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Gelfand

[11] **3,745,749**

[45] **July 17, 1973**

[54] **CIRCUITS FOR CONTROLLING THE POWER SUPPLIED TO AN ELECTRICAL PRECIPITATOR**

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[21] Appl. No.: **161,606**

[52] **U.S. Cl.** **55/105,** 323/9, 323/20, 323/24, 323/34, 323/82

[51] **Int. Cl.** **B03c 3/68**

[58] **Field of Search** .... 55/105; 317/31; 321/18, 19; 323/9, 20, 22 SC, 24, 34, 7, 82, 89 R

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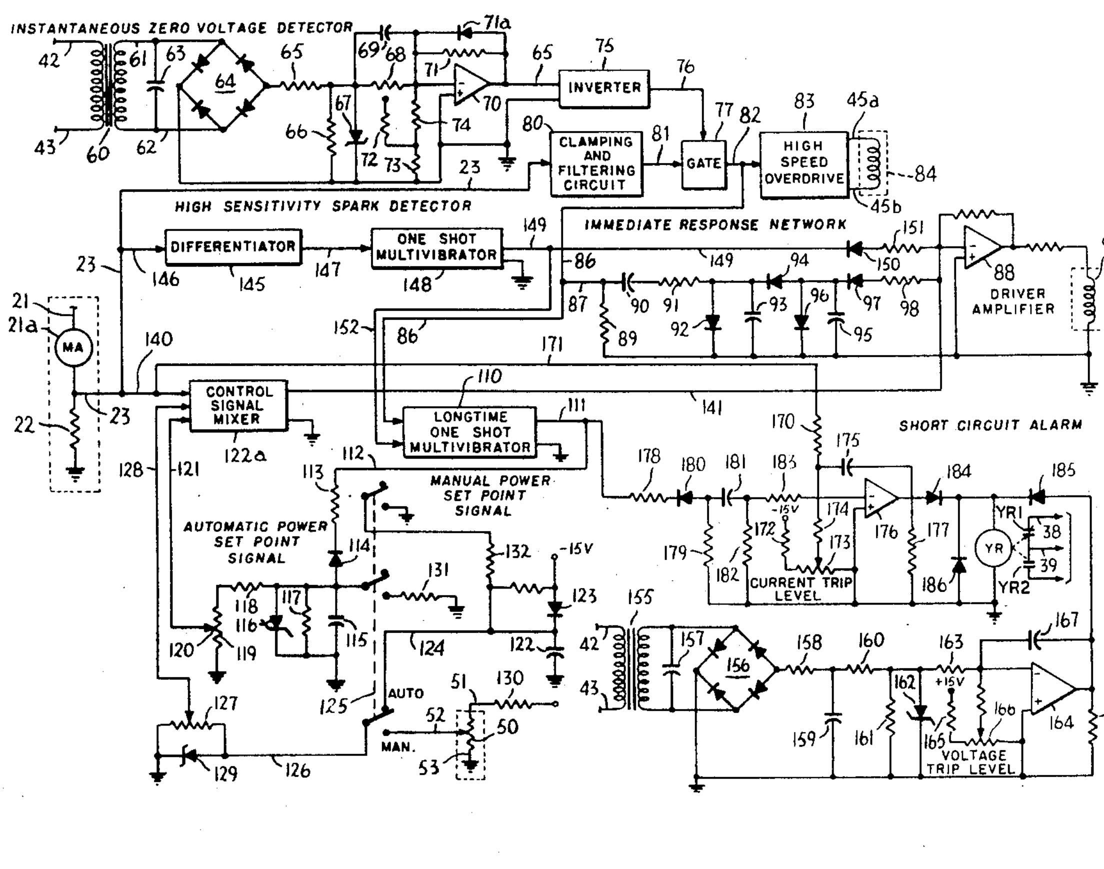
[57] **ABSTRACT**

A system for controlling the level of operation of a precipitator through the use of analog computer circuits programmed to respond to sparking and short circuits. Reference pulses representative of instantaneous zero excursions of voltage control a gate that receives precipitator current pulses. When the reference pulses coincide with the current pulses, due to sparking, output signals reduce the power level of the precipitator. A high sensitivity spark detector circuit also reduces the power level in response to low intensity precipitator sparks. Following reduction of the power level, power in the precipitator is rapidly reapplied to establish a new level of operation slightly lower than the original level, and this level is then slowly raised until sparking again occurs. The analog computer circuits are also programmed to monitor and compare precipitator voltage and current to shut down the precipitator power supply upon occurrence of a destructive short circuit.

37 Claims, 9 Drawing Figures



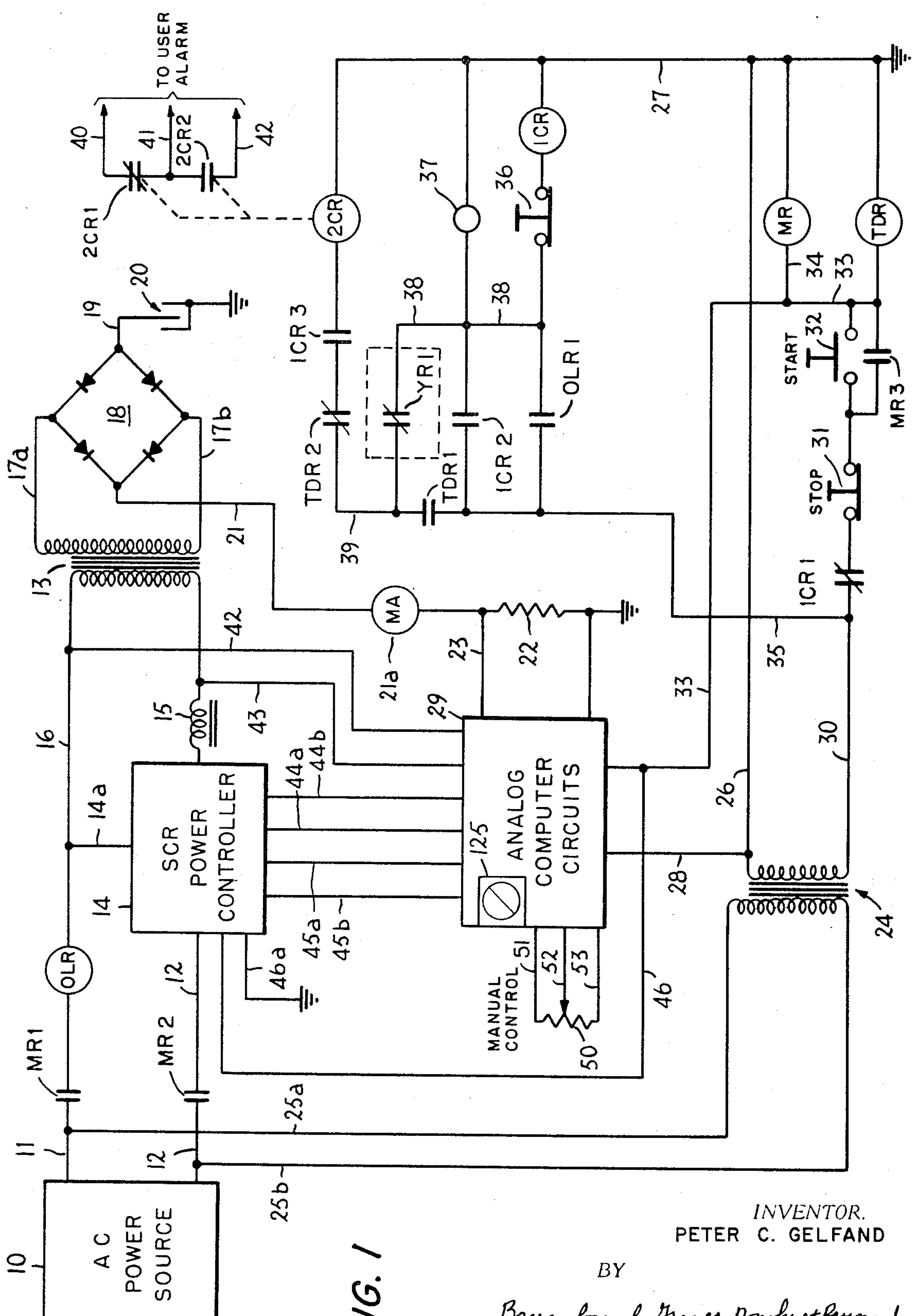


FIG. 1

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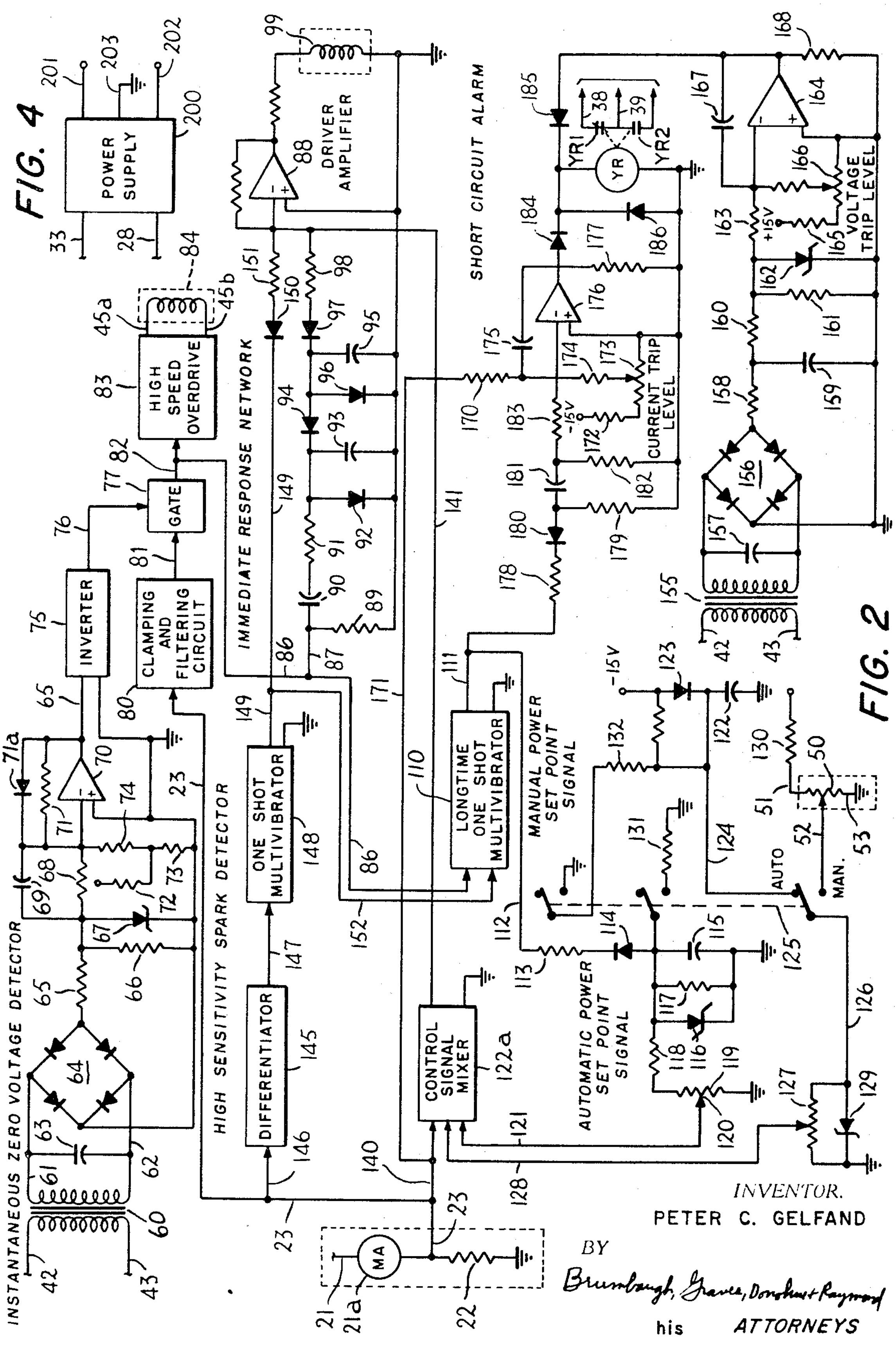

FIG. 4

FIG. 2

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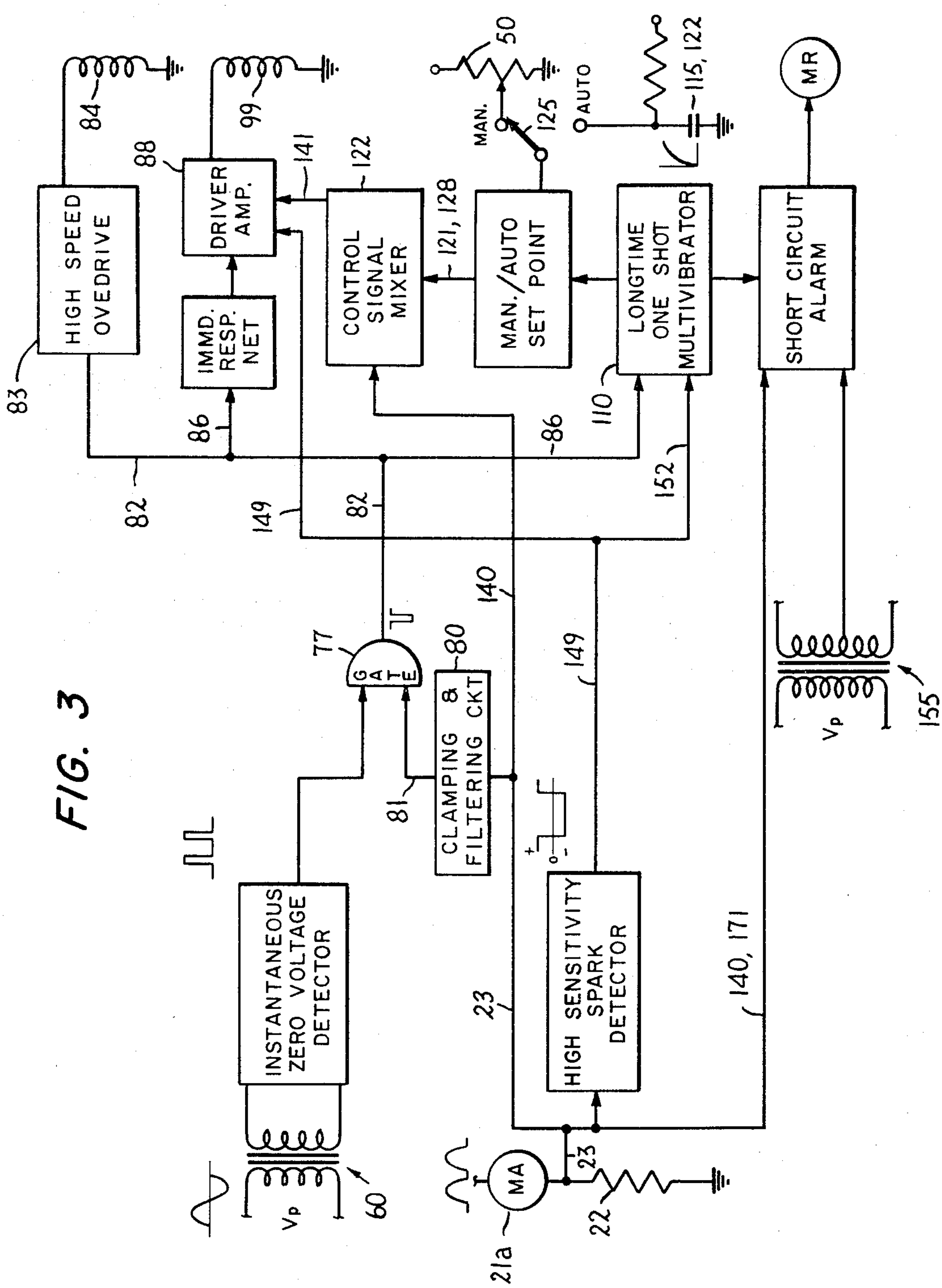

FIG. 3

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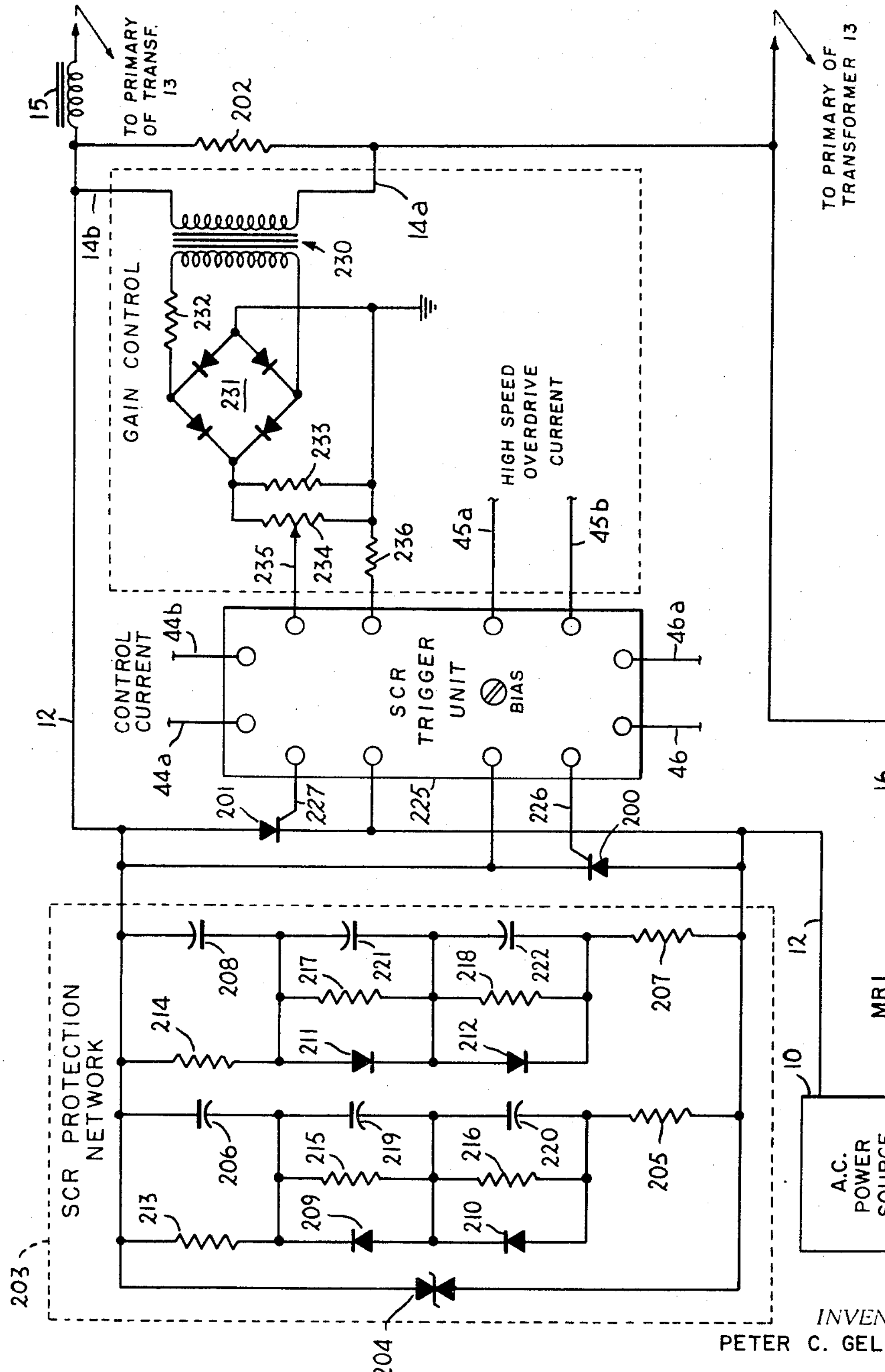

FIG. 5

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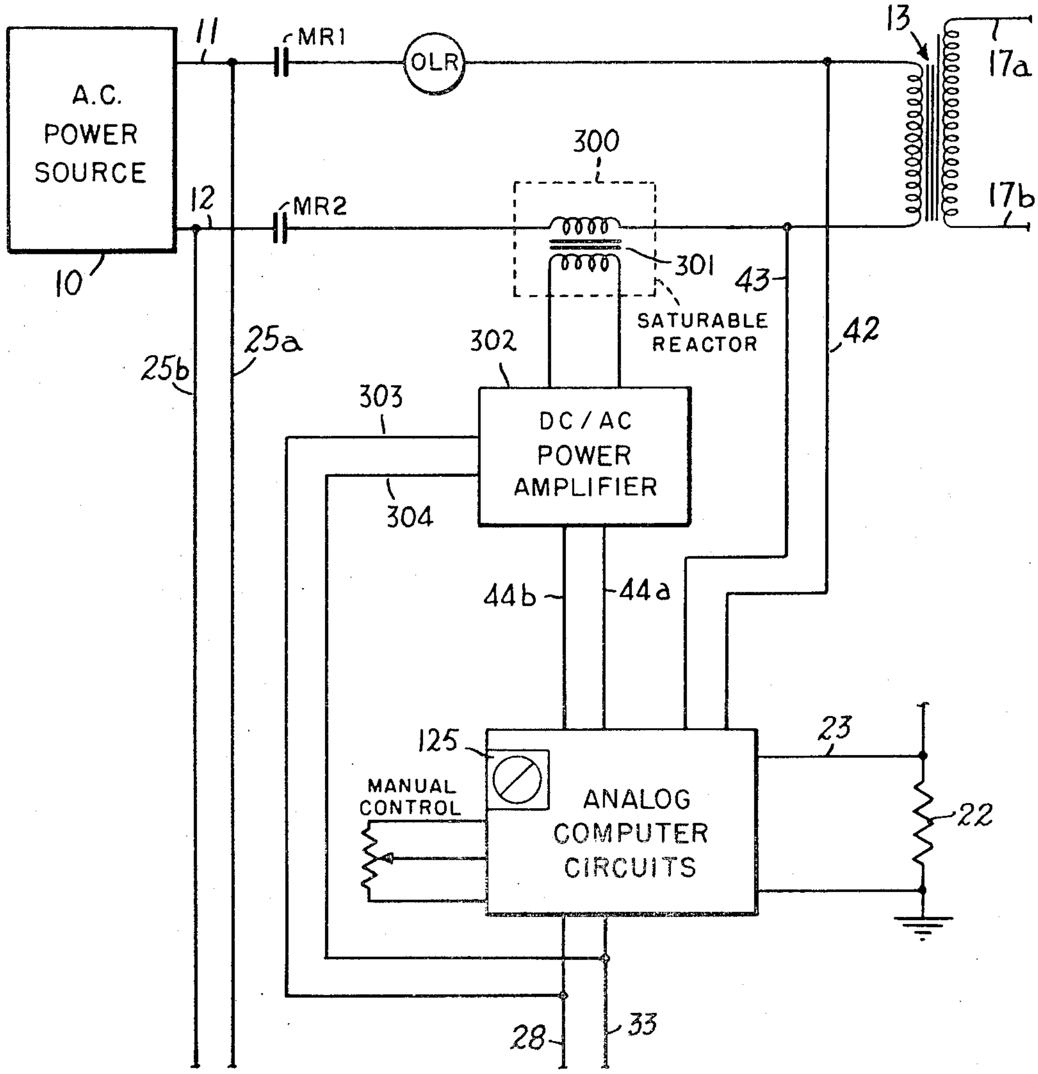

FIG. 6

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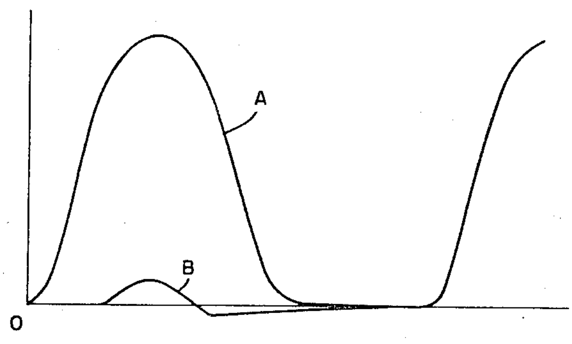

FIG. 7

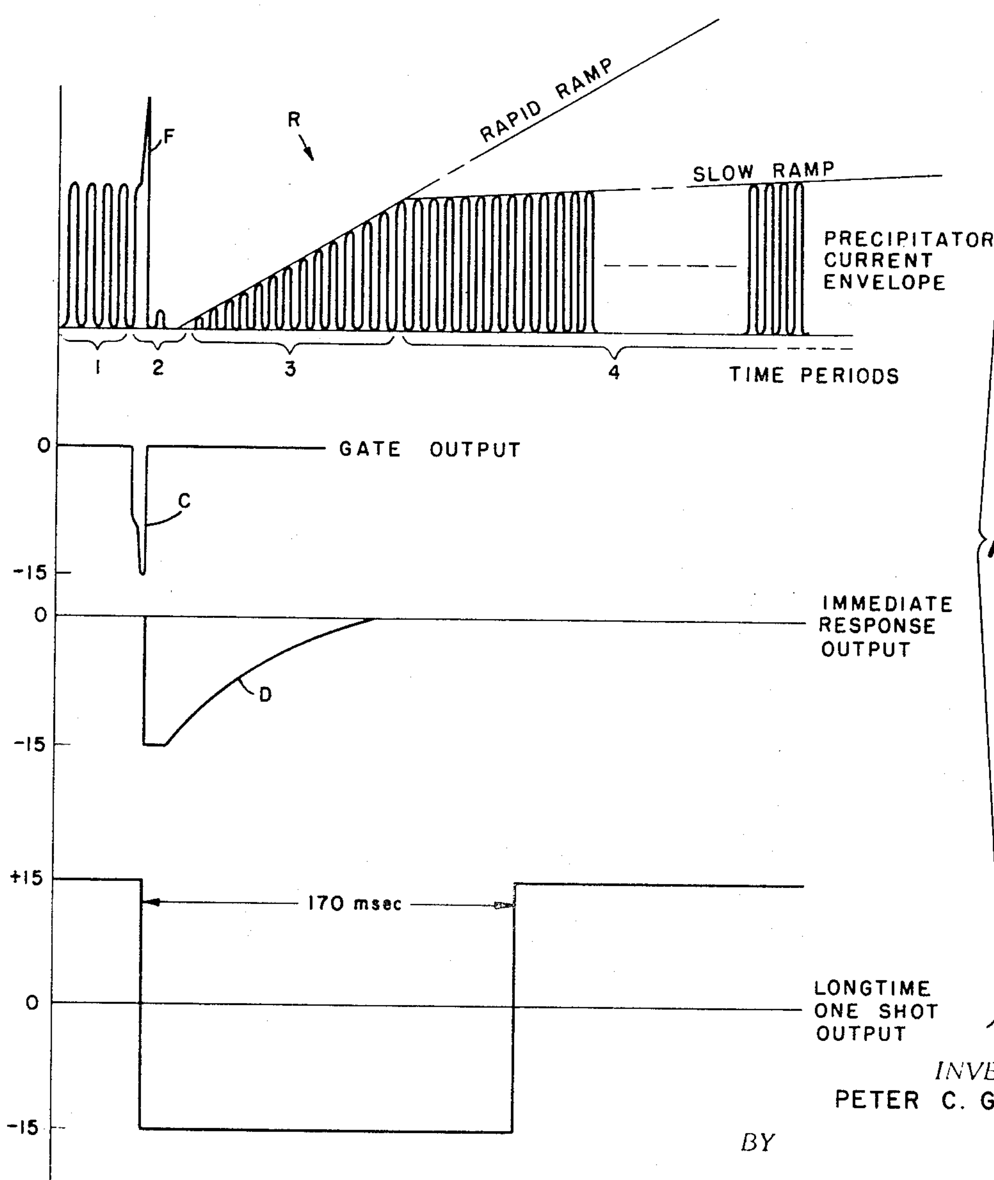

FIG. 8

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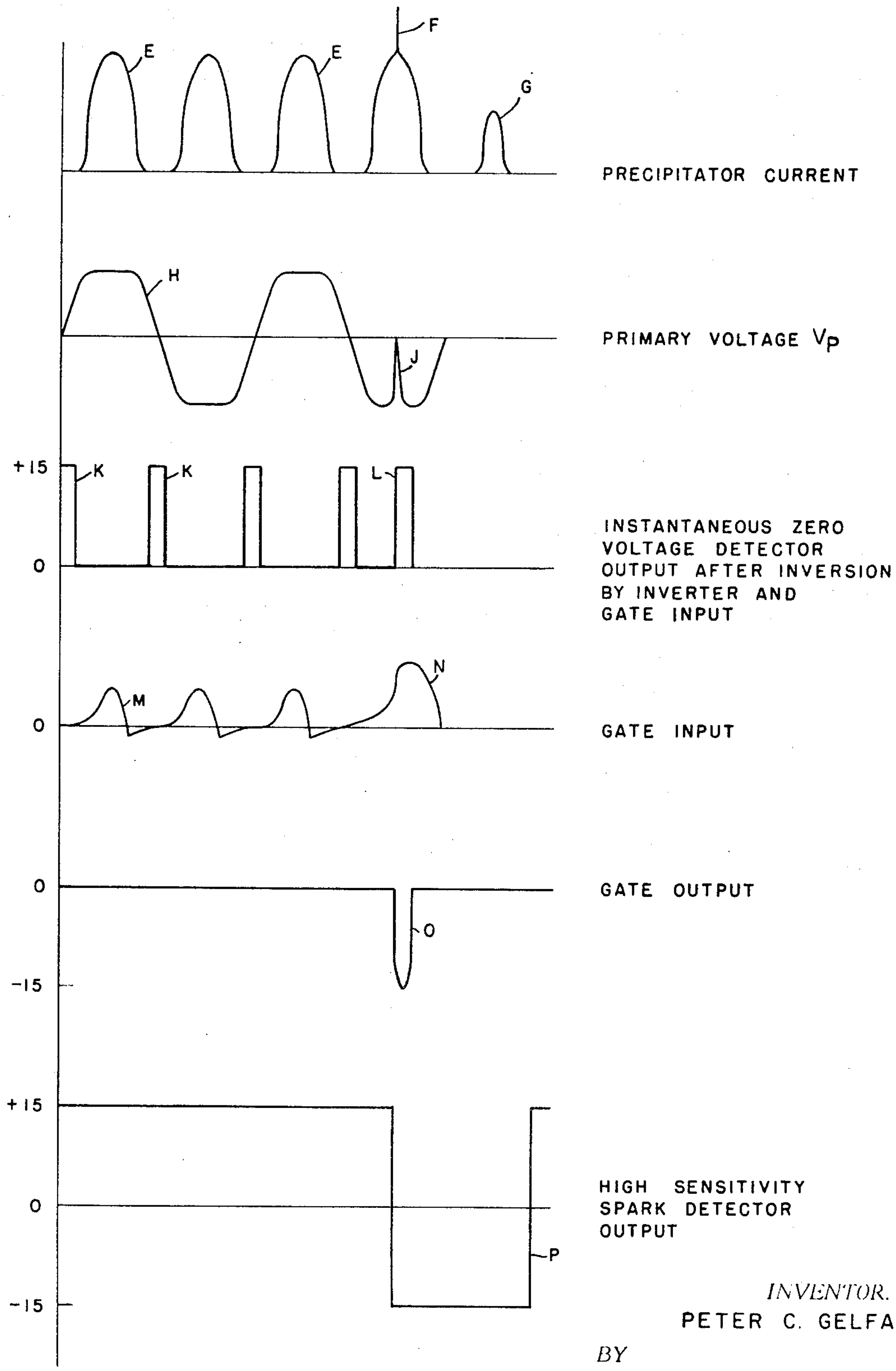

FIG. 9

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CIRCUITS FOR CONTROLLING THE POWER SUPPLIED TO AN ELECTRICAL PRECIPITATOR

BACKGROUND OF THE INVENTION

This invention relates to power control systems for electrical precipitators and, in particular, to such control systems that provide for operation of precipitators at maximum efficiency.

Conventional electrostatic precipitators, used to remove suspended particles from gas streams, operate with relatively high DC voltages applied across their collecting electrodes. Increasing the power level at which a precipitator operates to obtain maximum operating efficiency leads first to sparking and then to arcing between the electrodes. Precipitator efficiency is at its maximum during sparking and falls off sharply during arcing.

To maintain a power operating level of a precipitator to obtain optimum sparking but not arcing, the practice has been to sense the sparking and to integrate two times a signal representative of the sparking to produce a control signal used to vary the power level of the precipitator, such as shown in my U.S. Pat. No 3,173,772. It has been found in practice that such an integrated control signal can lead to higher precipitator operating levels and greater precipitator efficiency.

While using control signals derived by doubly integrating the spark pulses has afforded improved precipitator efficiency, there has remained a need for a control system for precipitators having greater flexibility and providing for immediate response in the event of sparking or arcing, and shut down of the system in the event of certain types of short circuits.

SUMMARY OF THE INVENTION

The present invention provides a system for controlling the power level of a precipitator through use of analog computer circuits programmed to respond to sparking and short circuits in a manner that affords optimum efficiency of the precipitator, and yet safeguards the precipitator from destructive arcs and short circuits. To this end, circuits are provided that produce reference pulses representative of instantaneous zero excursions of voltage supplied to the primary of the precipitator's high voltage transformer, and that provide an output for reducing the power level of the precipitator when precipitator current sparking pulses coincide with the reference pulses. High sensitivity spark detector circuits are also provided to reduce the power level in response to low intensity sparks. Power is then increased rapidly to a new level slightly lower than the original level, and then slowly raised until sparking again occurs.

To insure interruption of power to the precipitator upon the occurrence of destructive short circuits, the analog computer circuits are programmed to monitor and compare precipitator voltage and precipitator current and to shut down the precipitator power supply upon occurrence of a short circuit to safeguard the precipitator. At the same time, the user of the precipitator is advised of the short circuit.

DESCRIPTION OF THE DRAWINGS

The invention and its advantages will be better understood when the following detailed description is read in conjunction with the accompanying drawings, in which:

FIG. 1 is a block and schematic circuit diagram of an illustrative precipitator circuit embodying the principals of the present invention;

FIG. 2 illustrates a block and schematic circuit diagram of the analog computer circuits 29, shown in FIG. 1, which are programmed to control the power supplied to a precipitator in response to sparking and arcing, and to remove power from the precipitator and at the same time energize an alarm circuit in response to short circuits;

FIG. 3 is a block diagram of the analog computer circuits shown in the schematic diagram of FIG. 2;

FIG. 4 illustrates a power supply for the analog computer circuits;

FIG. 5 is a schematic diagram of the SCR power controller 14 shown in FIG. 1;

FIG. 6 is a circuit diagram showing substitution of a saturable reactor for thyristors used in the circuit of FIG. 1; and

FIGS. 7, 8 and 9 illustrate waveforms of signals at various points in the circuits of FIG. 2.

DESCRIPTION OF THE PREFERRED EMBODIMENT

THE PRECIPITATOR POWER CONTROL SYSTEM

Referring now to an illustrative embodiment of the invention with particular reference to FIG. 1, a power source 10 furnishing, for example, 440 volts at 60 hertz, supplies power to lines 11 and 12. Relay contacts MR1 and MR2 couple the power supply to the primary of a high voltage transformer 13 through an overload relay OLR and line 16 connected to its upper terminal, and through an SCR power controller 14 and an inductive reactor 15. The secondary of the high voltage transformer is connected by lines 17*a* and 17*b* across a bridge rectifier 18 having its output connected by conductor 19 to a precipitator 20, and by a conductor 21 to ground through a milliammeter 21*a* and a load resistor 22. A conductor 23 couples a voltage signal representative of precipitator current from the resistor 22.

Circuits to control the power supplied to the precipitator 20 are powered in part by a step-down transformer 24 having its primary coupled by conductors 25*a* and 25*b* to lines 11 and 12. The upper terminal of the secondary winding of the transformer 24 is coupled by a line 26 to a ground bus 27 and is also connected by a line 28 to analog computer circuits 29. The lower terminal of the transformer's secondary is joined by a conductor 30 to a series circuit including normally closed relay contacts 1CR1, a normally closed stop push button switch 31, a parallel combination of a normally open start push button switch 32 and relay contacts MR3, and a time delay relay TDR which is connected to the ground bus 27. Conductor 33 supplies power from the transformer 24 to the analog computer circuits 29.

A conductor 35, coupled to the transformer 24 through line 30, is connected to a series circuit including normally open overload relay contacts OLR 1, a normally closed push button switch 36 and a first control relay 1CR joined to the ground bus 27. Also coupled between the conductor 35 and the ground bus 27 is another series circuit including normally open control relay contacts 1CR2 and an alarm indicator 37. A conductor 38 joins the two series circuits and is connected to one side of relay contacts YR1, shown closed but normally open when the control circuits are energized, that are included in the analog computer circuits **29** as indicated by the broken line surrounding the contacts. The other side of the contacts YR1 is joined to a line **39** connected by contacts TDR1, normally closed a short time after the circuits are energized, to conductor **35**.

Another series circuit between the conductor **39** and the ground bus **27** includes relay contacts TDR2, normally open a short time after the circuits are energized, first control relay contacts 1CR3 and a second control relay 2CR. Conductors **40** and **41** are connected to second control relay contacts 2CR1 and conductors **41** and **42** to second control relay contacts 2CR2, the conductors **40, 41** and **42** leading to the user's alarm, as indicated in the legend on the drawing.

To supply information as to instantaneous zero excursions of the primary voltage of the transformer **13**, caused by sparking or arcing in the precipitator **20**, conductors **42** and **43** are coupled to the analog computer circuits **29**.

To control the SCR power controller by outputs from the analog computer circuits, two pair of conductors **44***a*, **44***b* and **45***a*, **45***b* lead from the analog computer circuits **29** to the power controller **14**. Another conductor **46** couples power from the conductor **33** to the power controller **14**, grounded through line **46***a*.

In order to select manual or automatic operation of the precipitator control circuits, a selector switch **125** that controls circuits in the analog computer circuits **29** is operated. If manual control is selected, a user can suitably adjust the circuits by varying potentiometer **50**. Lines **51, 52** and **53** connect the potentiometer to the analog computer circuits.

In operation, the start push button **32** is actuated to energize the main relay MR and the time delay relay TDR. The main relay contacts MR1, MR2 and MR3 close immediately to couple the main AC power supply **10** to the SCR power controller **14** and the high voltage transformer **13**. After a time delay, for example 13 seconds, the time delay relay contacts TDR1 close and the time delay contacts TDR2 open. The relay contacts MR3 act to hold the main relay and the time delay relay closed.

During the 13 second time delay, the SCR power controller **14** has been turned on by the analog computer circuits **29** to furnish power to the high voltage transformer **13**. This results in the power supplied to the precipitator increasing to a value determined, on the one hand, by the manual control **50**, if the selector switch **125** is in manual position, and on the other hand, by the automatic operation of circuits to be explained in detail hereinafter. Note also that the relay contacts YR1 open during the 13 second period.

Assuming a spark or arc in the precipitator **20**, the analog computer circuits **29** will receive signals representative of precipitator current on the conductor **23**from the resistor **22**, and signals from the conductors **42** and **43**. Assuming normal sparking, the analog computer circuits will respond to sparking signals by generating control signals that will cause the SCR power controller **14** to reduce temporarily the power supplied to the transformer **13**, as will be described in detail hereinafter.

If a short circuit exists in the precipitator **20**, the signals on the lines **23** and **42, 43** will satisfy certain conditions programmed into the analog computer circuits, as explained hereafter, and the relay contacts YR1 will close, thereby energizing the alarm indicator **37** and the first control relay 1CR. The normally closed 1CR1 relay contacts will open to drop out the main relay MR and the time delay relay TDR. The first control contacts 1CR2 will also close to hold the first control relay energized until actuation of the push button **36**. Closure of the first control relay control contacts 1CR3 will energize the second control relay to open the second control relay contacts 2CR1 and close the second control relay contacts 2CR2 to indicate to the user the short circuit condition in the precipitator.

Further operation of the power control circuits for the precipitator will be better understood after reading a description of the analog computer circuits **29** in connection with the drawings.

ANALOG COMPUTER CIRCUITS

In describing the analog computer circuits **29**, reference will be made to FIG. **2** which shows a schematic circuit diagram of the analog computer circuits **29**, to FIG. **3**, a block diagram of the analog computer circuits **29** which facilitates an understanding of the computer arrangement, and to FIG. **4** which illustrates the power supply for the analog computer circuits.

POWER SUPPLY

A power supply **200** is energized by the conductors **28** and **33**. The power supply provides +15 volts DC on conductor **201**, −15 volts DC on conductor **202**, and both voltages are with respect to ground line **203**. It should be understood that the several + and − voltage points in the schematic circuit diagram of FIG. **2** are connected to lines **201** and **202** and thus are energized upon energization of the conductors **28** and **33**, shown in FIGS. **1** and **4**.

INSTANTANEOUS ZERO VOLTAGE DETECTOR

Conductors **42** and **43**, which are at power line potential, lead to step down transformer **60**. Note that the precipitator voltage V_P across the lines **42** and **43** is the voltage across the primary of the power transformer **13**. The transformer **60** provides isolation from the primary of the high voltage transformer **13**. Conductors **61** and **62** leading from the transformer **60** are coupled-through a capacitor **63** that suppresses harmful high frequency component voltages. The input of a full wave bridge rectifier **64** is joined to the conductors **61** and **62**.

Coupled to the output of rectifier **64** is an instantaneous zero voltage detector which functions to provide negative 1 millisecond output pulse on line **65** whenever the voltage across the primary of the transformer **13**, and hence across the bridge rectifier **64**, makes a zero excursion. With respect to the precipitator voltage wave, note that this will provide reference or marker output pulses at the beginning, middle and end of a cycle of the voltage V_P. Reference pulses will also be generated when a sparking occurs in the precipitator and causes zero excursions of the voltage V_P.

Resistors **65** and **66** function as a voltage divider with the resistor **65** dropping most of the voltage present at the bridge output when the magnitude of the bridge voltage is sufficient to permit current to flow through zener diode **67**. Resistor **68** provides a discharge path for the voltage commutating capacitor **69** and also provides input impedance for the voltage applied to operational amplifier **70**. Resistor **71** functions as the amplifier feedback resistance when its output is negative in polarity. However, the feedback resistance in effect equals 0 and therefore provides a gain of zero when the amplifier's output attempts to swing positive due to the action of diode **71***a*.

A one millisecond negative pulse appears at the output of the amplifier **70** on line **65** whenever an excursion to zero occurs in the precipitator primary voltage V_P. This is accomplished by charging the capacitor **69** whenever the primary voltage V_P is above zero. When V_P drops to zero, due to normal zero crossing at zero, one half cycle or full cycle, or due to a spark or arc within the precipitator **20**, the negatively charged plate of the capacitor **69** is effectively connected to ground through the parallel combination of the resistors **65** and **66**. The net input voltage is therefore positive and the amplifier output will produce a negative pulse on the conductor **65**. The voltage divider formed by resistors **72** and **73**, combined with amplifier input resistance **74**, provides a fixed negative reference voltage to eliminate the possibility of the amplifier **70** producing false output signals.

INVERTER AND GATE

An inverter **75** functions to change the negative polarity 1 millisecond pulses provided on the conductor **65** to positive 1 millisecond pulses on an output conductor **76**. A gate **77** is placed in a pass or open condition by each pulse for 1 millisecond. Note that when the gate **77** is in pass condition, all signals passed are inverted in polarity.

CLAMPING AND FILTERING CIRCUIT

Precipitator current flows through conductor **21**, milliammeter **21***a* and the load resistor **22**, and these components are shown in dashed outline to facilitate explanation of the analog computer circuits. The conductor **23** leads from resistor **22** to a clamping and filtering circuit **80**. The output of the clamping circuit is supplied on line **81** to the gate **77** and appears on gate output line **82** when the gate is in condition to pass pulses; i.e., when it is opened by a 1 millisecond positive pulse from the inverter **75**.

To illustrate the function of the clamping and filtering circuits **80**, reference is made to FIG. **7** which illustrates signals at two points in the circuit. Waveform A shows a signal representative of precipitator current on the conductor **23** at the input to the clamping and filtering circuit **80**. Waveform B shows the output of the clamping and filtering circuit **80** on the line **81**. Note that this is the upper portion of waveform A and that the leading and trailing edges of the pulse B are well removed from zero and one half cycle zero. This prevents false signals at the output of the gate by insuring that the signal representative of precipitator current does not overlap the reference pulses from the inverter during normal non-sparking operation of the circuit.

HIGH SPEED OVERDRIVE

The output of the gate **77** is coupled by the line **82** to a high speed overdrive circuit **83** joined by conductors **45***a* and **45***b* to an SCR trigger unit winding **84** located in the SCR power controller **14**. The high speed overdrive circuit functions to switch an instantaneous high level control current into the SCR trigger unit when a gate output pulse appears on the line **82**. Thus a transistor switch can be used to cut in a strong current to the winding **84**. If the gate output at the input to the high speed overdrive results from strong sparking that causes ringing, the transistor switch will commutate current into the winding **84** to cause full phasing back of the SCR's by the trigger unit in one half cycle. If the sparking is relatively light, the current supplied to the winding **84** by the high speed overdrive in response to gate output will only partially phase back the SCR's.

The high speed overdrive **83** is required to compensate for the time lag inherent in magnetic amplifiers used to trigger the SCR's. The use of a forcing heavy current on the magnetic amplifier winding **84** overcomes such lag. If a trigger circuit is used that responds instantaneously to control currents, for example a transistorized SCR trigger unit, the high speed overdrive **83** may be omitted.

IMMEDIATE RESPONSE NETWORK

Gate output pulses on the line **82** are also coupled by lines **86** and **87** to an immediate response network formed by circuits providing double integration of the gate output pulses. As explained in my U.S. Pat. No. 3,173,772 for "Apparatus for Controlling an Electrical Precipitator," integrating a sparking signal twice provides a signal representative of the energy of the sparking pulses, their rate of rise, and their magnitudes. This feature enables derivation of a control signal that facilitates operation of precipitators at high power levels with greater efficiency.

The immediate response network integrates a negative polarity output signal from the gate output twice and applies a signal to the input of a driver amplifier **88**. The effect on the driver amplifier output is an instantaneous excursion to a positive polarity and a return on a ramp of 100 milliseconds to a negative polarity equal, if the effect of other inputs to be described hereinafter are neglected, to the level prior to the negative gate signal.

Examining the immediate response network in greater detail, resistor **89** is a load resistor providing a portion of the discharge path for coupling capacitor **90**. Resistor **91** limits pulse current and works with diode **92** to complete the discharge path for capacitor **90**. The resistor **91** and capacitor **93** functions to provide the first integration of the gate output pulse. Diode **94** and capacitor **95** function to perform the second integration. Diodes **96** and **97** are steering diodes and resistor **98** is the output resistance for the double integration circuit.

To illustrate the functioning of the immediate response network, reference is made to FIG. **8** which shows curve C, a waveform of a gate output pulse on line **87** applied to the double integration network. Waveform D indicates the signal supplied to the input of the driver amplifier **88** in response to the input signal generated by the double integration circuit from the pulse C. Note the immediate negative excursion and then the gradual ramp rise. This action provides a momentary and immediate reduction of the precipitator output level by reducing the current supplied to trigger unit control winding **99** located in the SCR power controller **14**. Power is then reapplied to the precipitator on a rapid ramp as shown in FIG. **8**, and this action will be described in greater detail below.

LONGTIME ONE SHOT MULTIVIBRATOR AND AUTOMATIC POWER SET POINT SIGNAL

In operation of a precipitator, optimum efficiency is obtained by applying a voltage across the precipitator plates just below the point at which sparking takes place; i.e., the threshold voltage. Thus it is desirable after sparking to adjust the precipitator operating voltage to a level slightly lower than that voltage which initiated the sparking or arcing. In the inventive system such threshold voltage or set point can be achieved automatically through functioning of a longtime monostable or one shot multivibrator **110**.

The gate output pulses on the line **86** are supplied to the input of the one shot multivibrator **110** which, when actuated, generates a 170 millisecond negative polarity pulse (see FIG. **8**) on output line **111**. A line **112**, resistor **113** and diode **114** function to couple the negative polarity output pulse from the one shot multivibrator **110** to storage capacitor **115**. Zener diode **116** sets an upper limit to the voltage which may appear across the capacitor **115** and also provides, with resistor **117**, some discharge impedance for the capacitor **115**. The voltage across the capacitor **115** appears across resistor **118** and potentiometer **119**. The voltage from potentiometer tap **120** is coupled by conductor **121** to a control signal mixer **122*a***.

RAMP START OPERATION

To initiate operation of the analog computer circuits, a capacitor **122** is charged through diode **123** to provide a ramp voltage coupled by conductor **124**, switch **125**, when in automatic position, conductor **126**, potentiometer **127**, which facilitates adjustment of the maximum set point level, and conductor **128** to the control signal mixer **122*a***. Zener diode **129** limits the amount of voltage that can appear across potentiometer **127** to prevent excessive signals from being supplied to the control signal mixer **122*a***.

MANUAL POWER SET POINT SIGNAL

If it is desired to set the threshold or set point manually, the switch **125** is operated to manual position. This has the effect of connecting the conductor **126** through the conductor **52** to the potentiometer **50** shown in FIG. **1**. The conductor **51** couples the potentiometer **50** through a resistor **130** to −15 volts DC. The set point may then be manually adjusted by operation of the potentiometer **50**.

Note that when the switch **125** is moved to manual position, the capacitor **115** is grounded through resistor **131** and the ramp start capacitor **122** is grounded through resistor **132**.

CONTROL SIGNAL MIXER

A line **140** couples the precipitator current signal to the control signal mixer **122*a*** which functions to add algebraically the three inputs and provide a resultant output signal on the line **141** coupled to the input of the driver amplifier **88**. The precipitator current signal acts as a feedback signal and, together with the signal from the capacitor **115**, tends to reduce the output on line **141** that would otherwise be caused by the signal from capacitor **122** or the potentiometer **50**. In other words, the control milliamperes produced by the driver amplifier **88** are reduced by turn off polarity signals from the capacitor **115** and the conductor **140** which oppose the effect of signals provided by the ramp start capacitor **122** or by the manual potentiometer **50**.

HIGH SENSITIVITY SPARK DETECTOR

With only slight sparking in the precipitator **20**, zero excursions of the voltate V_P may not be sufficient to produce pulses that open the gate **77**. Yet it is important to detect such light sparking and lower the voltage on the precipitator plates by decreasing the power supplied to the precipitator. To accomplish this function, a high sensitivity spark detector includes a differentiator **145** that receives signals representative of precipitator current from the conductor **23** on a line **146**. When the current pulses flowing through the precipitator are stable, such as shown during time period **1**, shown in composite waveform R in FIG. **8**, the differentiator **145** does not provide a pulse output on line **147**. However, a spark in the precipitator, which by its nature causes a rapid rise current pulse, produces an output pulse from the differentiator **145** which actuates a one shot multivibrator **148**. The resulting negative output pulse, 16 milliseconds long, on the output line **149** is coupled by a diode **150** and resistor **151** to the input of the driver amplifier **88**, thereby reducing the negative current supplied to the control winding **99** for one cycle. This phases back the SCR's to reduce the power supplied to the precipitator.

The negative output pulse on the line **149** is also supplied via conductor **152** to the longtime one shot multivibrator **110**. The resulting 170 millisecond negative pulse is coupled by the conductor **112** to the capacitor **115** which has the effect of lowering the threshold or set point level of the precipitator **20** as heretofore described.

SHORT CIRCUIT ALARM

A short circuit alarm system functions to remove power from the precipitator **20** during a short circuit condition between the high voltage elements within the precipitator and ground. A short circuit condition is detected by monitoring and evaluating the magnitude of the primary voltage V_P of the high voltage transformer and the magnitude of the precipitator current. A short circuit condition programmed into these analog circuits means that the primary voltage V_P will be low, for example two to forty volts RMS, and the precipitator current will be greater than or equal to 5 percent of the maximum precipitator current unless the one shot multivibrator **110** has been actuated. The functioning of the circuit will be more readily understood in connection with the following detailed description.

A transformer **155** energized by conductors **42** and **43** steps down the high voltage and isolates the alarm circuits from the power circuit. A bridge rectifier **156** is connected across the secondary of the transformer **155** and a capacitor **157** functions to bypass high frequencies and protect the bridge rectifier. Resistor **158** functions to limit current while capacitor **159** acts as a filter. The resistors **160** and **161** serve as a bleeder resistance and voltage divider. The maximum voltage which may exist across the resistor **161** is limited to 10 volts by zener diode **162**. Resistor **163** is an input resistance for an amplifier **164**. A voltage divider formed by resistor **165**, connected to a +15 volts, and potentiometer **166** together with input resistor **163** form an offset voltage source. A feedback capacitor **167** provides infinite gain characteristics for the amplifier **164** together with smooth transition between one saturated state and the other state. Load resistance is provided by resistor **168.**

A current monitoring circuit is similar to the just described voltage monitoring circuit. An input resistor **170,** connected to the resistor **22** by conductors **171** and **140,** is subjected to a voltage signal representative to the magnitude of precipitator current. A resistor **172,** connected to −15 volts, potentiometer **173** and resistor **174** function to provide an offset voltage source. The feedback capacitor **175** provides infinite gain characteristics to amplifier **176** with smooth transition between one saturated state and the other. Resistor **177** acts as a load resistance for the amplifier **176.**

Resistors **178, 179** and a diode **180** transfer a portion of the 170 millisecond negative pulse on the output line **111** of the longtime one shot multivibrator **110** to a differentiating network formed by capacitor **181** and resistor **182.** Supplying this signal to the amplifier **176** simulates a precipitator current greater than 5 percent of maximum precipitator current. This simulation occurs when a 170 millisecond multivibrator pulse is produced due to a precipitator short circuit at very low values of precipitator current. Resistor **183** functions as an input resistance for the amplifier **176,** for simulation of precipitator currents greater than 5 percent.

The voltage monitoring circuit and current monitoring circuit together perform a voltage and current comparison function. The outputs of the amplifier **176** and **164** respectively feed into diodes **184** and **185** and deenergize relay YR when both inputs to the diodes are negative in polarity. Diode **186** acts as a free wheeling diode for the relay YR when the signal commutates between the amplifier **164** and the amplifier **176.**

The relay YR is normally energized when the precipitator is operating to open relay contacts YR1 (see also FIG. 1). Upon deenergization of the relay YR, relay contacts YR1 close to permit current flow between lines **38** and **39** which, as will be fully understood from FIG. **1,** results in energization of the first control relay 1CR and the main relay MR, thus dropping out relay contacts MR1 and MR2 to remove power from the precipitator **20.**

SCR POWER CONTROLLER

Examining in greater detail the SCR power controller **14,** FIG. **5** illustrates a typical network that may be used in the precipitator power control system disclosed herein. Connected in parallel in line **12** are a pair of inversely related thyristors **200** and **201,** commonly referred to as silicon controlled rectifiers or SCR's. These thyristors may be, for example, Westinghouse Type 260ED to meet the necessary requirements of withstanding peak forward and reverse voltages greater than 1,200 volts, average currents on the order of 175 amperes, and holding currents on the order of 30 milliamperes. A holding current resistor **202** is connected across the lines **12** and **16** to provide a current through the SCR's slightly greater than their holding current.

The inductive reactor **15,** provided in the line **12** between the SCR's **200** and **201** and the primary of transformer **13,** functions in a normal manner to establish a minimum circuit impedance during sparking or short circuits in the precipitator. The inductive reactor also provides a smoothing effect on the voltage and current waveform applied to the primary of the high voltage transformer **13,** and, in addition, imposes a safe limitation to *di/dt.*

An SCR protection network **203** is connected across the thyristors **200** and **201.** It includes a thyrector **204** to establish an absolute maximum voltage which may appear across the SCR's. The thyrector **204,** a nonpolarized device, functions to conduct current from the power source **10** through the inductive reactor **15** if the voltage across the SCR power controller becomes too great.

Also included in the protection network is resistor **205** for charging capacitor **206** through diodes **209** and **210,** and resistor **207** for charging capacitor **208** through diodes **211** and **212.** Resistors **213** and **214** provide discharge paths for the capacitors **206** and **208.** Resistors **215** and **216** provide equal voltage distribution across the diodes **209** and **210,** and resistors **217** and **218** provide equal voltage distribution across the diodes **211** and **212.** High frequency bypass capacitors **219, 220, 221** and **222** protect the diodes **209, 210, 211** and **212** from high frequency voltages. Note that the values of the components in the SCR protection network are selected on the basis of providing a high resonant frequency with the ranges of inductances used and the lowest possible Q to insure that no oscillations occur. Q's range between **5** and **10,** and resonant frequencies between 4.5 KC to 2 KC.

An SCR trigger unit **225** furnishes properly phased gating pulses to the SCR **200** on line **226** and the SCR **201** on line **227.** The SCR trigger unit used with the inventive precipitator power system may be of a conventional design that incorporates a magnetic amplifier and associated circuits to supply fast rise gate pulses phased to afford SCR conduction angles of 0° to 180° with control currents from 0 to 5 milliamperes, for example, on lines **44*a*** and **44*b*** leading to control winding **99** (see FIG. **5**). The conductors **46** and **46*a*** supply power to the SCR trigger unit **225.** Lines **45*a*** and **45*b*** from the high speed overdrive **83** supply a forcing high level control current into the winding **84** on the magnetic amplifier in the SCR trigger unit to turn the SCR's off rapidly.

To provide gain control for the SCR circuits, a step down transformer **230** directly samples the output voltage to derive gain feedback ampere turns for the SCR trigger unit. A bridge rectifier **231** is coupled to the secondary of the transformer **230** by a current limiting resistor **232.** The transformer **230** is connected by conductor **14*a*** to power line conductor **16** at one side and by conductor **14*b*** to power line conductor **12** at the other side. A current divider resistor **233** connected across the output of the bridge **231** is in parallel with a potentiometer **234.** Adjustment of the potentiometer varies gain by regulating the amount of feedback to the SCR trigger unit through conductor **235** and a resistor **236.** A minimum resistance across the gain winding is set by the value of the resistor **236.**

In providing conduction of the SCR's **200** and **201,** the SCR trigger unit **225** responds to the summation of control current (control ampere turns), bias current provided by an internal bias source (bias ampere turns) and gain current (gain ampere turns). The control ampere turns are derived from a 0 to 5 milliamper DC current supplied to the lines **44*a*** and **44*b*** by the driver amplifier **88** (FIG. **2**). As has been pointed out, the control current is varied to adjust the level of operation of the precipitator.

Note that gain ampere turns are a direct function of the SCR power controller output voltage. By adjustment of the potentiometer **234** to adjust the magnitude of the substractive ampere turns, a variety of gain curves can be obtained.

A conventional SCR trigger unit may be used in this circuit, for example an SCR trigger unit available from Magnetic Specialties, SCR trigger unit Part No. 1395. Another SCR trigger unit that has been used is available from Firing Circuits Inc., Norwalk, Connecticut, Model No. 233F372. Note that the latter SCR trigger unit has an external bias connection which can be supplied with a suitable DC source.

SYSTEM OPERATION

To understand more clearly the analog computer circuits and the entire precipitator power control system, reference will be made to FIGS. **2** and **3** and the waveforms of FIGS. **8** and **9** in describing the operation of the system. To initiate operation of the precipitator **20**, the start push button **32** is depressed and, as explained heretofore in connection with FIG. **1**, main relay MR is energized and power is supplied to the analog computer circuits **29** and to the SCR power controlled **14**. With the switch **125** in automatic position as shown, the power applied to the precipitator will automatically increase due to voltage build up on the ramp start capacitor **122.** This ramp start voltage is fed into the control signal mixer **122*a*** where it is algebraically added to the precipitator current feedback signal on the line **140** (the voltage across the resistor **22**). The resultant signal at the output of the control signal mixer is coupled by line **141** to the driver amplifier **88** to cause control current to flow through winding **99** in the SCR trigger circuit. Depending on the power level at which the precipitator **20** operates most efficiently, which will be achieved in a manner to be described, a control current, for example up to 5 milliamps, phases the SCR's **200** and **201** on for a predetermined number of degrees to correspond with the correct amount of power to be transferred from the AC power source **10** to the precipitator **20.**

In the event manual operation is desired, the switch **125** is moved to its manual position and the potentiometer **50** gradually adjusted to increase the voltage supplied to the control signal mixer. The remaining circuits operate in the same fashion as described in connection with automatic control.

During steady state operation of the precipitator power control system as shown in time period **1** composite waveform R in FIG. **8**, the instantaneous zero voltage detector, the gate **77**, the high sensitivity spark detector, the one shot multivibrator **110** and the short circuit alarm have no influence on the SCR power controller.

As the power supplied to the precipitator **20** increases and the voltage on the precipitator electrodes rises, a point is reached when a spark occurs within the precipitator. Referring to the waveforms shown in FIG. **9** to better understand the action of the system upon occurrence of a spark, precipitator current pulses E, which are represented by the voltage across the resistor **22,** occur regularly until a spark F occurs in the precipitator. The control function of the system then causes the precipitator current to decrease to a value indicated by the pulse G.

The primary voltage V_P across the transformer **13** is shown as waveform H. Note the regular zero crossings which, following rectification by the bridge **64,** provide zero excursions of the pulsating voltage. Upon each zero excursion, the instantaneous zero voltage detector generates a one millisecond reference pulse of negative polarity which is changed to positive polarity by the inverter **75** to provide positive pulses K. A spark in the precipitator also results in a zero excursion J of the primary voltage V_P and the instantaneous zero voltage detector responds by generating another pulse L. At the same time the pulses K and L are fed to the gate **77** to place it in a pass or open condition, stable state pulses M, derived from the voltage across the precipitator current resistor **22** by the clamping and filtering circuit **80,** are supplied to the gate input **81.** Normally the pulses K and M are fed to the gate **77** in out-of-phase relationship and consequently there is no gate output. Upon occurrence of a spark, a pulse L is generated, as explained above, and a signal N representative of precipitator current flow coincides with the pulse L and results in the coupling of at least a portion of the pulse N through the gate **77.** The result is a gate output pulse O having a magnitude and shape dependent on the characteristics of the precipitator current flowing as a result of the spark or arc. For example, a high current spark often results in a disturbance and ringing which causes several zero excursions and greater gate output. The high speed overdrive **83** responds to the gate output pulse O by switching a high level turnoff current into the winding **84** in the SCR trigger circuit to phase back the SCR's and immediately reduce current flow to the precipitator, as shown by composite curve R in FIG. **8.**

In the event of a short circuit, such as a solid bus fault, which causes the precipitator current to lag the precipitator voltage by 90°, there will be a coincidence between the reference pulses K and the precipitator current M (FIG. **9**), thereby producing gate output signals.

The sparking signal F (FIG. **9**) will also be supplied to the high sensitivity spark detector and differentiated by the differentiator **145** to supply a turn on pulse to the one shot multivibrator **148.** The resultant 16 millisecond negative pulse P (FIG. **9**) is coupled by the line **149** to the driver amplifier **88** to reduce current flow in the control winding **99.** Thus the occurrence of a spark results in a reduction of power to the precipitator **20** even if the spark is so light that it failed to cause a detectable zero excursion of the primary voltage V_P and an output from the gate **77.**

The gate output pulse C (FIG. **8**) is also supplied on the lines **86** and **87** to the immediate response network formed by the double integrator. The parameters of the sparking pulse determine the output D, shown in FIG. **8,** of the double integrator which is supplied to the driver amplifier. Note that this causes a rapid reduction of current flowing in the control winding **99,** thereby reducing the precipitator current as shown in waveform R. However, a rapid but not instantaneous reapplication of power to the precipitator by flow of current through the winding **99** takes place if the spark has been not serious, such as a power arc, which, as will be explained hereinafter, shuts off the system. Thus, as part of the reaction of the double integration network, power is rapidly reapplied to the precipitator on a 100 millisecond ramp as best shown in FIG. **8.**

Examining the waveforms in further detail, note that the precipitator current is quickly reduced to zero during time period 2 following a sparking pulse F which terminates time period 1 — steady state operation. During time period 3 the double integration circuit provides a rapid ramp reapplication of power. The maximum power level achieved at the end of the rapid return ramp is equal to that operating level previous to the sparking minus an incremental reduction caused by a charge stored on the capacitor **115** by reason of the operation of the one shot multivibrator **110.** As explained heretofore, the 170 millisecond negative pulse is coupled to the capacitor **115** through line **112.**

During time period **4,** as shown in FIG. **8,** precipitator power is gradually raised due to discharge of the capacitor **115.** This results in an output from the control signal mixer **122***a* that causes the driver amplifier **88** gradually to increase the current to the control winding **99** on a slow ramp. This slow rise in the power level of the precipitator continues until a new sparking level is reached at which time the entire process will be repeated.

As heretofore explained, in certain instances sparking is so light in the precipitator that zero excursions in the primary voltage V_P are not sufficient to result in pulses from the instantaneous zero voltage detector that will open the gate **77** to provide output pulses to the immediate response network and high speed overdrive **83.** In those instances, the high sensitivity spark detector functions to provide a 16 millisecond negative pulse directly to the driver amplifier **88** to reduce the level of current in the control winding **99,** thereby reducing power supplied to the precipitator. In addition, the **16** millisecond negative pulse will fire the one shot multivibrator **110** to charge the capacitor **115** for the purpose explained above.

When a short circuit occurs in the precipitator, it is desirable to remove power completely from the system by energizing the main relay MR and opening the main relay contacts MR1 and MR2 (FIG. **1**). To accomplish this function, the short circuit alarm monitors and evaluates the magnitude of the voltage across the primary of the high voltage transformer **13** and the precipitator current. In summary, during a short circuit condition the primary voltage will be quite low, for example between 2 and 40 volts RMS, and the magnitude of the precipitator current will be greater than or equal to 5 percent of the maximum precipitator current unless the one shot multivibrator **110** has been operated.

Detection of a short circuit is provided by the analog computer circuits by defining levels of voltage and current combinations which would never represent a short circuit, programming these values into the short circuit alarm circuits and defining all other combinations of primary voltage V_P and precipitator current as representing a short circuit. A table of the logic function of the circuits follows, the table showing the conditions under which the alarm is activated.

TABLE 1

V_P	I Precipitator	170 msec. Monostable Multivibrator pulse	Alarm
< 100	< 5 %	No	No
< 100	< 5 %	Yes	Yes
< 100	> 5 %	No	Yes
< 100	> 5 %	Yes	No
> 100	< 5 %	No	No
> 100	< 5 %	Yes	No
> 100	> 5 %	No	No
> 100	> 5 %	Yes	No

It will be apparent from the description of the short circuit alarm that it functions in accordance with Table **1.** Thus, when the input to the diodes **184** and **185** from the amplifiers **176** and **164** are both negative, the relay YR is deenergized and drops out, and the contacts YR1 close. As explained above, this results in energization of the main relay MR, thereby opening the main relay contacts MR1 and MR2.

In connection with the operation of the short circuit alarm system, it should be remembered that the 170 millisecond negative pulse from the one shot multivibrator **110** simulates a precipitator current greater than 5 percent of maximum in the event of a short circuit at a very low value of precipitator current. Such a low value would not be sufficient to operate the amplifier **176** through line **140, 171** and resistor **170.** However, the high sensitivity spark detector may detect such short circuits, even at low precipitator currents, to cause actuation of the longtime one shot multivibrator **110.** Note also that a solid bus fault, even at very low values of precipitator current less than 5 percent of maximum, will cause the precipitator current to lag the precipitator voltage by 90°. As will be understood from a consideration of the waveforms of FIG. **9,** precipitator current lagging the primary voltage by 90°, no matter how small the current, will result in a coincidence of reference pulses K and current pulses M, thereby resulting in gate output which actuates the longtime multivibrator **110** to simulate precipitator current greater than 5 percent of maximum.

While the inventive system has been described with an SCR power controller regulating the power supplied to the precipitator **20,** the analog computer circuits and remaining circuits may also be used with a saturable reactor power control. Referring to FIG. **6,** in which elements similar to those in FIG. **1** have been given like reference numerals, a saturable reactor **300** is interposed in the power line **12** between the AC power source **10** and the high voltage transformer **13.** A control winding **301** in the saturable reactor **300** is supplied with current by a DC to AC power amplifier **302.** The control leads **44***a* and **44***b* from the driver amplifier **88** in the analog computer circuits **29** supply 0 to 5 milliamps DC current to the power amplifier. AC power is supplied to the power amplifier on the lines **303** and **304,** respectively connected to lines **28** and **33.**

In operation, the analog computer circuits function in the same manner as described in connection with the SCR controller except that the high speed over-drive **83** may be omitted. Note that the short circuit alarm functions equally well with the saturable reactor control circuit.

While the invention has been described with reference to particular embodiments, it will be understood that modifications thereof will be obvious to those skilled in the art. Therefore the invention is not limited to the particular embodiments described herein but is defined by the appended claims.

I claim:

1. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means: means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the transformer primary winding, means for generating signals representative of precipitator current, means coupled to said signal generating means for suppressing the leading and trailing edges of said current signals to thereby prevent overlap between the edges of said signals and said reference pulses during normal operation of said precipitator, gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide in time with said precipitator current signals as a result of sparking or arcing in the precipitator, and means responsive to the gate output signals for reducing the power supplied to the precipitator.

2. A system as defined in claim **1**, wherein said power reducing means includes means for double integrating the gate output signals.

3. A system as defined in claim **1**, in which means are provided for increasing the power supplied to the precipitator following said power reduction.

4. A system as defined in claim **3**, in which said power increasing means restores power to the precipitator rapidly during an initial period immediately subsequent to the sparking that resulted in the reduction of power and then more slowly following said initial period.

5. A system as defined in claim **4**, in which said power increasing means includes a capacitor, and means for charging said capacitor in response to the gate output signals.

6. A system as defined in claim **5**, in which said means for charging the capacitor comprises a one shot multivibrator responsive to the gate output signals.

7. A system as defined in claim **1**, in which is provided a high sensitivity spark detector means for generating output signals responsive to the precipitator current signals when there is lighter sparking in the precipitator than would cause said zero excursions of the primary voltage, and said power reducing means is responsive to said spark detector output signals independently of said gate output signals, for reducing the power supplied to said precipitator.

8. A system as defined in claim **7**, in which means are provided for increasing the power supplied to the precipitator following operation of said power reducing means.

9. A system as defined in claim **8**, in which said power increasing means includes a capacitor, and a one shot multivibrator responsive to the spark detector output signals for providing a pulse for charging the capacitor.

10. A system as defined in claim **1** wherein said power reducing means includes a saturable reactor interposed before the primary winding of the high voltage transformer to receive the gate output signals to reduce the power supplied to the precipitator.

11. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means: thyristors for supplying power to the transformer, a trigger unit for firing the thyristors at selected phase angles to control the power supplied to the precipitator, means for supplying control current to the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator means for supplying control current to the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator, means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the high voltage transformer primary winding, means for generating signals representative of precipitator current, means coupled to said signal generating means for suppressing the leading and trailing edges of said current signals to thereby prevent overlap between the edges of said signals and said reference pulses during normal operation of said precipitator, gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide with said precipitator current signals as a result of sparking or arcing in the precipitator, and means responsive to the gate output signals for changing the control current, the trigger unit responding to the changed control current for retarding the firing phase angles of the thyristors to reduce the power supplied to the precipitator.

12. A system as defined in claim **11**, wherein said control current changing means includes means for double integrating the gate output signals.

13. A system as defined in claim **11**, in which means are provided for changing the control current supplied to the trigger unit to advance the phase angles at which the thyristors are fired to increase the power supplied to the precipitator following said power reduction.

14. A system as defined in claim **13**, in which said control current changing means advances the phase angles rapidly during an initial period immediately subsequent to the sparking that resulted in the reduction of power and then more slowly following said initial period.

15. A system as defined in claim **14**, in which said control current changing means includes a capacitor, and means for charging said capacitor in response to the gate output signals.

16. A system as defined in claim **15**, in which said means for charging the capacitor comprises a one shot multivibrator responsive to the gate output signals.

17. A system as defined in claim **11**, in which is provided a high sensitivity spark detector means for generating output signals responsive to the precipitator current signals when there is lighter sparking in the precipitator than would cause said zero excursions of the primary voltage, and said control current changing means responsive to said spark detector output signals independently of gate output signals for retarding the the firing phase angles of the thyristors to reduce the power supplied to the precipitator.

18. A system as defined in claim **17**, in which means are provided for changing the control current supplied to the trigger unit to advance the phase angles at which the thyristors are fired to increase the power supplied to the precipitator following said power reduction.

19. A system as defined in claim **18**, in which said control current changing means includes a capacitor, and a one shot multivibrator responsive to the spark detector output signals for providing pulses for charging the capacitor.

20. A system as defined in claim **11**, which includes voltage monitoring circuit means providing an output when the level of voltage supplied to the primary winding of the high voltage transformer drops below a selected value, current monitoring circuit means providing an output when the level of precipitator current rises above a selected value, and means responsive to the outputs of said voltage circuit means and said current circuit means to interrupt the power supply to the transformer upon occurrence of a short circuit resulting in trans-former voltage below said selected value and precipitator current above said selected value.

21. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means: voltage monitoring circuit means providing an output when the level of voltage supplied to the primary winding of the high voltage transformer drops below a selected value, current monitoring circuit means providing an output when the level of precipitator current rises above a selected value, means for simulating a precipitator current level above said selected value when a short circuit occurs in the precipitator at a relatively low power level, and means responsive to the outputs of said voltage circuit means, said current circuit means and said simulating current means to interrupt the power supply to the transformer upon occurrence of a short circuit resulting in transformer voltage below said selected value and at least one of the precipitator current and the simulated precipitator current above said selected value.

22. A system as defined in claim **21**, wherein the precipitator current simulating means includes means for generating pulses in response to short circuit conditions in the precipitator that cause the precipitator current to lag the voltage across the high voltage transformer by **90°**, and circuit means responding to said pulses to provide output signals simulating precipitator current.

23. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means: voltage monitoring circuit means providing an output when the level of voltage supplied to the primary winding of the high voltage transformer drops below a selected value, current monitoring circuit means providing an output when the level of precipitator current rises above a selected value, means for simulating a precipitator current level above said selected value when a short circuit occurs in the precipitator at a relatively low power level, and means responsive to the outputs of said voltage circuit means, said current circuit means and said simulating current means to operate an alarm circuit upon occurrence of a short circuit resulting in transformer voltage below said selected value and at least one of the precipitator current and the simulated precipitator current above said selected value.

24. A system as defined in claim **23**, wherein the precipitator current simulating means includes means for generating pulses in response to short circuit conditions in the precipitator that cause the precipitator current to lag the voltage across the high voltage transformer by **90°**, and circuit means responding to said pulses to provide output signals simulating precipitator current.

25. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means: thyristors for supplying power to the transformer, a magnetic amplifier trigger unit for firing the thyristors at selected phase angles to control the power supplied to the precipitator, means for supplying control current to a first winding on the magnetic amplifier in the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator, means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the primary winding of the high voltage transformer, means for generating signals representative of precipitator current, means coupled to said signal generating means for suppressing the leading and trailing edges of said current signals to thereby prevent overlap between the edges of said signals and said reference pulses during normal operation of said precipitator, gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide with said precipitator current signals as a result of sparking or arcing in the precipitator, and means responsive to the gate output signals for changing the control current, the trigger unit responding to the changed control current for retarding the firing phase angles of the thyristors to reduce the power supplied to the precipitator.

26. A system as defined in claim **25**, in which is provided a second control winding on the magnetic amplifier, a circuit responsive to gate output for temporarily supplying high level currents to said second winding on the magnetic amplifier to rapidly overdrive the amplifier and retard the firing phase angles of the thyristors.

27. A system as defined in claim **26**, wherein said control current changing means includes means for double integrating the gate output signals.

28. A system as defined in claim **26**, in which means are provided for changing the control current supplied to the first control winding to advance the firing phase angles to increase the power supplied to the precipitator following said power reduction.

29. A system as defined in claim **26**, in which said control current changing means advances the phase angles rapidly during an initial period immediately subsequent to the sparking that resulted in the reduction of power and then more slowly following said initial period.

30. A system as defined in claim **29**, in which said control current changing means includes a capacitor, and means for charging said capacitor in response to the gate output signals.

31. A system as defined in claim **30**, in which said means for charging the capacitor comprises a one shot multivibrator responsive to the gate output signals.

32. A system as defined in claim **26**, in which is provided a high sensitivity spark detector response to the precipitator current signals representative of sparking for generating output signals, and said control current changing means responsive to said spark detector output signals for retarding the firing phase angles of the thyristors to reduce the power supplied to said precipitator.

33. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means:

A.

a. thyristors for supplying power to the transformer;

b. a trigger unit for firing the thyristors at selected phase angles to control the power supplied to the precipitator;

c. means for supplying control current to the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator;

d. means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the primary winding of the high voltage transformer;

e. means for generating signals representative of precipitator current;

f. gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide in time with said precipitator current signals as a result of sparking or arcing in the precipitator;

g. means responsive to the gate output signals for changing the control current, the trigger unit responding to the changed control current for retarding the firing phase angles of the thyristors to reduce the power supplied to the precipitator; and

B.

a. voltage monitoring circuit means providing an output when the level of voltage supplied to the high voltage transformer drops below a selected value;

b. current monitoring circuit means providing an output when the level of precipitator current rises above a selected value;

c. precipitator current simulating means for generating pulses in response to short circuit conditions in the precipitator that cause the precipitator current to lag the voltage across the high voltage transformer by 90°;

d. circuit means responding to said pulses to provide output signals simulating precipitator current; and

e. means responsive to the outputs of said voltage circuit means, said current circuit means and said current simulating means to interrupt the power supply to the trans-former upon occurrence of a short circuit resulting in transformer voltage below said selected value and at least one of the precipitator current and the simulated precipitator current above said selected value.

34. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means:

A.

a. thyristors for supplying power to the transformer;

b. a magnetic amplifier trigger unit for firing the thyristors at selected phase angles to control the power supplied to the precipitator;

c. means for supplying control current to a first winding on the magnetic amplifier in the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator;

d. means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the primary winding of the high voltage transformer;

e. means for generating signals representative of precipitator current;

f. gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide with said precipitator current signals as a result of sparking or arcing in the precipitator; and

g. means responsive to the gate output signals for changing the control current, the trig-ger unit responding to the changed control current for retarding the firing phase angles of the thyristors to reduce the power supplied to the precipitator; and

B.

a. voltage monitoring circuit means providing an output when the level of voltage supplied to the high voltage transformer drops below a selected value;

b. current monitoring circuit means providing an output when the level of precipitator current rises above a selected value;

c. means for simulating a precipitator current level above said selected value when a short circuit occurs in the precipitator at a relatively low power level; and

d. means responsive to the outputs of said voltage circuit means, said current circuit means and said simulating current means to interrupt the power supply to the transformer upon occurrence of a short circuit resulting in transformer voltage below said selected value and at least one of the precipitator current and the simulated precipitator current above said selected value.

35. A system as defined in claim **34,** wherein the precipitator current simulating means includes means for generating pulses in response to short circuit conditions in the precipitator that cause the precipitator current to lag the voltage across the high voltage transformer by 90°, and circuit means responding to said pulses to provide output signals simulating precipitator current.

36. In a system for controlling AC power supplied to a high voltage transformer energizing an electrical precipitator through rectifier means:

A.

a. thyristors for supplying power to the transformer;

b. a magnetic amplifier trigger unit for firing the thyristors at selected phase angles to control the power supplied to the precipitator;

c. means for supplying control current to a first winding on the magnetic amplifier in the trigger unit to advance and retard the phase angles at which the thyristors are fired to increase and decrease the power supplied to the precipitator;

d. means for generating reference pulses in response to instantaneous zero excursions of voltage supplied to the primary winding of the high voltage transformer;

e. means for generating signals representative of precipitator current;

f. gate means receiving said reference pulses and said precipitator current signals, said gate means providing output signals representative of said precipitator current signals when said reference pulses coincide with said precipitator current signals as a result of sparking or arcing in the precipitator; and

g. means responsive to the gate output signals for changing the control current, the trigger unit responding to the changed control current for retarding the firing phase angles of the thyristors to reduce the power supplied to the precipitator; and

B.

a. voltage monitoring circuit means providing an output when the level of voltage supplied to the high voltage transformer drops below a selected value;

b. current monitoring circuit means providing an output when the level of precipitator current rises above a selected value;

c. means for simulating a precipitator current level above said selected value when a short circuit occurs in the precipitator at a relatively low power level; and

d. means responsive to the outputs of said voltage circuit means, said current circuit means and said simulating current means to operate an alarm circuit upon occurrence of a short circuit resulting in transformer voltage below said selected value and at least one of the precipitator current and the simulated precipitator current above said selected value.

37. A system as defined in claim **36**, wherein the precipitator current simulating means includes:

A.

a. means for generating pulses in response to short circuit conditions in the precipitator that cause the precipitator current to lag the voltage across the high voltage transformer by 90°; and

b. circuit means responding to said pulses to provide output signals simulating precipitator current.

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