Dec. 3, 1963 M. J. HOBERMAN 3,113,093

CATHODIC PROTECTION SYSTEM

Filed Feb. 3, 1959 3 Sheets-Sheet 1

FIG. 1

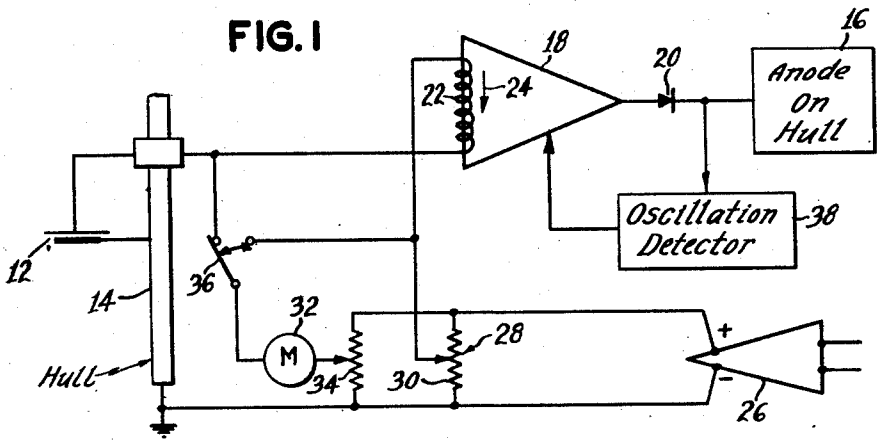


FIG. 2

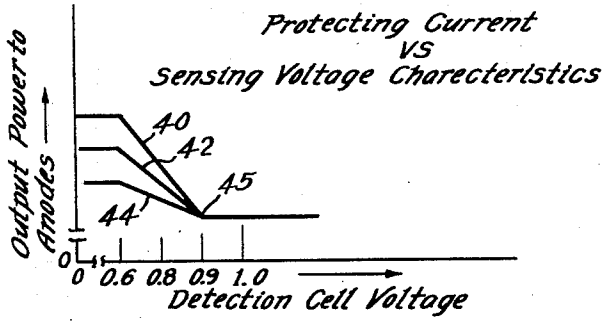
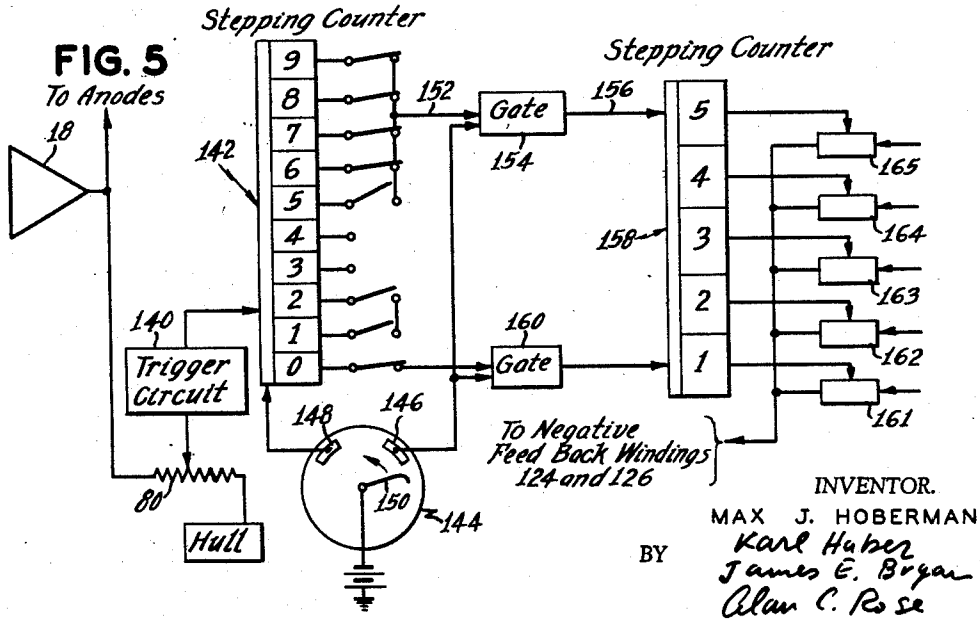


FIG. 5



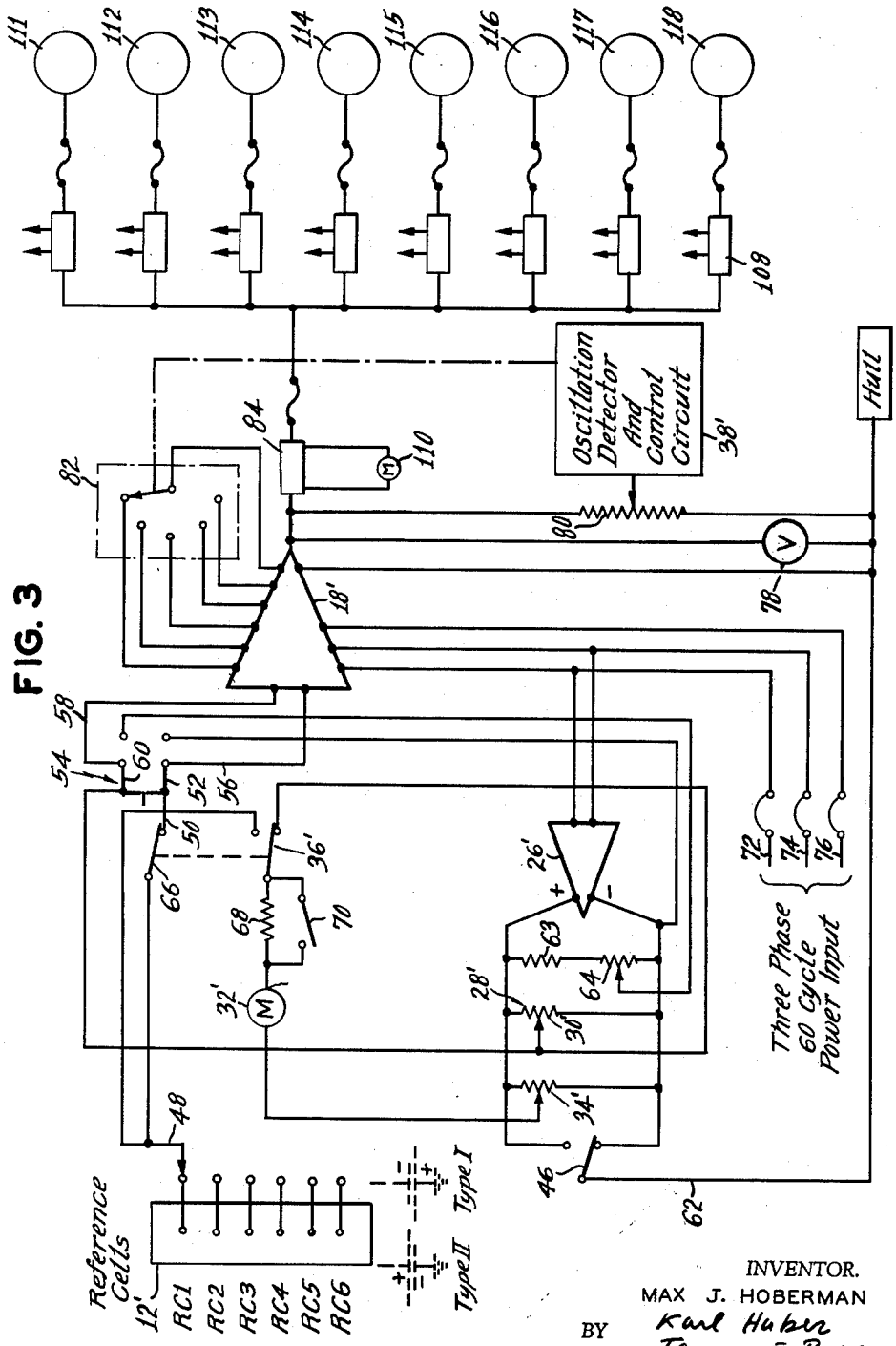
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FIG. 3



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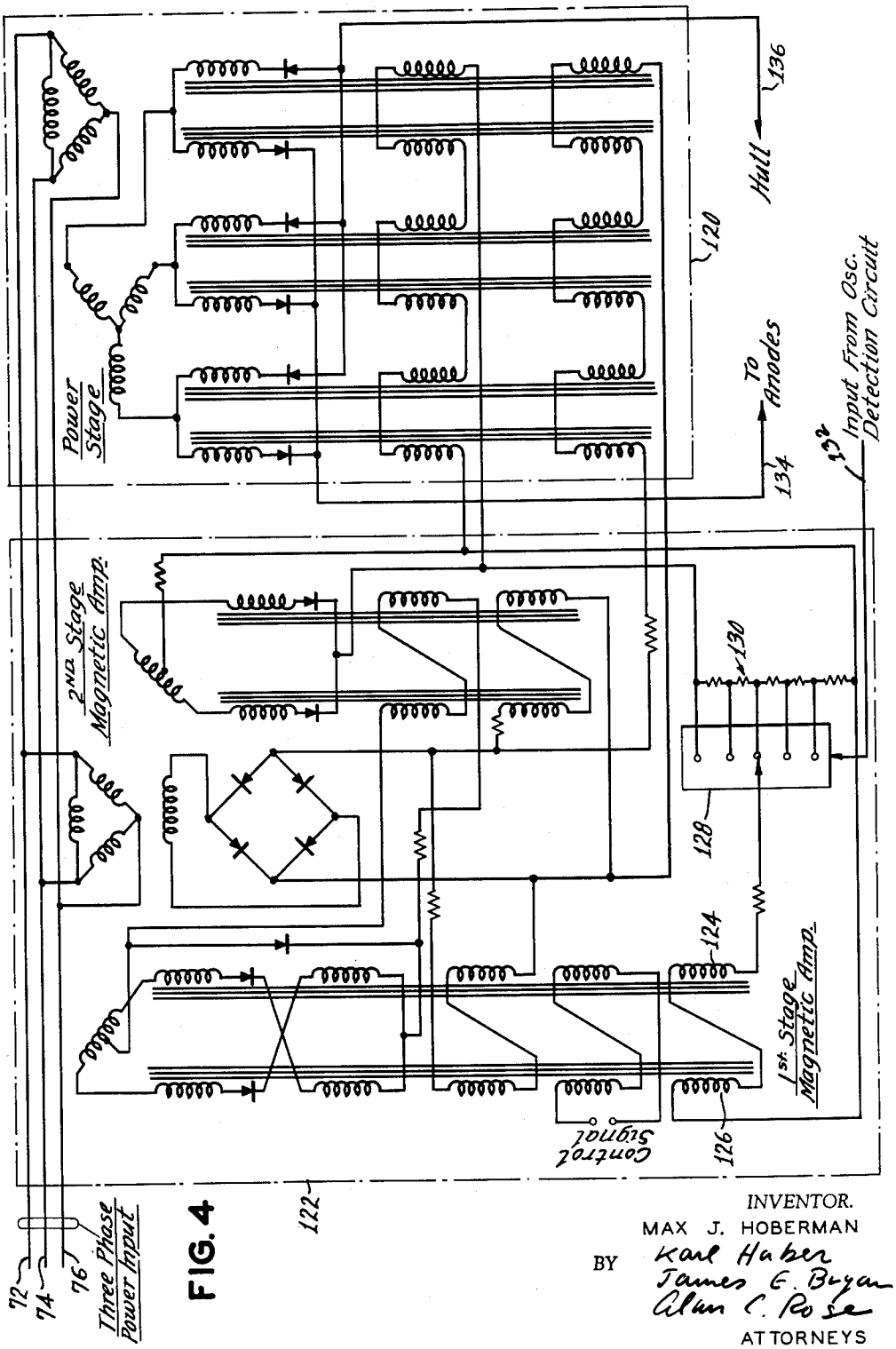


FIG. 4

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3,113,093

CATHODIC PROTECTION SYSTEM

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7 Claims. (Cl. 204—196)

This invention relates to cathodic protection systems.

It is known that the painted surfaces on the hulls of ships, for example, may be preserved against rust and corrosion by the flow of electrical current to the surface. This may be accomplished by metallic anodes located on the surface of the hull and insulated therefrom. The level of current must be regulated to provide sufficient protection and yet to avoid the high current levels which tend to damage the paint. As applied to a ship, for example, different levels of current are required at different speeds of the ship. Thus, for example, several times as much current must be provided when the ship is underway than when it is docked. Other factors which determine the required current level include the nature and the electrical resistance of the water in which the painted surface is submerged and its temperature.

In order to detect these changes in cathodic protection conditions, various sensing circuits have been proposed. Up to the present time, the most suitable sensing circuit has been considered to be a silver chloride "half cell" submerged in the water and having the surface to be protected as the other electrode. The voltage generated by this reference cell is about 0.85 volt when proper cathodic protection of the hull is taking place. When the voltage developed by this sensing cell increases or decreases significantly from this value of 0.85 volt, the current supplied to the main protecting anodes is increased or decreased until the desired voltage level is restored.

I have found that cathodic protection systems of the type described above may be subject to overshooting or oscillation when the sensing signals are amplified and applied at high levels to the control circuit. Because of the electrochemical phenomena which are involved, the time constant of oscillation tends to be quite slow, and may be of the order of one or more cycles every few seconds. A particular cathodic protection system may be subject to these oscillations under some operating conditions, whereas under other operating conditions the oscillations may not occur.

A principal object of the present invention is to avoid undesired overshooting or oscillation in cathodic protection system while concurrently providing rapid adjustment of the protecting current to the necessary level.

In accordance with the present invention, the magnitude of the control signals applied from the sensing circuit to the power supply are adjusted to the proper level so that rapid re-adjustment of power may be obtained without the occurrence of undesired oscillations. In a specific illustrative embodiment of my invention, the gain of an amplifier is adjusted in accordance with the output signals from an oscillation detector. If the output current has varied up and down more than a predetermined number of times during a given time interval, the gain of the amplifier is reduced to give more stability to the circuit. However, if no variation in the output current occurs during the preset time period, the gain of the amplifier is increased to step up the rate of response of the system.

Accordingly, one feature of my invention involves the provision in a cathodic protection system of means for adjusting the effective gain of a circuit interconnecting the sensing circuit and the power output circuit of the protection system. The cathodic protection system as described in the preceding paragraph may also include

an oscillation detection circuit which controls the gain of the circuit interconnecting the sensing circuit with the power output control circuit.

In the proposed illustrative circuits, a magnetic amplifier utilizes signals derived from the sensing cell to control the level of the protective current. Depending on the cathodic protection conditions, the voltage developed by the cell has a generally linear range between two extremes. Another aspect of the invention involves the provision of a reference voltage source poled in opposition to the sensing cell, and providing a bucking voltage which is about equal to one of the two extreme voltages of the sensing cell. The resulting signal, applied to the magnetic amplifier as the reference cell voltage varies, is of one polarity and varies from zero to a finite value. In addition, the current flowing from the sensing cell is only a function of the difference between the sensing cell and the reference voltages. Accordingly, much of the advantage of prolonged sensing cell life provided by the bucking voltage system described in copending patent application Serial No. 732,275, filed May 1, 1958, is retained in the present arrangements.

Other objects, features and advantages of the present invention will become apparent from a consideration of the following detailed description and from the drawings, in which:

FIGURE 1 is a block diagram of a cathodic protection system in accordance with the present invention;

FIGURE 2 is a plot of output current versus sensing voltage for the system of FIGURE 1;

FIGURE 3 is a more detailed circuit diagram of the circuit of FIGURE 1;

FIGURE 4 is a circuit diagram of the magnetic amplifier control and power output stages of the present circuitry; and

FIGURE 5 is a detailed block diagram of the oscillation detection and switching control circuit of the present invention.

With reference to the drawings, FIGURE 1 is an illustrative block diagram of a cathodic protection system using magnetic amplifiers and sensitivity control arrangements. In FIGURE 1 a reference cell **12** is associated with a painted surface **14**, which is to be protected cathodically. This surface **14** may, for example, be the hull of a ship. Regarding the reference cell **12**, the cathode of the cell is shown as connected to or forming part of the hull **14**. The anode of the reference cell is spaced from the hull and may be formed of silver chloride material. The electrolyte is the sea water in which the half cell and the hull are immersed. The anodes **16** which are mounted on and insulated from the hull **14** receive power from a magnetic amplifier **18**, the power being rectified as indicated by the rectifier **20**. The magnetic amplifier **18** is provided with an input control winding **22** arranged to require direct current control signals poled as indicated by the arrow **24**. To avoid drawing excessive current from the half cell **12**, a bucking voltage is provided by the reference magnetic amplifier **26**, with the magnitude of the voltage being determined by the position of the tap on the potentiometer **28**. More specifically, the voltage across the lower portion **30** of the potentiometer is arranged to buck the voltage provided by the reference cell **12**, at one end of the control range. The operation of this circuit will be more fully described below in connection with the plots of FIGURE 2.

The meter **32** is a null instrument which is employed in connection with the calibrated precision potentiometer **34**. It may be employed either to measure the voltage developed by the reference cell or to calibrate the variable resistance **28**. The meter **32** and its associated potentiometer **34** may be switched between these two circuits by the single-pole, double-throw switch **36**.

The oscillation detection circuit 38 detects undesired oscillations in output potential and controls the sensitivity of the initial stages of the magnetic amplifier 18. As will be described in detail below, the sensitivity of the magnetic amplifier 18 is adjusted to provide rapid response, while avoiding oscillation or overshooting.

FIGURE 2 is a graph of output protecting current supplied to the anodes, plotted as a function of detection cell voltage. Turning now to a brief consideration of the theory of cathodic protection, it is understood that the flow of current from the anodes on the hull toward the surface of the hull produces a thin film of hydrogen on the hull surface which inhibits corrosion. When a silver chloride reference cell is employed, the output voltage from the cell may range from approximately 0.6 volt to approximately 0.9 volt. The 0.6 volt level corresponds to the situation in which only a thin or partial film of hydrogen is provided. As a good and sufficient hydrogen film is developed on the hull surface, the strongly polarized hull has the effect of providing an increased voltage differential of 0.85 volt. A maximum of 0.9 volt is obtained with very high impressed currents and a thick hydrogen film. This increase in voltage may be accounted for by the greater availability of the mobile hydrogen ions on the hydrogen coated hull which forms one electrode of the sensing cell.

In FIGURE 2, therefore, the required characteristic shows increased output power levels when the detection cell is near the 0.6 volt value, and reduced output voltage levels when detected voltage comes closer to the 0.9 volt level. The characteristics of FIGURE 2 are implemented as shown in FIGURE 1 by the provision of a 0.9 volt bucking voltage from the portion 30 of the potentiometer 28. Accordingly, the reference voltage from the portion 30 of potentiometer 28 predominates over the reference cell 12 in the signal voltages applied to the input coil 22 of magnetic amplifier 18. When the reference cell output voltage is at the 0.9 volt level, no control signals are applied to the magnetic amplifier 18. A sustaining current of a minimum level is still applied between the anodes and the hull under these conditions. However, if the reference cell voltage is reduced, indicating reduced hydrogen film conditions on the hull, the signals applied to the coil 22 of magnetic amplifier 18 increase. This action provides the desired increase in output power to the anodes on the hull under the control of the magnetic amplifier. In FIGURE 2, three characteristic curves 40, 42 and 44 are shown. The upper characteristic 40 represents the situation of maximum control signal voltage sensitivity. In addition, the output power may be maximized by the control setting indicated by characteristic 40. The portion of the characteristics to the right of point 45 represent the minimum sustaining current mentioned above. If oscillations are detected by the circuit 38 of FIGURE 1, the sensitivity of the magnetic amplifier 18 is reduced so that its characteristics are given by one of the plots 42 or 44 in FIGURE 2. Under these circumstances, the oscillations will be eliminated and less rapid shifting of voltage levels will occur in the system. Similarly, if a characteristic such as 44 in FIGURE 2 is employed, and the oscillation detector 38 indicates no variation in output current over a substantial period of time, the sensitivity control will be shifted toward characteristic 42 or the upper characteristic 40 of FIGURE 2. In this manner, maximum sensitivity, consistent with the avoidance of oscillation, is maintained.

FIGURE 3 is a somewhat more detailed showing of the circuit of FIGURE 1. To indicate the correspondence between elements in the circuit of FIGURE 1 with those of FIGURE 3, primed reference numerals are employed in FIGURE 3 to indicate corresponding components. Thus, for example, the reference cell assembly 12' of FIGURE 3 corresponds to the reference cell 12 of FIGURE 1. Similarly, the potentiometers 34 and 28 and the oscillation detector circuit 38 of FIGURE 1 find their

counterparts in the potentiometers 34' and 28' and the oscillation detection circuit 38' of FIGURE 3. The magnetic amplifiers 18 and 26 of FIGURE 1 also appear in FIGURE 3 as the magnetic amplifiers 18' and 26'. Other components of FIGURE 3, which correspond to components in FIGURE 1, include the meter 32' and the switch 36'.

Now that a general correspondence of the circuit of FIGURE 3 with that of FIGURE 1 has been established, the detailed mode of operation of the circuit of FIGURE 3 will be considered. Initially, it may be noted that a number of different reference cells are available for the sensing circuit. In general, these sensing cells may provide either a positive sensing voltage or a negative sensing voltage, according to the material employed in the reference half cell, which is spaced from the hull. As indicated in FIGURE 3, the cells which generate a positive voltage are designated type II cells, whereas those which generate a negative sensing voltage are designated type I cells. As discussed above in connection with FIGURE 1, the widely used silver chloride cell generates a positive voltage and is therefore a type II reference cell. One example of a negative, or type I, cell is a cell employing zinc metal. Such a type I cell will produce a negative output voltage of from 0.1 to about 0.4 volt depending on the condition of the hull. As in the case of type II cells, the absolute magnitude of the output voltage will increase with increasing thickness of the hydrogen film.

In order to accommodate both types of sensing cells in a single apparatus and still provide proper input signals to the magnetic amplifier 18', the switch 46 is provided. With the switch 46 in the lower or "type II" position, a circuit including the reference cell and the bucking reference voltage at the output of magnetic amplifier 26' can readily be traced. Such a circuit includes one of the reference cells 12', the leads 48 and 50, the lower contact arm 52 of the switch 54, the two input leads 56 and 58 to the control winding of the magnetic amplifier 18', the upper switch arm 60 of the switch 54, and the lower portion 30' of the variable resistance 28'. The lower end of the variable resistance 28' is connected through switch 46 to the hull lead 62. This completes the circuit loop traced out above for the circuit of FIGURE 1.

When type I reference cells are employed, the switch 46 is moved to its upper position. In order to have an input signal of the proper polarity at the input winding of the magnetic amplifier 18', the sensing voltage provided by the type I cell must predominate over the bucking voltage supplied by the reference magnetic amplifier 26'. This is accomplished by having the potentiometer 28' adjusted to buck out the protecting current at the .01 voltage level, which is the minimum negative voltage provided by a zinc type I cell, for example. Then, as the negative voltage increases, the amount of control signal applied to the magnetic amplifier 18' will also become greater in magnitude in the negative direction, consistent with the polarity obtained when type II cells are employed. More specifically, the output of the magnetic amplifier will increase in response to increased control signals of a given polarity. The arrangements described above, particularly including switch 46, serve to provide increasing control signals of the same polarity for decreasing voltages of opposite polarity from the type I and type II cells. In passing, it may be noted that the upper portion of the variable resistor 28' is included in the electrical circuit for type I cells, whereas the lower portion of variable resistor 28' is employed to develop the bucking voltage for type II cells.

If it is desired to preset the variable resistor 28' to a specified value, additional variable resistors may be placed in parallel with it. The lead to the tapping point on resistor 28 could then be switched to the other resistor when a different sensing cell is employed. Preset variable resistors for different types of sensing cells would then be

immediately available to provide the desired bucking voltage.

The control winding of the magnetic amplifier 18' may also be energized manually. For manual operation, the double-pole, double-throw switch 54 is placed in its right hand position. Under these circumstances, voltage is applied to the magnetic amplifier control winding from the resistance network including resistor 63 and variable resistor 64 at the output of the reference magnetic amplifier 26'.

The meter 32' in FIGURE 3 may be switched from the reference cell to its other position by the switch 36'. When the meter 32' is switched away from the reference cell, the switch 66 is opened, disconnecting the reference cell from the circuit. The resistor 68 and the switch 70 are provided in the circuit of the meter 32' to control the sensitivity of the meter.

Commercial three phase power is provided on input leads 72, 74 and 76. This sixty cycle power is coupled to the magnetic amplifier 18'. In addition, the reference magnetic amplifier 26' is tapped across leads 72 and 74 to obtain single phase input alternating current power.

The voltmeter 78 is provided at the output of the magnetic amplifier 18'. An oscillation detector and control circuit 38' is connected to a variable resistance 80 which is, in turn, connected to parallel with the output meter 78. The oscillation detection and control circuit 38' is shown in detail in FIGURE 5 of the present drawings.

The magnetic amplifier 18' is provided with a negative feedback circuit, which includes the switching arrangements. As indicated schematically in the dashed line box 82, the switching circuit may be arranged to feedback, in the negative sense, various proportions of the output signal.

The switching circuit 82 may be controlled manually or may be under the control of the oscillation control and detector circuit 38'. The functions of the switching and oscillation detection circuits 82 and 38' have been discussed above and will be described in some detail below in connection with FIGURE 5. Resistors of relatively low values are provided at 84 and at 101 through 108. These resistors include tapping terminals to which a meter such as meter 110 may be connected for examination of the individual circuits. The anodes 111 through 118 are normally mounted on and insulated from the surface which is to be protected. The various power circuits included in FIGURE 3 are protected by fuses and circuit breakers as indicated in the drawings.

The magnetic amplifier circuit of FIGURE 4 is shown principally for the purpose of completeness. It includes the output power stage 120 and the input control stage 122. As mentioned above, three phase power is supplied on leads 72, 74 and 76. The various stages of the magnetic amplifier circuits include gate windings, bias windings, and control windings. Rectifier circuits are also provided for developing direct current bias and output signals. The negative feedback windings 124 and 126 associated with the input stage of the magnetic amplifier are coupled to the magnetic amplifier output by the switching circuit 128 in the manner indicated by the legends adjacent the resistance network 130 at the input to the switching circuit 128. Various amounts of feedback can be provided by adjustments of the switching circuit 128. As indicated by lead 132, the switching circuit 128 may be under the control of the oscillation detection circuit. The regulated output from the power stage 120 of the magnetic amplifier is applied on leads 134 and 136 between the individual anodes and the surface to be protected.

FIGURE 5 shows one illustrative embodiment of the oscillation detection circuit 38' of FIGURE 3. As indicated in FIGURE 5, the output from the magnetic amplifier 18 is shunted by the high variable resistance 80. The tapped output from the resistance 80 is applied to a trigger circuit 140. The trigger circuit 140 supplies an output pulse to the stepping counter 142 whenever the output voltage from the magnetic amplifier 18 exceeds a predetermined level. The trigger circuit 140 may, for example, include a regenerative, monostable, multivibrator which provides a single output pulse whenever a voltage transition in a predetermined direction takes place. When pulses are applied to stepping counter 142, its energized state is advanced from one of the numbered stages to the next higher numbered stage. The stepping counter may be implemented in any known manner, by magnetic cores or gas tubes, for example.

The timing circuit 144 has a sensing output contact 146 and a reset output contact 148. During each cycle of operation of the timer, the rotating contact arm 150 engages the sensing contact 146 and then the reset contact 148. A considerable time period elapses between the energization of contact 148 and the next energization of the sensing contact 146. This time period might, for example, be 10 or 15 minutes, or under certain circumstances could be extended to an hour. Following the reset of the stepping counter 142 to the "0" state by the energization of contact 148, oscillation of the output current from magnetic amplifier 18 produces voltage swings which, in turn, provide variations at the input to trigger circuit 140. Under these conditions, advance pulses are supplied to the stepping counter 142. If a predetermined number of pulses are received by the stepping counter 142, the energized state could be advanced to stages 6, 7, 8 or 9 of the counter. Under these conditions, an enabling input signal is supplied on lead 152 to the gate circuit 154. Upon the occurrence of a sensing signal derived from contact 146 and applied to gate 154, a pulse will be applied to lead 156 to step the counter 158 backward to its next lower numbered state. On the other hand, if the stepping counter 142 has not been advanced from the "0" state, the energization of the sensing contact 146 will produce an output signal from the gate circuit 160 to advance the stepping counter 158 to the next higher numbered state. It may also be noted that if the counter 142 is in states 1 through 5 as shown in FIGURE 5, no change in counter 158 or in the resulting sensitivity of the magnetic amplifier 18 will be produced.

The stepping switches 161 through 165 perform the function indicated in the block 128 of FIGURE 4 of the drawings. The switches 161 through 165 may, for example, be conventional relay circuits or suitable alternative transistor or other electronic equivalents to individual relay circuits. When state 1 of counter 158 is energized, a high level of negative feedback will be applied to the windings 124 and 126 of magnetic amplifier 18, and the sensitivity of the magnetic amplifier will be relatively low. With increasing levels of the stepping counter 158, the energization of the corresponding switch 161 through 165 will decrease the amount of negative feedback and increase the sensitivity of the amplifier. In this regard, it is noted in passing that the physical position of switches 161 through 165 are inverted with respect to the input terminals from the right hand side of the circuit 128 in FIGURE 4. Thus, for example, the 20 percent designation in FIGURE 4 indicates 20 percent of maximum sensitivity and only 20 percent of maximum current capacity from the magnetic amplifier. This lead would be connected to the lower switch 161 in the circuit of FIGURE 5. Similarly, the remaining input terminals associated with the switching circuit 128 of FIGURE 4 are coupled to the switches 162 through 165, with the "100 percent" input lead being coupled to switch 165 of FIGURE 5. This last mentioned lead is enabled by the energization of stage 5 of the stepping counter, and produces maximum sensitivity and the maximum possible output voltage from the magnetic amplifier.

It will be obvious to those skilled in the art that many more modifications may be made within the scope of the present invention without departing from the spirit thereof, and the invention includes all such modifications.

What is claimed is:

1. In a cathodic protection system, a surface to be cathodically protected, at least one anode mounted near said cathodic surface, means for applying direct current between the anode and the cathodic surface, a sensing cell mounted in spaced relationship with respect to said surface and constituting together with said surface, a sensing circuit for developing voltage control signals indicating cathodic protection conditions of the cathodic surface, variable gain circuit means responsive to said sensing circuit and coupling said control signals to said current applying means to control said current applying means, and means responsive to oscillations in the current applied between the anode and the cathodic surface and coupled to said variable gain circuit means for varying the amplification of said variable gain circuit means.

2. In a cathodic protection system, a surface to be cathodically protected, at least one anode, means for applying direct current between the anode and the cathodic surface, a sensing cell mounted in spaced relationship with respect to said surface and constituting together with said surface, a sensing circuit for developing voltage control signals indicating cathodic protection conditions of the cathodic surface, means coupling said control signals to the current applying means for continuously maintaining the current applied between the anode and the surface at levels determined by said control signals, means responsive to the applied current for determining fluctuations in the current applied between the anode and the surface and coupled to said control signal coupling means for varying the magnitude of the control provided by said control signals.

3. In a cathodic protection system, a surface to be cathodically protected, at least one anode mounted in spaced relationship with respect to the surface, a sensing cell also mounted in spaced relationship with respect to said surface, said sensing cell having an output voltage ranging from one extreme value to another extreme value depending on the electrochemical cathodic protection conditions of the system including said surface, means for supplying direct current power between said surface and said anode, magnetic amplifier means connected to said power supply means and including an input control winding for regulating the power supply means, a source of reference potential substantially equal to one of said two extreme voltages of said sensing cell, circuit means for applying the difference between the voltage developed by said sensing cell and that provided by the reference source to the input control winding of the magnetic amplifier means, and means responsive to oscillations of said direct current supply means and coupled to said magnetic amplifier for automatically varying the amplification factor of said magnetic amplifier means in response to output current variations.

4. In a cathodic protection system, a surface to be cathodically protected, at least one anode mounted in spaced relationship with respect to the cathodic surface, a sensing cell also mounted in spaced relationship with respect to said surface, said sensing cell having an output voltage ranging from one extreme value to another extreme value depending on the electrochemical cathodic protection conditions of the system including said anode and said surface, means for supplying direct current power between said surface and said anode, magnetic amplifier means connected to said power supply means and including an input control winding for regulating the power supply means, a source of reference potential substantially equal to one of said two extreme voltages of said sensing cell, and circuit means for applying the difference between the voltage developed by said sensing cell and that provided by the reference source to the input control winding of the magnetic amplifier means, and means responsive to oscillations of said direct current supply means and coupled to said magnetic amplifier for automatically varying the amplification factor of said magnetic amplifier means in response to output current variations.

5. In a cathodic protection system, a surface to be cathodically protected, at least one anode mounted near said cathodic surface, means for applying current between the anode and the surface, a sensing cell mounted in spaced relationship with respect to said surface and constituting together with said surface, a sensing circuit for developing voltage control signals indicating cathodic protection conditions, variable gain circuit means responsive to said sensing circuit and coupling said control signals to said current applying means to control said current applying means, and means responsive to the rate of oscillations in the current applied between the anode and the surface and coupled to said variable gain circuit means for varying the amplification of said variable gain circuit means.

6. In a cathodic protection system, a surface to be cathodically protected, at least one anode mounted near said cathodic surface, means for applying current between the anode and the surface, a sensing cell mounted in spaced relationship with respect to said surface and constituting together with said surface, a sensing circuit for developing voltage control signals indicating cathodic protection conditions, variable gain circuit means responsive to said sensing circuit and coupling said control signals to said current applying means to control said current applying means, and means responsive to oscillations in the current applied between the anode and the surface and coupled to said variable gain circuit means for varying the amplification of said variable gain circuit means, said last mentioned means including an oscillation counter and a timer for periodically sensing and resetting the counter.

7. In a cathodic protection system, a surface to be cathodically protected, at least one anode, means for applying direct current between the anode and the cathodic surface, a sensing cell mounted in spaced relationship with respect to said surface and constituting together with said surface a sensing cell for developing voltage control signals indicating cathodic protection conditions of the cathodic surface, means responsive to said sensing cell and coupling said control signals to the current applying means for continuously maintaining the current applied between the anode and the surface at levels determined by said control signals, means responsive to the applied current and coupled to said control signal coupling means for reducing the magnitude of the control provided by said control signals upon the occurrence of oscillations in the applied output current, and means responsive to the applied current oscillations and coupled to said control signal coupling means for increasing the magnitude of the control provided by said control signals in the absence of output voltage changes in the course of a preassigned timing interval.

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