

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

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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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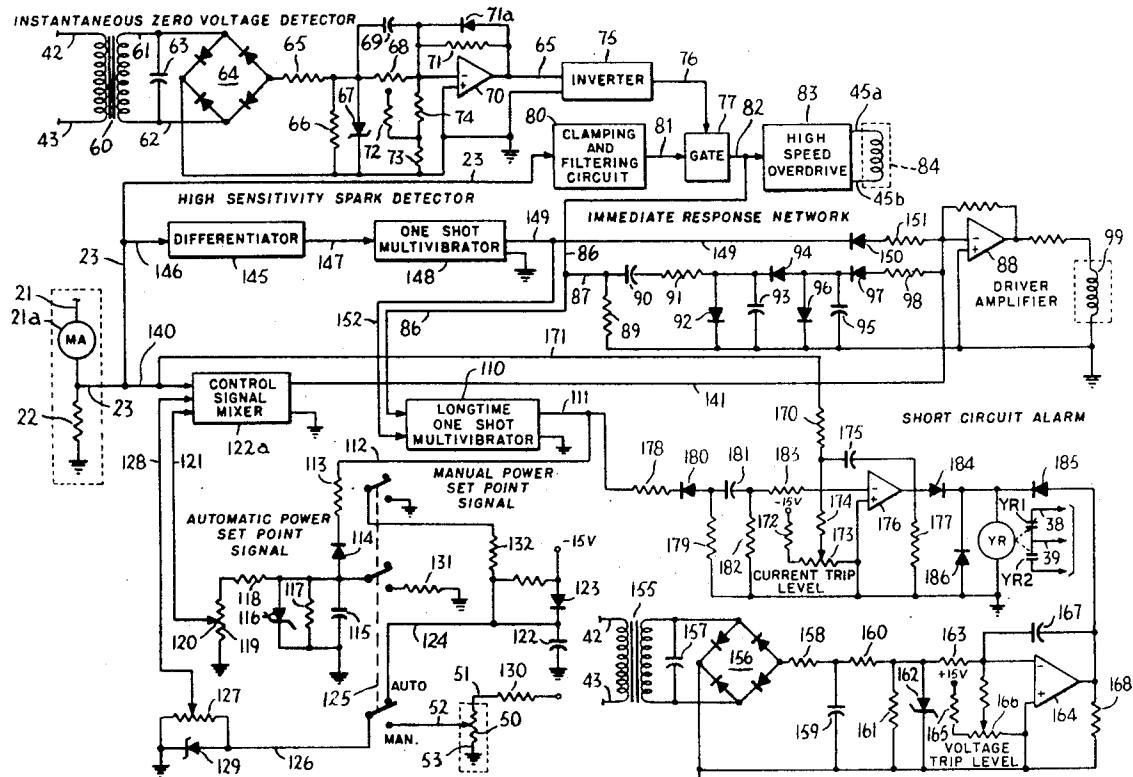
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[57] ABSTRACT

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**



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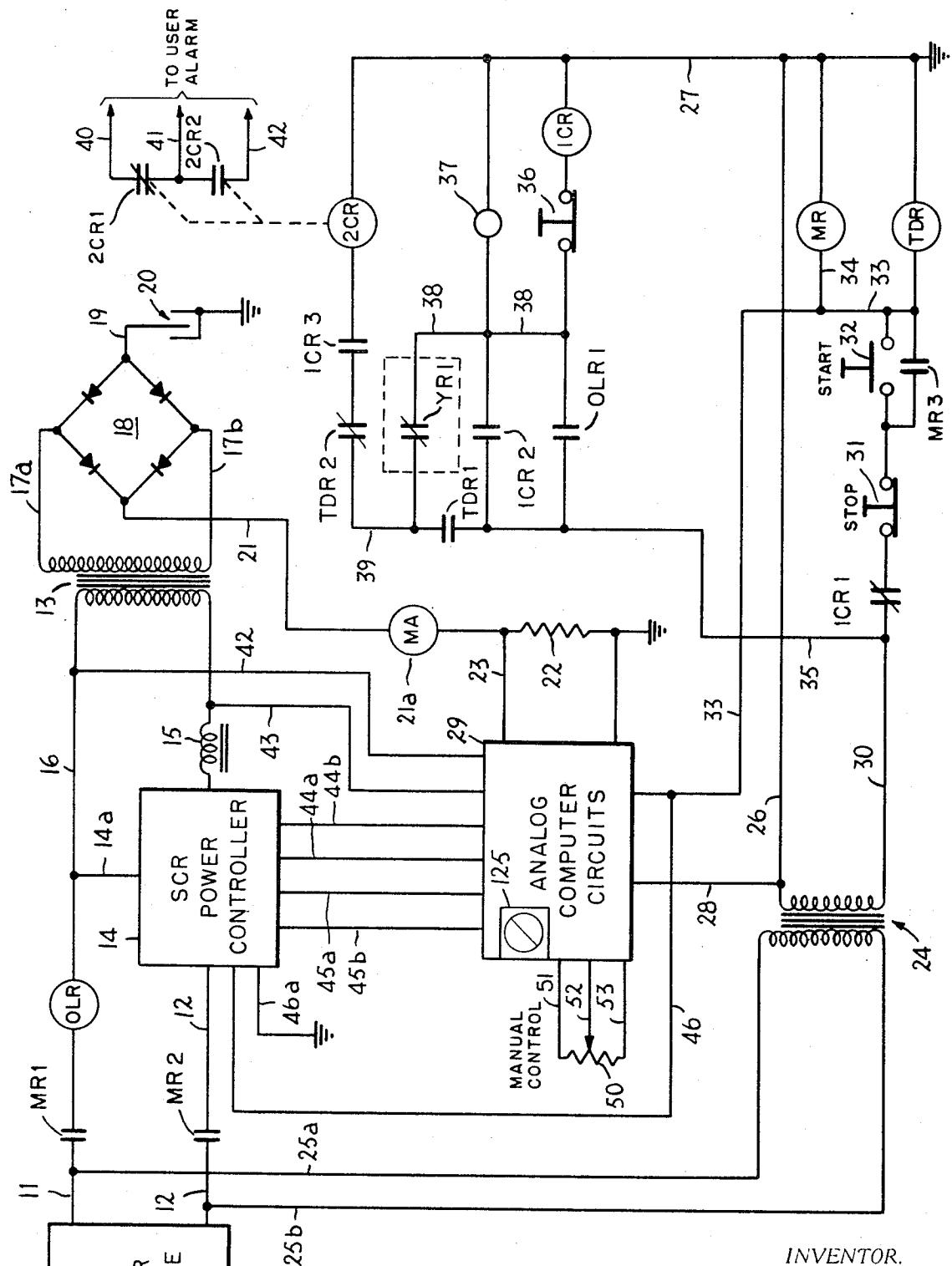


FIG. 1

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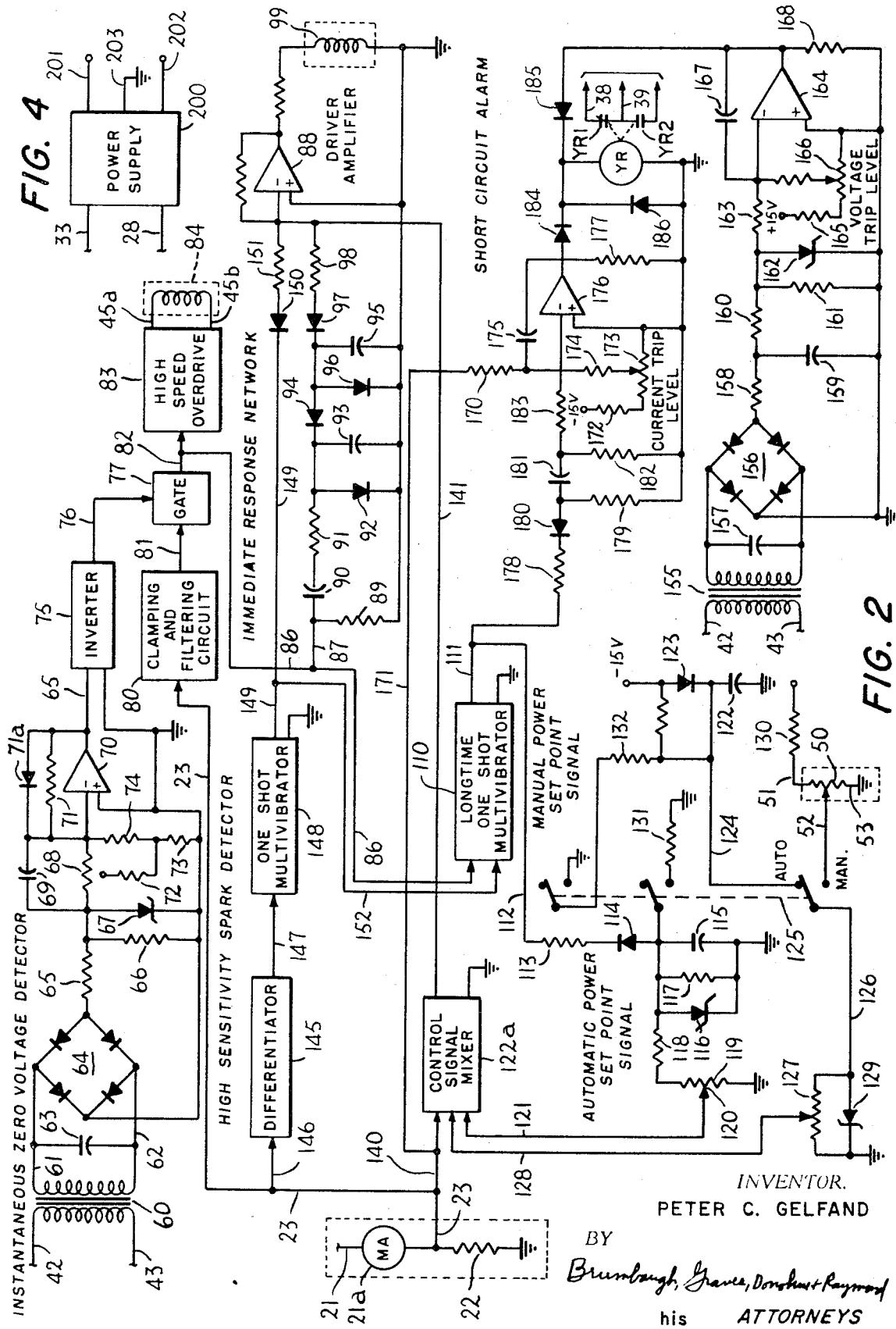
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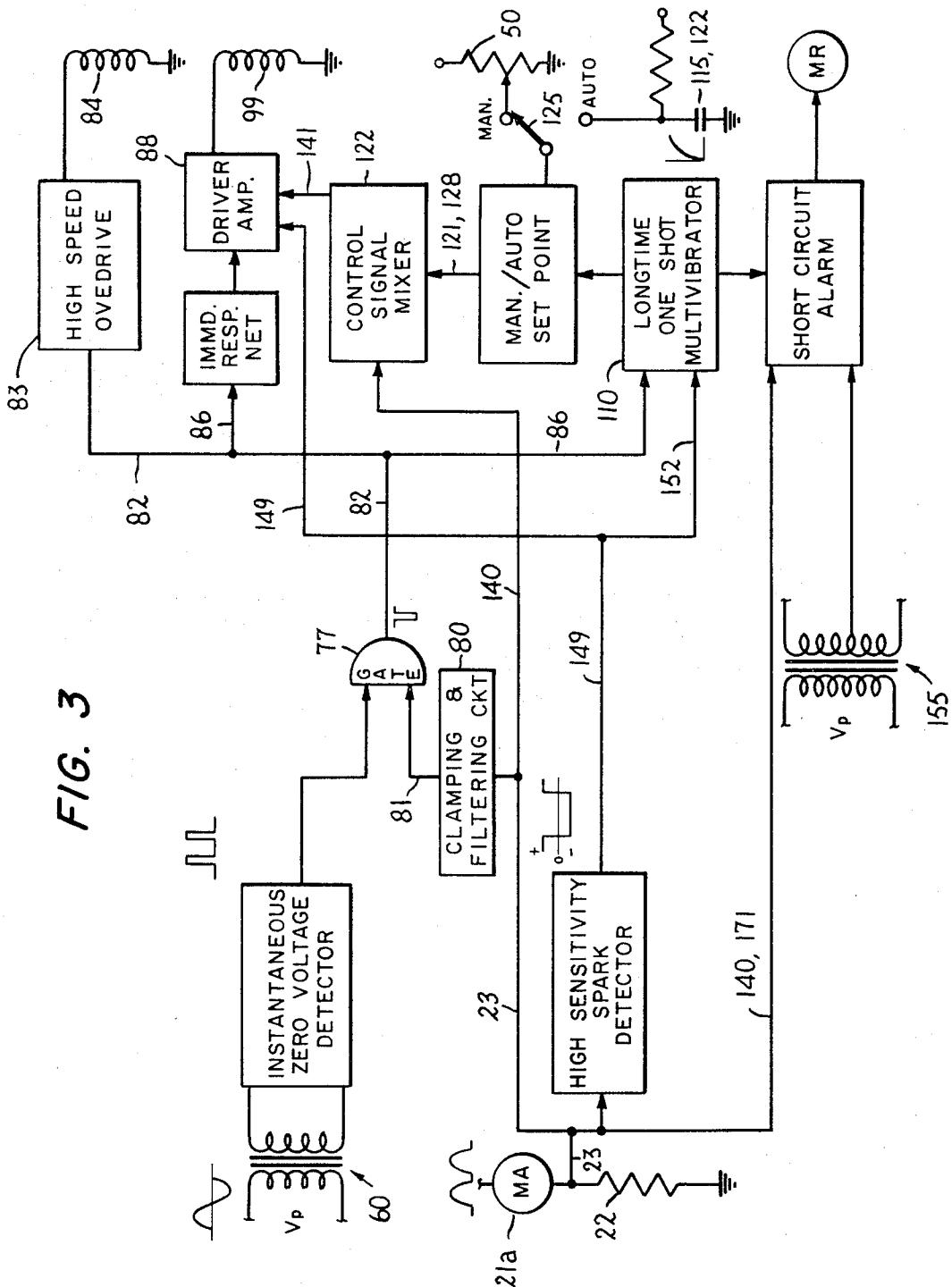
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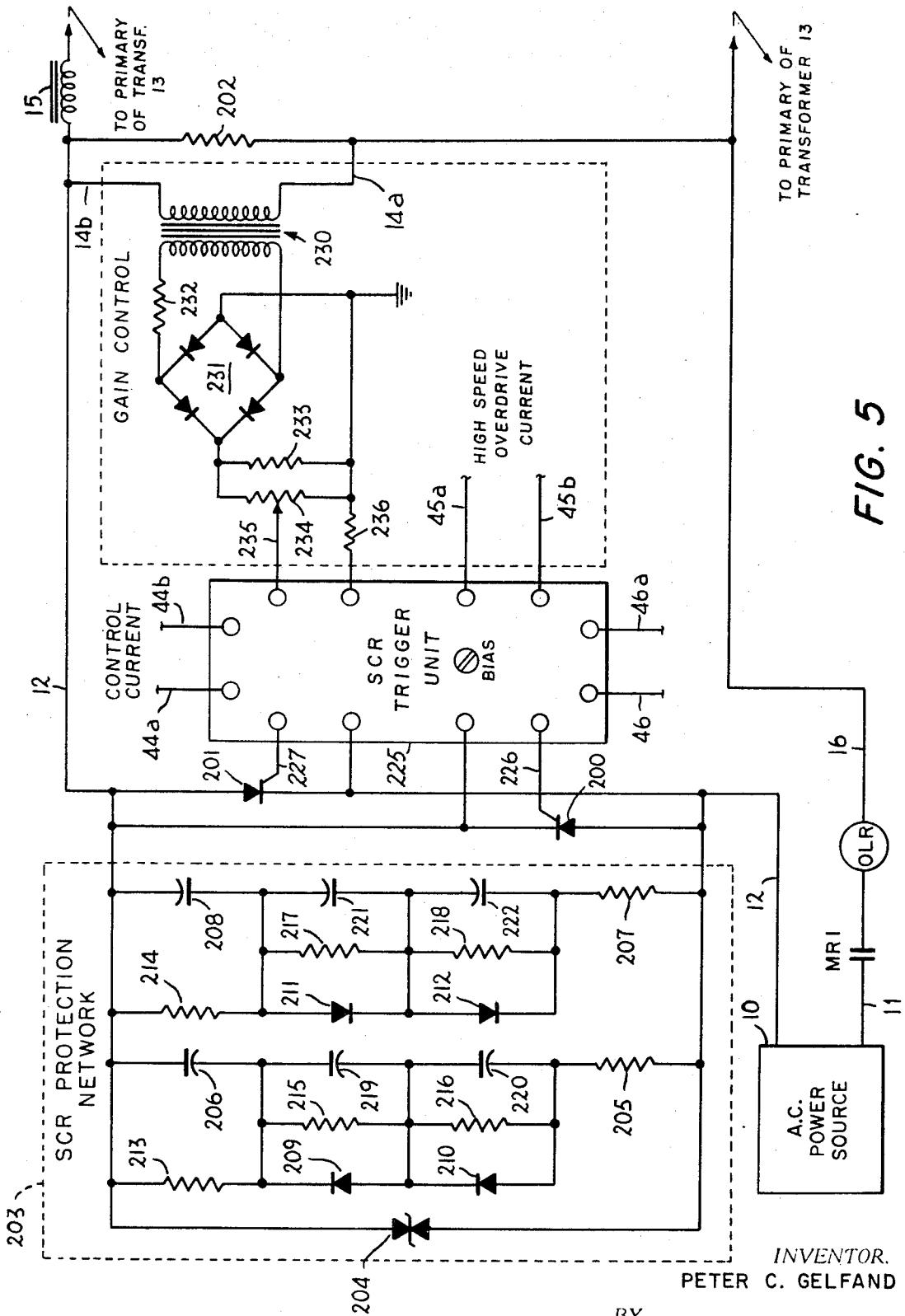


FIG. 5

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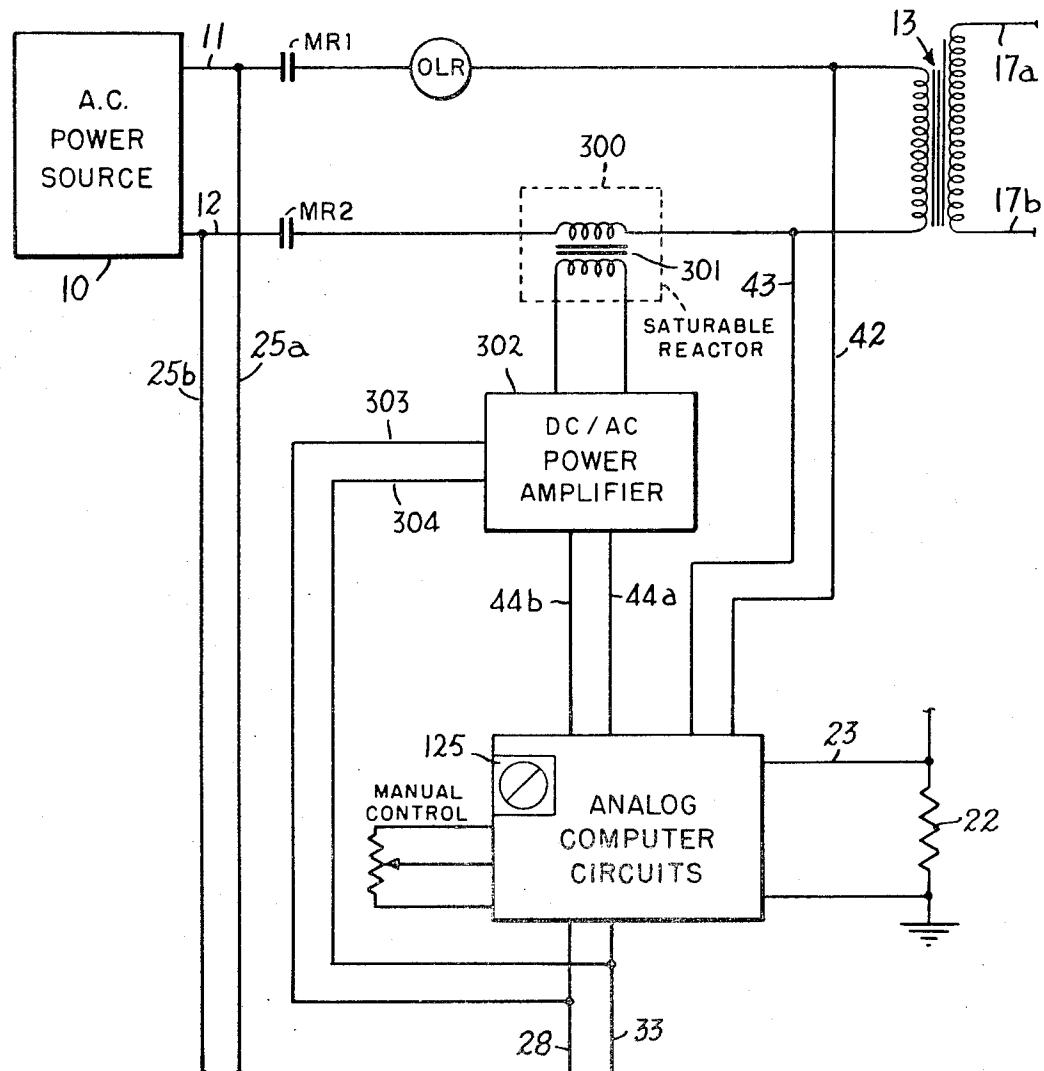


FIG. 6

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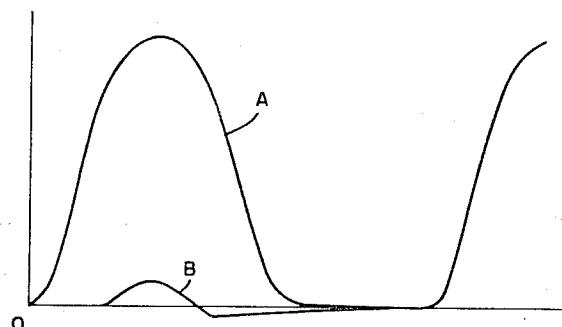


FIG. 7

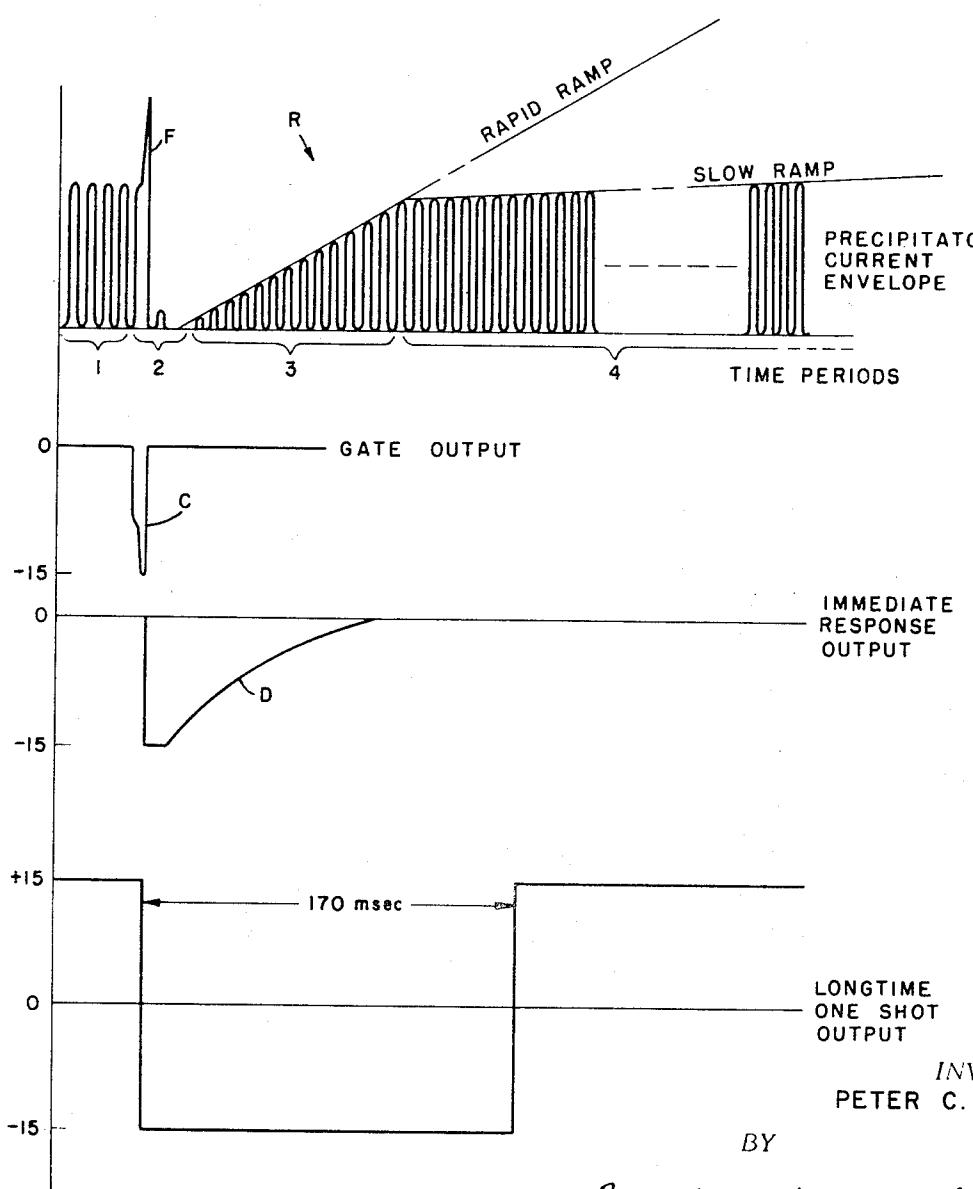


FIG. 8

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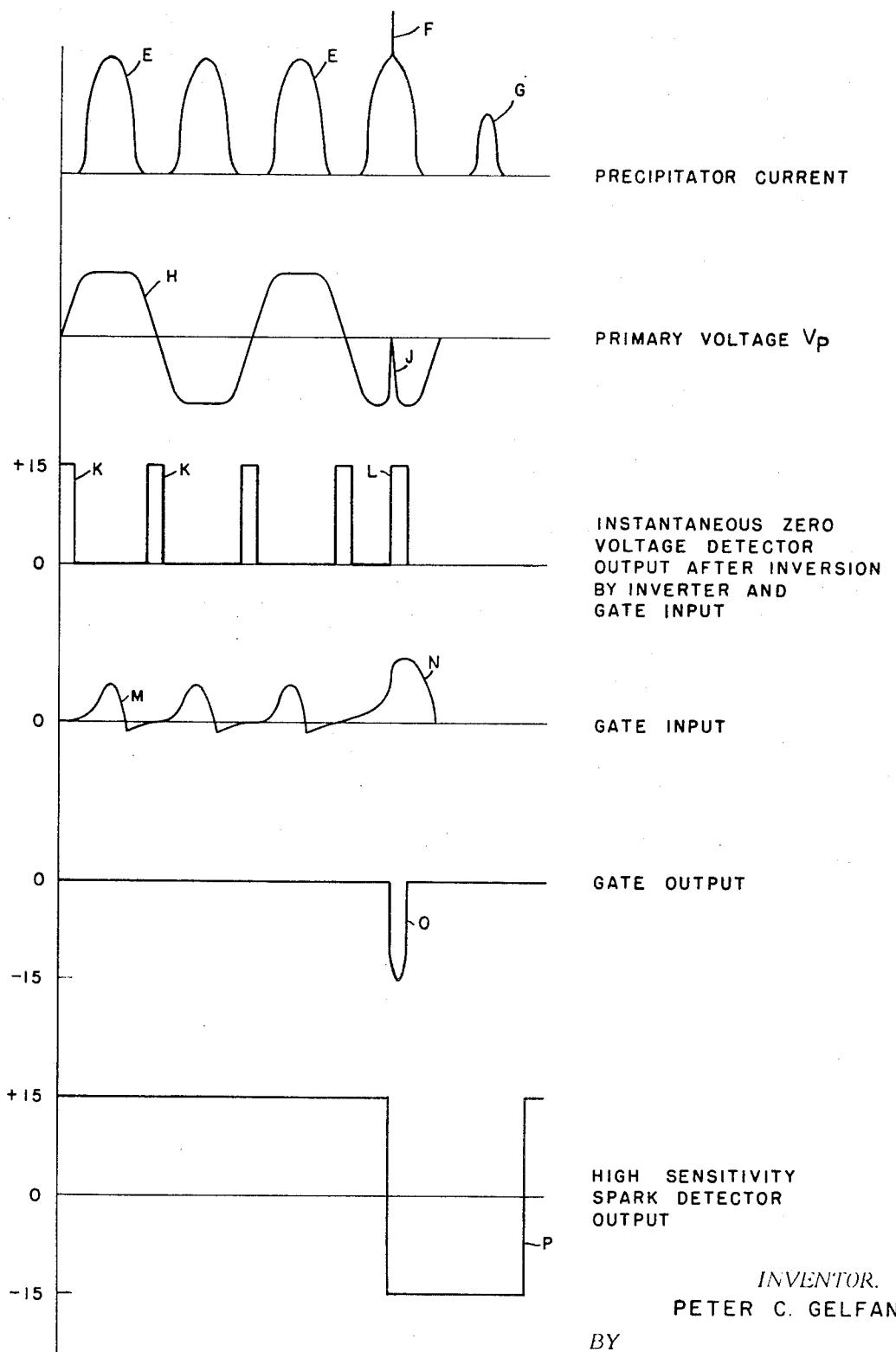


FIG. 9

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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 principles 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

#### 25 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 17a and 17b 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 21a 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 25a and 25b 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 44a, 44b and 45a, 45b 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 46a.

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 15 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 opera-

tional 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 71a.

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 21a 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 45a and 45b 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

5 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

10 gate output will only partially phase back the SCR's.

15 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

20 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.

25 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

30 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.

40 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.

45 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

50 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 122a.

### 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 122a. 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 122a.

### 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 122a 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 de-energize 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 commutes 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  $0^\circ$  to  $180^\circ$  with control currents from 0 to 5 milliamperes, for example, on lines 44a and 44b leading to control winding 99 (see FIG. 5). The conductors 46 and 46a supply power to the SCR trigger unit 225. Lines 45a and 45b 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 14a to power line conductor 16 at one side and by conductor 14b 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 44a and 44b 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 subtractive 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 122a 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 millamps, 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 5 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 10 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 15 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  $90^\circ$ , 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 122a 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 over-drive 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 %      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 44a and 44b 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 gen-

erating 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 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 transformer 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 volt-

age 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;

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 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.

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 sig-

nals 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 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 cir-

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cuit 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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