

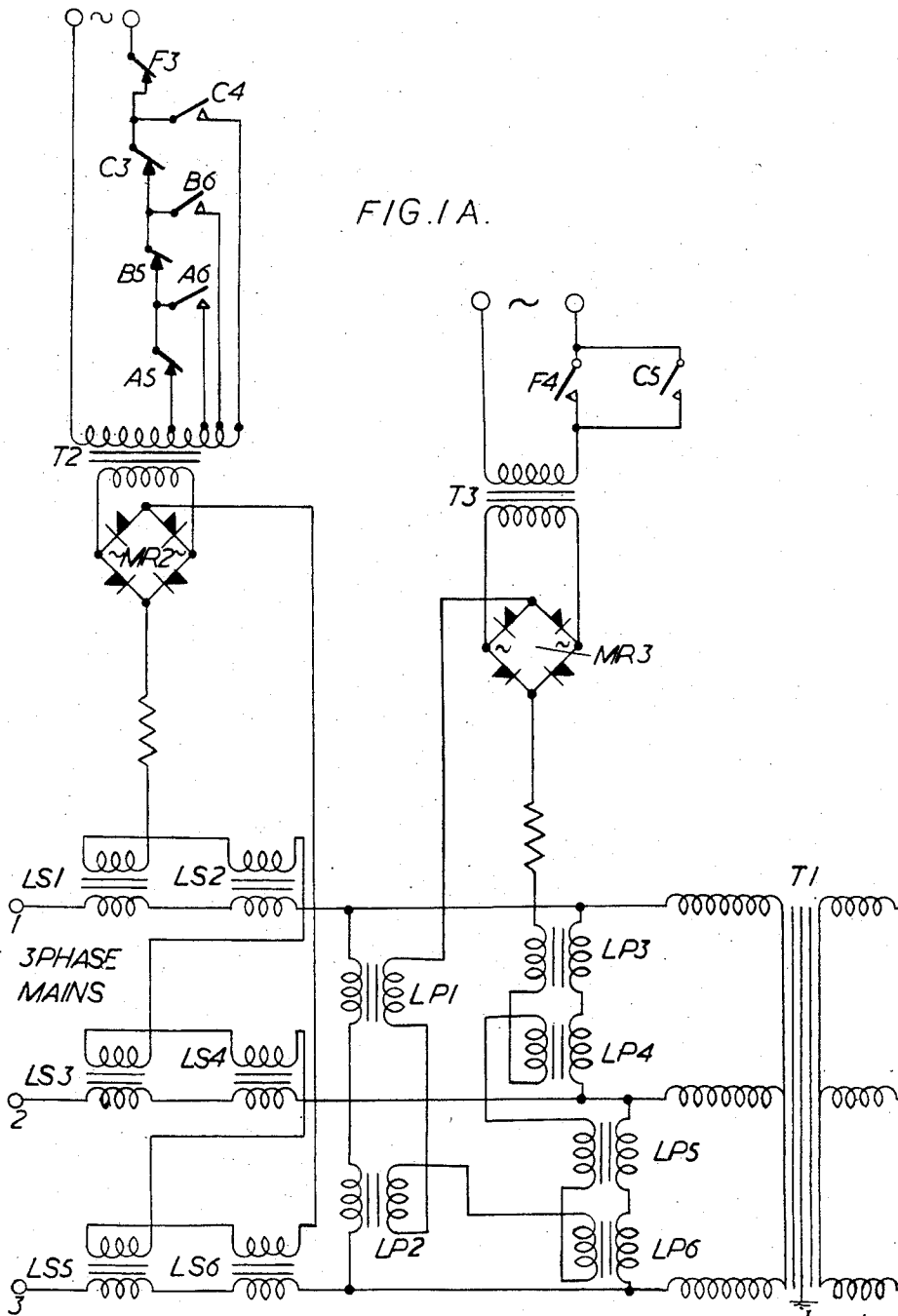
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T. P. ROBINSON ET AL
ELECTRICAL CONTROL CIRCUITS

2,881,856

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3 Sheets-Sheet 1



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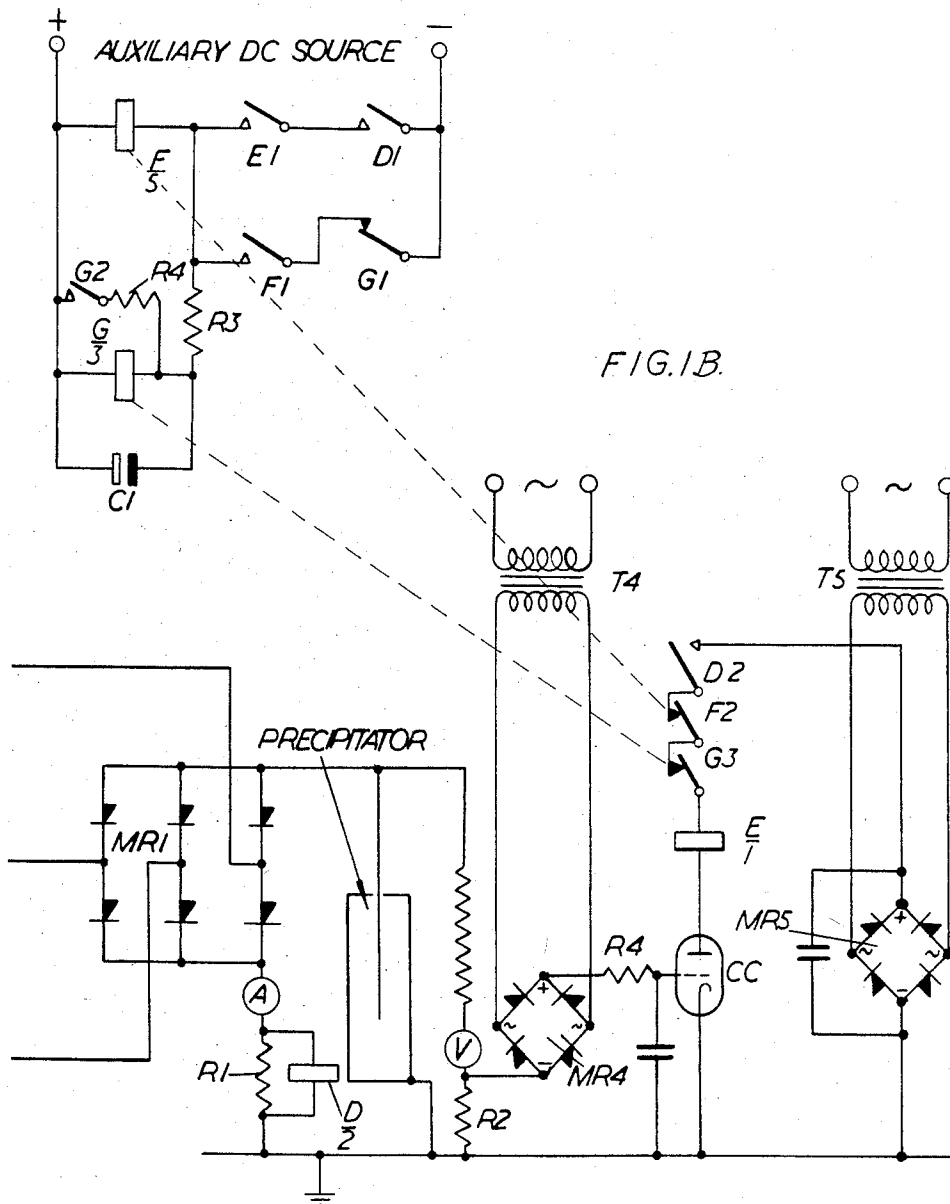
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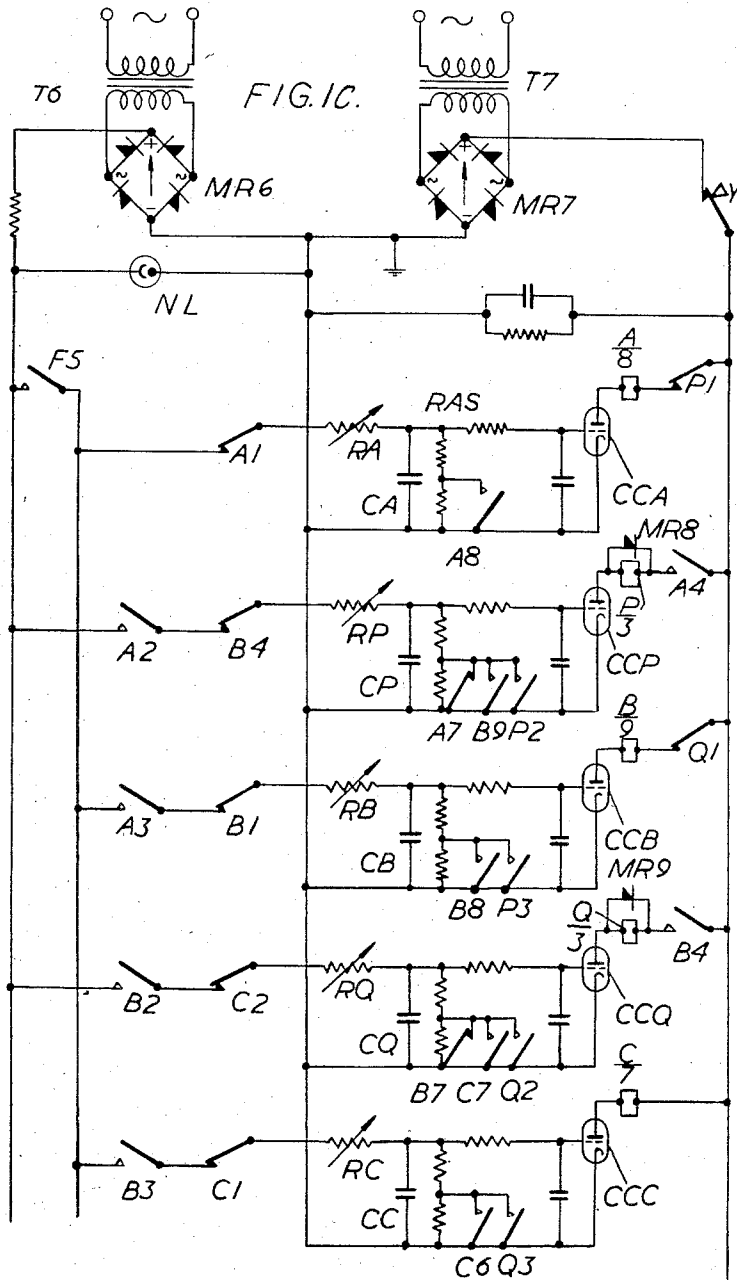
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ELECTRICAL CONTROL CIRCUITS

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9 Claims. (Cl. 183—7)

This invention relates to electrostatic precipitators, with particular reference to electrical controlling circuits therefor.

According to the invention, there is provided an electrostatic precipitator comprising controlling circuit means responsive to flash-overs in the said precipitator and arranged to reduce automatically the voltage applied to the said precipitator in response to each individual flash-over.

Also according to the invention, there is provided an electrostatic precipitator comprising controlling circuit means responsive to flash-overs and also to the rate of occurrence of flash-overs in the said precipitator, and arranged thereby to reduce automatically the voltage applied to the said precipitator so as to reduce the rate of occurrence of flash-overs.

Electrostatic precipitators are used, inter alia, for removing fine solid particles from flue gases before or during their discharge from a chimney, e.g. in an electrical power station, by electrostatic charging of the flue gases, and the efficient operation of such devices at all times is of great importance. One form of electrostatic precipitator is fully described in British patent specification No. 684,024 (Air Preheater Corporation) which shows an arrangement comprising a number of separate precipitator sectors used in turn in a cycle of operations lasting, for example, one minute, the fouled sectors being cleaned of their deposits during each cycle as each succeeding sector comes into use.

While each sector is in use, flash-overs tend to occur increasingly between the electrodes in the sector as it becomes fouled, and it becomes necessary to suppress such flash-overs, which cause interruption of the precipitator operation.

However, conditions tend to become steadily worse as fouling increases and the flash-overs become more frequent, and it is therefore an object of the present invention to provide a measure of control based for its operation on the rate of occurrence of flash-overs.

The invention will be described with reference to the accompanying drawing comprising Figs. 1A, 1B and 1C which illustrate a preferred embodiment comprising flash-over protection and controlling circuits for an electrostatic precipitator equipment.

The Figs. 1A, 1B and 1C, together constitute the circuit diagram of a complete control system and in reading the following detailed description with the drawings, Fig. 1B should be placed on the right of Fig. 1A and Fig. 1C above Fig. 1A. Moreover, in the drawings in the interest of simplifying the circuit, a convention is used which is now common in electrical circuits. Relay windings are indicated by a reference and a sub-numeral which represents the number of contacts controlled by the relay. The contacts controlled by the respective relays are not shown adjacent relay windings but are placed in such a position on the drawing that numerous cross-over points in the circuit are avoided and the contacts are

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identified with their relay windings by the use of related references, for example, the reference

$$\frac{P}{3}$$

against a relay winding indicates that the relay P has three sets of contacts, these contacts being given the references P1, P2, and P3, respectively. Make contacts are indicated by an open triangle and break contacts by a blacked in triangle.

Referring now to the accompanying drawing, the main supply circuit to the precipitator consists of saturable reactors LS1, LS2, LS3, LS4, LS5, LS6, Fig. 1A connected in series in pairs in each phase of a 3-phase A.C. supply (not shown) connected to terminals 1 to 3 for supplying a rectifier MR1, Fig. 1B feeding a load, in this instance an electrostatic precipitator, and further saturable reactors LP1, LP2, LP3, LP4, LP5, LP6, Fig. 1A connected in permutation across the lines feeding the rectifier and following the series reactors in the circuit.

A step up transformer T1 is normally employed to provide a suitable high voltage to feed the rectifier, and the first saturable reactors LS1 to LS6 may then be connected in series with the primary windings, and the second saturable reactors LP1 to LP6 in parallel with the primary windings of this transformer.

These series and shunt saturable reactors are employed in well-known manner to obtain control of the D.C. output from the rectifier by means of variations in the magnitude of saturating current applied to auxiliary windings of the reactors.

The controlling equipment shown in Fig. 1A provides means for ensuring quick suppression of flash-overs occurring in a precipitator in the following manner.

When the precipitator is working normally and ionisation is taking place, the D.C. voltage and current stand at their normal values. When the rectifier output voltage is reduced, as, for instance, for cleaning of the precipitator, the D.C. voltage is reduced to a value below ionisation level and the current is sensibly zero. These two sets of conditions are normal to the operation of the precipitator and the protective device is not required to function. When a flash-over occurs in the precipitator, however, the impedance of the load circuit is reduced and the load current is mainly limited by the impedance of the series saturable reactors LS1 to LS6, the transformer T1 and the rectifier MR1. The current in the precipitator rises to a high value and the voltage across the precipitator falls to a low value, but the arc is maintained. These changes in magnitude of D.C. voltage and current are then made to operate the protective circuit by the independent operation of a voltage sensitive relay

$$\frac{E}{1}$$

and a current sensitive relay

$$\frac{D}{2}$$

(Fig. 1B).

The current sensitive relay

$$\frac{D}{2}$$

is connected directly in series with, or across a resistor R1 in series with, the earthed pole of the D.C. output of the rectifier MR1 and will operate at any normal load current or higher value of current.

The voltage sensitive relay

$$\frac{E}{1}$$

3

is connected in the anode circuit of a cold cathode relay tube CC. This tube is arranged to be triggered by a voltage obtained conveniently from an A.C. source through transformer T4 and an auxiliary rectifier MR4 connected to the grid of the tube. In reverse series with this grid supply is the voltage developed across a resistor R2, which is proportional to the voltage applied to the precipitator. This voltage may be derived from a resistor R2 in series with the HV D.C. voltmeter B as shown in Figure 1B or from separate potential-divider resistor. When the voltage applied to the precipitator falls to a low value (as it does on flash-over) the voltage across R2, being connected in reverse sense to the grid voltage from MR4, permits the grid voltage to become sufficiently positive with respect to the cathode to fire the tube. Anode current then flows from rectifier MR5, also conveniently supplied from an A.C. source through transformer T5, through relay

$$\frac{E}{1}$$

contact D2 of relay

$$\frac{D}{2}$$

being by then closed.

Relay contacts D2, F2 and G3 are connected into the anode circuit for the following reasons: contact D2 prevents ignition of the tube when starting up, i.e. when the increasing D.C. voltage is approaching ionisation level but before there is any current flow in the precipitator; contact F2 of a relay

$$\frac{F}{5}$$

extinguishes the tube CC as soon as relay

$$\frac{F}{5}$$

is closed, and permits relay

$$\frac{E}{1}$$

to release, and in particular to open contact E1, and contact G3 of a relay

$$\frac{G}{3}$$

prevents the completion of the anode circuit until

$$\frac{G}{3}$$

a relay in a timing circuit shown in the upper left corner of Fig. 1B, is de-energised.

When both voltage and current relays

$$\frac{E}{1}$$

and

$$\frac{D}{2}$$

are energized, their contacts E1 and D1 in series will permit relays

$$\frac{F}{5}$$

and

$$\frac{G}{3}$$

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to become energised from an auxiliary D.C. source as shown in Figure 1B.

The immediate operation of relay

$$\frac{F}{5}$$

removes all D.C. saturation from the series saturable reactors LS1 to LS6 (Fig. 1A) in the main circuit by virtue of the opening of contact F3, and applies saturation to the parallel saturable reactors LP1 to LP6 in parallel with the transformer primary by closure of contact F4. The change of impedance in these series and parallel saturable reactors has the effect of transferring the major part of the voltage on the transformer primary to the series saturable reactors with the result that the output voltage from the main rectifier is reduced to a very low value and the arc in the precipitator is extinguished. Condenser C1 becomes charged via resistor

$$\frac{G}{3}$$

operates.

By this time, both the current and voltage relays

$$\frac{E}{1}$$

and

$$\frac{D}{2}$$

will be de-energised and contacts D1 and E1 will be open but by-passed by contact F1 (closed) and contact G1 (not yet open). Contact G1 now opening will de-energise relay

$$\frac{F}{5}$$

40

Contact G1 will also disconnect relay

$$\frac{G}{3}$$

45

from the source of supply and as contact G2 will quickly discharge condenser C1 via R4, relay

$$\frac{G}{3}$$

50

will quickly reset.

The release of relay

$$\frac{F}{5}$$

55

will remove D.C. saturation from the parallel saturable reactors LP1 to LP6 and restore it to the series saturable reactors LS1 to LS6. The precipitator will thus be restored to normal working conditions.

60

A time delay is necessary between reduction of saturation on the series reactors and increase of saturation on the parallel reactors, on the one hand, and the eventual restoration of normal saturation conditions, on the other, to allow the arc to be extinguished and to prevent hunting of the protective circuit which would otherwise occur owing to the time required for the saturable reactors to assume their new values of impedance and thus extinguish the arc.

65

A suitable choice of time delay in the operation of relay

$$\frac{G}{3}$$

70

75 will enable the flash-over to be suppressed and the pre-

5

cipitator returned to normal operation with a minimum loss of time and precipitation efficiency.

It will be seen that arc suppression is effected without a break in the normal supply circuit, and the interruption to normal working may be made as brief as desired by a satisfactory choice of delay times.

However, as noted earlier, flash-overs are likely to continue and to increase in frequency, and an overriding control derived from the frequency of occurrence is desirable to ensure satisfactory operation. Such a form of control is shown mainly in Fig. 1C, which includes relays

$$\frac{A}{8}, \frac{B}{9} \text{ and } \frac{C}{7}$$

having contacts A5, A6, B5, B6 and C3, C4, connected in the primary circuit of transformer T2 (Fig. 1A) to effect tap-changing as required. A contact C5 of relay

$$\frac{C}{7}$$

is also shown in shunt with contact F4.

Referring now to Fig. 1C, the contact F5, which constitutes a controlling function derived from the flash-over suppression circuit controlled by relay F, closes whenever a flash-over occurs in the associated equipment, and remains closed for a short period of time dependent upon the associated time-constant circuit, as previously described.

The controlling circuit in Fig. 1C comprises a number of cold cathode gas discharge devices such as CCA, CCP etc., and electromagnetic relays

$$\frac{A}{8}, \frac{B}{9}, \frac{C}{7}, \frac{P}{3} \text{ and } \frac{Q}{3}$$

energised from two independent unidirectional power supplies derived from the A.C. mains, one over transformer T6 and rectifier network MR6, and the other over transformer T7 and rectifier network MR7.

The first power supply, from network MR6, is voltage stabilised by neon limiter NL, and provides a source of relatively stable potential for the trigger circuits of the gas tubes CCA, CCP, etc., substantially unaffected by mains variations or the load current required (number of tubes fired at a given moment). The other supply is unstabilised and supplies the anode circuits (including the electromagnetic relays

$$\frac{A}{8}, \frac{B}{9}, \frac{C}{7}, \frac{P}{3} \text{ and } \frac{Q}{3}$$

This supply could well be identified with that obtained from MR5 in Fig. 1B. The negative sides of the two supplies are joined and earthed, and commoned to the cathodes of the gas tubes.

The first closure of contact F5 (assuming initial conditions, or after a long delay) causes condenser CA to commence charging from the stabilised source over back contact A1 of relay

$$\frac{A}{8}$$

and via variable resistance RA. At the same time, the shunt resistor RAS discharges condenser CA, but if the charging pulses received via F5 are received sufficiently rapidly, a voltage will be built up on CA sufficient to strike the cold cathode tube CCA, thereby energising relay

$$\frac{A}{8}$$

over contacts P1 and Y from the unstabilised source.

Operation of relay

$$\frac{A}{8}$$

causes the saturating current of the series saturable reactors LSI to LS6 (in Fig. 1A) to be reduced by the

6

opening of contact A5 and closure of contact A6 on transformer T3, thereby reducing the voltage applied to the main transformer T1. Operation of relay

$$\frac{A}{8}$$

also breaks the CA charging circuit at contact A1 and completes the charging circuits for condensers CP and CB at contacts A2 and A3 respectively, while contact A4 closes the anode circuit of tube CCP via the relay

$$\frac{P}{3}$$

Contact A8 modifies the time constant of the CA discharge circuit by shunting a part of resistors RAS, and contact A7 restores that of condenser CP to a normal value for charging.

A continuation of flash-overs will cause condensers CB to charge in a similar manner to that for condenser CA, while condenser CP charges steadily direct from the positive line of rectifier MR6, and cold cathode tube CCB will eventually fire, unless the timing period of condenser CP causes the previous firing of CCP. Which ever fires first, however, automatically prevents the other from firing. If CCP fires first, relay

$$\frac{P}{3}$$

becomes energised, relay

$$\frac{A}{8}$$

is de-energised and released at contact P1, and then relay

$$\frac{P}{3}$$

is de-energised at contact A4. The release of relay

$$\frac{A}{8}$$

causes the original value of saturation current to be restored by closing contact A5 and opening contact A6; and contacts P2 and P3, while closed, discharge condensers CP and CB respectively.

If, however, flash-overs have continued at such a rate as to cause CCB to fire before CCP, then relay

$$\frac{B}{9}$$

closes, the charging circuit to condenser CP is opened at contact B4, and the charging circuit to condenser CQ is completed by contact B2. At the same time, contact B5 opens and contact B6 closes in Fig. 1A, and the level of saturating current in LS1 to LS6 is still further reduced. Also, contacts B9 and B8 close to discharge condensers CP and CB respectively.

The circuit of relay

$$\frac{Q}{3}$$

like that of relay

$$\frac{P}{3}$$

is purely time conscious and will open the circuit of relay

$$\frac{B}{9}$$

at contact Q1 unless continued flash-overs cause operation of relay

$$\frac{C}{7}$$

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before relay

$$\frac{Q}{3}$$

has operated. Since the time delays before relays

$$\frac{P}{3}$$

and

$$\frac{Q}{3}$$

are energised are required to be of the order of tens of seconds, condensers CP and CQ may be electrolytic, and in order to overcome the possibility of self discharge of these condensers varying widely, it may be desirable to connect a fixed resistor of high value permanently across each condenser, as shown. This resistor is not used, therefore, for the same reason as the permanently connected resistors across condensers CA, CB, CC etc., which are used to create a limited "memory" of the charging impulses, the circuits with CA, CB and CC being thus in the nature of impulse integrating circuits.

Further stages may be added as desired, each stage consisting of a circuit to accept charging impulses from the contact F5 and including a condenser and discharge resistor of suitable value to provide an integration with time of the charging impulses (as circuits controlling relays

$$\frac{A}{8}, \frac{B}{9} \text{ and } \frac{C}{7}$$

together with a circuit to give restoring facilities and based solely on time delay (as circuits controlling relays

$$\frac{P}{3} \text{ and } \frac{Q}{3}$$

The last or any of the integrating circuits may also be made to operate an alarm to give warning that a certain stage or stages in the reduction of output have been reached. It may also be necessary to arrange, as shown at C5 (Fig. 1C), contacts to close the saturating supply circuit of the parallel saturable reactors LP1 to LP6 if the output of the main rectifier is to be reduced to a relatively low value. This may or may not be accompanied by complete removal of saturating power to the series saturable reactors.

Key Y may be included to trip all circuits at a specific time or other interval if, for instance, the precipitator is periodically purged of dust particles and it is desired to recommence operation at the higher voltage condition. If this is desired it is necessary to ensure that contacts under the control of key Y are also provided to discharge any condensers that have received a charge. These contacts are not shown on the diagram.

It is essential to disconnect the condenser charging circuit and to discharge the condenser of each circuit after its tube has fired. This can be done quite simply on the memory circuits A, B, C etc., as the appropriate relays remain closed for some few seconds at least and suitable contacts can be arranged as shown to perform these functions. In the case of the restoring circuits comprising relays

$$\frac{P}{3}, \frac{Q}{3}$$

etc., the relays are removed from circuit (by contacts A4 and B4) a few milliseconds only after they are energised and it may be necessary to make them slow-to-release by connecting rectifiers MR8 and MR9 across their windings as shown. It is also desirable to provide break contacts as shown at A7 and B7 in order to ensure that the condensers CP and CQ of the restoring circuits are completely discharged before they are required to receive a charge i.e. until the integrating circuit immediately prior to them in the chain has operated.

While the principles of the invention have been de-

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scribed above in connection with specific embodiments, and particular modifications thereof, it is to be clearly understood that this description is made only by way of example and not as a limitation on the scope of the invention.

What we claim is:

1. Control circuit for an electrostatic precipitator comprising an alternating current supply circuit, a high tension rectifier equipment connected to said precipitator, means including saturable reactors for connecting said supply circuit to said rectifier equipment, auxiliary controlling windings on said saturable reactors, first control means responsive to a flash-over in said precipitator, second control means including integrating means responsive to the rate of occurrence of flash-overs in said precipitator, a direct current supply circuit connected to said auxiliary controlling windings, and means responsive to said first and second control means for controlling said direct current supply circuit.

2. Control circuit for an electrostatic precipitator as claimed in claim 1 and in which said first control means comprises a first relay responsive to excessive load current, a second relay responsive to reduction of load voltage, and a delay circuit which co-operate to reduce temporarily the direct current supplied to the said auxiliary controlling windings on the occurrence of a flash-over.

3. Control circuit for an electrostatic precipitator as claimed in claim 2 and comprising a third relay, a circuit for said third relay including contacts of said first and second relays contacts on said third relay to effect the said reduction, and wherein the said delay circuit comprises a fourth relay, a resistance-condenser combination to slow its operation and contacts on said fourth relay which on operation of said fourth relay are effective to restore the reduced voltage to normal.

4. Control circuit for an electrostatic precipitator as claimed in claim 3 and in which the said second controlling means comprises a stable source of voltage and an integrating circuit comprising a condenser and a leak resistance, a make contact of said third relay being connected to charge the said condenser from said stable source of voltage on the occurrence of each flash-over, whereby the charge accumulated on the said condenser and the potential to which said condenser rises are in direct relationship to the rate of occurrence of flash-overs.

5. Control circuit for an electrostatic precipitator as claimed in claim 4 in which said integrating circuit further comprises a grid-controlled gas-discharge device having a relay in its discharge path and a connection from the said condenser to the control electrode of the said discharge device to cause it to fire upon the acquisition of a predetermined potential by the said condenser.

6. Control circuit for an electrostatic precipitator as claimed in claim 5 and comprising a chain of such inter-related integrating circuits for exercising successively increasing control on the said saturable reactors, and hence on the precipitator supply voltage, and comprising also an overriding control effective at regular and predetermined intervals to interrupt the said chain of control and to restore control to the first said integrating circuit for a further cycle of control.

7. Control circuit for an electrostatic precipitator as claimed in claim 5, comprising a further source of alternating current, a transformer and a further rectifier for deriving said direct current supply, taps on said transformer, connections to said taps and contacts on said integrating circuit relay connected to effect a change in the connections to said taps.

8. Control circuit for an electrostatic precipitator as claimed in claim 7, further comprising a plurality of similar integrating circuits for exercising successively increasing control of the current through said auxiliary controlling windings of said reactors and in which contacts of a respective integrating circuit relay are arranged to transfer the connection from said make contact of said third relay

to the said condenser of a succeeding integrating circuit.

9. Control circuit for an electrostatic precipitator comprising an alternating current, a high tension rectifier equipment connected to said precipitator, voltage controlling means connected between said supply circuit and said rectifier equipment, adjustable means for regulating the operation of said voltage control means to vary the voltage applied to said precipitator, first control means responsive to a flash-over in said precipitator and arranged to control said adjustable means to reduce automatically the voltage applied to said precipitator to such a value that the flash-over arc is extinguished, and second control means including integrating means responsive to the rate of occurrence of flash-overs and arranged to control said

adjustable means to reduce automatically the voltage applied to said precipitator to such a value that the rate of occurrence of flash-overs is reduced.

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