Instantaneous Circuit Breaker Settings for the Short-Circuit Protection of Three-Phase 480-, 600-, and 1040-V Trailing Cables

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Abstract—Present Federal regulations which specify maximum instantaneous circuit breaker settings for the short-circuit protection of coal mine trailing cables are discussed. The characteristics of mine power systems that limit short-circuit current in three-phase trailing cables are analyzed and minimum expected short-circuit currents for three-phase 480-, 600-, and 1040-V trailing cables are tabulated. New maximum instantaneous circuit breaker settings, based on minimum expected short-circuit currents and typical breaker tolerances, are proposed with emphasis on safety. Finally, atypical mine power systems are discussed and field tests cited.

I. INTRODUCTION

TRAILING CABLES on electric face equipment in underground coal mines undergo more severe service than most other cables in industrial applications. The normal operation of a unit of self-propelled mining equipment subjects its trailing cable to extreme tensile forces, severe abrasion, and frequent flexing, twisting, and crushing. As a result of this severe usage, electrical faults in trailing cables occur much more frequently than electrical faults in cables and wiring in stationary industrial installations.

Of the various faults which occur in trailing cables, the short circuit has proven to be one of the most hazardous. The energy expended in a short circuit in a trailing cable is capable of igniting loose coal and coal dust on the mine floor, as well as loose coal, coal dust, hydraulic oil and other combustible materials onboard a mining machine. Between 1952 and 1969, the Bureau of Mines investigated 265 mine fires caused by short circuits in trailing cables. These mine fires were responsible for 13 deaths and 50 injuries.

If the arc from a short circuit is not contained within the trailing cable jacket, and the short circuit occurs where an explosive mixture of methane and air is present, an ignition is likely to occur. During the period 1952-1968, 21 methane ignitions and explosions were caused by electrical faults in trailing cables [1]. These ignitions and explosions resulted in nine fatalities and 18 injuries.

Even if a short circuit in a trailing cable does not cause a fire or a methane ignition, the energy delivered into the fault can cause combustion of the cable insulation, generating dense smoke and noxious fumes. Furthermore, if a miner is handling the cable at or near the location of the short circuit, there exists the possibility of flash burns to the hands and eyes.

The frequency of short circuits in trailing cables, coupled with the potential hazards associated with their occurrence, makes adequate trailing cable short-circuit protection extremely important. This has been recognized for many years, and requirements for such protection have been included in Federal standards for permissible electric face equipment since Bureau of Mines Schedule 2C [2] was written in 1930. However, it was not until the Federal Coal Mine Health and Safety Act of 1969 was enacted that short-circuit protection for all trailing cables was required by Federal statute.

Section 306 (b) of the Act requires that each trailing cable be provided with short-circuit protection by means of an automatic circuit breaker. These requirements, however, were developed and promulgated when Section 75.601-1 became effective in the Mandatory Safety Standards for Underground Coal Mines (Title 30, Code of Regulations, Part 75, 30 CFR 75). Section 75.601-1, 30 CFR 75, specifies the maximum allowable instantaneous settings for circuit breakers used to provide short-circuit protection for trailing cables. These settings were determined by applying a 50 percent safety factor to the line-to-line short-circuit current calculated by assuming an infinite capacity 250-V dc power source and 500 ft of 2-conductor trailing cable. The 50 percent safety factor was included to account for power system impedance, voltage dips, and circuit breaker tolerances. In addition, a maximum circuit breaker setting of 2500 A was established. Section 75.601-1, 30 CFR 75, also contains provisions for allowing higher circuit breaker settings when special applications justify them.

Since the implementation of the Federal Coal Mine Health and Safety Act of 1969, there has been a significant reduction in the number of mine fires and methane ignitions caused by
short circuits in trailing cables. Since 1970, there have been only nine mine fires caused by short circuits in trailing cables. These fires did not result in any fatalities or injuries. During the same period there were no methane ignitions caused by short circuits in trailing cables. It is apparent that improvements in trailing cable electrical protection as well as improvements in trailing cable splicing, mine ventilation, and fire protection brought about by the Act have significantly reduced the number and severity of trailing cable short circuits. Nevertheless, 1972 and 1973 accident data reported in [1] indicate that electrical faults in trailing cables continue to result in a significant number of serious flash burn and electrical burn injuries to miners' hands and eyes.

Although the maximum circuit breaker settings specified in Section 75.601-1, 30 CFR 75, are based on the calculated short-circuit current in 250-V dc trailing cables, the settings are applied to all trailing cables, including three-phase trailing cables energized at 480, 600, and 1040 V. The significant reduction in the frequency of mine fires and methane ignitions caused by short circuits in trailing cables indicates that the settings specified in Section 75.601-1, 30 CFR 75, generally provide adequate short-circuit protection for three-phase trailing cables. Nevertheless, short-circuit surveys conducted by Mine Safety and Health Administration (MSHA) electrical engineers have shown that in certain instances these settings do not provide an adequate margin of safety for three-phase trailing cables, and in other cases the settings are lower than necessary to provide adequate short-circuit protection.

This paper will attempt to meet the need for a new table of maximum instantaneous circuit breaker settings for the short-circuit protection of three-phase 480-, 600-, and 1040-V trailing cables based on an analysis of the minimum expected short-circuit current in three-phase trailing cables and the characteristics of the circuit breakers commonly used to provide trailing cable short-circuit protection. The paper will also discuss conditions under which the maximum allowable circuit breaker settings should be reduced to afford an adequate margin of safety as well as the conditions under which the maximum settings may be raised without sacrificing safety.

II. MINIMUM EXPECTED SHORT-CIRCUIT CURRENT

Safety considerations demand that the circuit breaker trip whenever the minimum value of short-circuit current flows in the trailing cable. Consequently, the maximum specified circuit breaker setting must take into account the circuit breaker tolerance as well as the many factors that limit short-circuit current, including fault type and location, circuit voltage, power system impedance, section transformer impedance, and trailing cable impedance.

Safety considerations cannot be compromised. However, the short operating time of an instantaneous trip circuit breaker requires that the circuit breaker be set to trip at a current greater than the peak starting and/or operating current of the machine connected to the trailing cable. Otherwise, nuisance circuit breaker tripping would require a larger trailing cable than necessary for ampacity considerations alone.

In view of the above, any tabulation of maximum allowable circuit breaker settings should take into account sufficient parameters to assure that for the majority of situations encountered, the specified settings will provide the necessary protection without being overly restrictive. On the other hand, the tabulation should be presented in a simple and concise manner so that it is as easy as possible to use. Obviously, a tabulation of maximum circuit breaker settings would lose the usefulness if it was necessary to conduct a short-circuit survey of the mine power system to determine each circuit breaker setting.

A. Calculation of Minimum Expected Short-Circuit Current

Calculations to determine minimum expected short-circuit current differ from the more common calculations to determine circuit breaker interrupting current requirements. In the latter case, the bolted fault condition yielding maximum current flow (usually the three-phase fault) is used as the basis for the calculation. However, when calculating minimum expected short-circuit current, the fault location and fault condition yielding minimum current flow must be used as the basis for the calculation. Motor fault current contribution must be assumed to be zero, and a factor to account for reduced current flow due to the impedance of an arcing fault must be applied to the calculated bolted fault current.

1) Phase-to-Phase Faults: Of the variety of faults that can occur in a three-phase trailing cable, the phase-to-phase short-circuit current is used to determine maximum circuit breaker settings for trailing cable short-circuit protection.

The calculation of phase-to-phase fault current in three-phase circuits is treated extensively elsewhere; therefore, only the general equation is presented:

\[
I_{\phi\phi} = \frac{K_A E_{\phi\phi}}{2Z_1} \tag{1}
\]

where \(I_{\phi\phi}\) is the phase-to-phase fault current, \(E_{\phi\phi}\) is phase-to-phase voltage, \(K_A\) is the arcing fault factor, and \(Z_1\) is the total positive sequence impedance. It should be pointed out that an arcing fault factor \((K_A)\) has been applied to the traditional equation for bolted phase-to-phase fault current to account for reduced fault current due to the impedance of an arcing fault.

Because the difference in magnitude of the positive and negative sequence impedances is insignificant, the total impedance can be assumed to be \(2Z_1\).

2) Base Voltages: Representative manufacturers indicate that the standard nominal secondary voltage ratings of section transformers are 480, 600, and 1040 V. Consequently, these voltages were used as the base voltages \((V_B)\) for calculating supply system and transformer impedances. However, no-load phase-to-phase voltages \((E_{\phi\phi})\) of 456, 570, and 988 V were used to calculate minimum expected short-circuit current. These voltages, which are 95 percent of the base voltages, were chosen to account for reductions in section transformer no-load secondary voltages not uncommon in operating mine power systems.
B. Impedances that Limit Phase-to-Phase Fault Current

In estimating the impedances that limit phase-to-phase short-circuit current in a trailing cable, it is useful to assume a simplified model of a typical mine power system. From the model shown in Fig. 1, it is possible to identify three impedances which limit phase-to-phase short-circuit current in a trailing cable: supply system impedance, section transformer impedance, and trailing cable impedance.

1) Supply System Impedance: The supply system impedance includes the total power system impedance from the generating stations to the primary of the section transformer. For the purpose of calculating minimum expected trailing cable short-circuit current, a supply system positive sequence impedance equivalent to a three-phase short-circuit level of 12.5 MVA at the section transformer primary was assumed. This impedance is nearly equivalent to a 2-MVA substation transformer supplying 4.16-kV power to a section transformer through approximately 14,000 ft of number 4/0 American wire gauge (AWG), 5-kV SHD-GC cable.

The assumed supply system short-circuit level is indicative of a long high-voltage distribution system and therefore a rather low X/R ratio. Consequently, both the total supply system positive sequence resistance ($R_{1s}$) and reactance ($X_{1s}$) were calculated at the section transformer secondary base voltages with the results as shown in Table I.

2) Section Transformer Impedance: Representative manufacturers of mining transformers indicated that three-phase section transformers ranging in capacity from 300 to 1000 kVA and in impedance from 3.0 percent to 5.5 percent have been supplied to the mining industry. In recent years, 750 kVA has been the most common section transformer rating at the 480- and 600-V levels, although a considerable number of 500- and 600-kVA units have also been furnished. At the 1040-V level, section transformers are generally rated 750 or 1000 kVA. Based on these data, section transformer capacities and impedances were assumed to be as seen in Table II.

Once these assumptions were made, the section transformer positive sequence resistance ($R_{1s}$) and reactance ($X_{1s}$) were calculated for the appropriate base voltages with the results as shown in Table III.

3) Trailing Cable Impedance: Resistance and reactances for three-phase trailing cables were compiled from values calculated and published by the Anaconda Company [3] and values calculated by several other manufacturers of portable cables and cords. Since the resistance and reactance values were used to determine minimum expected short-circuit current, maximum values were of interest. Consequently, cable resistance values were based on a conductor temperature of 90°C. Likewise, reactance values were based on a flat rather than a round cable construction for the trailing cable sizes, which are manufactured in both constructions. Furthermore, the reactances for round trailing cables used in 1040-V circuits were based on a type SHD construction.

4) Arcing Fault Factor: In (1), a factor ($K_A$) is applied to account for reduced current flow due to an arcing fault. Kaufmann and Page propose a factor of 0.74 to relate the approximate minimum value of line-to-line arcing fault current to bolted three-phase fault current for a 480-V power system [4]. This value corresponds to 0.8545 of the bolted line-to-line fault current. Consequently, an arcing fault factor of 0.8545 was used to calculate minimum expected trailing cable short-circuit current at 480 V. Although there has been little work done to determine an arcing fault factor for 600-V and 1040-V power systems, it has been shown [4] that the arcing fault factor increases as the system voltage is increased. Consequently, arcing fault factors of 0.9 for 600-V systems and 0.95 for 1040-V systems have been assumed.

C. Short-Circuit Calculations

Once the arcing fault factor, phase-to-phase voltage, supply system impedance, section transformer impedance, and trailing cable impedance were determined, (1) was used to calculate minimum expected trailing cable short-circuit current. Since trailing cable length has a significant effect on the magnitude of short-circuit current, short-circuit calculations were made for each of the common lengths of trailing cables up to the maximum length permitted for permissible equipment by Section 18.35 of Schedule 2G [5]. A factor of 1.05 was applied to the calculated trailing cable impedance to allow for possible errors in determining trailing cable length. An example calculation of minimum expected short-circuit current for a phase-to-phase fault at the end of a 500-ft number 4/0 AWG 480-V trailing cable follows.
1) Substation transformer—MVA = 2.0, 13.9 kV/4.16 kV. 
\[ x = 7.0 \text{ percent}, kV_{\text{base}} = 0.480 \text{ kV}, kVA_{\text{base}} = 2000 \text{ kVA} \]

\[
Z_{\text{base}} = \frac{kV_{\text{base}}^2 \times 1000}{kVA_{\text{base}}} = \frac{0.48^2 \times 1000}{2000} = 0.115 \Omega \quad (2)
\]

\[
X = \frac{X_{\text{percent}} \times Z_{\text{base}}}{100} = \frac{7.0 \times 0.115}{100} = 0.0081 \Omega. \quad (3)
\]

2) Power feeder cable—number 4/0 AWG, 5-kV SHD-GC, length = 14,000 ft, \( R = 0.068 \Omega/1000 \text{ ft}, X = 0.032 \Omega/1000 \text{ ft} \), \( V_{1-1} = 4.16 \text{ kV} \):

\[
Z = (0.068 + j0.032) \times 14
\]

\[
= 0.952 + j0.448 \text{ at } 4.16 \text{ kV}. \quad (4)
\]

The impedance transferred to section transformer secondary is

\[
Z = (0.952 + j0.448) \times \frac{\left(\frac{0.480}{4.16}\right)^2}{100} = 0.0127 + j0.0060. \quad (5)
\]

3) Section transformer—kVA = 500, 4.16 kV/0.480 kV, \( X = 4.9 \text{ percent}, R = 1.0 \text{ percent}, kV_{\text{base}} = 0.48 \text{ kV}, kVA_{\text{base}} = 500 \text{ kVA} \):

\[
Z_{\text{base}} = \frac{0.48^2 \times 1000}{500} = 0.461 \quad (6)
\]

\[
Z = \frac{(R_{\text{percent}} + jX_{\text{percent}})}{100} \times Z_{\text{base}}
\]

\[
= \frac{(1.0 + j4.9)}{100} \times 0.461
\]

\[
= 0.0046 + j0.0226. \quad (7)
\]

4) Trailing cable—number 4/0 AWG length = 500 ft, \( R = 0.068 \Omega/1000 \text{ ft}, X = 0.027 \Omega/1000 \text{ ft} \), \( V_{1-1} = 480 \text{ V} \):

\[
Z = (0.068 + j0.027) \times 0.5
\]

\[
= 0.034 + j0.135 \Omega \text{ at } 480 \text{ kV}. \quad (8)
\]

5) Total positive sequence impedance—\( Z_1 = 1 + 2 \) + 3 + 4) above:

\[
Z_1 = j0.0081 + 0.0127 + j0.0060 + 0.0046
\]

\[
+ j0.0026 + 0.0340 + j0.0135
\]

\[
= 0.0513 + j0.0502. \quad (9)
\]

6)

\[
I_{\phi} = \frac{K_{e}E_{\phi}}{2Z_1} = \frac{0.8545(456)}{(2)(0.0513 + j0.0502)} = 2714 \text{ A}. \quad (10)
\]
<table>
<thead>
<tr>
<th>Conductor Size (AWG or kcmil)</th>
<th>Cable Length (ft)</th>
<th>Maximum Instantaneous Circuit Breaker Setting (A)</th>
<th>Present Instantaneous Circuit Breaker Setting (A)</th>
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This paper would be incomplete if the range of power system parameters over which the proposed circuit breaker settings are valid were not discussed. However, one must remember that the proposed settings were developed with the safety of the miner and protection of the trailing cable in mind. They should not be increased without serious thought and analysis of the mine power system and mining practices. The remainder of this paper deals with documented problems experienced by the coal mining industry to develop settings, and the alternatives possible in alleviating specialized problems without loss of safety.

Fig. 2 illustrates how proposed circuit breaker settings, based on trailing cable length, compare to the present settings. For all but the larger size cables, the number 2/0 AWG and above, the new settings are substantially higher for 500 ft of trailing cable, but decrease markedly for long lengths of cable.

A. Test Procedure

Several coal mine operators were contacted, and tests were made at their mines on various pieces of mining machinery. These tests were made in order to document problems and to demonstrate safe solutions to these problems. Tests at all the mines were conducted using basically the same test equipment. The only item that changed was the current sensor. In one mine, a 60 mV = 600 A shunt was used; in the other mine, a 1000:5 current transformer with a 0.1-Ω burden resistor was used. An oscillograph with a 0-5000-Hz response, along with two high-voltage preamplifiers with a 0-10 000-Hz frequency response, were used to record the current and voltage.

The preamplifiers were used to isolate the oscillograph from the high voltages present at the load center. Gains on the oscillograph and the preamplifiers were adjusted to provide adequate trace deflection on the oscillograph. There were two mine power systems tested. The machines tested were first started under normal conditions in order to record their normal inrush current. In order to record the highest currents possible, the machine was deliberately stalled. The two systems were then modified to simulate a weaker system in one mine and a stiffer system in the other mine. This was accomplished by adding 250 ft of number 4/0 AWG cable to the existing 600 ft of trailing cable, simulating a weaker system.

The current and voltage were then measured in the 600 ft of trailing cable. A stiffer system was simulated by eliminating the 500 ft of 500-kcmil cable which normally feeds the mine through a distribution box. The 480 ft of number 4/0 AWG continuous miner trailing cable was connected directly to the load center and voltage and current measurements were made. Recordings of current and voltage were also made at the distribution box, which is the normal operating condition and simulates a weaker system.

B. Test Results

Consider the following cases which will be referred to during the remainder of this report. Peak currents given are full cycle symmetrical rms values.

Case I: A loading machine with a total of 100 hp had a number 2 AWG trailing cable approximately 550-ft long which was connected to a distribution box. There were 500 ft of 500-kcmil cable between the distribution box and the power center with 38 MVA available at the primary of the 750-kVA power center transformer. Measurements taken at the distribution box indicated a peak inrush of 813 A at a no-load voltage of 478 V.

Case II: A continuous mining machine with 550 total hp was supplied power by a number 4/0 AWG trailing cable, 480-ft long, connected to a distribution box. The distribution box was fed from a 750-kVA power center through 550 ft of 500-kcmil cable with 38 MVA available at the transformer primary. The peak inrush current was 1569 A set at a no-load voltage of 478 V measured at the distribution box.

Case III: This consisted of the same equipment and setup as Case II. The only change was the elimination of the 550 ft of 500-kcmil cable and the connection of the number 4/0 AWG trailing cable directly to the power center. The peak inrush current measured was 1626 A at the above-no-load voltage.

Case IV: A loading machine with 110 total hp was supplied power by 700 ft of number 2 AWG trailing cable. The trailing cable was connected to a 750-kVA power center with 30 MVA available at the transformer primary. With a section voltage of 521 V, the peak inrush current measured was 838 A.

Case V: A continuous mining machine with 535 hp was fed power by 600 ft of number 4/0 AWG trailing cable. The trailing cable was connected to a 750-kVA power center with 30 MVA available at the transformer primary. The maximum inrush current measured was 1669 A and the maximum current during stall was 2518 A. No-load voltage was 521 V.

Case VI: The same setup was used as in Case V. The only modification was the addition of 250 ft of number 4/0 AWG trailing cable to give a total cable length of 850 ft of number 4/0 AWG trailing cable. The maximum inrush current measured was 1052 A with a no-load voltage of 521 V. The machine was stalled and the maximum current during stall was 2165 A.

C. Immediate Relief of New Settings

The possibility of the proposed settings relieving nuisance tripping on motor inrush is apparent. Consider Case I. Under the existing standard, a circuit breaker setting of 800 A is necessary for compliance. However, the proposed standard would allow a setting of 900 A, which is greater than the peak
measured inrush current of 813 A. Thus, for this case, the new settings should help alleviate the nuisance tripping problem without any loss of safety.

D. No-Load Voltage

The section transformer no-load voltage influences the amount of current necessary to start and operate a particular mining machine. For example, Case II demonstrated a peak inrush current of 1569 A at approximately 480 V and would be allowed a maximum setting of 2050 A. However, if the no-load voltage should drop, the inrush current would also drop at the same rate as would the minimum available fault current. Thus, one would expect to measure an inrush current of 1438 A at a no-load voltage of 440 V. Similarly, the instantaneous setting must be lowered to 1900 A to afford the same level of protection. If the system no-load voltage was higher than the recommended no-load voltage, nuisance tripping of the circuit breaker could occur. This is because the inrush and short-circuit are directly proportional to no-load voltage. Therefore, it is important that the section transformer no-load voltage be maintained at the recommended voltage level, that is, 480, 600, and 1040 V.

E. Power System Impedance

The power system impedance as seen by the trailing cable is an important factor in determining maximum allowable circuit breaker settings. Fig. 3 illustrates the effect this impedance has on the circuit breaker settings for various 480-V trailing cables. The impedance values vary from 0.0157 Ω for a stiff power system with a 43.7-MVA supply and a 1000-kVA section transformer to 0.0589 Ω for a weak power system with a 10-MVA supply and a 300-kVA section transformer. The impedance value indicated by the dashed line (0.0401 Ω) is the typical power system plus section transformer impedance used to calculate the maximum allowable circuit breaker settings; 12.5-MVA available at the primary of a 500-kVA section transformer.

If the power system characteristics differ from those assumed in the calculations, one can determine from the curves the maximum safe setting for a particular power system impedance. A high system impedance will fall in the right side portion of the graph for a particular trailing cable size and result in poor voltage regulation. A power system showing symptoms of poor voltage regulation, such as motor heating or failure, should be examined carefully. Systems unable to supply sufficient currents to loads would supply less than expected to faults. Lowered settings should be recognized not only as a necessary safety practice, but also as a necessary mining engineering practice, allowing a circuit breaker to operate to protect the trailing cable and machinery when faults occur. In a similar manner, a relatively stiff power system will demand higher minimum short-circuit currents and fall on the left side of the graph. If nuisance tripping occurs, the settings can be altered to the system parameters without sacrificing safety.

The effects of lower system impedance are clearly demonstrated in Cases II, III, V, and VI. In Cases II and III, the system impedance went from 0.0213 Ω in Case III to 0.0403 Ω in Case II. The starting current also changed from 1626 A in Case II (Z = 0.0213) to 1959 in Case II (Z = 0.0403), where Z is system impedance. The stall currents of Cases V and VI show even greater spread when system impedance is changed. In Case V the stall current was 2518 A and the system impedance was 0.0229Ω. In Case VI the stall current was 2165 A with a system impedance of 0.0357Ω.

The above cases demonstrate the need for circuit breaker settings to be lowered when the system impedance is higher than the 12.5-MVA 500-kVA typical mine power system used in the calculations. This also indicates that the settings can be safety raised when the system impedance is lower than the 12.5-MVA 500-kVA typical mine power system.

V. CONCLUSION

Based on a rigorous analysis of available short-circuit current in a three-phase trailing cable, the existing requirements for maximum instantaneous circuit breaker settings provide a varying margin of safety dependent upon cable size. For smaller size cables the margin of safety is adequate, but for the larger cables number 1/0 AWG and above, the degree of safety is unacceptable. The critical point occurs where the system and power center impedance become evident in the circuit. Further studies should include a device capable of detecting phase-to-phase faults on trailing cables.

REFERENCES

Laboratory Evaluation of Underground Coal Mine Trailing Cable Splices

ROBERT H. KING, MEMBER, IEEE

Abstract—Laboratory tests were developed for evaluating portable cable splices prior to their use in underground coal mines. The tests simulate mechanical and electrical destructive effects on cables supplying power to shuttle cars. Tests for splice tension, conductivity, flexibility, dielectric withstand, abrasion, and workmanship qualities are explained.

I. INTRODUCTION

UNDERGROUND coal mining machinery, particularly in room and pillar mining sections, utilizes portable electric cables to obtain power from the main distribution system. Portable cables are commonly called “trailing cables” and federal law requires them to be covered by a flame resistant jacket [1]. The flame resistance test is specified in the Code of Federal Regulations [2] and will not be examined in this paper. Tests for electrical and mechanical properties of splices in trailing cables are the subject of this paper.

Table I lists common cable types found on continuous and conventional mining sections. Not all mines use the same horsepower, voltages, and machine types, so the table should only be considered as a common example. A conventional section usually employs one cutting machine, one loading machine, one roof-bolting machine and two shuttle cars. A continuous section will ordinarily have one continuous miner, one roof bolter, and two shuttle cars. As a result, a variety of cable types and sizes are present in an environment of restricted space and highly mobile equipment.

Highly mobile equipment, poor lighting, and restricted operating room, in addition to machine operator mistakes, result in frequently damaged cables. Immediate repair or replacement is necessary to prevent fires or methane gas ignitions and minimize production delays. Repairing usually means splicing, which is the mechanical joining of one or more severed conductors, and replacing the insulation and jacket. Production may be delayed by approximately 30 min while the splice is completed. In addition, a weak point in the cable...