pole. This ground rod is connected in parallel to a ground rod just outside the switch-house. The ground conductors inside the SHD-type trailing cable which feeds the shovel are also connected to these ground rods.

The shovel was located on an upper bench near the perimeter of the pit, and a soil resistivity of 437 Ω-ft was measured there, with the electrode spacing at 20 feet. The actual earth resistance of the shovel was 21.7 Ω for a tread spacing of 11'8" center-to-center, and contact areas of 3 ft. by 14 ft. for each tread.

The resistivity of the quarry floor was very high, and increased with depth, as shown by Table A.65.

TABLE A.65. - Soil resistivity on quarry floor

Electrode spacing (ft)	Resistivity (Ω-ft)
3	2200
9	3090
27	6890

As previously mentioned, diabase trap is much harder than limestone (which is one reason for its use as railroad ballast) and it was quite difficult to drive stakes in this type of rock formation.

A small 480 V pump, located in one corner of the pit to provide water removal, was powered from the pit substation by a separate pole line. This overhead line terminated in a group of pole-top-mounted transformers, presumably 2300 V to 480 V, which then fed a trailing cable connected to the pump. The trailing cable ground conductors, the transformers, and their associated lightning arrestors were all tied to a driven rod at the base of the pole. The earth resistance of this rod was measured as 95.7 Ω, and a four-probe Wenner Array at 10 foot spacing indicated a soil resistivity of 6350 Ω-ft, which is quite high.

Mine personnel indicated that many inspectors have different interpretations of the various regulations, and there is no standardization. A practice which is OK on one visit may be a violation when the next inspector comes along. Also, the State inspectors (DER) want to know what the Federal inspectors (MSHA) looked at, and then they will disagree with MSHA. This competition between enforcement agencies is unfortunate, and seems to be counter-productive as well.

A.17 NEW ENGLAND QUARRIES

The first quarry visited on this trip to New England produces approximately 2400 cubic feet of salable dimensioned stone per week. The operation has a single large quarry pit with 8 derricks and a sawing mill which employs 15 persons. There are no actual electricians on the payroll.

The mill and derrick electrical distribution was a 2300 V three-wire Δ-Δ system (no static wire) owned by the local utility. Anywhere power is needed, a pole-mounted 3-phase step-down transformer is used. The utilization voltage is 220 V for derricks and air compressors although there is one 550 V derrick motor and one 440 V saw motor. There were lightning arrestors on only one substation. All of the machine frames in the quarry are bonded to an extensive network of buried air and water pipes. The pipe joints themselves are not bonded but metal clamps are used.

The pit itself has three feeds. Two 220 V pump motors, 1-100 HP and one 40 HP are fed by a G-GC cable from one engine house. Four 3/4 HP oil burner motors are fed by two Type S cables with a separate ground wires tied to water piping. There are no ground check monitors.

The protection circuitry was limited to fuses and circuit breakers on the equipment. Ground fault lights were present in each motor installation to signal ground fault but there was no tripping (ground fault).

A resistivity survey was taken near the saw mill as shown in Table A.66. It was impossible to drive electrodes into the quarry floor to take a resistivity survey.

TABLE A.66. - Mill site soil resistivity

Electrode spacing (ft)	Resistivity (Ω-ft)
3	5768
9	1628

The mine personnel indicated that the many MSHA inspectors have different interpretations of different regulations and there is no standardization. They also stated that the only time they have had lightning trouble was after they grounded all the pit machinery as requested by MSHA. State mine inspectors were no trouble.

The next quarry, also located in New England, produces approximately 300,000 cu.ft. of dimensioned stone per year. The operation employs 175 persons, two of them electricians, working 9 hr. shifts, 5 days a week.

A single 7200 delta - 600 delta substation provides power to the mill and air compressor station through a three-wire system with static line. The load is essentially two twenty-five HP hydraulic splitters, two 50 HP saw motors, and a 600 V-Δ to 120 V-Y connected transformer for lighting. Also three twenty-horsepower portable quarry pumps are fed from a 3-phase cable with internal grounds. All the machine frames are grounded to the static line which is also butt-grounded at each pole and tied to the substation ground.

The protection consists of appropriately sized breakers and fuses with ground fault lights on each circuit. There were no ground check monitors on the pump feeder cables. The derricks were all diesel powered.

No resistivity measurements were taken because of a lack of suitable areas to test.

The mine personnel indicated that some standardization of MSHA regulations and interpretations was necessary. Several questioned the effectiveness of MSHA in promoting safety. There has only been one electrical incident at the quarry in the last several years. It involved a slight shock when a motor frame was energized by mistake.

The last quarry, in southern New England, employs 175 persons. An electrical contractor has two full-time electricians on the property.

The main substation consists of an 11,500 V delta to 2300 V delta transformer bank. This 2300 V is distributed via 4-wire overhead line to the quarry and shops where it is transformed to 550 V delta. The mill has two 11,500 V delta to 550 V delta feeds. The 550 volts in further reduced to 220 volts or 110 volts for lighting and hand tools at various places on the property. The compressor plant has two 550 V/300 HP screw compressors and one 2300 V/400 HP Joy air compressor. One # 2 four-wire Type W cable feeds one 100 HP, one 60 HP and several smaller pumps in the quarry. There are also several 550 V/110 V lighting transformers in the pit. Protection is limited to properly sized fuses and breakers.

All steam, water and airlines are tied together and grounded at the water supply ponds. All machine frames, building frames, static wires and the fourth conductor in the pit cable are also tied into the water system. Each building also has at least one eight-foot ground rod connected to the steel framing. Measurements are taken on these rods by the contractor using a Tellurohm resistance tester after the rods are disconnected from the building.

Two sets of resistivity measurements were taken at the mill site and main substation. The results are shown in Table A.67 and Table A.68.

TABLE A.67. - Mill site resistivity

Electrode spacing (ft)	Resistivity (Ω-ft)
3	1200
9	540

TABLE A.68. - Quarry substation resistivity

Electrode spacing (ft)	Resistivity (Ω-ft)
3	1990
9	784
27	200

The electrical contractors indicated that MSHA has presented no problems. They were concerned however, with their ability to measure the ground bed resistance as required by MSHA. They had asked for assistance from MSHA with this measurement. One of the men who we talked to was intensely interested in the soil resistivity survey and asked a lot of questions about resistance and resistivity measurements.

A.18 CEMENT PLANT

On November 28, 1979, a visit was made to a large cement plant located in the northeast. A labor force of 200 workers produces about 650,000 tons per year of portland cement and mortar cement. The facility includes a rock quarry, which utilizes only diesel-powered equipment, and a very large plant for crushing, grinding, and bagging the cement products. There is one plant electrical engineer; 7 electricians, 4 motor tenders, and 3 instrumentation specialists are also employed.

The main substation transforms incoming power from 62.7 kV to 4160 V, using a delta-connected primary. The secondary is a resistance-grounded wye, and utilizes a separate safety ground bed. Both short-circuit and overcurrent protection is provided at the 4160 V level. The 4160 V distribution is carried to all the buildings in the plant, as well as to the primary crusher located in the pit, using either shielded underground cables or 4-wire overhead lines. Lightning arrestors are used on all overhead lines, and no problems have been experienced.

Seven small substations located throughout the plant are used to step the 4160 V distribution down to 480 V for supplying motor loads. Both the primary and secondary are delta-connected, using a 4-wire 480 V feed (3 phase wires plus one ground conductor). The ground conductor is tied to each motor frame as well as to the grounding grid which underlies each building. Some very large motors, which drive rod mills, are supplied directly at the 4160 V level.

With the advent of part 12.28 to the MSHA regulations, ground bed testing has become a part of the standard electrical practice at the plant. Personnel seemed unsure of the proper method for measuring ground bed resistance, so the WVU researchers demonstrated the fall-of-potential technique by testing the resistance of the ground bed at the primary crusher substation. This is a 4160 V to 480 V delta-delta transformer which feeds the pit crusher. The earth resistance of the ground bed was determined to be 0.32 Ω, using both the hand-cranked and battery-powered Biddle instruments. A resistivity test using the Wenner array at 10-foot spacing yielded a soil resistivity of only 76 Ω-ft, which was in keeping with the very low ground bed resistance. Surprisingly, the soil (rock) was quite hard, and considerable difficulty was encountered when driving the stakes into the ground. The WVU researchers expected to see very high resistivity figures, such as were experienced previously at the other quarries, but this surmise proved to be false. The plant electrical engineer had recently ordered a battery-powered Biddle instrument, but was concerned about its proper use. The many buildings at the plant are all quite close together, and their ground grids are rather large, which may make it impossible to place the remote current electrode far enough away to achieve accurate measurement data.

The plant manager and electrical engineer expressed their desire to adhere to all the MSHA regulations, but complained that MSHA does not provide them with any bulletins or information concerning the promulgation of new rules, changes in interpretation, etc. When the cement industry was policed by OSHA, that agency mailed all the requisite information to each plant operator, and it is felt that MSHA should do the same.

APPENDIX B

CERTS DEVICE DESCRIPTION

B.1 INTRODUCTION

For many years the mining industry has been interested in ways to measure the individual resistances of interconnected electrical power system ground beds without isolating each individual bed. Federal law now requires that ground beds be checked once each year, but specifies no clear method of doing so. Research at WVU has shown that it is possible to ascertain the individual ground bed resistances by applying a test current and measuring the individual ground bed currents. The Connected Electrode Resistance Test Set (CERTS) was developed to perform these measurements.

B.2 DESIGN OF CONNECTED ELECTRODE RESISTANCE TEST SET

The CERTS was designed to boost the current drive of a standard Bison Inc. Model 2350 Earth Resistivity Meter from 22 mA to 10 A in order to overcome very large 60 Hz stray currents and make the remote measurement of relatively small individual ground bed test currents easier. A block diagram of the CERTS is shown in Figure B.1. The Bison operation is normal except that the $\frac{2\Pi V}{I}$ reading must be multiplied by the current amplification fact K $(\frac{Io\ mA}{22\ mA})$. The amplified 11 Hz test current is read at each individual ground bed with a clamp-on Bell, Inc. Model CG-100 A Current Gun (Hall Effect current probe) and remote current meter. Given the individual current, ground resistivity and spacing of electrodes, the individual ground bed resistances can be calculated.

B.2.1 Remote Current Detector Design

The current detector consists of a Bell Current Gun, an 11 Hz low pass filter; precision rectifier and liquid crystal display digital voltmeter (LCD DVM). Synchronous detection methods were investigated, but the probability of large distances between the current amplifier and the individual ground beds produced long runs of connecting cable with inherent phase shift problems. These problems negated the benefits of synchronous demodulation.

The Bell Current Gun is a clamp-on device using a Hall-effect element to give a voltage waveform proportional ($\frac{10\ A}{V}$) to the current waveform. This voltage output is 11 Hz low-pass filtered to reduce the influence of large 60 Hz stray currents and amplified by 10 or 100 to give sensitivities of $\frac{1\ A}{V}$ and $\frac{.1\ A}{V}$ respectively. The filter response is shown in Figure B.2 and the filter schematic is presented in Figure B.3. The filter output is precision rectified by the circuit in Figure B.4 and the resulting dc voltage is displayed on a LCD DVM to give the magnitude of the 11 Hz test current detected by the clamp-on probe. Thus with test current injected at one

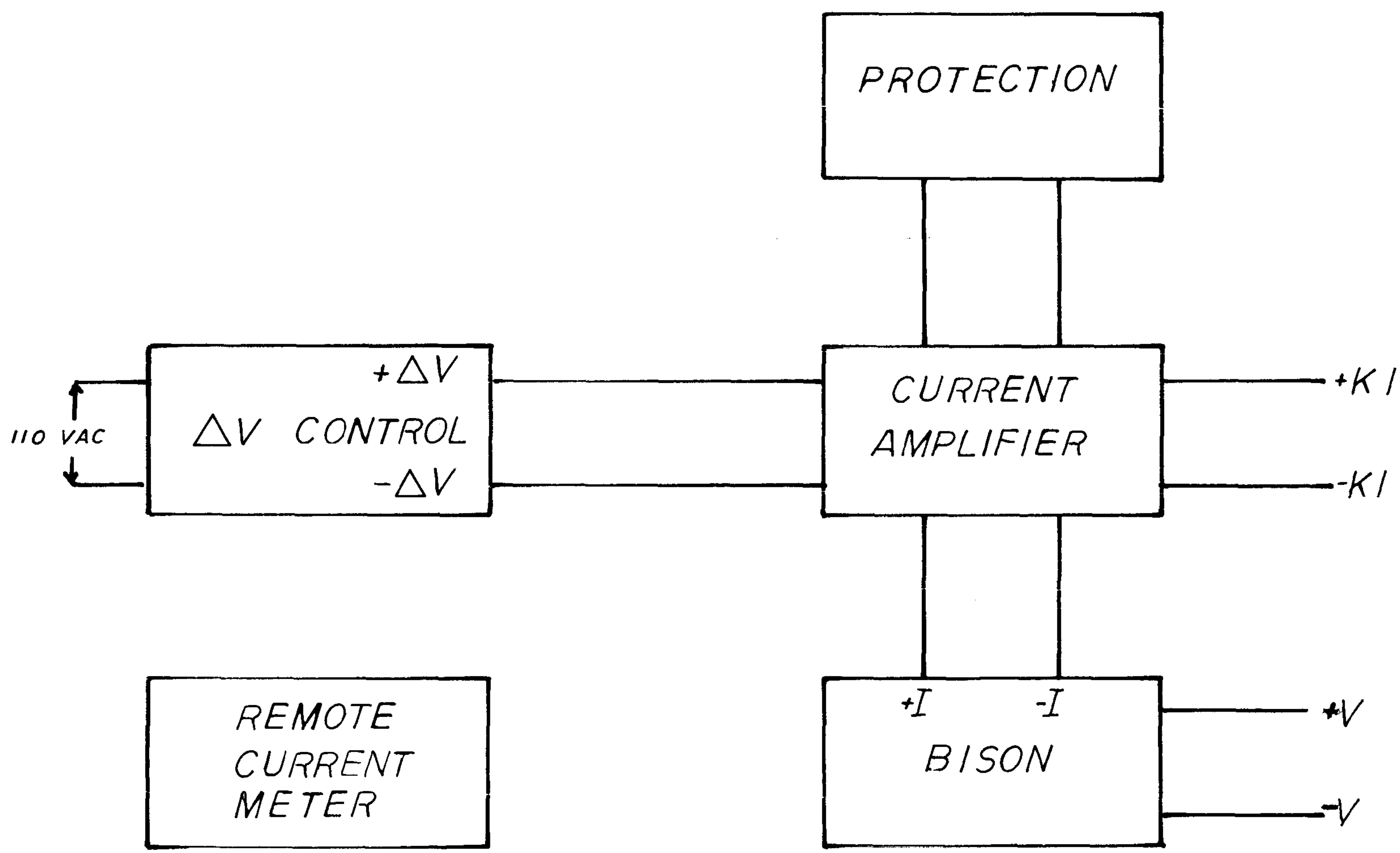


FIGURE B.1. - Block diagram of the CERTS.

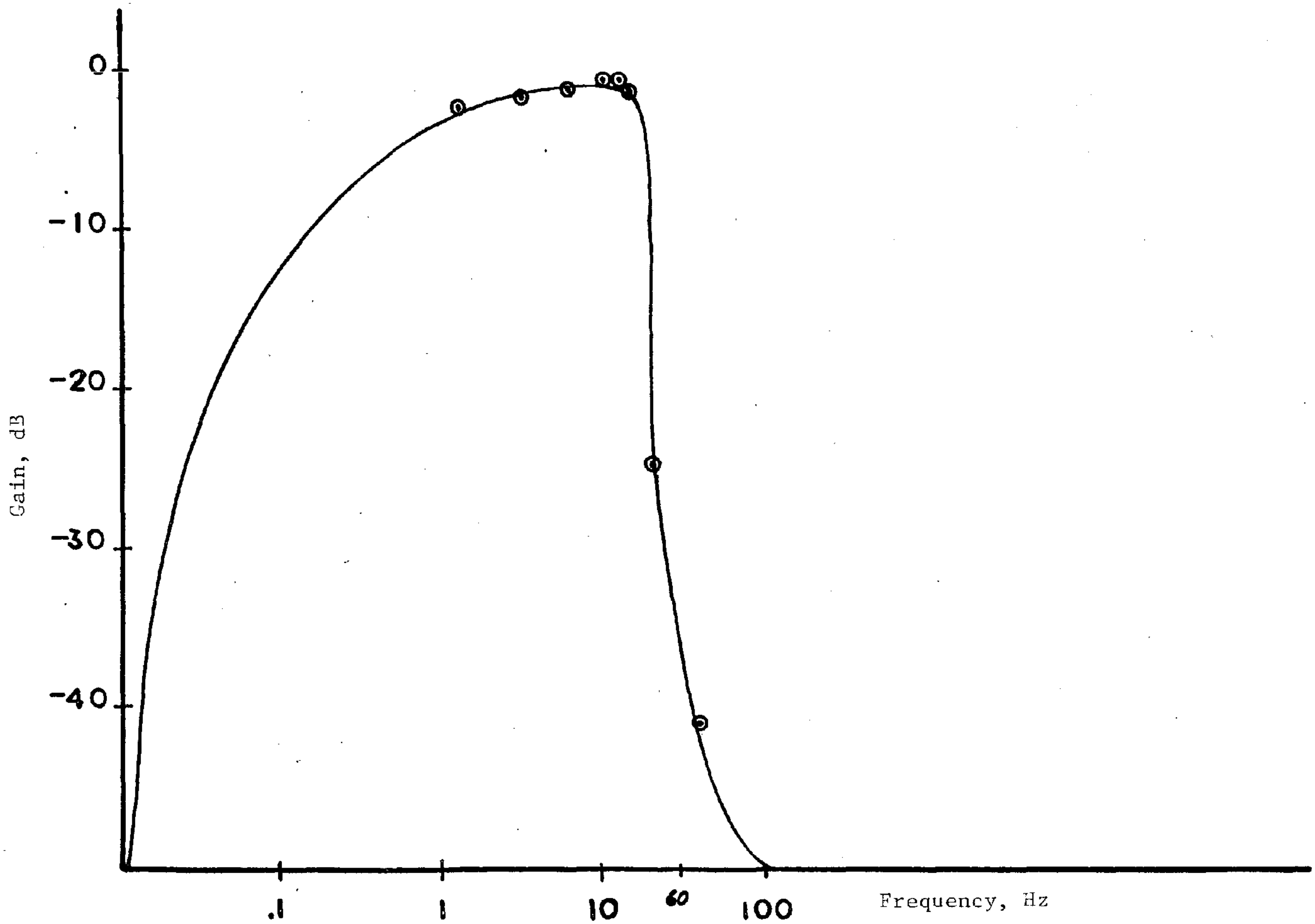


FIGURE B.2. - CERTS 11 Hz filter response.

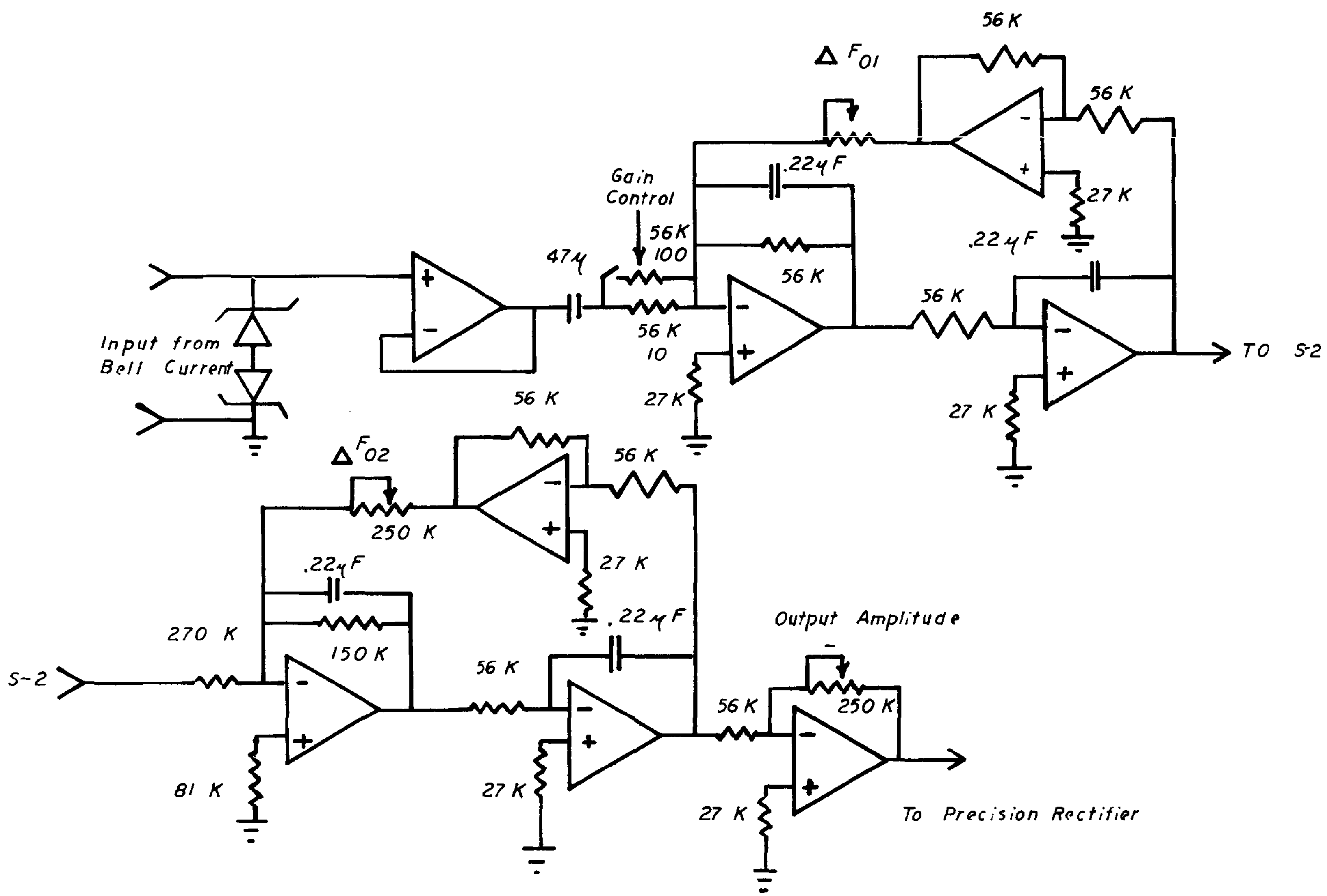


FIGURE B.3. - CERTS 11 Hz filter schematic.

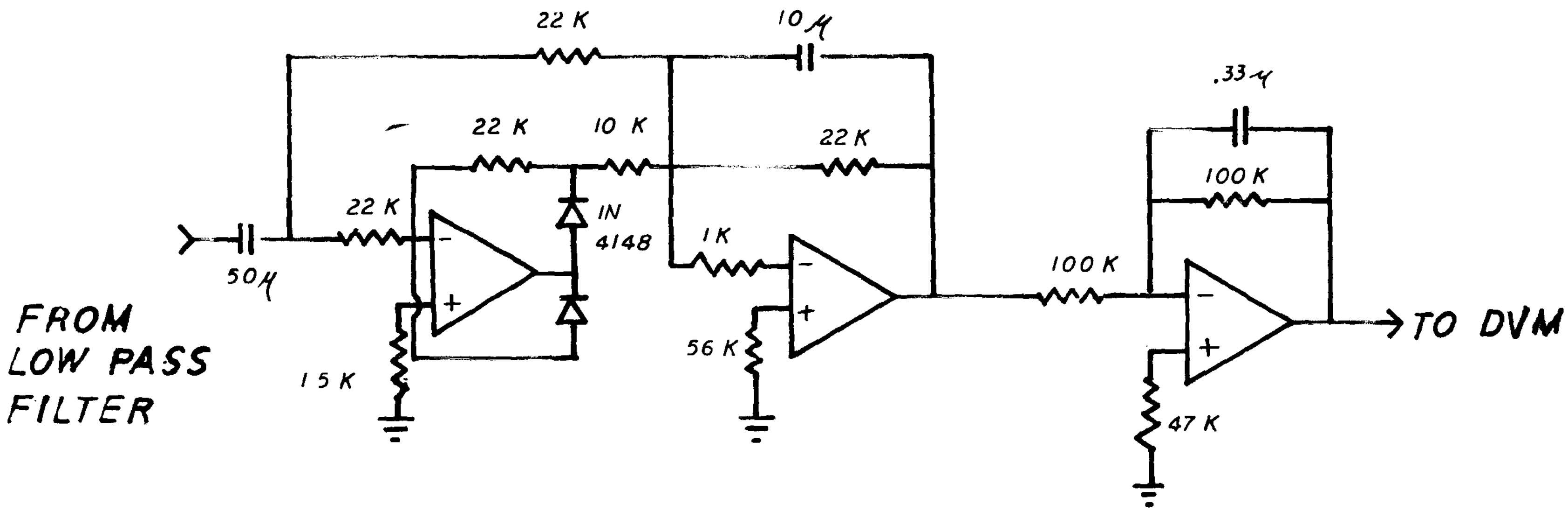


FIGURE B.4. - CERTS precision rectifier schematic.

point in a network, the current flow throughout the network can be measured with the remote current meter.

B.2.2 Current Amplifier Design

In order to provide sufficient test current for accurate current readings in the presence of large 60 Hz stray currents, the 22 mA output of the Bison must be increased by a factor of somewhere between 10 and 100. The amplifier consists of a voltage-controlled power supply, a class "D" switching output circuit and protection circuitry configured as a voltage-controlled current source.

The 110 V 60 Hz power supply is controlled by the triac circuit in Figure B.5. This circuit symmetrically controls the ON time of the triac by using a potentiometer to control the phase shift of the gate circuitry. L_1 C_1 form a snubber, allowing the circuit to control an inductive load (the isolation transformer) without problem. The chopped 60 Hz is applied to a bridge rectifier and then filtered by the circuit shown in Figure B.6. The resultant variable dc voltage is used as the supply voltage for the output amplifier.

The output amplifier is shown in Figure B.7. An 11 Hz squarewave signal from the protection circuitry is transformer coupled to the bases of Q_1 and Q_2 causing the transistors to saturate alternately. This in turn alternately saturates the output transistors Q_3 and Q_4 producing an 11 Hz squarewave output. This circuit is very efficient because only small currents are carried by Q_1 and Q_2 so that they dissipate very little power. The output transistors, Q_3 and Q_4 carry the load current, but only dissipate power equal to the load current times their saturation voltage. Even at maximum design current of 10 A less than 8 watts is dissipated. The problem with this switching amplifier is that the 11 Hz drive signal must be present if any supply voltage is present. If there is no drive, both output transistors will be on, effectively directly shorting the power supply to ground and destroying the output devices.

The protection circuitry is shown in Figure B.8. The 555 is configured as a 10 Hz squarewave oscillator driving the switching amplifier through the isolation transformer at all times. The Bison constant current output is terminated in a load resistor giving an 11 Hz squarewave with an amplitude of ±8 volts. This 11 Hz signal is applied to pin 4 of the 555, forcing it into synchronization with the Bison 11 Hz output. This allows the voltage detectors and resistance measurement circuitry of the Bison to be used and prevents destruction of the switching amplifier.

B.3 DATA AND CONCLUSIONS

The CERTS was field tested twice in October. The first test was at the WVU Research Ground bed. The bed consists of four eight foot ground rods arranged as a ten-foot square. Another eight foot rod placed ten feet

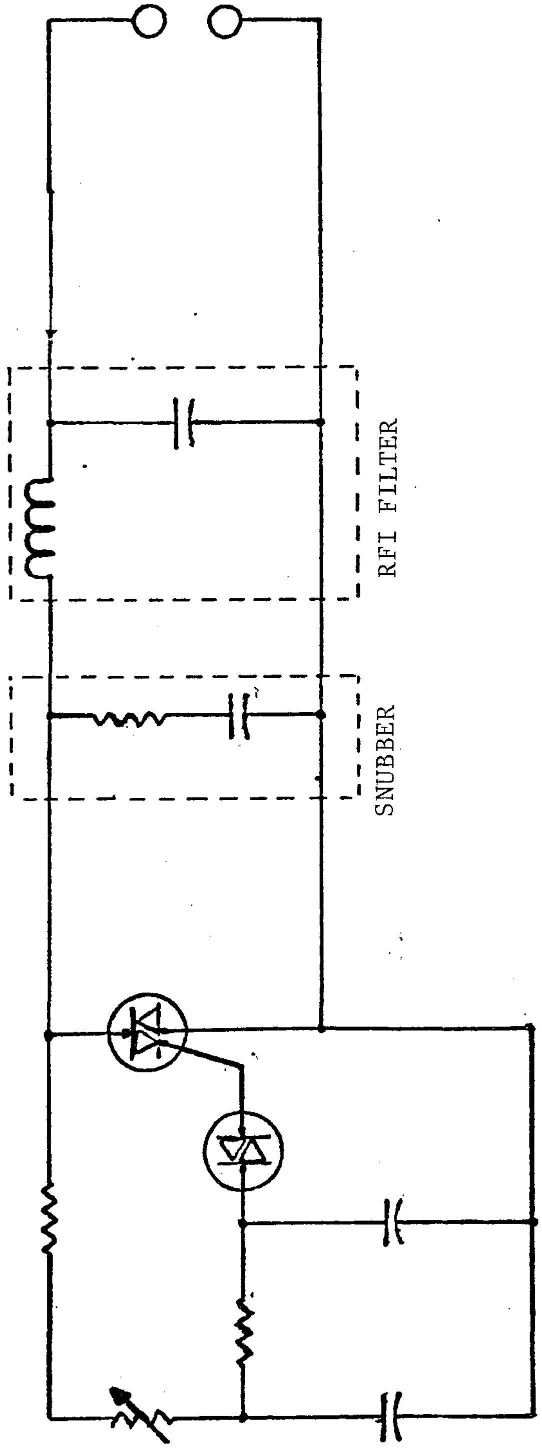


FIGURE B.5. - CERTS triac voltage control schematic.

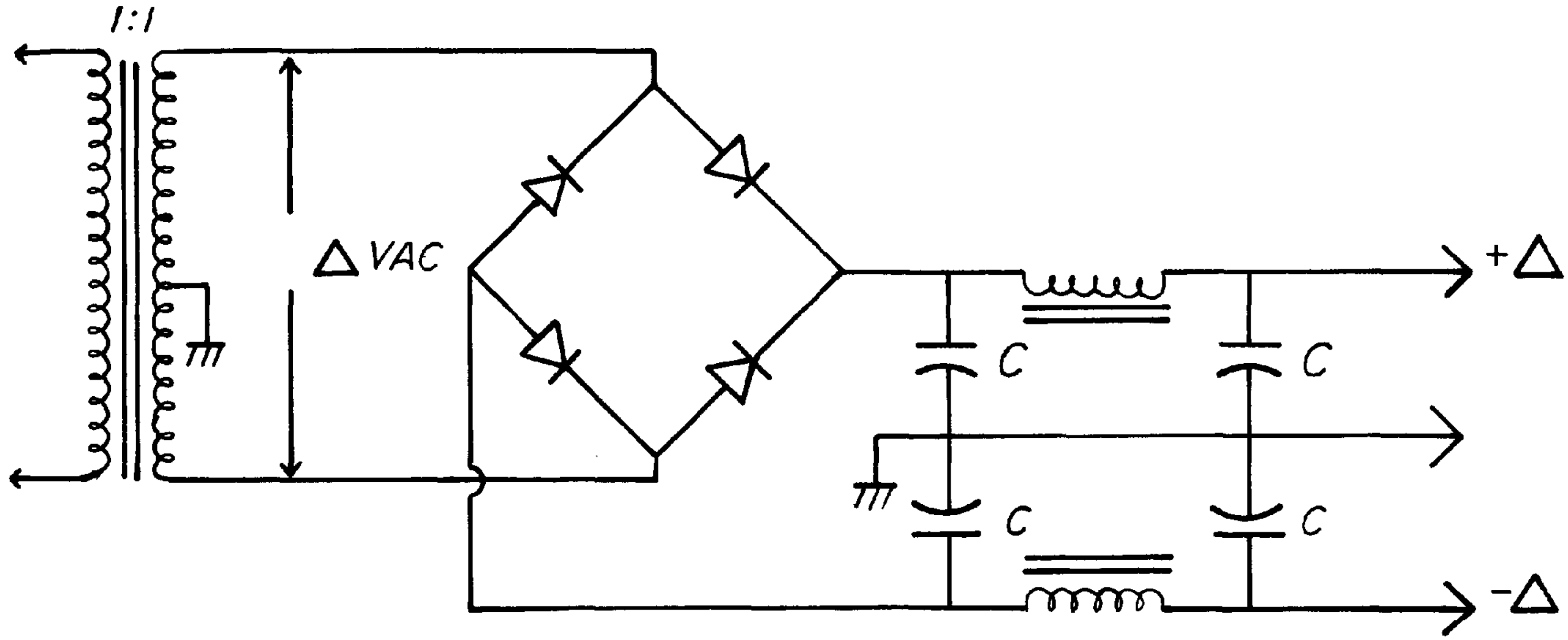


FIGURE B.6. - CERTS power supply schematic.

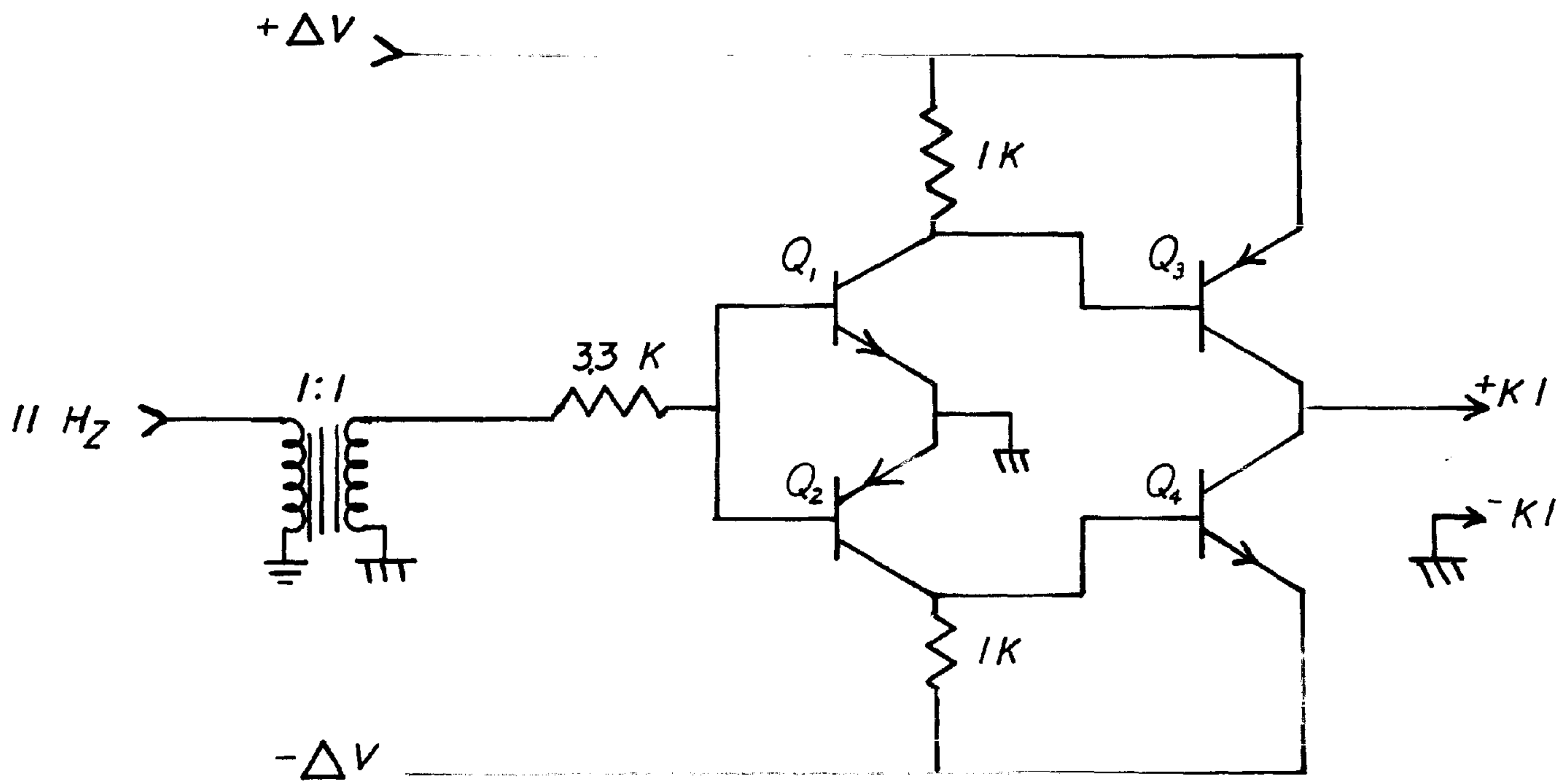


FIGURE B.7. - CERES output amplifier schematic.

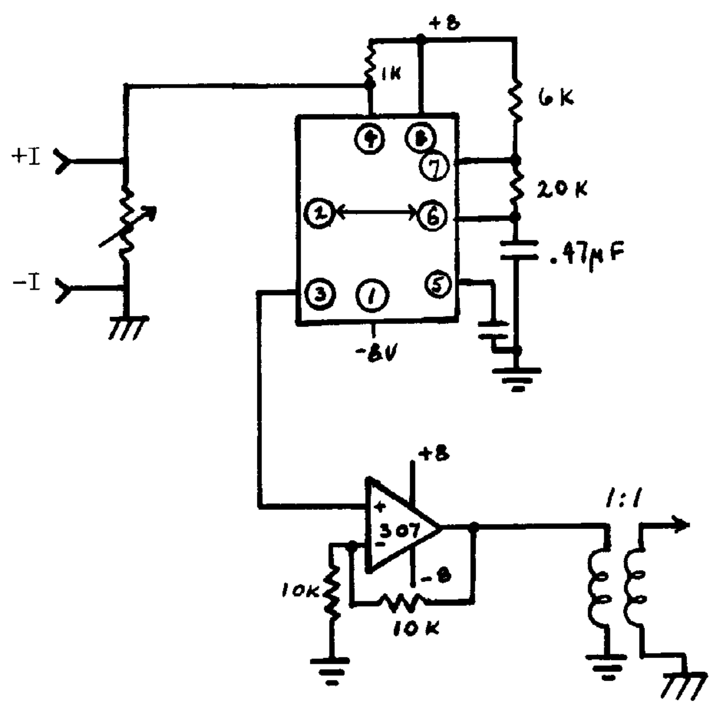


FIGURE B.8. - CERTS protection circuit schematic.

away from the main bed was used as the connected ground bed. The entire connected bed was measured with the Bison and then the fifth electrode was disconnected and measured. The connected bed was then hooked to the CERTS for measurement. The isolated electrode resistance is equal to the apparent bed resistance times 22 divided by the current through the isolated electrode. The results are given in Table B.1.

TABLE B.1. - CERTS field test #1.

Device	Current Output (mA)	Total Bed Resistance (Ω)	Electrode Resistance (Ω)	Main Bed Resistance (Ω)
Bison	22	2.83	15.2 (isolated)	3.18 (isolated)
CERTS	22	2.88	15.25 (connected)	3.50 (connected)
CERTS	44	2.92	15.40 (connected)	3.54 (connected)

The second CERTS test was made on a bed constructed of five one foot ground rods on the same arrangement as the WVU Research Ground Bed with a five foot spacing between rods. The results are given in Table III. Dividing the apparent total bed resistance of Table B.2 by the CERTS current gain is equivalent to the actual bed resistance.

TABLE B.2. - CERTS Field test #2.

Device	Current Output (mA)	Apparent Total Bed Resistance	Electrode Resistance (Ω)	Main Bed Resistance (Ω)
Bison	22	23.1	167.1 Ω-(isolated)	28 Ω-(isolated)
CERTS	220	244.3	163 Ω-(connected)	28.74
CERTS	500	552.3	168 Ω-(connected)	28.42
CERTS	660	728.13	162 Ω-(connected)	26.00
CERTS	880	974.82	165 Ω-(connected)	28.80

Comparing the isolated electrode resistance with the connected resistance shows that it is possible to accurately find connected electrode resistances by this method.

B.4 RECOMMENDATION FOR FURTHER WORK

The CERTS as described works well. However, reduction in size and greater operating convenience are desirable. A change to a high frequency dc-dc variable power supply would eliminate the bulky 60 Hz transformer and filters. Unfortunately, units having the required specification (5 amps, 0-±150 VDC) are not available off-the-shelf. A lighter, battery powered device is being built, but it has neither the current or voltage drive capabilities of the ac powered device due to battery limitations. A constant current circuit is also being tested which would allow the operator to "set it and forget it" allowing quicker and more consistent measurements.

APPENDIX C

MANUFACTURERS AND SUPPLIERS PROVIDING COST INFORMATION

1) Ohio Brass
Rectifier Division
P. O. Box 450
Oak Hill, WV 25901

2) Klein Tools, Inc.
7200 McCormick Rd.
Chicago, IL 60645

3) Bower Industries, Inc.
1601 W. Orangewood Ave.
Orange, CA 92668

4) Line Power Mfg. Co.
329 Williams St.
P. O. Box 677
Bristol, VA 24201

5) McGraw Edison
Power Systems Div.
P. O. Box 440
Canonsburg, PA 15317

6) Pennsylvania & West Virginia Supply Co.
Wall St.
Morgantown, WV 26505

7) The Okonite Company
Buncher Industrial Park
Leetsdale, PA 15056

8) S. R. Instruments
173 Robinson St.
North Tonawanda, NY 14120

9) Joy Manufacturing Co.
Electrical Products
Rt. 4 Box 156
Lagrange, NC 28551

10) National Mine Service Company
600 Grant Street
Pittsburgh, PA 15219

11) Cyprus Wire & Cable Co.
421 Ridge St.
Rome, NY 13440

12) TRW/J. H. Williams Div.
400 Vulcan St.
Buffalo, NY 14207

13) Westinghouse Electric Corp.
Low Voltage Breaker Div.
Beaver, PA 15009

14) Anaconda Wire and Cable Div.
East 8th St.
Marion, IN 46952

15) Essex Group
Power Conductor Division
P. O. Box 7000
Lafayette, IN 47903

16) Ohio Brass Co.
Mansfield, OH 44902

17) Anker Mining & Dev. Co.
Pittsburgh, PA
(412) 831-8200

18) Power Distribution Products
Point Pleasant, WV
(304) 675-6690

19) American Mine Research
P. O. Box 1628
Bluefield, WV 24701

20) Fairmont Supply Company
P. O. Box 501
Washington, PA 15301

21) FMC Corporation
Mining Equipment Division
Tenth and Belt Line
Fairmont, WV 26554

22) Harvey Hubbell Inc.
Ensign Electric Division
P. O. Box 7758
Huntington, WV 25778

23) Pemco Corp.
Box 1338
Bluefield, WV 24701

24) 3M Co. Electro-Products
3M Center Building
St. Paul, Minnesota 55101