MANAGING ELECTRICAL HAZARDS IN UNDERGROUND COAL MINES

By Jennifer Crisp MEng
Principal Engineer Research and Investigations
SIMTARS
Redbank, Queensland

Summary

This paper discusses the types of electrical hazard in underground coal mines, categorised as either low power or high power hazards. It describes transient overvoltages, and partial discharge problems, and discusses the hazards associated with arcing in flameproof and sheet metal enclosures. Strategies to manage specific electrical hazards are then proposed.

Introduction

Electrical hazards in underground coal mines can be classified broadly as high power hazards, such as short circuits and phase-to-phase arcing faults, and low power hazards such as sparks. The low power sparks may not be inherently dangerous but in the context of the underground coal mine they generate the risk of an explosion of a flammable mixture of methane and air. This paper will examine some of the sources of electrical hazard in underground coal mines, and the consequence of high power hazards as they affect equipment housed in sheet metal and flameproof enclosures. Philosophies and methods of managing the specific hazards identified will then be discussed.

Sources of Electrical Hazard

Low power electrical sparks are easily generated and in some cases may be difficult to avoid. Sources include mechanical damage to electrical equipment such as cables, static build-up on ducts, step and touch potentials on equipment resulting from earth currents, and improper use of intrinsically safe equipment.

High power hazards can be considered to be generated from one or both of two sources: excessive voltages and reduced impedance. This is easily understood in terms of Ohm's law ($I = V/R$). The sources of excessive voltage include accidental connection of high and low voltage circuits, poor voltage regulation , and transient overvoltages.

Transient overvoltages can be caused by switching operations, lightning impulses, faults and clearing of faults. Both the magnitude of the transient overvoltage and the rise-time of the transient are important parameters in determining the severity of transients. Very fast transients (with rise-times in the tens of nanoseconds) have been attributed to failures on transformer windings and motor windings, where the fast wavefront generates a very high electrical stress between turns or layers, resulting in insulation breakdown [1] [2]. A number of incidents are known to have occurred where rapid "motor jogging" has caused very high transient voltages sufficient to cause flashover in mining installations [3].

Vacuum switching devices have a reputation for being sources of transient overvoltages. Three different types of transient have been identified: *prestrikes*, on closing of circuit breakers, *chopping* on opening of a circuit breaker and *restrikes*. In order to avoid generation of a transient switching devices must close or open at a current zero cross-over on each pole. In practice as the contacts close there is a point at which dielectric breakdown occurs and an arc is initiated. This is called prestrike. Similarly, on opening, the current may be quenched prematurely, ahead of a natural current zero, which is called current chopping. If a highly inductive load current is chopped the high rate of change of current produces a large magnitude voltage spike. When, in breaking motor starting current, the switch contacts separate close to a current zero, a large transient recovery voltage will occur across the opening contacts, and this may be sufficiently high to establish an arc. [4]. This re-ignition causes adjacent capacitances to discharge through the switch causing a high frequency current to be superimposed on the power frequency component. These high frequency currents also create current zeros on which the vacuum switch will attempt to interrupt the current. This can continue until the contacts are far enough apart to prevent re-ignition. The multiple extinctions and re-ignitions are called restrikes, and can result is multiple transient voltages of increasing magnitude.

Transient overvoltages can also cause insulation breakdown if insulation is inadequate because of poor design or manufacture and/or is degraded in service and is a major factor in partial discharge problems.

Partial discharge is defined in AS 1018 - 1985[5] as "an electrical discharge that only partially bridges the insulation between conductors. This discharge may, or may not occur adjacent to a conductor". Partial discharge may occur in solid, liquid or gaseous insulators. In gaseous insulators it is called corona. Partial discharges can occur where electric field concentrations are highest, such as sharp points on conductors.

In solid insulation partial discharge may occur from ionisation within voids along insulating surfaces, or where adjoining surfaces of materials have different dielectric characteristics. In insulating liquids partial discharge may occur within gas bubbles. Once partial discharge has been initiated it can persist at a voltage lower than its inception voltage. The voltage at which the discharge is extinguished is called the extinction voltage. The charge flow during the discharge generates heat. Over time erosion of the insulating material occurs at the site of repetitive partial discharges, until failure occurs.[6]

Partial discharge and the resultant deterioration of inadequately rated or substandard insulating materials constitute a prime cause of insulation failure at moderate and high voltages. Partial discharge is also a symptom of insulation deterioration and this is, in fact, used to evaluate the health of insulation.

The level of insulation and immunity to failure of insulation is dependent on a number of factors, including the quality of the insulation materials used. In solid insulation tracking can occur across the surface of the insulator. In tracking very low level currents flow across the surface of an insulator gradually forming a preferred current path. Figure 1 is a photograph showing tracking across the surface of a Bakelite sheet. The partial discharge was initiated at the end of a pin forming part of the spring tensioning mechanism for contacts on a rotary earth switch. A low current arc occurred across the air space between the pin and the Bakelite sheet. The current tracked across the sheet to one edge, and from there across to the earthed frame of the switch. A phase-to-earth current flowed causing ionisation of the air within the small volume enclosed by the insulating disk of the switch and the Bakelite sheet, and a flashover ensued between phases separated by the insulating disk.

One measure of the resistance of an insulator to failure by this mechanism is the cumulative tracking index (CTI). Insulators with high CTI values are less susceptible to tracking than insulators with low CTI values. The distance across the surface of an insulator from one conductor to another (ie the minimum tracking distance) is called the creepage distance, which is an important parameter in insulation co-ordination. If the surface of an insulator is contaminated by coal dust, carbonisation, or the presence of moisture the insulation level will be reduced and the tendency to failure by tracking increased.

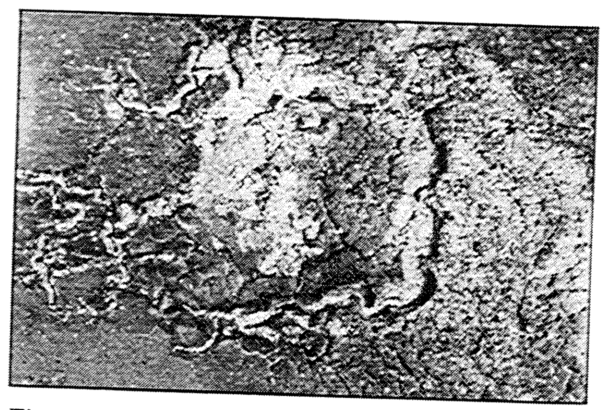

Figure 1 Site of partial discharge and tracking across a Bakelite insulating board, viewed through a microscope

Ageing of insulation is also an important factor in its continued reliability. Overheating of insulation can cause degradation. The presence of water is recognised as the most severe environmental condition for all polymeric insulating materials used on cables[7]. Electrical treeing and water treeing have been identified as important problems in cross-linked poly-ethylene (XLPE), (and to a lesser extent in ethylene-propylene rubber (EPR)) and are causes of premature cable failure [7][8]. The properties of EPR compounds have been found to vary considerably from one formulation to another. In water treeing, moisture is absorbed into the insulation, and dielectric failure may occur. Electrical treeing is tracking through the body of a solid insulator, rather than across its surface. The two effects may be linked together: recent work has shown that long vented water trees may initiate electrical trees and associated partial discharge signals when excited with an ac voltage of moderate magnitude (1.3 to 3.8 times rated voltage)[8]. To the author's knowledge this has not been shown to be a problem in underground EPR mining cables.

In liquid and gaseous insulation the presence of water degrades insulation. As for solid insulation the impulse level is affected also by material insulating properties as manufactured, overheating, ageing and contamination.

When a gas is used as insulation the insulation level is dependent on the insulating properties of the gas and the clearance distances between conductors (paths through air). The quality of the insulation can be affected by contaminants like carbon particles, and is also reduced by the presence of free ions. For instance, the flamefront from a methane explosion reduces the insulation resistance of the air. The presence of a low current arc can reduce the insulation level between exposed conductors, allowing breakdown between conductors whose spacing would normally be considered safe.

An example is the failure of a rotary switch investigated by SIMTARS. The rotary switch was closed, but the spring loaded contacts on one phase were not made with sufficient pressure to ensure a low resistance. While carrying load current the faulty contacts overheated, began to melt at the point of high resistance, and formed an arc. The arcing ionised the air space between the insulating disks and along the spindle of the switch mechanism, causing a flashover between all three phases. This was subsequently cleared by overcurrent protection. There was no switching operation or other source of transient overvoltage occurring at the time of the fault.

Apart from insulation degradation, there are a number of other mechanisms by which the impedance between conductors or from conductors to earth may be reduced. In underground coal mines mechanical damage such as pinching or shorting of cables is not uncommon. The human factor can also arise from tools being left in enclosures or similar errors. These sorts of problems may cause either arcing or short-circuit faults.

High Power Arc Faults in Flameproof Enclosures

Flameproof enclosures are designed to house equipment which may be susceptible to sparking, but high power faults can generate a hazard. In particular, the high power arcing fault can be of concern in flameproof enclosures.

There are two very important relationships which govern the effects of arc faults in enclosures. These are[9]:

$$\Delta Q \propto m \Delta T \quad (approximately) \tag{1}$$

and

$$PV \propto T \tag{2}$$

ΔQ represents an increment of energy being transferred to the gas inside an enclosure, m is the mass of that gas and ΔT is the change in temperature of the gas. The energy term in Equation 1 is only approximately proportional to the right hand side because the "constant of proportionality" is the constant volume specific heat of the gas, which varies with temperature and pressure. The second relationship derives from the ideal gas law, and says that the pressure rise P and volume V are proportional to the temperature. So an increase in temperature will produce a pressure rise in an enclosure of constant volume. When the two effects are combined we find that the same arc energy will produce a large pressure rise in a small enclosure and a small pressure rise in a large enclosure. However it has been observed in practice that the losses to the walls of a enclosure tend to be greater for small enclosures (the arc being closer to the enclosure walls)[10].

In the discussion it has been assumed that the arc uniformly heats the gas in the enclosure. In fact the energy input is not homogeneous, but occurs at the location of the arc. This introduces dynamic pressure effects where the peak pressure which occurs in an enclosure is much higher than the average pressure in the enclosure. These dynamic pressure effects are most noticeable in long narrow enclosures, enclosures where the gas flow is restricted in places (eg a narrow cross-section separating two chambers), and where the arcing occurs close to one end of an enclosure. These dynamic pressure effects are akin to pressure piling which is a phenomenon well-known in flameproof enclosures where it is associated with pre-compression of gases in an explosion. In arcing the phenomenon can be associated with pre-compression of gases and with superposition of reflected pressure waves.

A flameproof enclosure incorporates two important features:

(1) Its structure must be strong enough to withstand the pressure rise generated by an internal gas explosion and

(2) the flameproof enclosure must not transmit an internal explosion to an external gassy environment.

Flameproof enclosures may be sealed but are often not completely sealed: some pressure relief can occur through flamepaths. For particular hazardous gases there is an experimentally determined maximum safe gap width (mesg) for mating flanges which are used as flamepaths in a flameproof enclosure[11].

The presence of an arcing fault in a flameproof enclosure can impact on both the flame containment property and the structural integrity of a flameproof enclosure.

During arcing material which comes in contact with the arc is melted by the intense heat of the arc, particularly at the points which constitute the "electrodes" of the arc. Molten metal particles are sprayed out from the arc, and may be expelled through the flamepaths as the internal pressure rise is relieved. These particles, having higher heat content than the gas escaping from the enclosure may cause ignition of an external flammable atmosphere. The risk of this occurring seems to be highest when large quantities of molten particles are expelled from the enclosure. This effect is most likely to occur when there is a direct path from the arc through the flame path to the external atmosphere. Figure 2 shows a flameproof enclosure subjected to a three phase arc in a flame containment test. This enclosure failed the flame containment test with an arc current of only 3kA. There is also some evidence from overseas researchers[12] that under some conditions, thought to be associated with resonance of the enclosure, flame transmission from an enclosure during arcing can occur at gap widths much lower than the normal maximum experimental safe gap (mesg) for the hazardous gas.

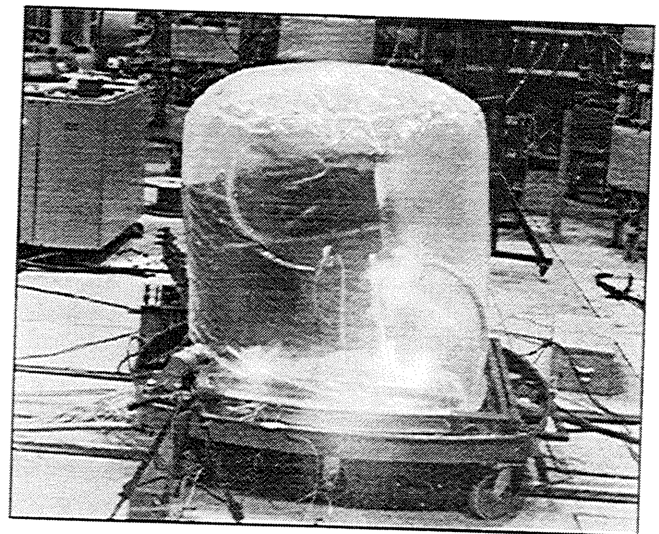

Figure 2 Time lapse photograph of a $0.3m^3$ enclosure under arcing conditions. Photograph shows gas curtain exploding, while large amounts of sparks are emitted from the bottom edge of the enclosure door panel.

The pressure rise for a methane explosion in an enclosure, ignoring losses and the potential for pressure piling, is about 700kPa [13], for atmospheric pressure and a temperature around 20 degrees Celsius. Under arcing the pressure rise can be larger than this for a small enclosure. In the worst case the pressure rise from arcing can be high enough to cause structural damage to an enclosure. Obviously, if the structural integrity of the enclosure is compromised the enclosure will also no longer contain an internal explosion. When an arc is present in a flameproof enclosure and methane is also present it has be found that the pressure rise is higher than for the arcing condition or the gas explosion alone. Some pressure relief can occur through the flamepaths, depending on the enclosure design, but for most enclosures the pressure continues to rise for the duration of the arc. (When methane is present the pressure tends to rise more quickly, and then flatten off after about 50-100ms.)

One further complication found is that some organic insulating materials when in close proximity to an arc, may liberate gases which tend to increase further the pressure rise in the enclosure. When organic insulating materials were placed in the path of the arc it was observed that the actual arc voltage increased with a consequent increase in the energy liberated in the enclosure. It is also thought that the gases given off by the insulating materials may themselves be flammable, thus contributing, by their ignition, directly to the pressure rise.

Pressure piling and other dynamic pressure effects can also contribute to the maximum pressure which the enclosure must withstand.

Arcing in Sheetmetal Enclosures

Sheetmetal enclosures are not nearly as strong as flameproof enclosures, because they are not required to withstand a gas explosion. Typically there is an order of magnitude difference in the strength of sheet metal and flameproof enclosures. In underground mines enclosures with intrusion protection ratings of IP55 or IP65 are used to prevent the ingress of dust and water which could impair the operation or reduce the life of electrical equipment housed within the enclosures. To achieve these IP ratings the enclosures must be well sealed. The enclosures may also be designed to vent an internal pressure rise generated by an arcing fault to the atmosphere. Hazards to personnel may arise from the structural failure of sheetmetal enclosures or from the arc products vented.

The weakest part of an enclosure will fail if the force from the internal arc pressure exceeds its strength. This will occur regardless of the vent. It has been observed that in practice the door fasteners/catches are often the weakest part of an enclosure. Note also that it is the pressure rise at the location of the weakest point that determines whether that part of the enclosure will fail - dynamic pressure effects can also affect the performance of the enclosure when subjected to an arc fault.

To maintain the IP rating of the enclosure it is necessary for the vent to be sealed initially, and then to open in response to the increase in internal pressure. The pressure rise at which the vent will operate depends on the method of sealing. When a vent is initially sealed the pressure rise experienced by the enclosure must necessarily be greater than or equal to the pressure at which the vent seal is broken. Hence the ideal vent seal is one which seals the enclosure perfectly from ingress of dust and water, is robust when external force is applied (so that the seal is not accidentally damaged) yet releases with the smallest abnormal pressure rise in the enclosure.

The material which is expelled from an enclosure under arcing conditions comprises white hot gas (see Figure 3), molten metal particles, and smoke. The arc column temperatures can reach around 20000°C[14], and the gas in the immediate vicinity of the arc can reach temperatures in the thousands. (We have had K-type thermocouples and N-type thermocouples melt!) The temperatures involved suggest the possibility of a fire hazard.

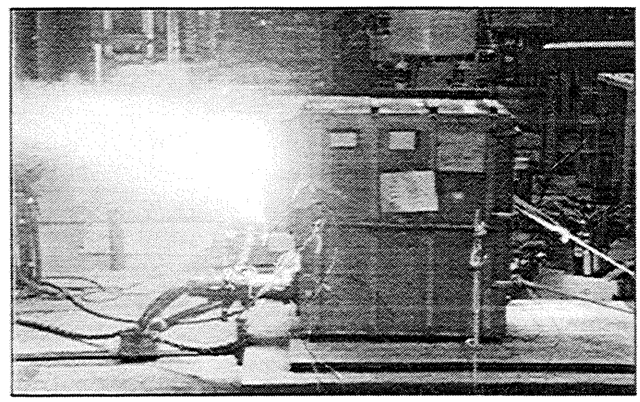

Figure 3 High temperature gas and molten metal expelled from a vented enclosure during arcing

Philosophies for Managing Electrical Hazards

Management of electrical hazards should incorporate two elements:
(1) Design the system to avoid hazards where possible
(2) Back-up design criteria which ensure that the systems contain and/or minimise damage if problems occur.

Equipment should be designed for high reliability - this will minimise injury and production loss. However it can be seen from the previous discussion even if equipment were perfectly reliable the human factor still permits the potential for major electrical hazards to occur. Hence backup systems of hazard management should always be provided. To ensure the reliability of the secondary management system it is necessary that type testing be carried out. Overall hazard management involves elements of design, maintenance and operation.

Designing for Electrical Hazard Minimisation

1. Control Fault Levels
The amount of damage that equipment will sustain when subjected to a fault and the consequential risk of personnel injury depends on the rate at which energy is released in a fault, and the duration of the fault. Two ways of managing the consequences of faults are to limit the fault level and to control the duration of the fault. A number of options are available for limiting fault current. These include using smaller, higher impedance supply transformers eg supply from two transformers instead of one. This will give benefits of potentially higher reliability (because all the eggs are not in one basket), lower fault level on each supply, and a fault in one part of the system will have a less disruptive effect on the system as a whole. There may be a trade off involved - the cost of the installation may be higher, and voltage droop problems on starting large drives may be an issue.

Other options include the use of current limiting fuses. These will rupture quickly enough to restrict damage and pressure rise in flameproof and sheet metal enclosures. An American study [15] showed clearance times around 8 to 12 ms for current limiting fuses in trials. The trade-off here of course is that fuses need to be replaced once they have cleared a fault, and phase-failure protection must be used to protect motor loads in the event of one or two fuses blowing. There is also a risk that a blown fuse might be replaced with one of the wrong rating. However, if combined with a contactor rated to handle overload and starting currents, current limiting fuses can be a very good option.

Current limiting circuit breakers are also available. Because they do not need to handle the full fault current they are made smaller than conventional circuit breakers, which may make them less robust. Circuit breakers are also more limited in the number of operations they can handle than are contactors.

2. Co-ordinate Protection carefully to ensure minimum clearance times
Care should be taken to ensure that correct discrimination is obtained between the various levels of protection used in the mine. Failure of relays to discriminate causes unnecessary delays in fault-finding and can mask serious problems on the system. It also encourages operators in the dangerous practice of reconnecting equipment after a fault without first finding the cause of the trip. Care should also be taken to minimise the clearance times set, for the reason given above, that the damage caused by a fault is minimised if the fault is cleared quickly. In the case of earth leakage protection there is another reason for this also: the fault current for an earth fault is limited by the neutral earthing impedance, but it has become apparent from many investigations that for restricted earth-fault systems, particularly when an arc is present, an earth fault can readily develop into a phase-to-phase fault, which is not restricted, except by the fault level of the system. Therefore discrimination times should be set as low as is practical to reduce the likelihood to fault propagation from phase-to-earth to phase-to-phase.

3. Select equipment ratings carefully
Consult standards to make sure that the conditions under which equipment ratings are quoted are thoroughly understood. For instance, moulded case circuit breakers may be derated in enclosure temperatures above 45°C, and ratings are determined with generous busbar and cabling arrangements.[16]

4. Consider how to protect cables against mechanical damage.
Mechanical damage to cables is a common problem in underground coal mines which causes serious electrical hazards. Eighteen reports of cable damage in underground coal mines were recorded by the Queensland Mines Inspectorate for the 95/96 financial year of which at least nine involved arcing in open air.[17]

5. Consider how to reduce the potential for transient overvoltage problems
Transient overvoltage problems seem to be a function of the type of equipment used at a site and the configuration of that equipment. Vacuum contactors are frequently used in mines because of their reliability, low maintenance requirements and small size.[18]. They have, however, a bad reputation for causing transients, particularly because of current chopping, prestriking and restriking, but some contactors are now made with contact materials designed to reduce the incidence of this problem. Experimental studies have shown that cable capacitance and conductance reduces the magnitude and the risetime of transients. [18] Systems with longer cable length between switching devices and motors or transformers are therefore less likely to have problems with failures on windings caused by steep-fronted voltage spikes. Work has been done in the United States towards optimising the design of shielded solid dielectric cable for attenuation of high frequency spikes [2]. However Morley [18] has shown that excess capacitance (eg surge capacitors) on a power system can also cause problems, particularly from prestriking transients.

6. Specify BIL for all equipment - get it in writing from suppliers
From the previous discussion it can be seen that it is difficult to eliminate transient overvoltages. The alternative strategy is to minimise the probability of equipment failure from transient overvoltages by the design of the equipment. AS1824-1995 [19] provides guidance as to the recommended BIL for various voltages levels. In this standard the BIL is referred to as the standard lightning impulse withstand voltage. It is recommended that equipment be specified to the applicable value in Table 2 of the standard. (Where two values are given the higher value is recommended.) It is also suggested that mines require their suppliers to give evidence that the equipment has been tested to the level specified.

7. Specify arc fault containment tests for flameproof equipment
Experiments have shown that flameproof enclosures can fail either structurally or by transmission of flame when subjected to high power arcing faults[20],[21]. In particular it has been shown that enclosures having small free volume (ie the volume not filled with equipment is small) are most at risk from arcing internal pressure rises. The susceptibility to transmission of flame is dependent on the enclosure design as well as the volume. Specifying that a design shall be tested by an arc fault test cannot guarantee against failure by these mechanisms (the worst arcing conditions cannot be guaranteed for the test) but will provide a measure of confidence in the design of the enclosure. Appendix A gives a suggested form for a combined arc fault containment and flame containment test.

9. Specify arc fault containment tests for sheet metal enclosures
The main electrical hazards associated with sheet metal enclosures result from arcing products being vented in such

a way as to cause severe burns to personnel. Anecdotal evidence, experience from overseas[22],[23] and experimental results[10] indicate that enclosures are often not built well enough to survive a high power arcing fault. Door catches may fail, and vents may not operate. Experimental work[10] has also shown that it is possible to reduce significantly the temperature of gases and the quantity of molten particles expelled through vents in order to minimise the risk of fires being started by arcing products. Once again, an arc fault test does not guarantee that an enclosure will survive an arc fault but the probability of survival and the risk to personnel will be greatly improved if design weaknesses are addressed. Australian Standard AS2086-1995 [24] Appendix AA suggests an arcing test which may be applied to sheet metal enclosures. Currently no standard exists for control of venting products from sheet metal enclosures under arcing conditions.

10. Specify EMC and EMI requirements

Electromagnetic compatibility and immunity issues are important to overall system reliability. Noise susceptibility can cause false tripping of equipment which encourages complacency about equipment trips, as well as causing unnecessary production downtime. New international and Australian standards are being released which cover the testing of equipment for electromagnetic compatibility and immunity. From 1 January 1997 compliance with appropriate emission standards will be mandatory for equipment used in commercial, light industry and residential environments (ie not mining). Immunity requirements will not be mandatory except for high risk devices such as medical devices. Nevertheless, it is recommended that electro-magnetic-immunity verification be specified when purchasing electronic equipment for underground mines. Some of the new IEC 1000-4 series standards[25] which may be of use include:

IEC 1000-4-5:1995 Part 5: Surge Immunity Requirements;

IEC 1000-4-6: 1996 Part 6: Immunity to Conduct Disturbances Induced by RF Fields;

and

IEC 1000-4-11:1994 Part 11: Immunity to Supply Dips and Power Supply Variations.

A general electro-magnetic immunity standard covering heavy industry for Australia and New Zealand is currently being drafted, and may be available in 1997.

11. Specify suitable flexible communications and condition monitoring/fault reporting

A coordinated flexible communications systems for monitoring and fault reporting can improve the safety and reliability of operations. Ideally such a system would provide a standard interface for data from different types of equipment, and could support the monitoring of personnel health and vehicle location in a mine.

Alarm and protection trip records provide valuable tools for identifying and isolating power system problems. Considerable research has been conducted on condition monitoring in the past few years including on-line monitoring for partial discharge on motors and cables (eg [26]). Continuous monitoring of transient overvoltages is technically feasible.

12. Earthing System

In Australia a restricted earth fault system is used. There is some debate as to whether resistors or reactors should be used for neutral earthing impedances. The earth system is normally limited to either 5 or 10 A by the neutral - earthing impedance. However in the event of a phase-to-phase fault the earthing system can carry full fault current. Hence, in order to limit step and touch potentials it is essential that the impedance of the earth circuit be maintained at a level that is as low as possible, for the protection of personnel in the vicinity of a fault, and to reduce the likelihood of sparking, particularly since phase-to-phase fault currents may be circulated through the earthing system.

Maintenance

Good maintenance practices promote safety. Some points towards managing electrical hazards include:

1. It is essential that equipment is kept clean - in order to maintain BIL.

As previously discussed, the dielectric strength of solid insulation is critical to its ability to withstand transient overvoltages. Any contamination such as coal dust deposits on the surfaces of an insulator will reduce the BIL of the equipment. Therefore it is essential to maintain a clean environment for high voltage electrical equipment.

2. Inspect equipment regularly for signs of overheating, partial discharge and mechanical damage

Overheating of insulation and partial discharges cause degraded insulation. In the extreme the failure may occur at normal operating voltages, but it is more likely to occur when a transient overvoltage is occurring on the power system. Overheating of insulation can generally be detected from discolouration and smell. Partial discharge sites may be more difficult to detect, as they often occur internally in solid insulation. Occasionally evidence of pin-pricks or bubbling of insulation may be detectable, especially if the discharge is through open air. The smell of ozone may be detectable. Severe tracking is visible as charring along the surface of an insulator. (However if you can see it, it has probably already failed!) Cable connections terminations and contacts on circuit breakers and switches should be inspected for signs of overheating. Such problems can cause electrical fires or arcs to occur. When maintenance is carried out on high voltage equipment, care should be taken to maintain (or improve!) the creepage and clearance levels. All terminations should be insulated and bare metal avoided if at all possible as this will significantly limit the initiation and travel of arcs.

3. Inspect earthing points regularly

The earthing system protects personnel from shocks, and reduces the likelihood of sparks in hazardous locations. It is therefore essential to inspect the earthing system regularly, including the earth fault limiting impedance circuit.

Operational Considerations

Part of the management of electrical safety hazards is to engender in the workforce an attitude where failure of equipment is not accepted at face value and where safety is an issue for each employee. In particular, false tripping and multiple failures of equipment should not be tolerated. If equipment can be shown to be failing to meet specifications then mine operators have a right to demand rectification of the problems. In order to have faulty or substandard equipment fixed it is first necessary to identify and understand the nature of the problem. When an electrical fault occurs it is very important that proper records of observations and actions by operators be made, in order to expedite the process of solving the problem. Manufacturers may not be able to solve a problem without accurate field data. Operators should be strongly discouraged from reconnecting equipment which has been tripped by a protection operation without first understanding the cause of the trip. Elimination (or at least minimisation) of false tripping of equipment will help to solve this problem, which is born of complacency. Training may be of value for electrical staff in the techniques of investigating faults.

Conclusions

Electrical hazards are not entirely avoidable in underground coal mines. However the risk should be minimised. As the requirements for high power equipment in underground coal mines in Australia increases we are seeing the use of higher voltages and higher fault level equipment, and therefore, without appropriate action the risks will increase. Hence while the incidence of low power electrical hazards is probably unchanged we are faced with an apparent increased incidence of high power hazards. Some problems, like partial discharge are much more likely to occur at higher voltages, while the higher fault levels mean that the consequences of failures are also likely to be more severe. As a result it is timely for mines to assess their level of risk from electrical hazards and to develop strategies for management of these hazards.

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Appendix A

Arc Fault Containment Test for Flameproof Equipment

The test should be carried out at the supply voltage and at least the current level for which the enclosure is to be used, with a three phase fault. The electrode separation should be at least the minimum spacing required for the voltage level for use in underground coal mining equipment (69mm for 1.1kV, 3.3kV, and 105mm for 6.6kV from AS2067-

1984 [27]). The test should be carried out with a (8.5 - 9.5% by volume) methane/air mixture present in the enclosure and external to it. Prototype equipment or mock-ups of the equipment should be located during the test as they would be used in service. It is preferable to use actual equipment including cables since the insulation may contribute to the pressure rise. The location of the electrodes should be chosen (i) as a location where the equipment layout has bare phase conductors, and (ii) at a location likely to result in highest pressures (eg close to one end of a long narrow enclosure). To initiate the arc, a piece of fine copper wire should be tied between electrodes. The fault should be applied for a period not less than the protection operating time for the system in which the equipment is to be installed.

The enclosure shall be considered to have passed the test if the external flammable atmosphere does not ignite. (Flame containment will be compromised if the structural integrity of the enclosure is breached.)