Assessment, Testing and Certification of Intrinsically Safe Active Power Supplies

David R Turner — **Manager - Engineering, Testing and Certification Centre (ETCC) SIMTARS**
Mark Walpole — **Researcher - Engineering, Testing and Certification Centre (ETCC) SIMTARS**

1.0 Introduction - Intrinsically safe power supplies in underground coal mines.

1.1 What is an intrinsically safe power supply?

Intrinsically safe power supplies have been designed, manufactured and certified to meet specific criteria in accordance with Australian and/or International standards. These standards specify the amount of energy that the power supply is permitted to deliver to the circuit and connected intrinsically safe devices. Intrinsically safe power supplies restrict the amount of energy delivered to the circuit by limiting the output voltage and current. The methods by which the current and voltage are limited, regulated and protected categorise the intrinsically safe power supply as linear or non-linear/active.

Intrinsically safe active power supplies characterise themselves by their ability to control the output voltage over the full range of current demands. An intrinsically safe active power supply will regulate the output voltage whilst the current demanded is within a specified range. If an excessive amount of current is demanded, or a short circuit occurs the voltage will rapidly reduce to ensure that energy delivered to the circuit is below the minimum energy required to ignite the specified explosive atmosphere.

Intrinsically safe electrical devices such as sensors, actuators and communication systems require a power source. Intrinsically safe power supplies are used to drive these intrinsically safe electrical and electronic devices.

1.2 Where are intrinsically safe power supplies used in underground coal mines?

The electrical power system for underground coal mines starts from a local generator or from the nearest connection to the electricity grid. From this source the local electrical power system will comprise of protection devices, transformers, distribution and switching electrical apparatus which will extend across the mine site and into the underground coal mine up to the coal face. The local electrical power system is monitored and controlled at critical points from its source to its destination points where it is utilised for motive power, processing, lighting, heating, cooling, general power for domestic and office facilities, and ancillary equipment such as communication, information and control systems etc.

The power supplies that are discussed in this paper are used to drive the electrical devices and equipment that are used to monitor and control the local electrical power system, machinery, environmental monitoring, processing, communication, information and control systems. Where any of this equipment is located or extends into a hazardous area such as in underground coal mining where there is a risk of an explosion of flammable gasses and dusts, statutory requirements and standards may stipulate that intrinsically safety devices must be used.

1.3 Intrinsically safe active power supplies have received some recent notoriety.

Recently within Australia during the re-certification of an intrinsically safe active power supply it was discovered that the device when assessed using the spark test apparatus was capable of incendive sparking and thus failing the intrinsic safety requirements as set out in the Australian standards. This particular type of intrinsically safe active power supply was in current use in hazardous areas in underground coal mines throughout Australia. Upon discovering the failure of the intrinsically safe active power supply to meet intrinsically safe standards the New South Wales Department of Mineral Resources issued a safety alert industry wide. Consequences of this failure to meet intrinsic safety requirements resulted in temporary closures of some New South Wales underground coal mines and the revoking of a number of certificates and mining approvals in both New South Wales and Queensland. This has led to a re-certification requirement for a number of intrinsically safe active power supplies to ensure that they do comply with the appropriate Australian intrinsic safety standard.

These events have bought to light that certification bodies have an onerous task to ensure that equipment submitted to them for certification fully conforms to the relevant Australian Standards thus ensuring the safety of these devices in hazardous areas.

2.0 The roles of the participants in ensuring intrinsic safety.

2.1 The intrinsic safety equipment designer and/or supplier.

Designers of intrinsic safety equipment have a responsibility to ensure that their equipment is functional and safe. The design process of a commercial device traditionally involves a compromise between design costs, device performance, and market price while still satisfying the requirements of the intrinsic safety standards. Market demands, new technologies and competition influence designers in their quest to produce a saleable item. In designing, manufacturing and supplying intrinsically safe equipment the certification process is also a cost to be considered. The costs associated with the design, supply, sales and marketing of a commercial design are ultimately passed on to the customer.

2.2 The third party accredited certification body.

The role of the certification body is to assess and test where necessary to determine conformance to the appropriate Australian and/or International Standards. The assessment, testing and certification process are themselves covered by relevant standards to which the certifying body must conform to ensure that it retains its accreditation, its authority to certify equipment. In Australia, any testing of explosion protected equipment must be covered by NATA (National Association of Testing Authorities) laboratory accreditation and the certification activities accredited by JAS-ANZ (Joint Accreditation System of Australia and New Zealand). The services provided by certification bodies are utilised by designers, suppliers, and users of intrinsic safety equipment.

The main factors that determine the cost and/or duration of the certification process which are mainly the responsibility of the party seeking certification are as follows;

- type of certification requested,
- quality of the design and manufacture of the equipment,
- nature and complexity of the equipment,
- level of pre-compliance review
- quality, completeness and accuracy of the equipment’s documentation,
- time taken to modify and resubmit the equipment if required, and
- quality and responsiveness of the communications between the party seeking certification and the accreditation body.

The main factors that determine the cost and/or duration of the certification process, which are the responsibility of the certification body are as follows;

- assessment, testing and certification processes - which are the methods used to determine conformance to the requested certification standard, and
- quality and responsiveness of the communications between the certification body and the party seeking certification.
- The current work volume of the certification body

2.3 The users of the intrinsically safe equipment.

The users of the intrinsic safety equipment have a responsibility to ensure that their equipment is functional and safe for the serviceable life of the equipment. That is the application and usage, maintenance and repair of the equipment, maintaining documentation, and other statutory and inspectorate requirements. This also includes addressing any issues arising from publication of safety alerts, product recalls, requests for re-certification and the like.

2.4 Standards bodies.

Australian and International Standards bodies set the requirements by which certification is determined. Maintaining these standards with industry trends, technology advances and ensuring that the standards are relevant and result in acceptable levels of risk associated with the use of the equipment in specified hazardous locations.

Australian and International Standards are usually written by working groups that include participation from designers, manufacturers, suppliers, accreditation and certification bodies, testing laboratories, regulators and relevant user industry representatives.

2.5 Industry associations.

The Australian coal industry has a number of industry associations which promote, lobby and influence matters which have an effect upon the coal industry. In addition to this numbers of coal industry associations offer research grants to suitable individuals or groups whose research falls under the umbrella of interest to the coal industry.

3.0 Principles of intrinsic safety.

Intrinsic safety is an explosion protection method utilising energy limitation to reduce the risk of ignition in a specified hazardous environment such as those found in underground coal mines. The basic concept behind intrinsic safety relies on energy limitation to ensure that an ignition cannot occur by either:

- Spark Ignition: Should a spark occur, there will be insufficient energy within the circuits located in the hazardous area to cause an ignition.

- Thermal Ignition: There will be insufficient energy to heat components and wiring within the circuits located in the hazardous area to cause an ignition.

3.1 Minimum ignition energy, most easily ignited atmospheric concentration, and explosion limits.

The smallest amount of energy that is required to ignite the MEIC (most easily ignited atmospheric concentration) of the gas or vapor is called the MIE (minimum ignition energy). Scientific research laboratories have established the values the MEIC and MIE for the most commonly used flammable gasses and vapors. For example the MIE of methane gas (coal gas) is 0.28 mJ (milli-joules) [British Bureau of Mines Report 500 (high voltage, capacitive discharge)]. The explosive concentrations of methane are between 5% and 15% and methane's MEIC is in the range of concentrations between 5.6% and 9% (Note: values are dependent upon environmental conditions and test apparatus used).

When the concentration of the flammable gas is below the LEL (lower explosion limit) or above the UEL (upper explosive limit) an explosion does not occur. The LEL and the UEL is typically expressed as a percentage which are the normalised ratio of the volume of the flammable gas or vapours to the volume of air. Between the LEL and UEL it is possible, depending on the amount of energy in the incendive test spark, to generate an explosion. A number of factors such as volume of the gas, temperature, humidity, atmospheric pressure all directly influence the MIE and thus the LEL and UEL.

3.2 Minimum ignition current.

In an electrical circuit the possible sources of spark ignition are as follows:
- discharge of a capacitive circuit,
- interruption of an inductive circuit,
- intermittent making and breaking of a resistive circuit, and
- hot wire fusing.

When the circuit voltage is set at a particular value and the current through the spark test apparatus is increased from zero amps then the MIC (minimum ignition current) can be determined for that particular circuit configuration, voltage, test gas type and concentration. The MIC is the value of current at which an incendive spark occurs (Note: values are dependent upon environmental conditions and test apparatus used).

Test laboratories have performed numerous tests utilising the spark test apparatus in typical circuit configurations and have derived graphical information for a variety of circuit parameters such as voltage, current, resistance, inductance and capacitance. These curves are included in the standards and used by the third party accredited test and certification bodies along with other forms of assessment in determining whether an electrical circuit is intrinsically safe.

3.3 Spontaneous automatic ignition temperature.

In an electrical circuit the possible sources of thermal ignition are as follows;
- heating of a small gauge wire strand,
- glowing of a filament, and
- high surface temperature of components.

Intrinsically safe equipment utilise components whose power ratings have been derated such that the auto ignition temperature of the hazardous atmosphere is not exceeded.

4.0 Methods of achieving intrinsic safety.

4.1 Design of intrinsically safe equipment.

Typical steps in the design are as follows:

(i) Identify the circuit to be made intrinsically safe.
(ii) Compute currents and voltages under normal conditions, compare with permitted values, and adjust circuit constants if necessary.

Normal operation shall include all of the following:
- supply voltage at maximum;
- environmental conditions within ratings given for the apparatus or associated apparatus;
- tolerances of all components in the combination that represents the most unfavourable condition;
- adjustments at the most unfavourable settings; and
- opening, shorting, and grounding of the field wiring of the intrinsically safe circuit being evaluated.

(iii) Conduct ignition tests if necessary to validate step (ii) (this step is not usually necessary because currents and voltages in a carefully designed system will be well below reference values.)

(iv) Review the layout, spacings and other construction features to identify what faults must be considered.

Fault conditions shall include the following:

- the most unfavourable single fault and any subsequent related faults, with an additional factor of 1.5 applied to energy;
- the most unfavourable combination of any two faults and any subsequently related faults, with no additional factor.

(v) Review suitability of infallible components (values, ratings etc). Components on which the intrinsic safety depend (voltage and current limitation) may include:

Component	Limitation
▪ Zener diodes	Voltage
▪ Semiconductor regulators	Voltage or current
▪ Rectifier diodes	Voltage or current (blocking)
▪ Resistors	Current

(vi) Using the results of steps (iv) and (v), analyse the circuit under fault conditions and compare currents and voltages with reference values.
(vii) Select fault combinations that must be simulated for spark ignition testing.
(viii) If the system passes spark ignition testing, review the design with respect to the general purpose and remaining construction requirements of the intrinsic safety standard.

4.2 Assessment, testing and certification of intrinsically safe equipment.

4.2.1 Statutory requirements.

Intrinsically safe and associated electrical equipment are certified as one of the following:

- Self Contained Equipment: The whole apparatus may be used and installed in the hazardous area with no external connections.

- Integrated Systems: Comprises a number of intrinsically safe equipment and usually includes associated electrical equipment connected with defined cabling. When assessing a system, faults are applied to the system as a whole.

- Entity Concept Equipment: This technique separates the individual apparatus used in systems to allow more flexibility in the design and modification of a complete system built up with compatible entity concept devices. Depending on the application of the apparatus, input and/or output parameters are assigned. When assessing entity concept equipment, faults are applied to each component.

4.2.2 Assessment and Testing.

A testing and certification body can determine conformance of the spark ignition requirements of the standard by;

- circuit analysis
- spark ignition testing
- or a combination of both

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The process of assessment, testing and certification of intrinsic safety equipment includes:

(i) Identification of energy sources - The principle of intrinsic safety is energy limitation, therefore an assessment should firstly identify all sources of energy.

Internal Sources	**External Sources**
• Cells and Batteries • Piezo-electric Devices • Capacitors • Inductors	• Power Supplies • Zener Diode Barriers • Transformer Isolators • Communications Equipment • Battery Chargers • Any external connections

(ii) Identification of components on which the intrinsic safety depend (voltage and current limitation components).

(iii) Calculations to determine the power ratings for all components on which intrinsic safety depend. Using the circuit parameters, maximum power dissipation should be determined to ascertain whether testing is required.

(iv) Creepage and clearance distances around the components (and through insulation) on which intrinsic safety depends should be verified as compliant with the relevant standard. This is to ensure that these components cannot be bypassed effectively disabling the protection. Components on which segregation depends should also be assessed for suitability. These may include:

- Transformers
- Capacitors
- Relays
- Opto-couplers

(v) Analysis and/or testing to determine the maximum energy capacity of the circuit. Circuit parameters (i.e. maximum voltages and currents) should be determined. This can be used to verify that the internal capacitance and inductance will comply with the limits set by the curves or the energy values stated in the standards. Alternatively, especially for complex circuits, the circuit can be tested on the spark test apparatus as specified in the standard.

4.2.3 Assessment and testing of active power supplies

As the complexity of the electrical/electronic device increases it becomes more difficult and less reliable to determine the equipment's conformance to the relevant standard by analysis only. Under these circumstances a combination of both analysis and testing are utilised. Intrinsically safe active power supplies fall into this category.

When it comes to the testing phase of the certification process further difficulties may arise as the built in energy shutdown mechanisms within the electric circuit need to be disabled. Using the spark test apparatus also tests that the rate of response of the energy limitation control circuitry is adequate for the task.

Due to the nature of non-linear/active power supplies their output characteristic under a variety of resistive, inductive and capacitive loads must be tested. The interaction between the load devices and the active components within the power supply are not easily analysed if at all. It is also possible due to the non-linear nature of the active power supplies that the output characteristic may closely follow the ignition curves as stated in the standards. It is for these reasons that the use of the energy limitation curves set out in the standard is no longer appropriate.

It is essential to ensure the intrisic safety of the active power supply is tested using the spark test apparatus under numerous variations of the load parameters and over the full range of its output characteristics to ensure that incendive sparking is not possible. These are time consuming tests and are not required for most linear power supplies.

5.0 Conclusion

In the past twelve months a number of problems have occurred with the use of intrinsically safe (IS) active power supplies in underground coal mines in Australia. The problems arise in part because the philosophy of intrinsic safety in active power supplies did not exist when the Australian and International Standards were developed. It also arises because there is continual economic pressure on manufacturers of IS power supplies to deliver more power to equipment, and to reduce installation costs for the user. This pressure threatens the intrinsic safety boundaries, which are currently in place.

This paper has outlined the nature of active power supplies, the processes of testing and certification and the increased extent of spark testing required for active power supplies compared to linear power supplies.

SIMTARS has been awarded an ACARP research grant related to the assessment and testing of active power supplies with the following objectives:

- To identify the different forms of power supplies and clearly define the differences between active/passive and linear/non-linear power supplies.

- Collate and summarise in a form suitable for use by mine electrical personnel, IS manufacturers and testing stations the current world best practice and standards, if any, in assessment and testing of the various forms of IS active power supplies.

- To examine possible strategies for controlling the output of IS active power supplies in order to maximise output power and cable lengths while at the same time satisfying the concerns of mining legislators.

- To perform analysis of electronic circuitry to determine energy outputs likely to cause gas ignitions under dynamic conditions.

- To design and carry out experimental programs to verify the analysis.