INTEGRATED CURRENT SOURCE FEEDBACK AND CURRENT LIMITING ELEMENT

A circuit (200) for supplying power to an intrinsically safe load having an integrated current source feedback and current limiting element. The circuit (200) includes a power supply (PS) and output terminals (T1-T2) that connect the circuits to the intrinsically safe load. Voltage limiting circuitry (Z1) between the power supply (PS) and the output terminals (T1-T2) limit is the voltage across the load. Current limiting circuitry (202) includes barrier resistors which convert current to voltage for comparison in an operational amplifier (OA) that adjust the impedance across a variable impedance device (Q1) and limits current applied to the load.
Integrated Current Source Feedback and Current Limiting Element

Field of the Invention

This invention relates to a power supply for an intrinsically safe loads. More particularly, this invention relates to circuitry that limits the current supplied to the load to meet intrinsically safe standards.

Problem

Electronic devices are often used in hazardous environments containing volatile material. It is often a problem that a spark or heat from the electronic devices can cause the volatile material to ignite. Therefore, makers of electronic devices for use in these hazardous environments must provide some protection to ensure that the electronic devices do not ignite the volatile material.

One such form of protection is to make a circuit intrinsically safe. Intrinsically safe standards are set by regulating authorities such as the UL in the United States, CENELEC in Europe, CSA in Canada, and TIIS in Japan. In order to be intrinsically safe the current, power, and voltage through the circuit are limited to levels that prevents ignition of the volatile material from a spark or heat generated by the circuit.

It is a problem to deliver electricity to an intrinsically safe device. The power, voltage and current of the electricity are limited to the levels insufficient to ignite the volatile material. Therefore, components are needed in the power supply to limit the power, voltage, and current delivered to the intrinsically safe device.

In a conventional power supply, voltage is limited by connecting one or more zener diodes between supply line connecting a power supply to output terminals. The zener diodes limit voltage to $V$. Current limiting is provided by connecting a resistor having a resistance of $R$ in series with a high potential output terminal. The resistor limits current to $V/R$. Power is controlled by the limiting of current and voltage.

The limiting components, i.e. the diodes and resistors, must be protected to prevent the components from exceeding published rating in the event of a fault. A fuse is typically added to the circuit to limit the amount of current that can be delivered to the components. A fuse is chosen that has a rating that ensures power dissipation ratings are not exceeded.

Although not required for intrinsical safety standards, a current limiting circuit is often added to the power supply circuit to prevent the fuse from blowing. There many current limiting topologies that may be employed on either a high potential or
low potential side of a power supply. Most current limiting topologies include a resistor to convert current to voltage in order to provide feedback that is proportional to current. A comparison to a reference voltage is performed. The impedance of a series element is adjusted in response to the comparison. A problem with adding a current limiting circuit is that the conversion of current to voltage adds to the total output resistance and causes additional voltage loss beyond the voltage loss required to meet intrinsic safety standards.

Solution

The above and other problems are solved and an advance in the art is made by power supply having an integrated current source feedback and current limiting element in accordance with this invention. One advantage of an integrated current source feedback and current limiting element is the voltage loss may be minimized to the voltage that must be limited for intrinsic safety standards. A second advantage is that the number of components of a power supply circuit are reduced which lowers the cost of producing a power supply.

In accordance with the present invention, the function of a current conversion resistor in a power limiting circuit is combined with the function of barrier output resistance. This allows output resistance to be no more that the resistance required to prevent ignition of a hazardous material. The combination of function is provided by moving parts of the current limiting circuit to a point after the barrier resistance. In particular, a vary impedance device is moved to a point after the barrier resistance. One example of a vary impedance device is a MOFSET transistor.

When an MOFSET transistor is moved, there are two new paths to the output terminals. A first is a an op-amp control output and a feedback from a feedback from the barrier resistance. An input to an operational amplifier and the gate for the MOFSET transistor are of high impedance and relatively large value resistors compared to a barrier resistor placed in each of these paths. The total barrier resistance in a combination of resistor placed in a path with inputs into the MOFSET gate and operational amp input. This limits the power supply to an output resistance which is negligibly lower than the barrier resistance alone.

One aspect of this invention is a circuit for supplying power to an intrinsically safe load having a power supply, output terminals that affix to said load, voltage limiting circuitry between said power supply and said node, and current limiting
circuity that includes barrier resistors which convert current to voltage for comparison in an operational amplifier and limit current applied to said load.

A second aspect of this invention is a fuse that limits the amount of current applied by said power supply to said voltage limiting circuitry and said current limiting circuitry.

A third aspect of this invention is zener diodes connected between supply line from said power supply to said terminal.

A fourth aspect of this invention is wherein the current limiting circuitry includes a variable impedance device connected to said output of said operational amplifier.

A fifth aspect of this invention is wherein the variable impedance device is a MOFSET transistor.

A sixth aspect of this invention is wherein a gate of said MOFSET is connected to an output terminal and a second gate to the power supply.

A seventh aspect of this invention is wherein the current limiting circuitry includes a first resistor connected between said output of said operational amplifier and said MOFSET transistor.

An eighth aspect of this invention is wherein the current limiting circuitry includes a second resistor between the power supply and the MOFSET transistor.

A ninth aspect of this invention is wherein the current limiting circuitry includes a third resistor connected between the MOFSET transistor and the input of the operational amplifier.

**Description of the Drawings**

The above and other features in accordance with this invention can be understood from the Detailed Description and the following drawings:

FIG. 1 illustrating a prior art power supply for an intrinsically safe load;

FIG. 2 illustrating a power supply for an intrinsically safe load in accordance with this invention; and

FIG. 3 illustrating a Coriolis flowmeter incorporating a power supply in accordance with this invention into meter electronics.

**Detailed Description**

A power supply in accordance with this invention allows the total output resistance to be no more than is required to prevent ignition of volatile material in a hazardous environment. A typical intrinsically safe power supply 100 is illustrated in
FIG. 1 to show the differences between a power supply in accordance with the present invention and a typical intrinsically safe power supply.

Intrinsically safe power supply 100 is a power supply that delivers sufficient power to a load to ensure that the load may operate properly while limiting the worst case voltage, current, and power to levels insufficient to cause ignition of a hazardous material. Voltage limiting circuitry 101 limits the voltage across the load. In power supply 100, voltage limiting circuitry 101 is a Zenor diode Z1 connected between paths 110 and 120. One skilled in the art will recognize that more than one Zenor diode may be connected between paths 110 and 120 to limit the voltage. For purposes of this discussion, voltage limiting circuitry 101 limits the voltage across a load (Not Shown) to $V_v$.

Instantaneous current limiting circuitry 102 limits instantaneous current applied to a load. In power supply 100, instantaneous current limiting circuitry includes resistor Rb which is connected in series with output terminals T1 and T2. In this embodiment, resistor Rb is connected between positive output terminal T1 and power source PS along path 110. This limits the instantaneous current to $V_v / R_b$ where $R_b$ is the resistance of resistor Rb. Power delivered to the load (Not Shown) is limited by the limits of voltage and current.

Fuse F1 is connected between power source Ps and positive output terminal T1 to protect voltage limiting circuitry 101 and instantaneous current limiting circuitry 102 in case of a fault in the circuit. Fuse F1 prevents voltage limiting circuitry 101 and instantaneous current limiting circuitry 102 from exceeding published rating of components.

Average current limiting circuit 103 prevents fuse F1 from blowing in the event that output terminals T1 and T2 are shorted. There are many well known current limiting topologies that can be used to provide average current limiting circuit 103. In power supply 100, average current limit circuit is provided by the following components. A collector of transistor Q1 is connected to negative output terminal T2. An emitter of transistor Q1 is connected to a resistor Rv. Resistor Rv converts the current to voltage to provide feedback that is proportional to current. An input into operation amplifier OA is connected between the emitter of transistor Q1 and resistor Rv. Reference voltage ref is also applied to op-amp OA and a comparison is performed. The output of op-amp OA is then connected to the gate of transistor Q1.
and current is applied to the gate based on the comparison to adjust the impedance of transistor Q1. The current limit is set to \( I_{\text{ref}} = \frac{V_{\text{ref}}}{R_v} \) where \( I_{\text{ref}} \) is the current limit, \( V_{\text{ref}} \) is the reference voltage ref, and \( R_v \) is the resistance of resistor Rv.

One skilled in the art will recognize that values of components in power supply 100 are constrained by tables and formulas that characterize power and energy at which an ignition of a volatile material occurs. In normal operation, the load (not Shown) is connected to output terminals T1 and T2, draws current and voltage is lost across an output resistance. In order to maximize power transfer, it is desired to limit output resistance to that needed to prevent ignition of the volatile material.

It is a problem that adding average current limiting circuit 103 results in additional voltage loss beyond the voltage limits for preventing ignition. Voltage is lost because the voltage conversion resistance add to the total output resistance.

Power supply 200 illustrated in FIG. 2 solves this problem in accordance with the present invention. Power supply 200 is an intrinsically safe power supply that limits current, power and voltage delivered to a load (Not Shown). Voltage limiting circuitry 201 limits the voltage across the load. In power supply 200, voltage limiting circuitry 201 is a Zenor diode Z1 connected between paths 210 and 220. One skilled in the art will recognize that more than one zener diode may be connected between paths 210 and 220 to limit the voltage. For purposes of this discussion, voltage limiting circuitry 201 limits the voltage across a load (Not Shown) to \( V_{\text{ref}} \).

In accordance with the present invention, the functions of limiting the instantaneous and average current are combined into one circuit. The use of one circuit for both function allows the total output resistance to be reduced to the amount of resistance required to prevent ignition of a volatile material. This is accomplished by moving components of the average current limiting circuits to a point after the instantaneous current limiting circuitry. In particular, the variable impedance device, transistor Q1 is moved to a point after the barrier circuitry. The moving of the variable impedance device creates two new paths to output terminals T1 and T2. The new paths are the operation amplifier OA output and the feedback from a conversion resistor. Therefore total output resistance is a parallel combination of resistors along the two new paths and path 210 to power source PS.

In power supply 200, the current limiting circuit 202 in accordance with the present invention is provided in the following manner. A collector of MOFSET
transistor Q1 is connected to negative output terminal T2. A barrier resistor R3 along path 220 between transistor Q1 and power source PS. A second transistor R2 is connected between an emitter of transistor Q1 and an input of op-amp OA to generate a comparison voltage. Op-amp OA has an input connected to resistor R2 and receives a reference voltage Ref. Op-amp OA performs a comparison and applies a current to a gate of transistor Q1 to adjust impedance of transistor Q1. A resistor R1 is connected between op-amp OA and the gate of transistor Q1. Those skilled in the art will recognize that the values of Resistors R1, R2, and R3 may be large and that the total output resistance is a combination of the three resistors in parallel which is negligibly smaller than the value of the barrier resistance. Thus power transfer is optimized.

One device where power supply 200 is needed is a power supply for electronics in a Coriolis flowmeter operating in a hazardous environment. FIG. 3 illustrates a Coriolis flowmeter 300 incorporating power supply 200. Coriolis flowmeter 300 includes a flowmeter assembly 310 and meter electronics 350. Meter electronics 350 are connected to a meter assembly 310 via leads 320 to provide for example, but not limited to, density, mass-flow-rate, volume-flow-rate, and totalized mass-flow rate information over a path 375. A Coriolis flowmeter structure is described although it should be apparent to those skilled in the art that the present invention could be practiced in conjunction with any apparatus having intrinsically safe circuits requiring an intrinsically safe power supply.

A Coriolis flowmeter structure is described although it should be apparent to those skilled in the art that the present invention could be practiced in conjunction with any apparatus having a vibrating conduit to measure properties of material flowing through the conduit. A second example of such an apparatus is a vibrating tube densitometer which does not have the additional measurement capability provided by a Coriolis mass flowmeters.

Meter assembly 310 includes a pair of flanges 301 and 301’, manifold 302 and conduits 303A and 303B. Driver 304, pick-off sensors 306 and 306’, and temperature sensor 307 are connected to conduits 303A and 303B. Brace bars 305 and 305’ serve to define the axis W and W’ about which each conduit oscillates.

When Coriolis flowmeter 300 is inserted into a pipeline system (not shown) which carries the process material that is being measured, material enters flowmeter
assembly 310 through flange 301, passes through manifold 302 where the material is directed to enter conduits 303A and 303B. The material then flows through conduits 303A and 303B and back into manifold 302 from where it exits meter assembly 310 through flange 301'.

Conduits 303A and 303B are selected and appropriately mounted to the manifold 302 so as to have substantially the same mass distribution, moments of inertia and elastic modules about bending axes W-W and W'-W', respectively. The conduits 303A-303B extend outwardly from the manifold in an essentially parallel fashion.

Conduits 303A-303B are driven by driver 304 in opposite directions about their respective bending axes W and W' and at what is termed the first out of phase bending mode of the flowmeter. Driver 304 may comprise any one of many well known arrangements, such as a magnet mounted to conduit 303A and an opposing coil mounted to conduit 303B and through which an alternating current is passed for vibrating both conduits. A suitable drive signal is applied by meter electronics 350 to driver 304 via path 312.

Pick-off sensors 306 and 306' are affixed to at least one of conduits 303A and 303B on opposing ends of the conduit to measure oscillation of the conduits. As the conduit 303A-303B vibrates, pick-off sensors 306-306' generate a first pick-off signal and a second pick-off signal. The first and second pick-off signals are applied to paths 311 and 311'. The driver velocity signal is applied to path 310.

Temperature sensor 307 is affixed to at least one conduit 303A and/or 303B. Temperature sensor 307 measures the temperature of the conduit in order to modify equations for the temperature of the system. Path 311" carries temperature signals from temperature sensor 307 to meter electronics 350.

Meter electronics 350 receives the first and second pick-off signals appearing on paths 311 and 311', respectively. Meter electronics 350 processes the first and second velocity signals to compute the mass flow rate, the density, or other property of the material passing through flowmeter assembly 10. This computed information is applied by meter electronics 350 over path 375 to a utilization means (not shown).

It is known to those skilled in the art that Coriolis flowmeter 300 is quite similar in structure to a vibrating tube densitometer. Vibrating tube densitometers also utilize a vibrating tube through which fluid flows or, in the case of a sample-type
densitometer, within which fluid is held. Vibrating tube densitometers also employ a drive system for exciting the conduit to vibrate. Vibrating tube densitometers typically utilize only single feedback signal since a density measurement requires only the measurement of frequency and a phase measurement is not necessary. The descriptions of the present invention herein apply equally to vibrating tube densitometers.

In Coriolis flowmeter 300, the meter electronics 350 are physically divided into 2 components a host system 370 and a signal conditioner 360. In conventional meter electronics, these components are housed in one unit.

Signal conditioner 360 includes drive circuitry 363 and pick-off conditioning circuitry 361. One skilled in the art will recognize that in actuality drive circuitry 363 and pick-off conditioning circuitry 361 may be separate analog circuits or may be separate functions provided by a digital signal processor or other digital components. Drive circuitry 363 generates a drive signal and applies the drive signal to driver 304 via path 312 of path 320. In actuality, path 312 is a first and a second lead. Drive circuitry 363 is communicatively connected to pick-off signal conditioning circuitry 361 via path 362. Path 362 allows drive circuitry to monitor the incoming pick-off signals to adjust the drive signal. Power to operate drive circuitry 363 and pick-off signal conditioning circuitry 361 is supplied from host system 370 via a first wire 373 and a second wire 374. First wire 373 and second wire 374 may be a part of a conventional 2-wire, 4-wire cable, or a portion of a multi-pair cable.

Pick-off signal conditioning circuitry 361 receives input signals from first pick-off 305, second pick-off 305', and temperature sensor 307 via paths 311, 311' and 311". Pick-off circuitry 361 determines the frequency of the pick-off signals and may also determine properties of a material flowing through conduits 303A-303B. After the frequency of the input signals from pick-off sensors 305-305' and properties of the material are determined, parameter signals carrying this information are generated and transmitted to a secondary processing unit 371 in host system 370 via path 376. In a preferred embodiment, path 376 includes 2 leads. However, one skilled in the art will recognize that path 376 may be carried over first wire 373 and second wire 374 or over any other number of wires.

Host system 370 includes a power supply 372 and processing system 371. Power supply 372 receives electricity from a source and converts the received
electricity to the proper power needed by the system. Processing system 371 receives the parameter signals from pick-off signal conditioning circuitry 361 and then may perform processes needed to provide properties of the material flowing through conduits 303A-303B needed by a user. Such properties may include but are not limited to density, mass flow rate, and volumetric flow rate.

In this embodiment, power supply 372 includes the circuitry of power supply 200 shown in Fig. 2. This allows power supply 372 to provide power meeting intrinsically safe limits to signal conditioner 360 which includes circuitry meeting intrinsically safe standards.

The above is a description of a power supply circuitry that has an integrated current source feedback and current limiting element in accordance with this invention. It is expected that those skilled in the art can and will design alternative systems that infringe this invention as set forth in the claims below either literally or through the Doctrine of Equivalents.
What is claimed is:

1. A circuit (200) for supplying power to an intrinsically safe load comprising:
   a power supply (PS);
   output terminals (T1-T2) that affix to said intrinsically safe load;
   voltage limiting circuitry (Z1) between said power supply and said output terminals; and
   current limiting circuitry (202) that includes barrier resistors which convert current to voltage for comparison in an operational amplifier (OA) and limit current applied to said load.

2. The circuit (200) of claim 1 further comprising:
   a fuse (F1) that limits the amount of current applied by said power supply to said voltage limiting circuitry and said current limiting circuitry.

3. The circuit (200) of claim 1 wherein said voltage limiting circuitry comprises:
   a diode (Z1) connected between supply line (210) from said power supply to said terminals.

4. The circuit (200) of claim 1 wherein said current limiting circuitry (202) comprises:
   a variable impedance device (Q1) connected to said output of said operational amplifier (OA).

5. The circuit (200) of claim 4 wherein said variable impedance device (Q1) is a MOSFET transistor.

6. The circuit (200) of claim 5 wherein a gate of said MOSFET is connected to said output and a second gate to said power supply.
7. The circuit of claim 6 wherein said current limiting circuitry further comprises:
   a first resistor (R1) connected between said output of said operational amplifier and said MOFSET transistor.

8. The circuit of claim 7 wherein said current limiting circuitry further comprises:
   a second resistor (R3) connected between said power supply and said MOFSET transistor.

9. The circuit of claim 8 wherein said current limiting circuitry further comprises:
   a third resistor (R2) connected between said MOFSET transistor and said input of said operational amplifier.

10. The circuit of claim 9 wherein said load is meter electronics for a Coriolis flowmeter.
INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 H02H/02 G05F1/569

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H02H G05F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>DE 37 04 982 A (BERGWERKSVERBAND GMBH) 25 August 1988 (1988-08-25) abstract</td>
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<td>US 5 365 420 A (CADMAN GARY R) 15 November 1994 (1994-11-15) column 6, line 54 - column 7, line 45; figure 4</td>
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