1.0 PURPOSE

This document is intended to provide the criteria to evaluate electrical apparatus, or parts of such apparatus, that utilize active overvoltage or overcurrent protection circuits that are intended to create intrinsically safe outputs.

2.0 SCOPE

These requirements apply to any circuit that uses some form of active voltage or current limiting in whole or in part to provide an intrinsically safe output.

3.0 REFERENCES

3.1. 30 CFR Part 18 "Electric Motor-Driven Mine Equipment and Accessories"

3.2. 30 CFR Part 19 "Electric Cap Lamps"

3.3. 30 CFR Part 20 "Electric Mine Lamps Other Than Standard Cap Lamps"

3.4. 30 CFR Part 22 "Portable Methane Detectors"

3.5. 30 CFR Part 23 "Telephones and Signaling Devices"

3.6. 30 CFR Part 27 "Methane-Monitoring Systems"

3.7. ACRI2001 "Criteria for the Evaluation and Test of Intrinsically Safe Apparatus and Associated Apparatus"

4.0 DEFINITIONS

Intrinsically Safe Active Voltage/Current Limited Circuit – A circuit that utilizes non-passive components such as transistors or other solid state devices that either shunt overvoltage or overcurrent conditions or limit the output of the power source fast enough to prevent an ignition of a methane-air atmosphere.

5.0 CRITERIA

5.1. In addition to this criteria, the circuit must comply with all other applicable parts of ACRI2001.

5.2. <u>Documentation</u>.

5.2.1. A detailed explanation on the operation of the circuit shall be supplied to aid in the evaluation. This must include components comprising overvoltage protection circuits, components comprising overcurrent protection circuits, maximum trip settings of each overcurrent/overvoltage circuit, the reset time between trips (note the reset time may need to be reduced on the safety-factored circuit to aid in testing as described below in section 5.7.1.1), and any other critical features of the circuit such as circuitry that activates the protective circuits based on the rate of change of the load current (di/dt).

Note: To aid in the spacing analysis of the circuitry, it is recommended that all components of a particular circuit (e.g. overvoltage protection circuit) are circled on the layout drawing and the minimum creepage and clearance in these areas indicated. It is also recommended that either Gerber files or transparencies of all layers of the circuit board are supplied for verification of the creepage and clearance distances.

5.2.2. The final drawings must specify:

5.2.2.1. The maximum voltage and current settings for each active circuit affecting intrinsic safety. This includes active limiting stages that indirectly affect the output voltage and current, di/dt circuits, etc.

5.2.2.2. The maximum non-safety-factored output voltage and output current for the power source with zero, one, and two faults applied. A circuit using identical triplicate circuits would have the same voltage and current for each quantity of faults.

5.2.2.3. Maximum acceptable directly connected load capacitance for zero, one, and two fault conditions.

Note: This is not a requirement for application specific power sources. Alternatively, the worst case capacitive circuit(s) comprised of internal and/or external capacitance may be tested in combination with the system.

5.2.2.4. Maximum source inductance appearing at the output terminals for zero, one, and two fault conditions and the associated minimum resistance for these conditions.

Note: This is not a requirement for application specific power sources. Alternatively, the worst case inductive circuit(s) comprised of internal and/or external series inductance will be determined during the system evaluation.

5.3. Evaluation and Design Requirements.

5.3.1. All components of each protection circuit affecting intrinsic safety shall be operated, in normal operation, at not more than 2/3 of their rated current, voltage, or power, as appropriate (ref. ACRI2001 section 8.1.1). Special attention must be applied to the evaluation of duplicative protection circuits, since for most cases, it can be assumed that current, voltage, and power are not shared among the duplicated circuits. Instead, due to tolerances in the settings, only one of the duplicated circuits trips or activates.

For example, three equivalent zener diodes or three identical active voltage limiting circuits limit the output voltage of a power source. Each zener diode or voltage limiting circuit shall comply with ACRI2001 section 8.1.1 since one will begin conducting or activating prior to the other two.

5.3.2. A two fault analysis according to ACRI2001 shall be applied. Special attention must be applied to the evaluation of duplicative protection circuits, since for most cases, it can be assumed that current, voltage, and power are not shared among the duplicated circuits. Instead, due to tolerances in the settings, only one of the duplicated circuits trips or activates. The ratings of components after the application of faults shall be adequate to prevent subsequent faults.

For example, there are three active current limiting circuits that limit the current to 2, 4, and 6 amperes to three equivalent zener diodes. In accordance with ACRI2001 section 8.1.1, the zener diodes need to each be rated 3A (2/3 rating at 2 amperes). However, to determine adequacy after application of two faults (short circuit failure of the 2 and 4 ampere current limiting circuits), each zener diode must be capable of withstanding 6 amperes without failing in a manner that would affect intrinsic safety.

5.3.3. When a single sense resistor is shared for multiple protection circuits, the sense resistor must be connected to each protection circuit through separate circuit board traces so that one common trace failure does not disable all protection circuits. The resistor must also comply with ACRI2001 as a protective current limiting resistor. Note: Infallible traces are not an acceptable alternative according to ACRI2001.

Alternatively, the resistor does not need to be connected via separate circuit board traces provided disconnection of the sense resistor maintains an intrinsically safe output with up to two faults applied.

5.3.4. Circuits which are powered from an AC line and are not powered through a protective transformer as defined in ACRI2001 must have input protection that passes a two fault analysis per ACRI2001 for the AC line voltage.

For example, if a power source is to be powered by 40 VDC which is supplied by a 120 volt line powered, generic power supply that is not documented, then the power source must withstand without damage that would affect intrinsic safety, an input of 144VAC, or 1.2 times the nominal line voltage for higher AC input voltages.

5.3.5. Since it is not feasible to conduct a spark ignition test at the instant an overvoltage condition occurs, the overvoltage protection circuit shall be accepted on the basis of its response time. The response time is considered the time at which the maximum input fault voltage exceeds the maximum trip voltage and returns to less than or equal to the maximum trip voltage. For purposes of the test, the maximum input fault voltage shall be simulated with a DC input voltage equal to the maximum DC input voltage or maximum peak AC input voltage. A response time of 100μS or less is acceptable without additional testing or justification provided there is no damage that would affect intrinsic safety. Response times in excess of 100μS shall be justified. The response time of the overvoltage protection circuit of the non-safety factored version shall be documented by means of an oscilloscope trace.

Factors to be considered in the justification of response times in excess of 100µS may include: probability of overvoltage and a short-circuit fault condition occurring at the same time, level of the output voltage and current during the overvoltage exposure time in excess of 100µS, whether the overvoltage condition is a one time event (e.g. fuse blows) or could occur multiple times, etc.

Note: The test shall be conducted by applying the worst case input voltage and applying the two worst case faults according to ACRI2001. Subsequent faults as a result of this test are not countable.

5.3.6. Where active circuit settings that affect intrinsic safety are adjustable, the adjustable components must be inaccessible to the user and resistant to vibration.

An example of an acceptable method is encapsulating potentiometers. An example of an unacceptable method is the use of special fasteners on the power supply enclosure.

5.3.7. The maximum source inductance appearing at the output terminals for zero, one, and two fault conditions and the associated minimum resistance for these conditions shall be verified. This data will be used in the evaluation of the future connected inductive loads and either compared with published spark ignition curves or tested to determine acceptability.

5.4. Samples Required To Be Submitted.

5.4.1. One fully assembled version of the power source in marketable form for testing and comparison to the drawings. If any of the circuitry is encapsulated, then a second unencapsulated sample must also be submitted for measurements and application of faults.

5.4.2. One fully assembled version of the safety-factored power source. If any of the circuitry is encapsulated, then the submitted sample shall be unencapsulated for measurements and application of faults. The following requirements shall be included in the construction of the safety-factored power source:

5.4.2.1. An electrical safety factor is required for all spark ignition tests of zero and one faults. A safety factor obtained through the use of a more easily ignitable gas is not acceptable. The safety-factored version of the power source shall be adjusted to provide 1.5 times the output energy. This is typically achieved by increasing the voltage/current by 1.225 times each, with unaltered shut-down speed. Power sources employing special features such as di/dt circuits shall also have these circuits safety factored if necessary to achieve a 1.5 factor of safety on energy. Note: The shut-down time may vary slightly due to the change in voltage/current. If considered to be providing a less than desirable safety factor, then the shut-down time will need to be decreased.

5.4.2.2. Care should be taken to construct the safety-factored power source as close as practical to the marketable form version (e.g. equivalent components such as transformers, voltage regulators, and transistors) if possible, and in cases when this is not feasible, components shall be chosen with similar characteristics or from the same family of components.

5.4.2.3. The safety-factored power supply shall include either a description of changes made to construct the safety-factored version, or a marked-up bill of material and/or schematic to describe the changes.

Note: Reference note in section 5.7.1 regarding special test considerations.

5.5. Measurements. The following measurements shall be taken on both the non-safety-factored and safety-factored versions of the power source. The measurements shall be taken at 1.2 times the nominal voltage, unless measurements at the nominal input voltage or less result in higher output values.

5.5.1. Voltage and current measurements at critical stages of the circuit such as output of the transformer, output of the rectifier, output of the rectifier plus capacitance, output of the overvoltage protection, output of the overcurrent protection, etc. Note: it may be necessary to open circuit downstream circuitry to prevent any affect on the desired measurements.

5.5.2. Load lines (e.g. output voltage versus output current for varying resistive loads including open circuit and short circuit) with all critical faults that would affect the output characteristics. The purpose of these load lines is to compare the safety-factored and non-safety-factored load lines for similarity, and to document the characteristics of the non-safety factored circuit for future testing/evaluation of connected devices. A minimum of 15 data points shall be obtained. Note: A voltage limiting circuit consisting of a voltage regulator and two active voltage limiting circuits will need to have a separate load line for multiple fault scenarios.

5.5.3. Oscilloscope traces of the output waveforms with all critical faults that would affect the output characteristics. Additional oscilloscope traces must be obtained to confirm special features of the power source such as a di/dt circuit. The purpose of obtaining the oscilloscope traces is to compare the safety-factored and non-safety-factored traces for similarity, and to record the speed of the tested circuits for future reference.

5.6. Spark Ignition Testing General Requirements.

5.6.1. Testing should be conducted with only one of the identical duplicated circuits to prove adequacy and reliability unless including multiple circuits can be proven to be a more severe condition. Note: This may be a more stringent test (e.g. two faults with a safety factor), but may be used if it simplifies testing. Failure to pass this test does not imply the circuit is unsafe. If a failure occurs, additional consideration to the worst case test will need to be made.

5.6.2. Testing shall be conducted at 1.2 times the nominal input voltage (AC or DC) unless testing at the nominal input voltage or less can be proven to be a more severe condition.

5.7. Spark Ignition Tests.

5.7.1. The power source must be subjected to a minimum of 4,000 short circuit make sparks, and 4,000 maximum current break sparks. Two characteristics of active power sources may prevent a single continuous spark ignition test of 1,000 revolutions to be the most severe test. If the power source exhibits either of the following characteristics, then the spark ignition testing of the power source output must include the prescribed additional test(s). Note: Segmenting the test(s) is allowed (e.g. four 1,000 cycle segments) provided a calibration is obtained before and after each segment.

- If the active protected circuit shuts down on the first make short circuit of the spark test apparatus, and does not reset quickly enough to the maximum open circuit voltage between the break short circuit and the next make short circuit of the apparatus, then the additional test described by section 5.7.1.1 must be conducted.

- If the active protected circuit employs features such as di/dt circuits that trip/activate on the make spark and result in a break spark of less than the maximum output current, then the additional test described by 5.7.1.2 must be conducted.

  Note: It is the applicant's responsibility to provide power source samples for spark ignition testing to allow automated testing on the spark test apparatus. Techniques used to manufacturer these samples include: reset circuits, where none exist; modified reset circuits; or outboard circuitry. Where this is not practical, the spark ignition testing will be conducted by manually starting and stopping the spark test apparatus. When these manual techniques are required, the fee estimate should be increased to allow for the substantial increase in test time.

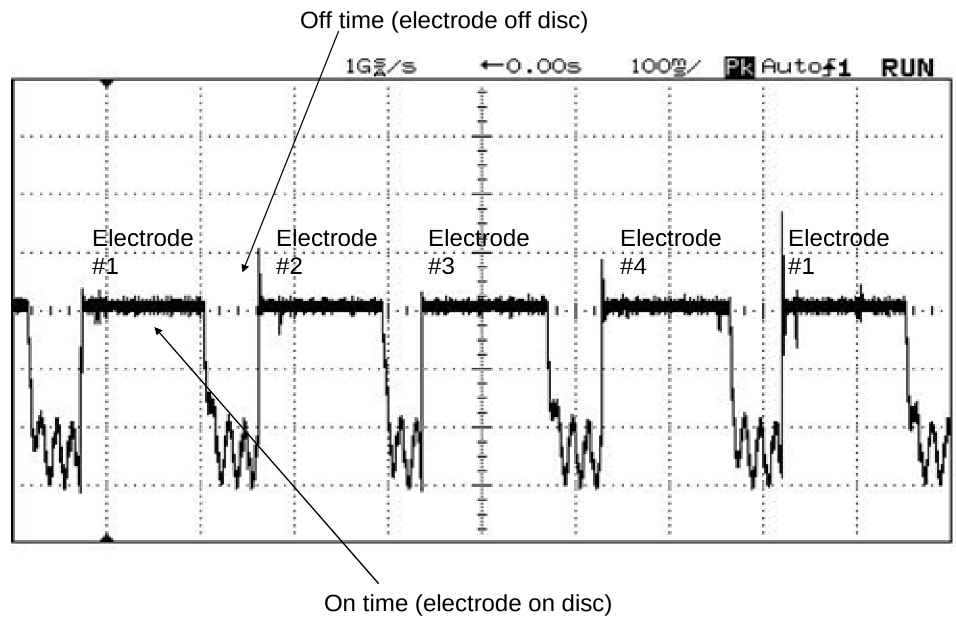
5.7.1.1. The make-spark ignition test may either require stopping the electrodes off of the disc to allow adequate time for the power source to reset or reducing the quantity of electrodes to prevent stopping and starting of the spark test apparatus. An oscilloscope trace shall be obtained and included with the spark ignition test sheet to confirm adequate reset time was allotted during the spark ignition test.

The time for a complete cycle of one electrode is approximately 750.0mS (132.5mS X 4 plus 55mS X4). The spark test apparatus speed shall not be reduced to allow for increased reset time.

Note: The standard disc with the two grooves must be utilized during all spark ignition testing.

Below is a table listing the approximate reset times at 80RPM for the quantity of electrodes installed, and the scope trace from which these were calculated. The scope trace was obtained at 80RPM with four electrodes installed using a non-typical disc without the two required grooves.

Quantity of Electrodes	Open circuit or reset time
4	55mS
2	242.5mS
1	617.5mS



5.7.1.2. The break-spark ignition test may be conducted by either of the two following methods:

5.7.1.2.1. By inserting a resistive load selected to draw an output current just below the current trip point while maintaining continuous rotation of the spark test apparatus, or

5.7.1.2.2. By stopping the electrode on the disc, reducing the variable resistive load to obtain safety-factored current, and then starting the spark test apparatus to initiate the break-spark.

5.7.2. Test(s) to determine the maximum acceptable capacitance across the output for the worst case zero and one fault (safety-factored power source), and two fault (non-safety-factored power source) conditions shall be conducted. The test(s) is/are necessary to provide data for evaluating applications utilizing capacitive loads since published spark ignition curves only consider the energy stored in the capacitor and not the energy from the power source. Note: Testing of an application specific power source shall include worst case zero and one fault (safety-factored power source), and two fault (non-safety factored power source) tests utilizing the worst case capacitance values determined from the system evaluation.

5.7.3. If a power source includes features such as a di/dt circuit, then special consideration has to be given to devising a spark ignition test that simulates the worst case resistive loading condition for a make or break spark. A detailed understanding of the operation of the circuit is required to properly configure the spark test.

An example where another spark test may produce a more severe condition than a direct short circuit is as follows: Assume the power source has an ultimate trip value of 6A, and has a rate of change trip of 2A, a test in which the power source is loaded to 4A and then the load is partially shorted to produce a 6A load may produce a more incendive spark than a direct short (0 to 6A).

Alternatively, the di/dt circuit could be bypassed for testing. Failing the spark ignition test with a triplicated di/dt circuit bypassed does not necessarily constitute a failure.

5.7.4. Any additional tests deemed necessary.

5.7.5. Repeat the tests described by sections 5.7.1 through 5.7.4 using the non-safety-factored power supply.

5.8. <u>Conditions of Use.</u> The approval letter shall include the following conditions of use for active circuits that are not application specific:

5.8.1. Nominal input voltage.

5.8.2. If the power source has multiple output voltage and/or current settings, then all MSHA approved power sources must be marked so the user can determine the voltage/current version. This may be accomplished by marking each power source with the voltage and current setting, by model number, by MSHA approval number, or any similar method.

5.8.3. Any other conditions of use deemed necessary.

5.9. Final Report Documentation. In addition to documenting how the power source complies with this criteria and ACRI2001, the final report is also required to include the following:

5.9.1. The maximum voltage and current settings for each active circuit affecting intrinsic safety. This includes active limiting stages that indirectly affect the output voltage and current, di/dt circuits, etc.

5.9.2. The maximum non-safety-factored output voltage and output current for the power source with zero, one, and two faults applied. A circuit using identical triplicate circuits could have the same voltage and current for each quantity of faults.

5.9.3. Maximum acceptable directly connected load capacitance for zero, one, and two fault conditions. As an alternative for application specific power sources, the worst case situation(s) may be tested.

5.9.4. Maximum source inductance appearing at the output terminals for zero, one, and two fault conditions and the associated minimum resistance for these conditions. As an alternative for application specific power sources, the worst case situation(s) may be tested.