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[54] **OVERVOLTAGE PROTECTIVE DEVICE**
11 Claims, 3 Drawing Figs.

[52] **U.S. Cl.** **317/16,** 310/11, 317/31, 317/33
[51] **Int. Cl.** **H02h 7/06**
[50] **Field of Search** 317/31, 16, 33; 174/5; 310/11

[56] **References Cited**

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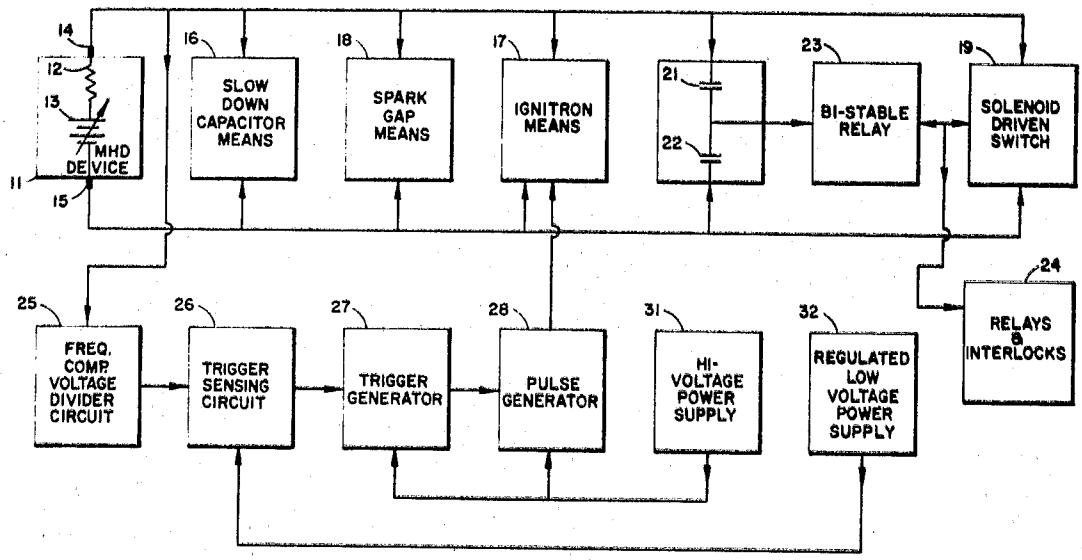
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ABSTRACT: A high voltage, high current, short circuiting device which can sense a condition overvoltage at the output of a magnetohydrodynamic generator or the like and initiate a short circuit in microseconds. The device incorporates a high voltage, high current ignitron actuated by a voltage sensing circuit; a spring-loaded switch to assist the ignitron in carrying the short circuit current; a spark gap as back up for the ignitron; and a bistable relay for use in combination with the spring-loaded switch and to actuate auxiliary apparatus such as fuel cutoff valves and the like.



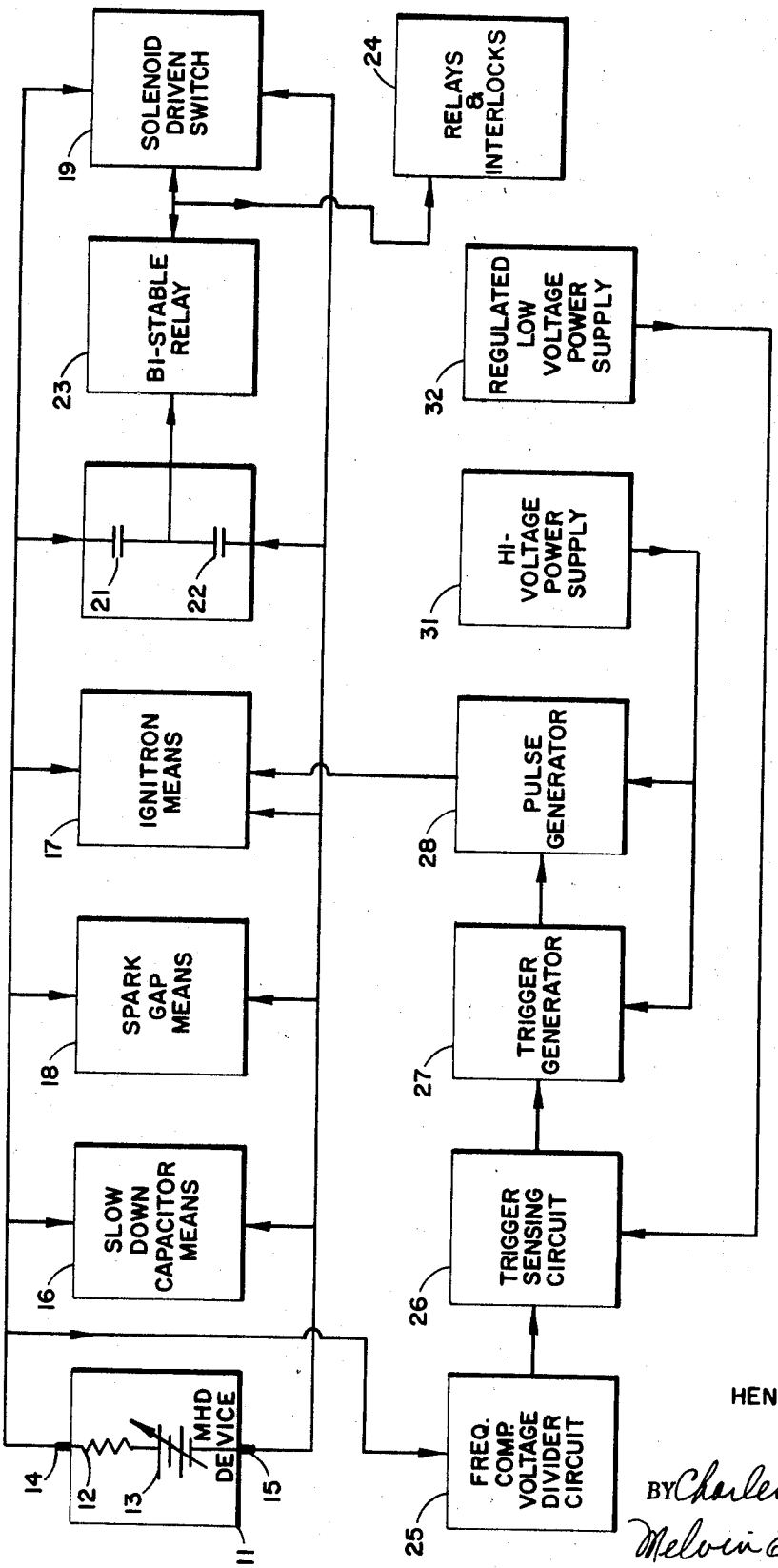


FIG. 1

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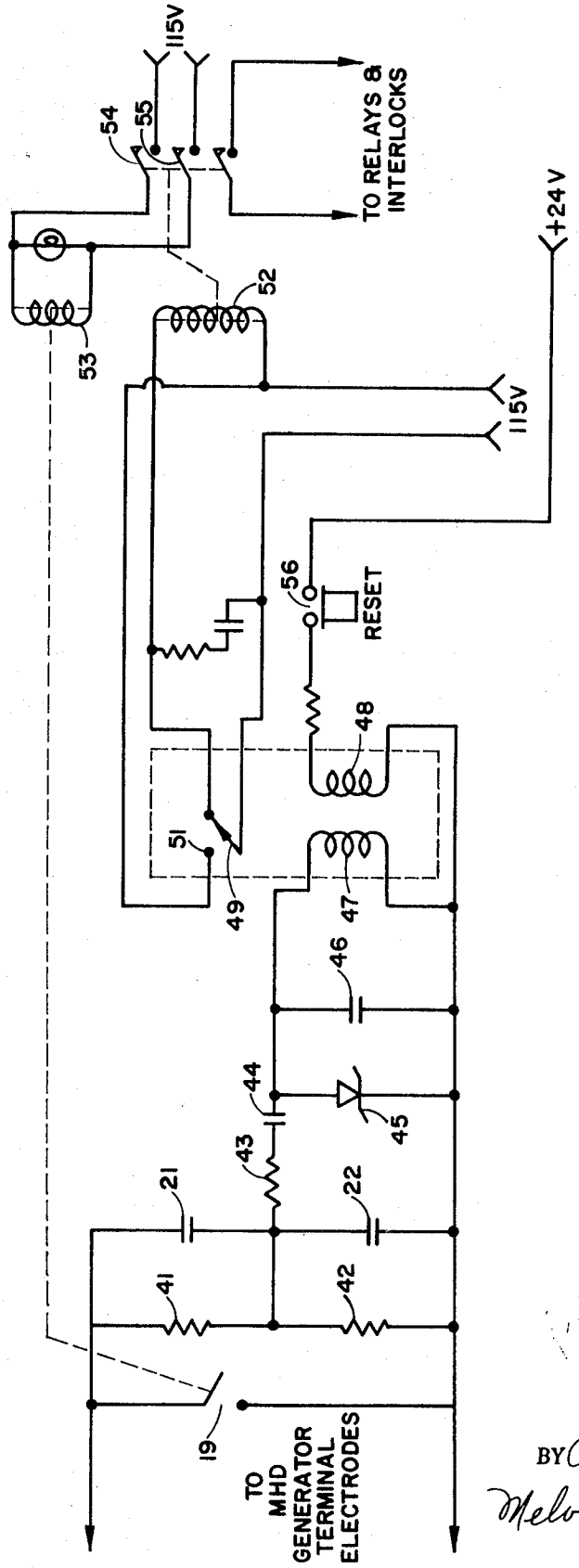


FIG. 2

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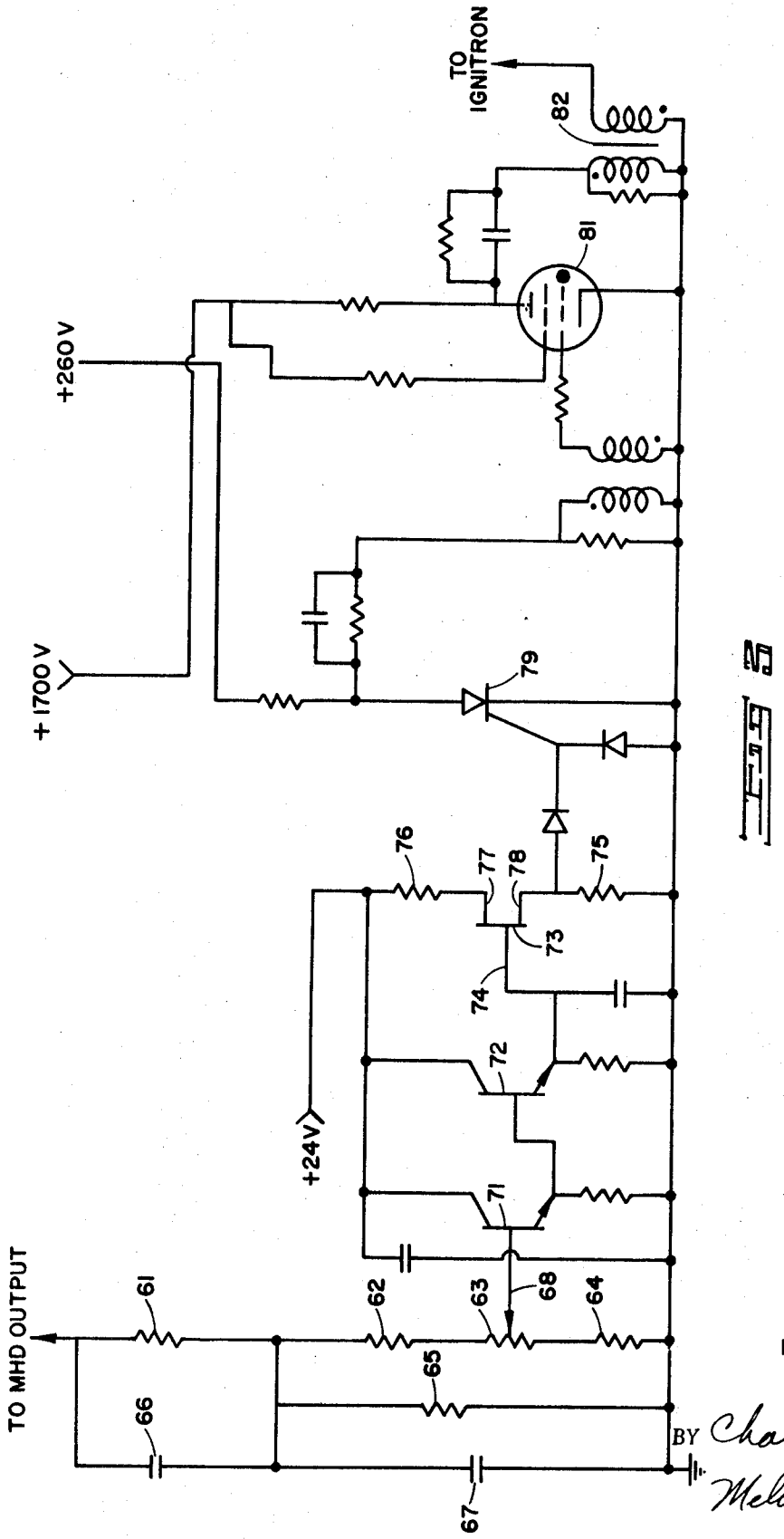


FIG. 2

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OVERVOLTAGE PROTECTIVE DEVICE

The present invention relates to apparatus for protection of DC devices and in particular to apparatus for protection of magnetohydrodynamic (hereinafter abbreviated "MHD") generators and accelerators.

In general terms, MHD generators produce electrical power by movement of electrically conductive fluid relative to a magnetic field. The fluid employed is usually an electrically conductive gas from a high temperature, high pressure source. From the source, the fluid flows through the generator and, by virtue of its movement relative to the magnetic field, induces an electromotive force between opposed electrodes within the generator. The gas may exhaust to a sink, which may simply be the atmosphere; or, in more sophisticated systems, the gas may exhaust to a recovery system including pumping means for returning the gas to the source.

Several different gases may be used; the gas may be products of combustion or may comprise inert gases, such as helium or argon. In open systems, i.e., those in which the gases are not recovered after passing through the power plant, products of combustion are normally used. In closed systems, in which the gases are recovered and recirculated, it is feasible to use relatively expensive gases, such as helium and argon. To promote electrical conductivity, the gases are heated to a high temperature; conductivity is also increased by the addition to the gases of a substance that ionizes readily at the operating temperature of the generator. Regardless of the gas used, it comprises a mixture of electrons, positive ions and neutral atoms which, for convenience, may be termed "plasma."

The temperature of the plasma is highly significant, not only to the overall efficiency of the system, but also to the design of the MHD generator. With a higher temperature available at the inlet of the generator, a larger isentropic drop can be developed as the plasma expands through the generator, resulting in improved efficiency. Further, since the electrical conductivity of the plasma increases greatly as temperature increases, it is possible to generate a given amount of power in a relatively smaller generator and employ a smaller magnetic field than would otherwise be possible. The increased efficiency of the system, considerably above that of conventional steam turbine power plants, and the absence of hot moving parts in the generator suggests that, in time, MHD power plants of the type generally disclosed in U.S. Pat. No. 3,264,501, issued Aug. 2, 1966, and entitled "Magnetohydrodynamic Power Plant" to which reference is made, will replace power generating systems of conventional design.

Combustion products from burning natural gas, oil or coal do not ionize until extremely high temperatures are reached. However, as previously noted, if a small amount of a material which ionizes more easily, such as an alkali, is added to the gas, sufficient ionization can be achieved at temperatures which feasibly can be produced in combustion chambers. For a plasma consisting essentially of combustion products, combustion temperatures in excess of 4000° F. are required for good performance. The impurity added is called seed; and the process, seeding. In practice, seeding is done by adding an alkali salt to the plasma rather than the more expensive pure metal.

To date, potassium has been selected as seed for economic reasons. The least expensive potassium salt, KCL, is not considered suitable as seed because the chlorine atom is strongly electronegative and captures the electrons given off by the potassium. It is therefore necessary to use a more expensive salt, such as, for example, potassium carbonate or potassium hydroxide, as seed.

The amount of potassium carbonate, potassium hydroxide, and the like, required to obtain sufficient conductivity of the plasma in a coal fired generator will be of the order of 2–5 percent of the fuel weight. This corresponds to a seed concentration of about 0.1–0.3 percent by volume after combustion. The aforementioned amount of seed required is about 10

times or more the amount of the potassium commonly present in coal ash and of course in a natural gas fired MHD generator the natural gas per se will not contain seed. Accordingly, seed must be added to the combustion products of coal, oil, natural gas and the like.

For a more thorough discussion of conductivity and the provision of a suitable plasma for MHD generators as by oxygen enrichment or preheating, reference is made to the aforementioned patent; however, for present purposes, suffice it to say that conductivity is a very strong function of the gas temperature and gas conductivity of more than about one mho per meter is required, corresponding to a minimum gas temperature of about 4000° F.

The use of seed is required in the operation of MHD generating systems and the cost of the seed represents a not insignificant portion of the operating costs of MHD electrical generating plants. Because the efficiency of an MHD generating plant is inherently higher than that of conventional steam generating plants, the cost of net power generated may be expected to be less than that for steam generating plants. However, without seed recovery in an MHD plant, the cost of fuel plus seed exceeds the cost of fuel for a comparable steam generating plant.

In the conventional or so called Faraday-type MHD generator, the plasma flows through a magnetic field, which is directed perpendicular to the direction of plasma flow. The movement of the electrically conductive plasma relative to the magnetic field produces as an EMF that is normal both to the direction of the flow of the plasma and the magnetic field, the load current flowing transversely of the field between opposed electrodes at the sides of the generator. In such a generator, a separation of positive and negative electrical charges occurs along the length of the plasma stream producing a potential gradient known as the "Hall potential," which promotes a longitudinal circulation of current internally of the generator. In the Faraday-type MHD generator, such longitudinal currents cause energy losses which are detrimental to the operation of the generator and various schemes have been devised to prevent their formation. A generator which takes advantage of the aforementioned Hall potential is referred to as a Hall generator.

Briefly, a Hall generator comprises a duct in a magnetic field normal to the access of the duct. Movement of plasma through the duct and the field induces an electromotive force between opposed electrodes that are interconnected, preferably as a short circuit to accommodate circulation of current transversely of both the magnetic field and the direction of plasma flow. The terminal or load electrodes, i.e., the first and last electrodes along the length of the duct, are connected to the load, making possible circulation of Hall current longitudinally through the plasma and the load circuit. This arrangement of elements is not only quite simple and effective but also minimizes heat and viscous drag losses. The geometry also simplifies a creation of a strong magnetic field through the duct of the generator. As noted above, to distinguish this type of generator from a conventional or Faraday-type MHD generator, it is termed for convenience "Hall generator."

The open circuit voltage of Faraday-type generators can be several times their design load voltage and the open circuit voltage of Hall generators can be of the order of 10 times their design load voltage. Further, because the internal resistance of both Faraday and Hall type generators is almost entirely resistive, i.e., very little inductance or capacitance, upon loss of their load as by an open circuit either intentionally or accidentally, these generators will reach their open circuit voltages in a matter of microseconds. Since the design output voltage of MHD generators is generally in the range of 1000 to 6000 volts or more, it will now be apparent that upon loss of its load, the design load voltage of 6000 volts, for example, of a Hall generator can almost instantaneously rise to a magnitude of as high as 60,000 volts, a value which due to arcing will normally destroy the generator channel or duct.

It is therefore an object of the present invention to provide apparatus for protecting MHD devices.

It is a further object of the present invention to provide new and improved apparatus for protecting MHD generators, accelerators and the like.

Another object of the present invention is to provide a new and improved fast acting high voltage, high current, short circuiting device.

Another object of the present invention is to provide a high voltage, high current short circuiting device for MHD generators which can sense a condition of overvoltage at the output of the generator, initiating a short circuit in microseconds and initiate shutdown of the generator in milliseconds.

The novel features that are considered characteristic of the invention are set forth in the appended claims; the invention itself, however, both as to its organization and method of operation, together with additional objects and advantages thereof, will best be understood from the following description of a specific embodiment when read in conjunction with the accompanying drawings, in which:

FIG. 1 is a block diagram of apparatus in accordance with the invention;

FIG. 2 is a schematic diagram showing details of the mechanical shorting switch circuit; and

FIG. 3 is a schematic diagram showing details of the ignitron actuating circuit.

Referring now to FIG. 1, an MHD device such as a generator or accelerator operative in conventional manner with a flow of electrically conductive fluid through a magnetic field is represented at **11**. The electric circuit of the MHD device, shown as a generator for purposes of illustration in this case, is represented by a resistance **12**, a battery **13**, and terminal electrodes **14** and **15**. Apparatus comprising the invention is connected to the aforementioned terminal electrodes **14** and **15**. Thus, connected across or in parallel with the terminal electrodes **14** and **15** are means **16** such as preferably a capacitor of sufficient capacitance and voltage rating to provide a predetermined rate of rise of voltage over a finite time period to prevent the runaway or open circuit voltage of the generator from increasing to a destructive value before ignitron means **17** and its associated voltage sensing means, more fully described hereinafter, can effect a short circuit of the terminal electrodes. Ignitron means **17** connected across terminal electrodes **14** and **15** may be a conventional ignitron such as a 7703 ignitron having a conventional trigger electrode (not shown). Also connected across the terminal electrodes **14** and **15**, which is also to say connected across the terminals of the ignitron, is conventional spark gap means **18** adjusted to fire at a voltage only slightly higher than that for which ignitron is set to fire.

Switch **19**, preferably of the solenoid driven type, is also connected across the terminals of the ignitron to effect upon actuation by suitable actuating means short circuiting of the generator. Suitable actuating means may comprise, for example, capacitors **21** and **22** and a bistable relay **23**. The ignitron means **17** upon a sufficient increase in voltage across the generator may be easily fired in a matter of 1 or 2 microseconds or less whereas a switch such as switch **19** can not. However, ignitrons generally have a maximum current carrying capacity less than the rated current of a typical MHD generator and a switch such as switch **19** may easily carry such a rated current. Accordingly, switch **19** functions to carry for the time necessary to shut the generator down, a sufficient proportion of the generator current as to prevent destruction of the ignitron. As more fully described hereinafter, switch **19** is actuated by capacitors **21** and **22** and relay **23** upon short circuiting of the generator terminal electrodes by ignitron **17** or in the event of failure thereof, by spark gap **18**. Actuation of switch **19** not only provides high voltage, high current short circuiting of the generator for substantial periods of time but also effects shutdown of the generator by actuating suitable relays and interlocks **24** to, for example, cut off the supply of fuel, seed and the like to the generator.

Ignitron **17** is actuated or triggered by voltage sensing means which upon a sufficient rise in voltage across capacitor **16** provides (after a short delay of for example 1–2 microseconds to prevent triggering on noise) a signal of sufficient voltage and current. Such voltage sensing means may comprise a frequency compensated voltage divider circuit **25** to provide a signal to a trigger sensing circuit **26** which actuates a trigger generator **27** which in turn actuates a pulse generator **28** to provide the signal required to trigger ignitron means **17**. High voltage supply **31** and a regulated low voltage power supply **32** provides the necessary voltage required by the various circuits such as trigger sensing circuit **26**, trigger generator **27**, and pulse generator **28**.

Attention is now directed to FIG. 2 which shows details of suitable means for actuating a switch which may be of the conventional solenoid operated high voltage, high current-type. Series connected resistors **41** and **42** are connected in parallel and center tap across capacitors **21** and **22** to provide an output signal to the aforementioned bistable relay **23** via resistor **43**, capacitor **44**, diode **45**, and capacitor **46**. Upon application of a short circuit to the terminal electrodes **14** and **15** (which is to say actuation of ignitron **17** or spark gap **18**) the charge on capacitors **21** and **22** is dumped through the winding **47** of relay **23** to move arm **49** from its normal position as shown to contact **51**. Actuation of arm **49** to contact **51** breaks the circuit to winding **52** and thereby breaks the circuit to winding **53** by actuation of arms **54** and **55** to their open position. Winding **53** functions to hold the main contacts of switch **19** in their normally open position as shown in FIG. **2**, hence, removal of the source of current from winding **53** results in the closure of switch **19** and thereby short circuit of the terminal electrodes of the generator. Switch **19** can be actuated in about 12 milliseconds or less. Simultaneously, with actuation of switch **19**, relays and interlocks controlling the supply of fuel and the like to the burner are actuated and shut down the generator.

The closing of switch **19** results in the flow of the short circuit current therethrough rather than through the ignitron and assures that the generator will remain short circuited and, hence, protected until it is reset as by closing reset switch **56** connected in series with winding **48**.

Attention is now directed to FIG. 3 which shows details of voltage sensing means for actuating ignitron **17**. The frequency compensated voltage divider circuit **25** comprising resistors **61**, **62**, **63**, **64**, and **65**, and capacitors **66** and **67** provide at a reasonable amplitude an output voltage that follows the operating voltage of the generator. Such an operating voltage may vary from 1000 to 14,000 or more volts at a current of 14,000 amperes or more. Accordingly, the MHD output voltage, greatly reduced in magnitude, appears at the potentiometer arm **68** of variable resistor **63**. The voltage divider **25** is frequency compensated by capacitors **66** and **67** to permit a response time of 2 microseconds or less at the potentiometer arm **68** of resistor **63**. Transistor **71** is connected as an emitter follower to present a very high impedance at its base to prevent interference with the frequency compensation of the voltage divider or the DC setting of potentiometer arm **68**. Transistor **72** functions as a buffer between transistor **71** and the emitter of unijunction transistor **73** which is connected in a highly stable configuration. When the voltage on the emitter **74** of unijunction transistor **73** reaches a threshold value determined by resistors **75** and **76** connected in series with respectively its bases **77** and **78**, a fast rising trigger pulse will appear at resistor **75**. This fast rising trigger pulse is coupled to a silicon controlled rectifier **79** which when fired also produces a fast rising trigger pulse but at a higher voltage. The trigger pulse provided by the silicon controlled rectifier **79** is coupled to and fires a gas tube **81** such as, for example, a Krytron KN6 which produces at transformer **82** a very high power pulse. The pulse at transformer **82** is coupled to and triggers the ignitron **17**. As will now be evident, if the voltage on the potentiometer arm **68** of resistor **63** rises beyond a preset level, ignitron **17** will be fired and short circuit the

generator. However, since a signal of considerable power is typically required to trigger the ignitron, the unijunction transistor **73**, silicon controlled rectifier **79** and Krytron **81** are utilized to produce the required trigger pulse. Transistors **71** and **72** are utilized to reduce the loading effect on the potentiometer arm **68** of resistor **63**.

If desired, the power supplies **31** and **32** may be monitored by providing a normally open switch (not shown) in series with winding **52** (see FIG. **2**). Such a switch in series with winding **52** must be closed for proper operation. Since the proper operation of the switch in series with winding **52** may be made to depend on the proper operation of the power supply, protective circuitry in accordance with the invention will either short circuit or refuse resetting depending on the state of the protective device when it was previously used if the power supplies are not operating. Further, circuitry in accordance with the invention may be tested by the provision of a test signal to the ignitron **17** with potentiometer arm **68** set to its minimum setting and the circuitry disconnected from the terminal electrodes of the generator. Thus, with potentiometer arm **68** set at its minimum value, upon application of the test signal the ignitron **17** will be fired and a short circuit situation will be provided indicating that the circuitry is operating satisfactorily.

It has been previously pointed out that capacitor means **16** functions to slow down the rate of rise of the generator runaway voltage so that the firing time of the ignitron, such as, for example, 2 microseconds, is fast enough to provide protection. Alternatively, the capacity of capacitors **66** and **67** in the voltage divider circuit may be selected to provide overcompensation. If this is done, an ignitron firing time of as little as 0.1 microseconds may be provided. However, in this case, AC ripple on the generator output voltage could result in short circuiting of the generator. For this reason, slight undercompensation in the voltage divider network and the provision of slowdown capacitor means **16** is preferred.

The various features and advantages of the invention are thought to be clear from the foregoing description. Various other features and advantages not specifically enumerated will undoubtedly occur to those versed in the art, as likewise will many variations and modifications of the preferred embodiment illustrated, all of which may be achieved without departing from the spirit and scope of the invention as defined by the following claims.

1. In magnetohydrodynamic apparatus having terminal electrodes and operative with a flow of electrically conductive working fluid through a magnetic field, the combination comprising:

a. ignitron means connected across said terminal electrodes for short circuiting said terminal electrodes;
b. voltage sensing means coupled to said terminal electrodes for actuating said ignitron means when the voltage at said terminal electrodes reaches a first predetermined value;
c. mechanically actuated switch means connected across said terminal electrodes for short circuiting said terminal electrodes;
d. means operative upon a short circuit of said terminal electrodes by said ignitron means for actuating said switch means; and
e. spark gap means connected across said terminal electrodes for short circuiting said terminal electrodes when the voltage at said terminal electrodes reaches a second predetermined voltage greater than said first predetermined voltage.

2. The combination as defined in claim **1** and additionally including means connected across said terminal electrodes for providing a predetermined rate or rise of voltage over a finite time period at said terminal electrodes.

3. The combination as defined in claim **2** wherein said voltage sensing means actuates said ignitron to short circuit said terminal electrodes before the voltage at said terminal electrodes substantially increases over said first predetermined value.

4. The combination as defined in claim **3** wherein said voltage sensing means includes input means comprising a frequency compensated voltage divider circuit connected across said terminal electrodes.

5. The combination as defined in claim **4** wherein said voltage divider circuit is comprised of first and second resistor means connected in parallel with respectively first and second capacitor means, the ratio of said capacitor means being substantially the inverse of the ratio of said resistor means to provide an output signal across said second resistor and said second capacitor means.

6. In magnetohydrodynamic apparatus having terminal electrodes and operative with a flow of electrically conductive working fluid through a magnetic field, the combination comprising:

a. ignitron means connected across said terminal electrodes for short circuiting same, said ignitron means having a trigger input signal terminal;
b. voltage sensing means coupled between said terminal electrodes and said trigger input terminal for triggering said ignitron means to short circuit said terminal electrodes when the voltage at said terminal electrodes increases from its normal value to a first predetermined value;
c. switch means connected across said terminal electrodes for short circuiting same; and
d. means operative upon a short circuit of said terminal electrodes by said ignitron means for actuating said switch means.

7. The combination as defined in claim **6** wherein said voltage sensing means includes a frequency compensated voltage divider circuit for providing a signal proportional to said first predetermined value in not less than about 2 microseconds and more than 1 millisecond; and additionally including capacitor means connected across said terminal electrodes for providing a substantially exponential rate of rise of voltage at said terminal electrodes prior to actuation of said ignitron means.

8. In apparatus for protecting devices subject to overvoltage conditions and having first terminals at which said voltage appears, the combination comprising:

a. ignitron means having second terminals adapted for connection across said first terminals for short circuiting same;
b. voltage sensing means coupled to said second terminals for actuating said ignitron means when the voltage at said first terminals increases over its normal value to a first predetermined value;
c. switch means connected across said second terminals for short circuiting same; and
d. means operative upon a short circuit of said second terminals by said ignitron means for actuating said switch means.

9. In apparatus for protecting devices subject to overvoltage conditions and having first terminals at which said voltage appears, the combination comprising:

a. ignitron means having second terminals adapted for connection across said first terminals for short circuiting said first terminals;
b. voltage sensing means coupled to said second terminals for actuating said ignitron means when the voltage at said first terminals reaches a first predetermined value;
c. mechanically actuated switch means connected across said second terminals for short circuiting said second terminals;
d. means operative upon a short circuit of said second terminals by said ignitron means for actuating said switch means; and
e. spark gap means connected across said second terminals for short circuiting said second terminals when the voltage at said second terminals reaches a second predetermined voltage greater than said first predetermined voltage.

10. The combination as defined in claim 9 and additionally including means connected across said second terminals for providing a predetermined rate of rise of voltage at said terminals.

11. The combination as defined in claim 10 wherein said voltage sensing means includes input means comprising a frequency compensated voltage divider circuit connected across said second terminals.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,601,657 Dated August 24, 1971

Inventor(s) Henry R. Guarino

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Abstract, line 2, after "condition" insert--of--; and
Column 5, line 69, for "or" read--of--.

Signed and sealed this 31st day of October 1972.

(SEAL)
Attest:

EDWARD M.FLETCHER,JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents