

[54] **AUTOMATIC VOLTAGE CONTROL
APPARATUS FOR ELECTROSTATIC
PRECIPITATORS**

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[22] Filed: **Sept. 9, 1971**

[57] **ABSTRACT**

[21] Appl. No.: **178,880**

[30] **Foreign Application Priority Data**

Sept. 24, 1970 Great Britain 45,679/70

[52] U.S. Cl. **55/105, 55/139, 321/19,
323/20, 323/24, 323/38**

[51] Int. Cl. **B03c 3/68, G05f 1/64**

[58] Field of Search **55/105, 139; 321/18,
321/19; 323/19, 20, 22 SC, 24, 34, 38**

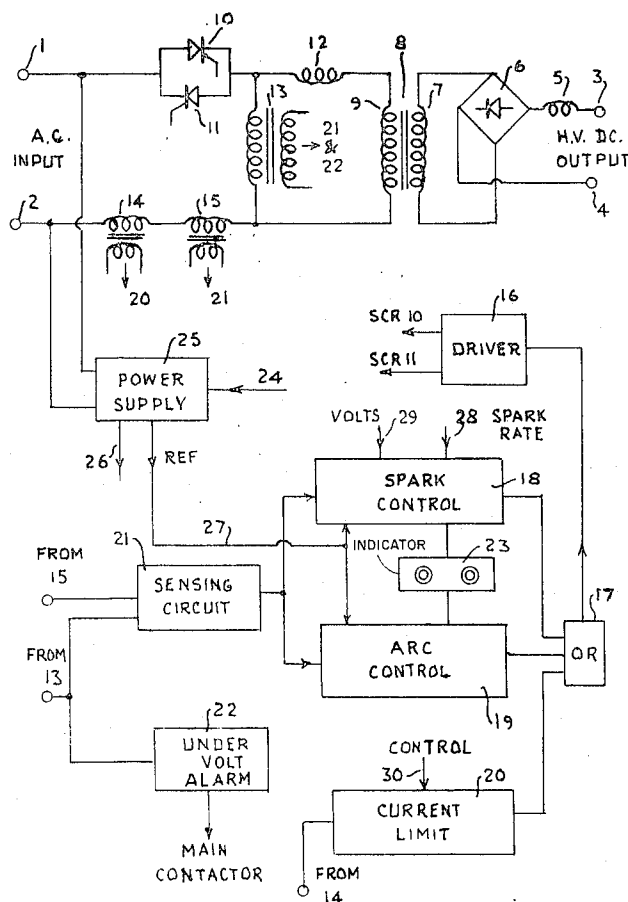
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A thyristor power supply control circuit for an electrostatic precipitator which operates to tend to drive up the volts applied to the precipitator load and step it back by increments in response to sparking, the sparking being detected as a change from predominantly capacitive load circuit to a predominantly inductive load circuit and the change being instanced by current tending to flow after a.c. supply voltage zeros. Arcing within the precipitator is detected as such an inductive condition existing in two successive supply half cycles and leads to suppression of the arc by collapsing the precipitator volts for a suitable interval.

10 Claims, 9 Drawing Figures



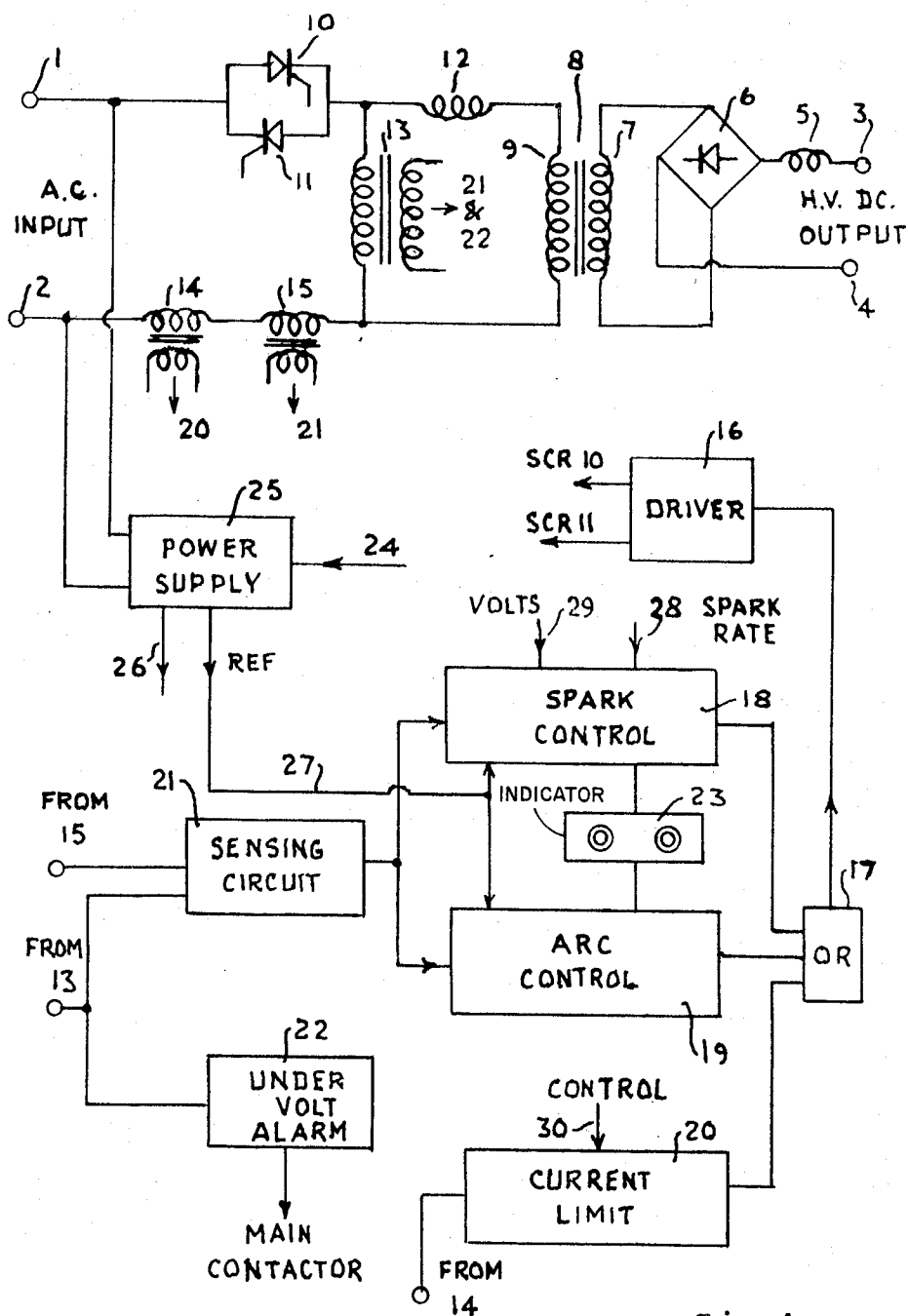


Fig. 1.

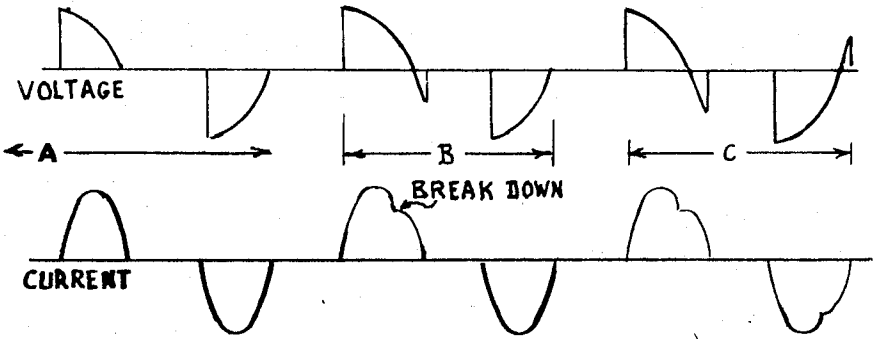


Fig. 2.

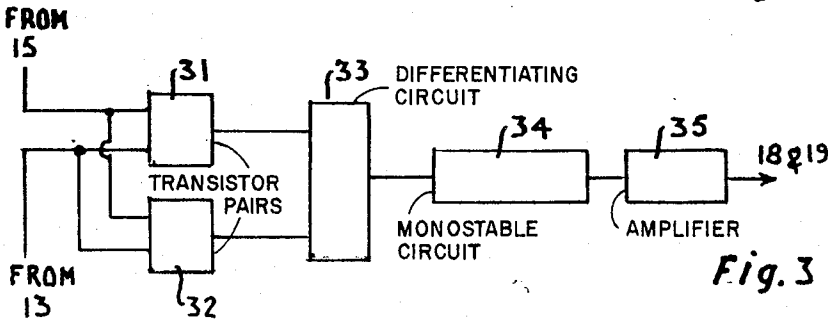


Fig. 3

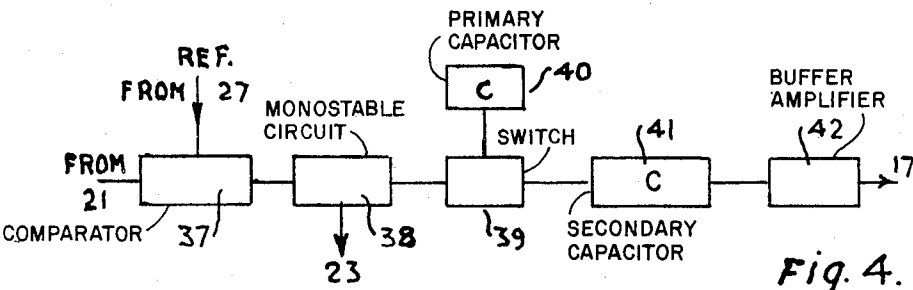


Fig. 4.

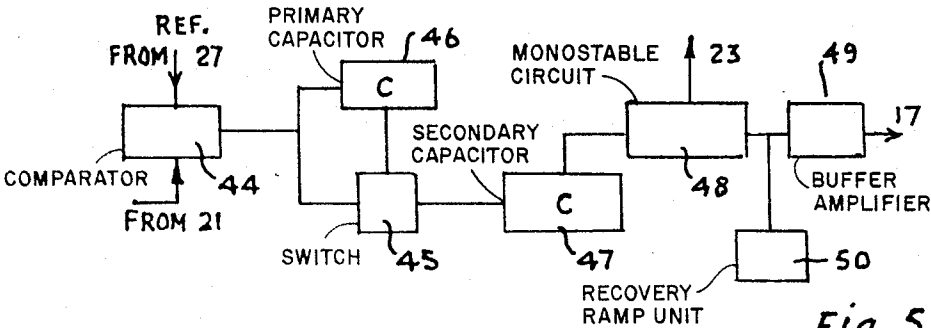


Fig. 5.

FIG. 7.

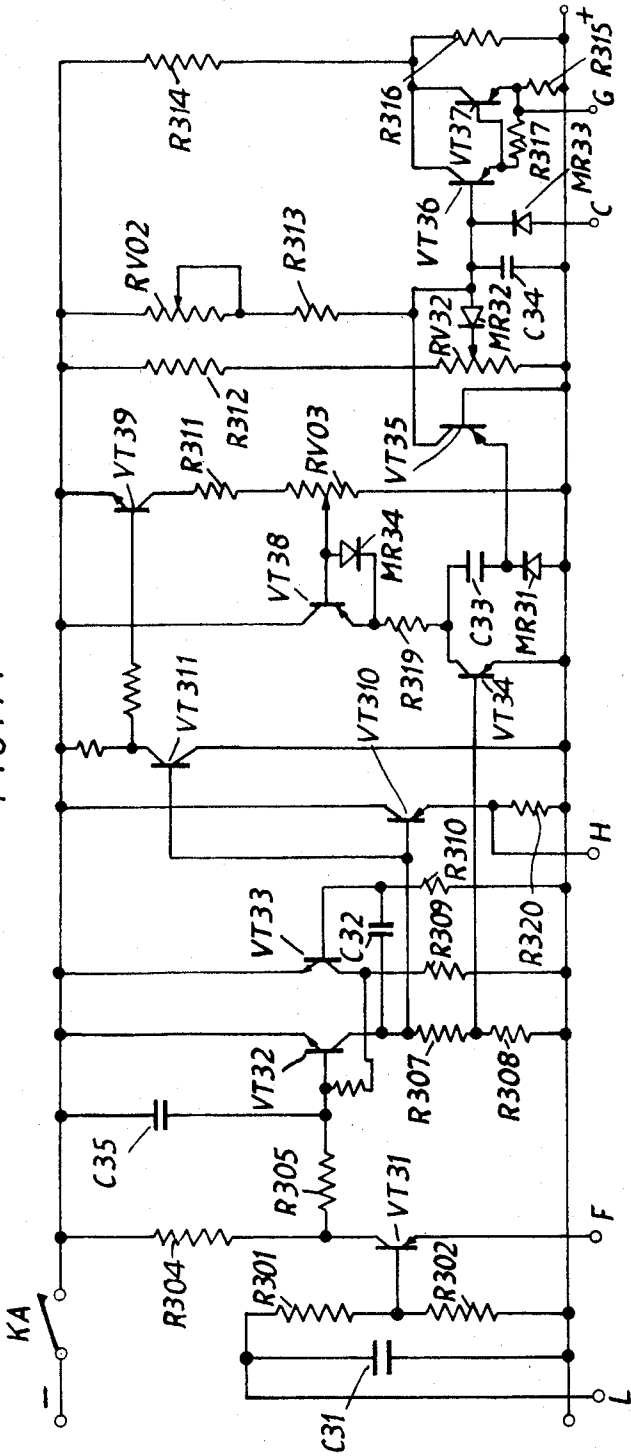


FIG. 8.

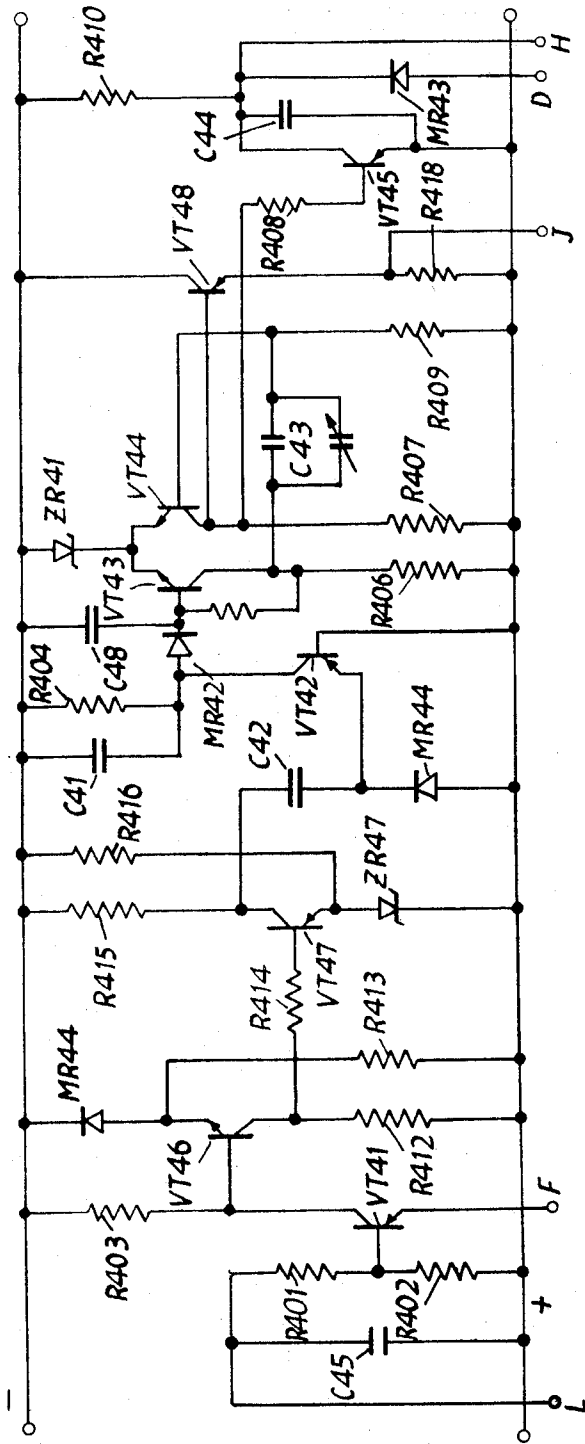
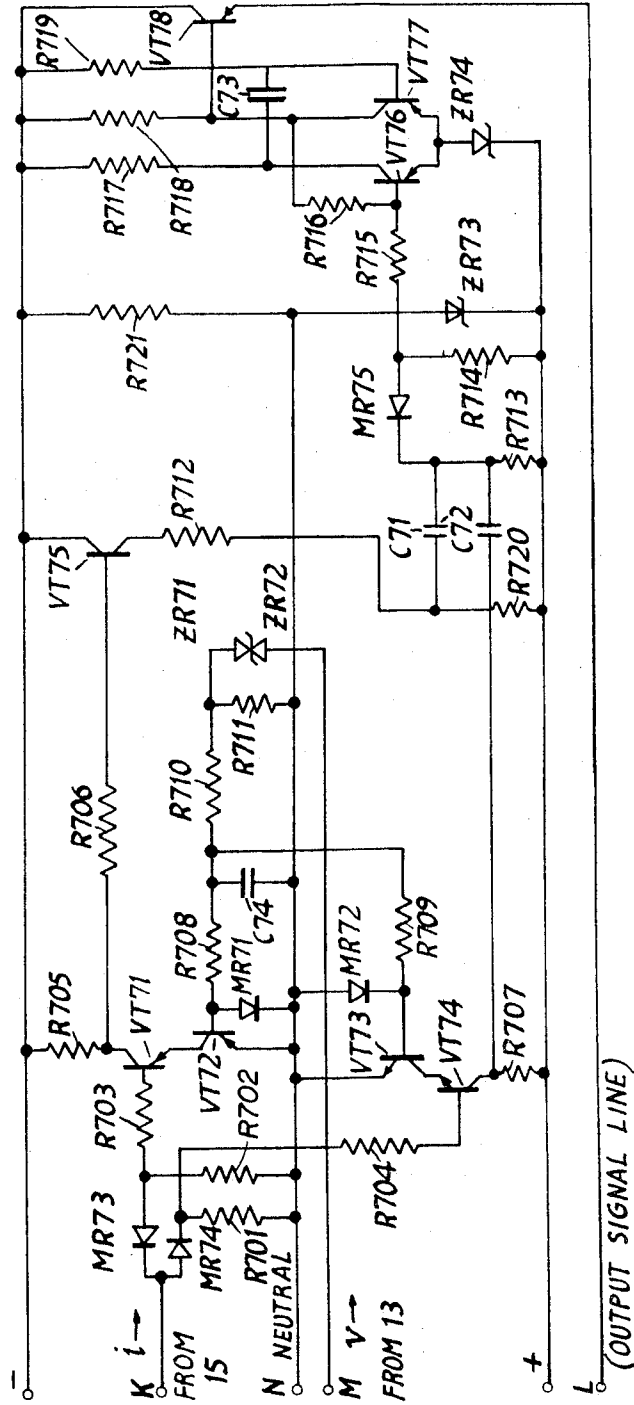


FIG. 9.



AUTOMATIC VOLTAGE CONTROL APPARATUS FOR ELECTROSTATIC PRECIPITATORS

This invention relates to electrical power supply control circuits and relates more especially but not exclusively to a circuit for the control of an electric supply for an electrostatic precipitator.

In an electrostatic precipitator it is usual to provide electrodes in a chamber, between which electrodes gases in which finely particulate material is suspended are permitted to flow. By applying a high tension d.c. supply to the electrodes the particulate material may be precipitated from the gas. The efficiency of operation of such a precipitation process is dependent upon the potential between the electrodes which present a generally resistive and capacitive load, being maintained at a value which at least approaches the potential at which break-down in the form of flashovers between the electrodes is likely to occur. The precise value of voltage for a flashover to occur is indeterminate and depends upon many variables such as gas density, humidity, and build-up of deposit on the electrodes. Arcs due to sustained flashovers moreover need to be prevented or at least extinguished as soon as they develop since, although it is possible to provide overcurrent protection for the apparatus, an arc when established is accompanied by a collapse of voltage and a complete collapse of the efficiency of precipitation. There is therefore a requirement for a continuous adjustment of the high tension supply to a precipitator which seeks to take account of the varying conditions within the precipitation chamber.

With the above object in view, it has previously been proposed to provide means for gradually increasing the high tension supply voltage to the precipitator electrodes up to a point at which sparking occurs and on detection of such sparking, to effect an immediate predetermined stepped reduction of the voltage before permitting the voltage to rise again under a controlled law. By such means, the voltage level can be arranged to adjust itself to keep the sparking rate to an acceptable value. Means are also usually required which are operable to temporarily suppress the supply in the event of an arc occurring.

The more usual form of control for precipitation supplies has hitherto included a transducer via which the supply to the primary winding of a high voltage transformer rectifier feeding the precipitator is connected. Whilst a transducer has a capability of limiting fault currents in the event of a flashover or arcing, and also permits of ready spark and arc detection by sensing voltage depressions across the primary of the transformer, it may present a substantial disadvantage in that it has an appreciable response time and the efficiency of a precipitator may thereby be impaired.

Accordingly, in view of their much higher response rate for control it is considered to be advantageous to employ a semiconductor controllable rectifier device as the control means in place of the hitherto more usual transducer.

According to the present invention there is provided an electrical power supply control circuit responsive to a control signal for controlling the supply to a generally resistive and capacitive load and including means for rectifying an a.c. supply to provide a d.c. output, regulating means for regulating the mean output voltage, the regulating means being responsive to load condi-

tions by virtue of current waveform responsive means operable to detect a step increase in the inductive reactive nature of the supply circuit as a whole to modify the control signal.

It will be understood that a step increase in the inductive reactive nature of the circuit will in general be accompanied by a discontinuity in the current wave form and as such the current waveform responsive means can enable detection of the existence of such a discontinuity. As will be observed hereafter, where the regulating means regulates the mean output voltage by means such as thyristors having variable firing angle control, a convenient means of detecting the presence of such a discontinuity consists in means for detecting a widening of a pulse of current flowing corresponding to a particular supply voltage half cycle.

Such a widening is detected more particularly in the resulting preferred manner of putting the invention into practice by utilizing also a signal corresponding to the supply voltage and detecting the presence of significant output current flowing after a supply voltage zero in a unilaterally conducting path due to said increase of the inductive reactive nature of the circuit.

The flow of current past a supply voltage zero and therefore a discontinuity in the current waveform is detectable by detecting the presence of a reversal of voltage in the circuit at the end of a supply voltage half cycle.

In accordance with one aspect of the invention, circuit means can be included responsive to the occurrence of a discontinuity of the current waveform in a predetermined number of successive half cycles of the supply to effect a control function which is distinct from the control function initiated by the detection of the presence of such a discontinuity in a lesser number of half cycles.

The occurrence of such a discontinuity in a predetermined number of half cycles may be regarded as indicative of the onset of an arc within an electrostatic treating apparatus being supplied whereas such an occurrence in a lesser number of half cycles, may be regarded as merely an indication of a flashover within the apparatus.

Control of detection of flashovers as defined above may be effected by step reductions of the supply voltage whereas control in response to detection of the onset of an arc as defined above may be effected by a temporary complete suppression of the supply voltage.

In order that the present invention may be more clearly understood and readily carried into effect, the same will now be further described by way of example with reference to the accompanying drawings in which,

FIG. 1 illustrates in largely diagrammatical or block schematic form one embodiment of a precipitator supply control circuit in accordance with the invention,

FIG. 2 illustrates current and voltage waveforms to be referred to,

FIGS. 3 to 5, illustrate in greater detail the contents of certain of the blocks of the arrangement of FIG. 1,

FIG. 6, gives circuit details of a typical power supply circuit for the precipitator control circuit of FIG. 1,

FIG. 7, gives circuit details of a typical spark control circuit for the precipitator control circuit of FIG. 1,

FIG. 8, gives circuit details of a typical arc control circuit for the precipitator control of FIG. 1, and

FIG. 9 gives circuit details of a typical sensing circuit for the precipitator control of FIG. 1.

Referring to FIG. 1, an a.c. mains supply is assumed connected to the terminals 1 and 2 and the electrodes of an electrostatic precipitator are assumed connected to the terminals 3 and 4. The supply to the terminals 3 and 4 is via a suitable reactor 5 from the secondary winding of a high voltage rectifier bridge 6 supplied from the secondary winding 7 of a high voltage transformer 8 the primary winding 9 of which is supplied via a fullwave thyristor regulator including inverse parallel connected thyristors two of which are shown as 10 and 11, via a current limiting reactance 12. The reactance 12 may if desired be built into the transformer 8. Across the series combination of the current limiting reactance 12 and the transformer primary winding 9 there is connected a voltage sensing transformer 13 the purpose of which will be apparent hereafter. Also, in series with the supply to the transformer primary winding 9 there are connected two current transformers denoted 14 and 15. The secondary windings of these three transformers have connections to various of the blocks about to be referred to in the control position of the circuit.

The series regulator operates by adjusting the firing angle of the controllable rectifier devices 10 and 11 in respective half cycles of the a.c. supply at terminals 1 and 2 to control the mean value of the voltage at terminals 3 and 4. For the purposes of such control there is provided a suitable thyristor driver circuit represented by block 16 having a control input from an OR gate and buffer stage represented by block 17. Variable phase-angle controlled controllable rectifier circuits are familiar to persons skilled in the power supply circuit art and therefore further specific details of this precipitator supply appears unnecessary here.

The block 17 has three input connections. One input to 17 is derived from a manual and automatic spark control block 18 a second input to 17 is derived from an arc control block 19 and a third input to 17 is derived from a current limit block 20. The latter receives an input from the current transformer 14 to provide current limit protection for the apparatus and blocks 18 and 19 receive an input from a phase change sensing unit represented by block 21 which receives one input from the current transformer 15 and another input from the voltage transformer 13. The system also includes an undervoltage protection alarm circuit represented by block 22 and the spark and arc control units 18 and 19 have an associated neon indicator represented by block 23.

Various manual adjustments are provided the first comprising a manual adjustment 24 for a stabilized power supply which provides a stabilized power supply to the various circuit blocks via the output 26 and also supplies a reference voltage over line 27 to the blocks 18 and 19. Secondly, the spark rate control block is provided with a manual spark rate control 28 and a voltage threshold control 29. Additionally, the current limit unit 20 is provided with a suitable manual control represented at 30 for setting the upper current limit, for the apparatus. Referring in general terms to the operation of the arrangement of FIG. 1, the driver circuit is normally controlled via the OR gate 17 from the spark rate control block 18 and tends to progressively drive up the output of the circuit at terminals 3 and 4 towards a point at which a flashover occurs. Such a flashover is detected by the phase change sensing circuit 21 to produce an input to the blocks 18 and 19 in response to the

relationship between the waveforms appearing at the two inputs derived from transformers 13 and 15.

The circuit of the spark control block 18 operates in response to each spark detected, to cause an elemental change in the control signal to the driver 16, to correspondingly retard the firing angles of the thyristors in the precipitator supply circuit. Between such sparks, the block 18 allows the signal to the driver to adjust to tend to progressively advance the firing angle. Accordingly for a given set of conditions, the system tends to settle down to an optimum mean state with occasional flashovers, the rate of occurrence of which is suitably adjustable at 28.

In view of the high rate of response of the apparatus, it is desirable to detect at the earliest instant the onset of a possible arc in the apparatus and for this purpose, the circuit 19, which is the arc suppression circuit, detects the occurrence of a flashover condition in two successive half cycles of the supply waveform to override the control from block 18 and to effect a temporary suppression of the supply to extinguish any tendency for arcing to occur before allowing the supply voltage to rapidly recover to a value set by the block 18.

From this, it will be apparent that the output voltage is regulated by advancing or retarding the firing angle of the controllable rectifier devices 10 and 11 in respective half cycles and in the absence of arcing allows the voltage to progressively increase, such increase being intermittently interrupted by step reductions of voltage on occurrence of flashovers as distinct from arcs detected as defined above.

Returning now to the manner of detection of arcs and flashovers as defined, reference may be made to the graphical illustration of FIG. 2. This illustrates idealised waveforms of the voltage appearing after the semiconductor controllable rectifier regulator comprising devices 10 and 11 and of the line current for a firing angle of 90°. The cycle shown over the period A is a normal cycle, the cycle shown over the period B is a cycle in the first half of which a flashover is assumed to occur. This flashover is effectively a short-circuit and the load on the supply therefore changes from precipitator load which tends to be predominantly capacitive to predominantly inductive load due principally to the current limiting reactance 12 in the primary circuit of the transformer. As a result of the change to this predominantly inductive condition, the thyristor which is conducting tends to conduct beyond the supply voltage zero and a reverse voltage tail of the half cycle waveform occurs as shown. The occurrence of an arc or a tendency to arcing as defined above is illustrated over the period C. In this case, a voltage tail is shown to occur in two successive half cycles of the voltage waveform.

Accordingly, the sensing circuit for sensing the occurrence of flashovers is designed to respond to a significant reverse voltage tail associated with a single half cycle and for the purposes of detecting the imminent occurrence of arcs, two successive half cycles are detected having reverse voltage tails. It is worthy of note that inevitably there is always a small reverse voltage tail due to the presence of line circuit reactance and the sensing circuit is therefore provided with a suitable threshold below which it is unresponsive and so that the circuit does not respond to such reverse voltage tail which are not significant.

In the sensing circuit 21, to be described in greater detail with reference to FIG. 9, signals are derived from the line current via transformer 15 and from primary voltage via transformer 13 in directions of normally opposed polarity and applied to the bases of two pairs of series connected transistor switches. One such pair is provided for each half cycle of the supply. In view of the opposed polarity connection of the transistors in a given pair, only one transistor of each pair is turned on at any given instant and normally no output results. In the event however of a voltage reversal during a unidirectional current conducting period such as occurs at a flashover as discussed above, there is a period of time when both the devices of a pair can conduct together and common collector current flows. The common output is subsequently applied to actuate the circuit 18 and/or 19.

Because of the above-mentioned small tail voltage which always exists due to the line circuit reactance, a suitable backing off zener diode is provided and is trimmed so as to provide the necessary threshold for response thereby to preclude switching due to the small normal tail voltage.

FIG. 3 illustrates in block form the phase change sensing circuit of block 21, the two transistor pairs referred to above being represented by blocks 31 and 32. Since the duration of the output pulse from the transistor pair 31 or the transistor pair 32 is not constant, but depends upon the instant of flashover, the nature of the load and the firing angle for the respective thyristor, its leading edge is utilized to trigger a one millisecond monostable circuit represented by block 34 via a differentiating circuit 33 to obtain an output of constant magnitude and duration to a buffer amplifier stage 35 before applying the output thereof to blocks 18 and 19 of FIG. 1.

Referring now to the operation of the flashover responsive circuit represented by block 18 of FIG. 1, reference may be made to the block diagram of FIG. 4. When a flashover occurs a signal is derived from the sensing circuit 21 and applied to a comparator 37 which if it is greater than the reference derived from the stabilized power supply and therefore indicates the existence of a flashover, trips a monostable circuit 38 the output of which extends for approximately 3.5 milliseconds. One output of the monostable circuit 38 energizes a charge transfer network comprising a switch 39 with associated primary and secondary capacitors 40 and 41 respectively. Here the preset voltage stored on the primary capacitor 40 is instantaneously transferred to the secondary capacitor in terms of voltage step-down at the output of the secondary capacitor 41. The resultant step-down is the product of the change of voltage on the primary capacitor and the ratio of the primary and secondary capacitances. This step-down of voltage is applied via the buffer amplifier 42 to one input to the circuit 17 referred to above causing the firing angle to increase before the next supply half cycle to result in a reduced output voltage from the power circuit. Following such a step-down, recovery of the driver voltage and output is relatively slow following the recharge of the secondary capacitor towards the level dictated by a setting of an output voltage control in the circuit.

The monostable circuit 38 provides an additional output to a suitable flashover indicating neon in the block 23 of FIG. 1. In the block 23, the duration of the

basic period of the pulse of 38 is extended by a suitable delay sufficiently to enable a flash of the neon to be recognized by the observer or engineer in charge who may thereby decide whether the rate of flashing of the treater is as required.

Referring now to the control of arcs, it being remembered from the foregoing that in the present example an arc is interpreted as accompanied by flashovers in two successive half cycles. Reference may be made to the block diagram of FIG. 5 which illustrates in greater detail the contents of block 19 of FIG. 1. The occurrence of a flashover is accompanied by a pulse from the circuit 21 as an input to the comparator and switch represented by block 44 of FIG. 5. This pulse is greater in voltage than the reference from the stabilized supply on line 27 and actuates a charge transfer network in which a fixed voltage transfer occurs via a switch 45 from a primary capacitor 46 to a secondary capacitor 47. The voltage which is thereby gained by the secondary capacitor 47 is arranged to be insufficient to switch a monostable circuit 48 into its astable state and if no subsequent pulse is received during the next half cycle of the supply, the capacitor 47 discharges over one cycle of the supply and is thus reset to the initial condition. If however a second flashover occurs accompanied by a pulse to produce a second discharge of 46 into 47, the cumulative voltage of the secondary capacitor 47 is sufficient to cause switching of the monostable circuit 48 to produce an output pulse both to the arc indicating neon unit 23 and via the buffer amplifier 49 and the gate 17 of FIG. 1 to suppress the firing pulses to the thyristors for sufficient period for the arc to be prevented. A recovery ramp unit 50 is provided whereby a retarded recovery of the output voltage towards a level set by the spark rate circuit 18 is achieved.

In addition to the current limiting function afforded by the control 30 and the circuit block 20 of FIG. 1, the under voltage circuit 22 is also provided with means of which the mean primary voltage to the high voltage transformer is applied to a suitable comparator the switching point of which is preset to a control level. With adequate input voltage, full supply is applied to an included under-voltage relay to hold the main contactor of the apparatus closed. In the event however of the output voltage being lost or falling below a preset level, the voltage to the under-voltage relay is interrupted after a suitable delay to initiate an alarm and open the main contactor. The delay enables short-term voltage reductions to have no effect.

A further feature which may be incorporated includes a suitable means for limiting the energy of the current transformers 14 and 15. Across the resistive load of the current transformer 15 for example, there may be connected a full wave rectifier bridge having a zener diode across the d.c. terminals. In the event of a single flashover occurring, particularly when the normal load of the treater is predominantly resistive rather than capacitive, the current transformer is prevented thereby from storing sufficient magnetizing energy that distortion of the voltage may occur in the next half cycle. The zener conducts and limits the volt-second energy absorbed by the core of the transformer. The duration of the current pulse at the resistive load of the current transformer is unaffected as also is operation of the sensing system. In the event of an arc as defined above, the core of the current transformer is inherently

reset by the two opposite polarity primary current pulses but here again the zener diode is an effective energy limiter.

Hitherto, the circuits of the apparatus have been described only in general terms to provide a general picture of the overall manner of operation of the circuits. In order to enlarge upon the circuit details reference can now be had to the remaining drawings.

Referring to FIG. 6, which shows the power supply circuit, this is based upon conventional transistor circuit techniques and in response to an a.c. supply applied to the rectifier bridge formed of diodes MR11 to MR14, provides a stabilized supply voltage on the negatively and positively marked d.c. lines A and B respectively, for the purposes of supplying the remaining transistor circuits to be discussed.

The a.c. supply applied to the rectifiers MR11 to MR14 is derived from a power supply transformer which is not shown and the d.c. output of the rectifier is smoothed by a capacitor C11 and delivered to a series regulator transistor VT15. Control of the base current to the transistor VT15 is effected via transistors VT13 and VT14 which are connected in parallel as shown in conjunction with a transistor VT12. A transistor VT11 operates as a comparator amplifier and has a load resistor R102 in its collector lead and a reference zener diode ZR11 in its emitter lead. The zener diode thereby forms a reference and the input signal to the base of the transistor VT11 is derived from a chain of resistors R104, RV11, R105 and R106, RV11 having an adjustable tap which is used to set the output to a desired voltage. A capacitor C13 provides smoothing and closed loop stability is achieved by means of the capacitor C12 and the resistor R101 connected in series across the resistor R102.

Included in the power supply circuit arrangement is an adjustable resistive supply chain formed of resistor R107 and resistor RV12 having a variable tapping to a further remotely disposed variable resistor RV01 on which an output at terminals C and D is derived. In practice, the resistor RV12 is adjusted to preset the maximum firing angle of the main controllable rectifier devices supplying the precipitator when the position of the movable tap on the resistor RV01 is set to give maximum output. This maximum setting point is also used to provide a clamp voltage for output voltage from the arc control circuit to be discussed in greater detail.

Additionally, the power supply circuit includes a circuit network consisting of resistors R108, RV13 which has an adjustable tapping, an emitter follower transistor VT16 with associated emitter resistor 109, a capacitor C14 connected to the base circuit of the transistor VT16. The transistor VT16 is thus arranged to provide a suitably adjustable reference level for the input switching transistors of the spark and arc control functions, this reference level being derived at the output terminal F. The capacitor C14 is desirable to suppress high frequency oscillation of the transistor VT16.

Referring now to the circuit arrangement of FIG. 7 which illustrates the details of the spark rate control circuit, in normal operation when there is no flashover, a controlling voltage is applied from the manual control potentiometer RV01 of FIG. 6 and appearing at the line C, is applied to the base electrode of the transistor VT36 in the final stage of the spark rate control circuit of FIG. 7. Transistors VT36 and VT37 are connected to operate as cascaded emitter follower transistors with

a high input impedance. The output voltage across a resistor R315 in the emitter lead to the transistor VT36 appears on the line G and is led away thereby to constitute one input to the OR gate circuit referred to above as block 17 of FIG. 1. The collector circuit supplies to these two transistors are stabilized by the chain of resistors R314 and R316. When the position of the potentiometer RV01 of FIG. 6 is moved rapidly by the operator, the driver voltage to the driver 16 is prevented from changing equally rapidly by a built-in delay which is afforded by virtue of the fact that a capacitor 34 charges or discharges via a resistor 313 and a variable resistor RV02 in series therewith. This ensures a soft start for the main thyristors supplying the high voltage transformer of the precipitator supply circuit. When the position of the potentiometer RV01 is adjusted to increase output voltage, capacitor C34 charges towards the negative rail of the transistor circuit and charges in this direction until it is clamped at a value determined by a diode MR33 and the setting of the output voltage control. On closing of the main isolator of the apparatus, all circuits except that for the spark rate control circuit of FIG. 7 receive the basic d.c. supply derived from terminals A and B of the power supply circuit of FIG. 6. Even if the potentiometer RV32 has been allowed to rest in a high output voltage position, its potential cannot be passed to the driver circuit because the diode MR33 blocks the feed to the transistor VT36 referred to above. Thus, when the main contactor of the apparatus is subsequently closed, the thyristors are not initially at an advanced firing angle but remain initially blocked.

Shortly after the closing of the main contactor, an auxiliary contact of the contactor which is denoted by the reference KA in FIG. 7, connects the negative transistor circuit supply rail A to the spark control circuit of FIG. 7 and the capacitor C34 can thus commence to charge, permitting a smooth increase of driver control voltage and therefore smooth advancement of the thyristor firing angle. The capacitor C34 charges rapidly initially via the relatively low resistive circuit including resistor R312 and variable resistor RV32. This continues until clamping by diode MR32 at the setting of the variable resistor RV32, which is adjusted to provide a driver signal voltage just below the threshold level corresponding to minimum conduction of the thyristors. The capacitor C34 then continues to charge at a slower rate into the higher resistance presented by the resistance R313 and the variable resistor RV02 until MR33 clamps. Since the maximum setting required from the variable potentiometer RV01 of FIG. 6 even for full conduction of the thyristors, is arranged to be such as to produce a very low voltage, at the terminal C, whereas capacitor C34 tends to charge towards the supply rail, the small portion of the exponential charging curve which is utilized in charging C34, afforded an approximately linear control voltage ramp.

Considering now the automatic spark rate controlling action of the circuit, a signal pulse derived from the phase sensing circuit, is applied to the input line L and therefore to the base electrode of a transistor VT31 through a two-to-one attenuation afforded by a potential divider formed of resistors R301 and R302. A capacitor C31 is connected across this potential divider and prevents high frequency disturbances causing spurious triggering. As will be seen, the input signal pulse is derived from a monostable circuit and is of fixed

magnitude and duration and ensures that the transistor VT31 is turned on when its emitter reference level has been preset to an optimum level by means of the potentiometer RV13 of the power supply circuit of FIG. 6. Turning on of the transistor VT31 causes an input transistor VT32 of a monostable pair of transistors VT32 and VT33 to be switched on. Immunity to noise is afforded by a capacitor C35. A pulse is emitted by the collector electrode of the transistor VT32 and this pulse is utilized in three ways. Firstly, after being attenuated by the resistors R307 and R308, the output pulse of VT32 causes a further transistor VT34 to be turned on. Prior to this, a capacitor C33 is charged to a level which is determined by the value of a resistor RV03 and a fixed resistor R311. As the transistor VT34 turns on and bottoms, the negative plate of the capacitor C33 falls in voltage to that of the positive potential line and causes the emitter electrode of a transistor VT35 to move positively so that this transistor also turns on. An immediate charge transfer therefore occurs between the capacitor C33 and the capacitor C34 such that the voltage decrease on the capacitors C34 equals the product of the voltage change on the capacitor C33 and the ratio of the capacitors C33 and C34.

Owing to residual resistance in the charge transfer path, the voltage transfer is not a total transfer but is substantial and the step-down of voltage level on the capacitor C34 is transferred as a step reduction in the control voltage to the driver circuit via the output lead G referred to above. At this time, the diode MR33 is biased into reverse and disconnects the manual supply derived from the variable potentiometer RV01 of FIG. 6. The magnitude of such a step is controlled by the position of the variable resistor RV03 which predetermines the charge on the capacitor C33. During the transfer process, the upper plate of the capacitor C33 is disconnected from the charging supply by a transistor VT39 (which is in series with R311 and RV03) switching off through the transistor VT311 as a result of a signal to the base electrode thereof from the collector electrode of the first monostable circuit transistor VT32. At the same time, a signal from the collector of transistor VT32 is applied to the base electrode of a transistor VT310 which operates as an emitter follower and the pulse appearing across the emitter resistor R320 of this emitter follower is applied to the line H which is carried away to the neon indicator represented by block 23 of FIG. 1. The diode MR34 acts as a clamping device to prevent excessive reverse bias occurring on the transistor VT38. The diode MR31 permits the capacitor C33 to recharge after the pulse has ended and the transistor VT35 has turned off again. Recovery of driver voltage after the step, occurs at the rate of the normal starting ramp while the capacitor C34 recharges through resistor R313 and the variable resistor RV02. The variable resistor RV02 therefore affords a spark rate control which can be mounted on the panel of the apparatus.

Referring now to FIG. 8 of the drawings, this shows details of the arc control circuit which applies an output to the OR gate 17 of FIG. 1 when an arc is deemed to occur, the criterion for an arc being as discussed previously in the general description. When a flashover occurs, the sensing circuit, yet to be described in detail, delivers a switching pulse through an attenuating potential divider, consisting of resistors R401, and R402, to the base electrode of a transistor VT41 the potential

on the emitter electrode of which, since it is connected to the line F, is determined by the setting of the potentiometer RV13 of the power supply circuit. The capacitor C45 serves the same purpose as the capacitor C31 of FIG. 7. The switching level is determined in the same manner as for the spark control circuit and after a polarity reversal by the further transistor VT46 the base of which is coupled to the collector circuit of transistor VT41, the switching signal causes a transistor VT47 to become conducting through resistor R414. The diode MR44 in the emitter circuit of transistor VT46 affords a threshold immunity against noise. The collector electrode of transistor VT47 therefore falls from the potential of the negative power supply line to a level which is within a few volts of the positive supply line. This level is set by the emitter reference diode ZR47 and is sustained through the resistor R416. The capacitor C42 is initially charged to a voltage which is near the negative supply line voltage and the subsequent substantial voltage descent in the potential of the collector electrode of transistor VT47 causes the emitter electrode of transistor VT42 to swing positively and the transistor VT42 is turned on. A substantial charge transfer therefore occurs from the capacitor C42 to a capacitor C41 such that the voltage increase on the capacitor C41 is equal to the product of the voltage drop across the capacitor C42 and the ratio of the capacitances of capacitors C42 and C41. Again, as in the case of the spark control circuit the resistance in series with the charge transfer path prevents a complete dissipation of the charge which is initially stored on the capacitor C42 but the voltage change which occurs across the capacitor C41 is a consistent change. Further, at this time the increased voltage on C41 is not higher than the threshold level of the zener diode ZR41 which is associated with a monostable pair of transistors VG43 and VG44, so that no switching results. If no further flashover occurs the capacitor C41 subsequently discharges through the resistor R404 and resets to zero within a short period chosen to be about 20 milliseconds. However, if an arc has occurred the criterion for deciding the presence of which is determined as described above, a second signal pulse is received at the transistor VT41 10 milliseconds after the first and the capacitor C41 after such a short time has only partially discharged so that the second charge transfer which then occurs causes a net voltage on the capacitor C41 to exceed the threshold level which is set by the zener diode ZR41. The monostable transistor circuit formed of transistors VT43 and VT44 therefore switches into its alternative state, in which VT44 conducts. A rectangular pulse is therefore fed to the base electrode of transistor VT45 to turn this transistor on, the base current flowing through resistor R408. The collector electrode of transistor VT45 therefore falls to the potential of the positive supply line and an output signal is therefore fed from this point to the driver circuit on the line H through the OR gate. This signal causes the removal of the driver control signal such that the thyristors in the main supply circuit to the precipitator are blocked. At the same time, the output pulse of the monostable circuit also delivers a switching signal to the neon indication unit 23 via the output line J.

The output voltage from the arc control circuit on the line H remains in the zero condition for the duration of the period in which the monostable circuit of VT43 and VT44 is in the switched state. This period

may be adjusted to approximately two or three cycles of the supply frequency by use of a suitable de-ionisation control, which switches in alternative timing capacitors and is denoted as capacitor C43. Capacitor C43 is adjusted to an optimum hold-off period which guarantees de-ionisation of the precipitator gases in order to normally prevent a restrike of an arc when the output voltage is allowed to be restored. When the transistor VT45 turns off again, the capacitor C44 re-charges rapidly via the resistor R410 and this causes a ramp increase of driver control voltage up to a point where it is clamped by the diode MR43 the anode of which is preset at the maximum potential of the manual output control afforded by the variable resistor contact RV12 of the power supply circuit described above with the reference to FIG. 6. Components of the circuit are so adjusted as to obtain maximum recovery rate for the output voltage which is consistent with no problems arising due to current inrush in relation to the high voltage transformer of the precipitator main supply circuit. Typically, the period of recovery is that of approximately three cycles of the a.c. supply. Like the capacitor C45 across the potential divider R401 and R402, the capacitor C48 connected between the base electrode of VT43 and the negative supply line, affords noise immunity of the arc control circuit.

Reference may now be had to FIG. 9 which illustrates circuit details of the phase sensing circuit denoted by the block 21 of FIG. 1. In normal running, signals derived from the line current transformer 15 and from the voltage between the lines connected to the primary winding of the high voltage transformer, are connected in antiphase to the inputs K and M respectively of the circuit of FIG. 9, the line N being a common signal neutral line. Considering the half cycle when the input line K proceeds negatively with respect to the common signal line N, so that the transistor VT71 attempts to turn on via the resistor R703, since the input line M is positive-going in that half cycle owing to the connections provided, transistor VT72 is held off and no current flows through resistor R702. During this same period, the transistor VT73 is switched on by the voltage signal appearing at the input line M. However the transistor VT74 is maintained in the off condition by the voltage at the line K and therefore no current flow in the resistor 707. In the next half cycle when the input line K goes positive and the input line N goes negative relative to the neutral line, the transistors VT74 and VT72 are rendered conducting but transistor VT71 and transistor VT73 are held non-conducting so that again no current flows in resistor R705 or resistor R707.

If a flashover occurs in the precipitator, the resulting nature of the load on the main precipitator power supply circuit becomes inductive because the high voltage transformer itself receives an effectively short-circuited secondary winding impedance and all primary voltage is developed across the fault limiting reactance by leakage reactance of the transformer together with any additional primary ballast inductance which is used. In this case this inductance is denoted by the inductance 12 in FIG. 1. Under these conditions, as explained previously, transformer primary winding current continues to flow after the voltage applied to the thyristors has fallen to zero and in fact a voltage cross-over occurs during the period of current flow. Consequently, a point arrives in time during the supply frequency half cycle when both the current and voltage signals at input

lines K and M respectively are in phase. One of the pairs of cascaded transistors VT71, VT72 or VT73, VT74 are now switched on together and the voltage across either the resistor R705 or the resistor R707 swings from zero voltage to a voltage which is equal to half the supply voltage to the transistor circuit. The series combination of the zener diode ZR73 and the resistor R721 fixes this proportion. Even when the voltage signal at the input line M is of a polarity appropriate to turn on its associated transistor VT72 or VT73, the magnitude of the voltage signal has to be sufficient to exceed the backing potential provided by the a.c. zener diode pair labelled ZR71 and ZR72 in series with the line M. This backing off is provided to prevent the possibility of false sensing on normal load conditions because the magnitude of the line reactance is sufficiently large to cause a small amount of voltage overswing during current load but not to the same extent as that created by flashover. This is already referred to in the foregoing.

When a signal equivalent to half the supply line potential appears across the resistor R707 it appears also across the output of a differentiating network comprising capacitor C72 and resistor R713. The leading edge of such a signal is therefore able to produce a negative going spike at this point. Similarly, the signal pulse across the resistor R705 is phase changed by the transistor VT75 but maintained at a voltage of approximately half the circuit line voltage by the attenuator comprising resistors R712 and R720. After differentiation in the differentiating circuit comprising capacitor C71 and resistor R713 causes a sharp negative voltage pulse to appear coincident with the leading edge of the signal. From the resistor R713 which is therefore common to both signals the negative going pulse is transmitted via the diode MR75 to resistor R714 and is therefore effective via resistor R715 to cause a monostable pair of transistors VT76 and VT77 to switch from one state to a second state in which VT76 is conducting, to produce an output pulse via the emitter follower transistor VT78. A zener diode ZR74 is provided in the emitter leads to the monostable pair of transistors VT76 and VT77 to afford some degree of threshold immunity against noise at the input to the circuit and the diode MR75 which is included between the two resistors R713 and R714, prevents any tendency for the transistor VT76 to be forced into the "off" condition at an advanced point at the trailing edge of the original collector load pulse on resistor R705 or resistor R707, by blocking the positive going voltage spike produced across resistor R713 after the differentiation. The output signal pulse derived from the transistor VT78 corresponding to a flashover is fed to the spark control circuits and the arc control via the line L. The duration of this pulse output is of constant magnitude and duration regardless of variation of the switching signal which appears at the resistor R707, or the resistor R705, which may be caused by the randomness with which a flashover may occur during any given supply a.c. half cycle.

The neon circuit referred to above with reference to block 23, merely consists of a pair of neon lamp indicators with appropriate associated circuit means to enable visual indication to be provided of the occurrence of arcs and flashovers.

The under-voltage circuit 22 of FIG. 1 is not described in detail since a suitable form of such circuit will be readily apparent to the skilled engineer. An out-

put from the transformer 13 of FIG. 1, is thus rectified and applied to a transistor circuit which in operation removes the supply to a main circuit contactor when the rectified voltage derived from 13 falls below a preset level. The circuit may include suitable resistance and capacitive time constant circuits to provide adequate delay before tripping to prevent spurious interruption of the power supply during, say, a succession of flashovers in the recipitator, which may lead to a short reduction in the main high voltage transformer primary voltage due to normal action of the spark control circuit.

The current limit circuit 20, which provides one input to the "OR" circuit 17 can again be of any suitable conventional electronic transistor circuit form. Typically, the line current signal derived from the current transformer 14 as applied to a smoothing circuit from points if it attains a threshold level, it switches a long-rail pair to a state in which via a capacitor delay feedback circuit, it brings an emitter follower amplifier into operation. This amplifier assumes control of the driver circuit 16 in preference to the outputs 18 or 19 (FIG. 1). The capacitive feedback delay network makes it necessary for the current limit to be exceeded for a given minimum time of (say) 10 seconds for the limit circuit to take over control of the driver portion of the apparatus which applies variable phase angle control pulses to the thyristors 10 and 11.

It will be understood from the above described operation of a system using a circuit in accordance with the invention that if a precipitator arc occurs, drastic and immediate action results to prevent prolongation of the arc or restriking after extinction. Thus a complete switch-off of the voltage applied to the high voltage transformer is effected within half a cycle of the instant at which the arc is sensed. This switch-off is then followed by a period of zero voltage which is long enough for the gas in the vicinity of the flashover area to become de-ionised sufficiently to prevent a restrike. The recovery of voltage to the precipitator is then quite rapid in order to maintain a high mean voltage to the precipitator.

In the event of a spark only, the action is seen to be less drastic and control is afforded by the limited voltage reduction which is effected within a half cycle of sensing. A succession of sparks produces a progressive decrease of voltage to the high voltage transformer until the sparking rate is reduced and there is a relatively slow recovery of voltage whilst maintaining a high mean output voltage to the precipitator.

Having thus described our invention what we claim is:

1. An automatic voltage control apparatus for an electrostatic precipitator, said apparatus comprising semiconductor controllable rectifier means for controlling the electrical power supplied to the precipitator and control means for controlling the conduction of said semiconductor controllable rectifier means so as to maintain the operation of the precipitator notwithstanding the tendency of the voltage supplied to the precipitator to be such as to cause a voltage breakdown thereacross, said control means including flashover sensing means including means for sensing the current waveform flowing to the precipitator, means for sensing the voltage waveform across the precipitator, and means responsive to said current waveform sensing means and said voltage waveform sensing means for de-

tecting the presence in said current waveform of current flow in excess of a predetermined value subsequent to a voltage zero as sensed by said voltage waveform sensing means and for producing a control signal for controlling said semiconductor controllable rectifier means responsive thereto.

2. An automatic voltage control apparatus as claimed in claim 1 wherein said current waveform responsive means includes means responsive to a widening of the output current pulses produced by said semiconductor controllable rectifier means corresponding to an increase in the inductive reactive nature of the apparatus.

3. An automatic voltage control apparatus as claimed in claim 1 wherein said current waveform and voltage waveform responsive means includes means for sensing at least a predetermined reversal of the voltage waveform following a supply voltage a.c. half cycle.

4. An automatic voltage control apparatus as claimed in claim 3 wherein said current waveform and voltage waveform responsive means comprise first and second switching devices responsive to said voltage waveform, the second switching device switching to the same condition as the first switching device in response to a said predetermined reversal of the voltage waveform to produce a said control signal.

5. An automatic voltage control apparatus as claimed in claim 4 wherein said first and second switches comprise transistors.

6. An automatic voltage control apparatus as claimed in claim 4 wherein said first and second switching devices comprise first and second pairs of series connected switching transistors, one transistor of each pair being provided for each polarity of the a.c. supply waveforms.

7. An automatic voltage control apparatus as claimed in claim 1 further comprising arc control means responsive to the presence of current flow in excess of said predetermined value for a predetermined number of successive half cycles of the a.c. supply for controlling said semiconductor controllable rectifier means so as to control precipitator arcing.

8. An automatic voltage control apparatus as claimed in claim 7 wherein said arc control means includes a storage capacitor, a further capacitor, and means responsive to the said presence of current flow in excess of said predetermined value for said predetermined number of cycles for connecting said further capacitor to said storage capacitor to effect an elemental transfer of current between the capacitors and means responsive to said charge transfer for controlling conduction of said semiconductor controllable rectifier means.

9. An automatic voltage control apparatus as claimed in claim 7 wherein said arc control means includes a bistable circuit for, when switched between a first state and a second state, overriding said control signal to reduce the output of said semiconductor controllable rectifier means to a value such that precipitator arcing is extinguished within a half cycle of the supply voltage, a capacitor the charge upon which controls switching of said bistable circuit, and a capacitor charge transfer circuit for, upon detection of the presence of current flow in excess of said predetermined value subsequent to a voltage zero, transferring a predetermined charge to said capacitor, said capacitor including a charge leakage path requiring a plurality of said charge transfers within a given time interval before causing switching of said bistable circuit from said first state to said second state.

10. An automatic voltage control control apparatus as claimed in claim 7 further comprising light emitting visual indicator means for indicating the occurrence of sparks and for indicating the occurrence of arcs.

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