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REGULATOR SYSTEM

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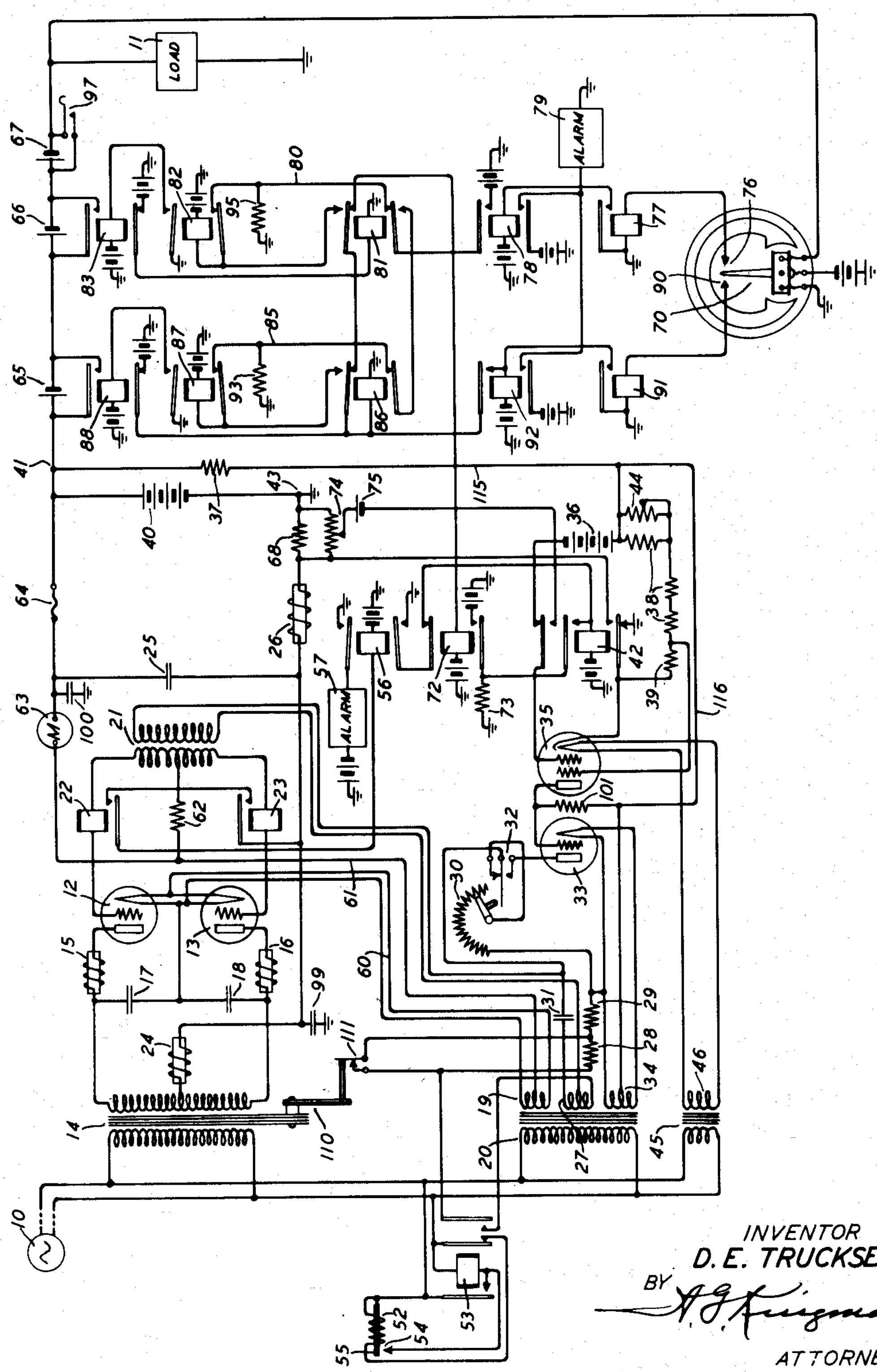

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REGULATOR SYSTEM

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This invention relates in general to a system of voltage regulation and particularly to a regulated rectifier system of the type wherein the rectifier output is regulated in accordance with the terminal voltage of a direct current circuit served by the rectifier.

In certain types of power plants, such as the small central office of a telephone system, it is sometimes desirable to regulate the voltage of the storage batteries, which supply power to the telephone equipment, more closely than is practicable with the well-known rectifier systems ordinarily used for this purpose. A considerable extension in the life of the battery and a reduction in the cost of maintenance may thus be attained.

It is the object of this invention to simplify and improve regulated rectifier systems of the type commonly used to float storage batteries, maintain them charged and regulate their voltage and to provide for a more precise regulation than has been available heretofore.

This object is attained in accordance with a feature of the invention by the provision of a full wave rectifier of the grid controlled type whose output is controlled in accordance with variations in the terminal voltage of the direct current circuit served by the rectifier, by changing the relative phase relations of the potentials applied to the grid and plate electrodes of the rectifier tubes.

Another feature of the invention resides in the use of a phase shift bridge circuit whose controlling element comprises the plate-cathode resistance of a three-element vacuum tube and in subjecting the grid thereof to a biasing potential which varies in accordance with variations in the terminal voltage of the direct current circuit served by the rectifier.

A further feature of the invention insures against overloading of the rectifier which would otherwise occur upon the resumption of power after a prolonged interruption thereof. This result is attained by automatically transferring the control of the rectifier from voltage regulation to constant current regulation after a prolonged failure of the power supply and the consequent excess drop in voltage of the direct current circuit.

A still further feature of the invention contemplates the use of electromagnetic switching means in the rectifier grid conductors which function in response to power or tube failures to actuate alarm signals.

Another feature of the invention resides in the use of novel means for delaying the flow of the rectifier anode current until the rectifier filament has been heated to its normal operating temperature.

Still another feature of the invention is embodied in the use of screen grid type tube in the regulator circuit and in subjecting the screen thereof to a potential which varies in accordance with the regulated voltage. The screen grid type of tube has a characteristic such that its plate voltage can be changed over wide limits with little effect on the plate current provided the screen voltage is maintained substantially constant. By supplying the screen with a voltage which varies with the regulated voltage, which is substantially constant, the screen voltage is maintained constant and is therefore unaffected by variations in the alternating current supply voltage. The gain of the tube is also increased by supplying voltage to the screen in this manner.

These and other features of the invention not specifically identified, will be readily understood from the following detailed description made with reference to the accompanying drawing which constitutes a complete disclosure of the regulated rectifier system of this invention and its associated charge and discharge circuits.

The rectifier consists essentially of two three-element mercury vapor tubes which are grid controlled and connected for full-wave rectification. The output current of these tubes is controlled by changing the relative phase relations of the voltages applied to their grids and plates. When the grid voltage is in phase with the plate voltage, the tubes deliver maximum current and when 180 degrees out of phase they deliver no current. The phase of the grid voltage is changed by varying the resistance of one arm of a phase shift bridge circuit. For manual control this resistance comprises a variable rheostat whereas for automatic operation the plate-cathode resistance of a three-element vacuum tube, which is controlled by the battery, or direct current circuit, voltage is used. The voltage phase relations and consequently the output current of the rectifier are changed under these conditions by varying the bias on the grid of the tube in the phase shifting circuit. The direct current voltage for biasing the grid of this tube is obtained from a regulating circuit which consists of a one tube direct current amplifier. This is required to increase the fractional voltage changes of the direct current circuit to several volts before applying it to the grid of the phase shifting tube. As the battery or direct current circuit voltage varies, the regulator changes the bias on the phase shifting tube which in turn varies the output current from the rectifier in a direction to cause the battery voltage to return to its original value.

After a prolonged power failure, the grid of the regulating tube is transferred from the voltage potentiometer to the terminal of a rheostat which is connected across a resistor in the charge lead to the battery. A constant potential source is included in the grid lead under this condition. The circuit functions in the same manner as described above except that a constant voltage is maintained across the series resistor which maintains a constant output current from the rectifier. The value of this constant output current may be adjusted by the rheostat at any value but the full load current is usually selected in order to recharge the battery rapidly.

The single figure on the accompanying drawing is a diagrammatic representation of a regulated rectifier system embodying the features of the invention.

Referring to the drawing, a suitable source of alternating current is shown at 10 from which power is supplied to the load circuit, generally indicated at 11 by way of the rectified which comprises essentially, the two three-element mercury vapor tubes 12 and 13 which are connected for full wave operation. A plate transformer 14 is interposed between the rectifier and the alternating current source 10, the plate electrode of the tubes 12 and 13 being connected respectively to opposite terminals of the secondary thereof by way of the choke coils 15 and 16 respectively. Condenser 17 is bridged across the filament and plate leads of the tube 12 and a similar condenser 18 is bridged across the filament and plate leads of tube 3, the condensers 17, 18 and the choke coils 15 and 16 constituting filters which act to suppress radio frequency disturbances caused by the operation of the tubes. The filaments of tubes 12 and 13 are supplied with heating current from secondary 19 of transformer 20. The grids of tubes 12 and 13 are connected to opposite terminals of the secondary of grid transformer 21, each by way of the winding of the relays 22 and 23 respectively. The purpose of relays 22 and 23 will be indicated in a later description.

Retard coil 24 is provided in the rectified circuit for filtering the direct current output. A condenser 25 and an additional retard coil 26 are used in the connecting charge and discharge circuit for additional filtering.

The phase shift circuit comprises the two halves of secondary 27 of transformer 20, resistances 28, 29 rheostat 30 and condenser 31 connected in a Wheatstone bridge arrangement with the primary winding of transformer 21 constituting the galvanometer arm. As shown, one terminal of the transformer secondary is connected to the midpoint of secondary 27 of transformer 20 and the other terminal to the lead interconnecting condenser 31 and rheostat 30.

For manual regulation the switch arm of the rheostat is manipulated to increase or decrease the value of resistance of the bridge arm including resistances 28 and 29 as conditions warrant such adjustments. As the resistance of the rheostat is varied there is a corresponding phase displacement of the potential impressed on the grids of tubes 12 and 13 by way of transformer 21 with respect to the phase of the potential impressed on the plates of the rectifier tubes by way of transformer 14 with the result that the rectifier output current is increased or decreased.

For automatic operation, the rheostat switch is actuated to such a position as to cause contact 32 to be closed which results in a substitution of the plate-cathode resistance of tube 33 for the rheostat resistance 30. The filament heating current for tube 33 is supplied by the secondary 34 of transformer 20. The grid of tube 33 is directly connected to the plate of the regulating amplifier tube 35 whose grid is connected to the negative pole of battery 36. The tube 35 is of the screen grid pentode type.

An input potentiometer, comprising resistors 37, 38 and 39 is connected across the battery 40, or direct current circuit terminals whose voltage is to be regulated, one side of the potentiometer being connected to the direct current circuit terminal indicated at 41 and the other side to ground at the lower armature and back contact of relay 42, it being understood that the other direct current circuit or battery terminal is grounded as indicated at 43. A rheostat 44 is connected across one section of the potentiometer and is used to adjust the regulated voltage and compensate for a reduction in the voltage of battery 36 as it wears out. The voltage drop over the combined resistances 37, 38, 39 and rheostat 44 is connected in series opposing with the battery 36 and the voltage difference is applied to the grid of the regulator amplifier tube 35. This net grid voltage varies, therefore, in proportion to the variations in voltage across the points 41, 43.

This varying grid voltage is amplified in the tube 35 and is impressed on the grid of the phase shift tube 33, by means of resistance 101 to control the bias thereof. Any change in the bias on the grid of the phase shift tube 33 results in a corresponding change in the plate-cathode resistance of the tube and a consequent shift in phase of the potential impressed on the grids of the rectifier tubes 12 and 13. The rectifier output current is accordingly varied. It follows, therefore, that any drop in voltage of the direct current circuit or battery 40 is accompanied by a change in the phase relation between the potentials impressed on the rectifier grids and plates respectively, and this change is in such a direction as to increase the rectifier output current which in turn causes the direct current voltage to be raised. Conversely, any rise in the direct current circuit or battery voltage results in a lowering of the rectifier output current, and the consequent lowering of the direct current terminal voltage. By selecting suitable values for the resistors 28 and 29 the system may be so adjusted that under normal load conditions the rectifier supplies the entire load and the battery 40 merely floats on the line.

It will be understood that the regulator delivers no current, only a voltage to the control circuit of the grid controlled rectified.

Transformer 45 supplies filament voltage to the screen grid type amplifier tube 35 by way of the secondary winding 46. The plate of tube 35 is connected to the positive terminal of battery 40 by way of resistance 101 and conductors 110 and 115 and since the cathode of tube 35 is grounded, as is the negative terminal of the regulated battery, the amplifier tube plate voltage is furnished by the battery 40 whose voltage is being regulated. The screen voltage for tube 35 is supplied by the voltage drop across resistance 39 which is supplied by battery 40 and since the voltage of the battery is regulated and therefore substantially constant the screen voltage of tube 35 will be maintained substantially constant.

A description of the operation of the complete system, including the charge and discharge circuits will now be made.

It will be noted that as soon as the source 10 has been connected to the equipment herein disclosed by the operation of any suitable switching means, the primary windings of all the transformers utilized become energized. The plate potentials for the tubes 12 and 13 are therefore applied at the same time that the heating current is applied to the filaments. These plate and grid potentials however, are 180 degrees out of phase so that the rectifier anode current is blocked and the tubes 12 and 13 do not fire. The phase displacement of the plate and grid potentials is obtained by maintaining the resistance arm of the phase shift circuit open. This open is effected at the outermost armature and front contact of relay 53.

When the source 10 is effectively associated with the equipment an obvious path for the heater winding 52 of the thermostatic device is completed. The passage of current through the heater winding 52 for a predetermined period of time causes the flexing of element 55 and the consequent closure of contact 54 whereupon relay 53 is connected across the terminals of the supply source and operates. Relay 53 locks up directly to the source 10 independent of the thermostatic element 55 and opens the heater circuit allowing the heater element to restore to its normal condition. In actuating its outermost armature, relay 53 closes the resistance arm of the phase shift circuit to cause the phase of the grid potential to shift in such a direction as to permit the rectifier tubes to fire. The advantage of this arrangement over well-known time delay expedients heretofore employed is that the relay contacts need handle only a small current, in the order of milliamperes, instead of the main rectifier current of many amperes. The cost of the relay is materially reduced and the same relay may be used for all sizes of rectifiers.

The rectifier tubes 12 and 13 function as a full wave rectifier delivering rectified current to the direct current load circuit indicated at 11. It will be assumed, at this stage of the description that the voltage of battery 40 and the load conditions are such that the battery merely floats on the line and the load is handled entirely by the rectifier. Relays 22 and 23 in the rectifier grid leads accordingly operate causing relay 56 to operate and maintain the alarm circuit indicated at 57 open. The operating circuit for relay 56 extends from ground battery, winding of relay 56, front contacts and armatures of relays 22 and 23 to ground at the point 43. The relays 22 and 23 remain operated as long as the tubes 12 and 13 are functioning.

The path for the rectified current may be traced from the plate electrode of tube 12 to the filament thereof, conductor 60, lower half of the transformer secondary 19, conductor 61, meter 63, charge fuse 64 to the battery terminal 41, through the counter cells 65, 66 and 67, through the load 11 to ground at 43, resistance 68, coils 26 and 24, upper half of the secondary of transformer 14, choke coil 15 to the plate electrode of tube 12. A similar path may be traced for the rectified current from tube 13. The load 11 is accordingly supplied by the rectifier and the battery 40 floats on the line.

The counter cells 65, 66 and 67 are inserted in the discharge lead to maintain the load voltage within limits of the voltage responsive relay 70.

As hereinbefore described, any variation in the voltage of the direct current circuit results in a corresponding variation in the net voltage impressed on the grid of regulator tube 35 and a corresponding change in the bias on the grid of phase shift tube 33. The overall effect is to vary the rectifier current output whereby the voltage of the direct current circuit is brought back to normal.

In the event of a power failure or rectifier tube failure, relays 22 and 23 restore their armatures, opening the circuit to relay 56 which relay thereupon releases establishing an obvious circuit to the alarm 57. Relay 56 may also cause the functioning of an auxiliary charging circuit if so desired. As this feature does not constitute a part of the present invention no further reference thereto will be made.

At its lower armature and back contact relay 56 completes a circuit for the energization of relay 42, this circuit extending through the upper armature and back contact of relay 72. Relay 42 operates and locks up through resistance 73 to ground. At its lower armature relay 42 connects the cathode of tube 35 to one terminal of the rheostat 74 and at its upper outer armature transfers the grid lead of tube 35 from the negative terminal of battery 36 to the negative terminal of battery 75 whose positive plate is connected to the other terminal of rheostat 74. The control of the regulated rectifier has accordingly been transferred from voltage regulation to constant current regulation. It will be noted that the cathode grid circuit of tube 35 is now connected across the constant potential 75 and a portion of rheostat 74 so that the bias on the grid of tube 33 is maintained constant with the result that the rectifier current output is held at a constant value and the battery 40 charged accordingly, assuming that the power or tube failure has been corrected and the rectifier again in operating condition.

If the failure is of such a duration as to permit the voltage of battery 40 to fall to such an extent as to operate relay 70, the low voltage contact 76 thereof is closed to battery. Relay 77 thereupon operates over an obvious circuit and causes the operation of relay 78. Relay 78, at its lower armature and front contact establishes an obvious circuit for the alarm 79 which functions to give a low voltage alarm. At its upper armature, relay 78 places battery on the lead 80 by way of the lower armature and front contact of relay 81 thereby causing the release of the normally operated relay 82. At its upper armature and back contact relay 82 established an obvious energizing circuit for relay 83 which relay operates and short-circuits the counter cells 66 thereby raising the output voltage.

Relay 83, at its lower armature, removes battery from the winding of relay 81 causing this relay to release.

If the power failure continues until the low voltage contact 76 of relay 70 is made a second time, relays 77 and 78 again operate, the latter, at its lower armature and front contact establishing a circuit for the alarm 79. At its upper armature and front contact relay 78 places battery on the conductor 85 by way of the back contact and lower armature of relay 81 and the lower armature and front contact of relay 86. Relay 87 accordingly restores its armature establishing an obvious circuit for relay 88. Relay 88 at its lower armature removes battery from the winding of relay 86 causing this relay to release and at its upper armature and front contact short-circuits the counter cells 65 causing a further increase in the output voltage.

Upon resumption of power or replacement of the defective tube, the rectifier operates under constant current output under control of relay 42 as hereinbefore described. As the rectifier functions, relays 22 and 23 operate in the tube grid circuits, as previously pointed out, to cause the operation of relay 56 which, in turn, opens the circuit to the rectifier alarm 57. The silencing of the alarm 57 indicates the correction of the condition which manifested itself in the failure of the rectifier.

The battery 40 continues to be charged at a constant current from the rectifier until its voltage and that of the direct current circuit reaches a value sufficiently high to cause relay 70 to function and close its high voltage contact 90. Relay 91 accordingly operates in an obvious circuit and establishes an operating circuit for relay 92. At its lower armature and front contact relay 92 causes the operation of alarm 79 and at its upper armature and front contact establishes a circuit extending from grounded battery, winding of relay 87, back contact and upper armature of relay 86 (released), upper armature and front contact of relay 92, front contact and armature of relay 91 to ground. Relay 87 operates and locks up through resistance 93 to ground and opens the energizing circuit to relay 88. Relay 88 upon release of its upper armature removes the short circuit from the counter cells 65 causing them to be effectively inserted in the discharge circuit and to reduce the output voltage. At its lower armature and back contact relay 88 connects battery to the winding of relay 86 causing this relay to operate.

The voltage of battery 40 continues to rise under constant charging current from the rectifier and the output voltage increases until the high voltage contact 90 of relay 70 is closed a second time. Relays 91 and 92 again operate, causing the actuation of the alarm 79 and establishing a circuit for relay 82 extending from grounded battery, winding of relay 82, back contact and upper armature of relay 81 (released), front contact and upper armature of relay 86, upper armature and front contact of relay 92 to ground on the front contact and armature of relay 91. Relay 82 operates in this circuit and locks up through resistance 95 to ground. At its upper armature relay 82 opens the energizing circuit for relay 83 which relay restores its armatures thereby effectively inserting the counter cells 66 in the discharge circuit to lower the output voltage and connecting battery to the winding of relay 81 to cause this relay to operate.

The voltage of battery 40 continues to rise from the constant current output of the rectifier increasing the output voltage until the high voltage contact 90 of relay 70 is closed a third time giving an alarm at 79 and causing relay 72 to operate in a circuit extending from grounded battery, winding of relay 72, front contacts and upper armatures of relays 81 and 86, upper armature and front contact of relay 92 to ground on the front contact and armature of relay 91.

Relay 72 at its lower armature and front contact places battery on the locked up contact of relay 42 causing relay 42 to restore. Relay 42 at its upper outer armature disconnects the grid of tube 35 from the negative terminal of battery 75 and connects it to the negative terminal of battery 36 thereby returning the control of the regulated rectifier from constant current to voltage regulation at normal floating limits of the battery 40. A manually operated switch 97 is provided for the purpose of short-circuiting the counter cells 67 to permit operating the battery to a higher overcharge voltage after a power failure, if desired.

It is apparent from the foregoing description that applicant has devised a regulated rectifier system which provides for precise voltage regulation of the rectifier under normal operating conditions and which guards against overloading of the rectifier in the event of a prolonged power failure and a subsequent resumption of power. In the latter instance it will be noted that during a power failure, the battery 40 furnishes power to the load and the longer the failure persists the lower the terminal voltage attained by the battery. Unless provision is made for the transfer from voltage regulation to constant current regulation under this condition the phase of the potentials impressed on the grids of tubes 12 and 13 would be displaced with respect to the phase of the potentials impressed on the rectifier plates upon resumption of power, to such an extent that the rectifier current output would experience an abnormal increase, with the result that the rectifier is overloaded and the fuse 64 in the charge circuit becomes overtaxed and blows.

A further guard against overloading the rectifier is effected by selecting resistors 28 and 29 to give a high overload current when the rectifier starts to recharge after a power failure, which will continue until the transformer heats to the allowable limit. A thermostat, indicated at 110, attached to the core of transformer 14 will be operated by the heat of the transformer and its contacts 111 operated to remove the short circuit from resistor 28, reducing the current to a safe limit. The addition of this thermostat permits the rectifier to be adjusted for a high charging rate to bring the battery 40 back quickly after a power failure by using the rectifier at its highest capacity during the heating period of the transformer 14, and then reducing the charging current to a value which the transformer will carry continuously.

The condensers 99 and 100 are interposed between ground and the charging conductors for the purpose of further insuring against radio interference.

What is claimed is:

1. In a regulator system, a direct current circuit, an alternating current supply circuit, means comprising a three-element space discharge rectifier tube connected to supply rectified current to said direct current circuit, means including a potentiometer connected across said direct current circuit for regulating the output current of said rectifier in accordance with the voltage of said direct current circuit, means for maintaining the output current of said rectifier at a constant value irrespective of the voltage of said direct current circuit, a relay for rendering said last-mentioned means effective and means for indicating a failure of said supply circuit controlling said relay.

2. In a regulator system, a direct current circuit, an alternating current supply circuit, means comprising a thermionic rectifier connected to supply rectified current to said direct current circuit, means including a phase shifting bridge circuit for varying the output current of said rectifier, a vacuum tube included in said phase shifting bridge circuit and having a grid whose bias determines the extent to which the phase shifting circuit functions to vary the rectifier output current, means for biasing the grid of said vacuum tube in accordance with output voltage of said rectifier, and means responsive to an in-

terruption of the alternating current supply circuit for rendering said biasing means effective upon a subsequent completion of said alternating current supply circuit to maintain the output current of said rectifier constant after a power failure.

3. In a regulator system, a direct current circuit, an alternating current supply circuit, means comprising a thermionic rectifier connected to supply rectified current to said direct current circuit, means including a phase shifting bridge circuit for varying the output current of said rectifier, a vacuum tube included in said phase shifting bridge circuit and having a grid whose bias determines the extent to which the phase shifting circuit functions to vary the rectifier output current, means normally biasing the grid of said vacuum tube in accordance with the voltage of said direct current source, means for biasing the grid of said vacuum tube in accordance with the output current of said rectifier, switching means for interchanging said grid biasing means and means for indicating an interruption of the alternating current supply circuit and controlling said switching means whereby the normal voltage regulation of said rectifier is replaced by a constant current regulation after a failure of the supply circuit.

4. In a regulator system, a direct current load circuit, an alternating current supply circuit, means comprising a grid controlled rectifier connected to supply rectified current to said load circuit, means comprising a phase shifting bridge circuit for varying the potential impressed on the grid of said rectifier, a vacuum tube included in said phase shifting circuit and having a grid whose bias determines the extent to which said phase shifting circuit functions to vary the potential impressed on the grid of said rectifier, a potentiometer connected across said load circuit which is subject to voltage variations experienced by the load circuit, a resistance-rheostat combination included in the output circuit of said rectifier and subject to the current output of said rectifier, an amplifier having its plate circuit connected to the grid of said vacuum tube, switching means connecting the grid of said amplifier with said potentiometer whereby the grid of said vacuum tube is biased in accordance with the voltage of said load circuit, and means responsive to an interruption of said supply circuit for actuating said switching means to connect the grid of said amplifier to said resistance-rheostat combination whereby upon a subsequent completion of said supply circuit, the grid of said vacuum tube is biased in accordance with the output current of said rectifier.

5. In a regulator system, a direct current load circuit, an alternating current supply circuit, means comprising a grid controlled rectifier connected to supply rectified current to said load circuit, a battery connected across the output terminals of said rectifier and adapted to be charged by current from said rectifier, means comprising a phase shifting bridge circuit for varying the potential impressed on the grid of said rectifier, a vacuum tube included in said phase shifting circuit and having a grid whose bias determines the extent to which said phase shifting circuit functions to vary the potential impressed on the grid of said rectifier, a potentiometer connected across said battery and subject to variations in the voltage thereof, a resistance-rheostat combination included in the output circuit of said rectifier and subject to the output current of said rectifier, an amplifier having its plate circuit connected to the grid of said vacuum tube, switching means connecting the grid of said amplifier with said potentiometer whereby the grid of said vacuum tube is biased in accordance with the voltage of said battery and the charging current to said battery varied accordingly, means responsive to an interruption of said supply circuit for actuating said switching means to connect the grid of said amplifier to said resistance-rheostat combination whereby, upon a subsequent completion of said supply circuit, the grid of said vacuum tube is biased in accordance with the output current of said rectifier and said battery charged at a constant rate, and means effective upon a predetermined increase in the battery voltage for releasing said switching means and reconnecting the grid of said amplifier with said potentiometer whereupon the charging current to said battery is again regulated in accordance with the voltage of said battery.

6. In a regulator system, a direct current circuit, an alternating current supply circuit, means comprising a three-element space discharge rectifier tube connected to supply rectified current to said direct current circuit, means for regulating the output current of said rectifier in accordance with the voltage of said direct current circuit, and means responsive to the failure of said alternating current source for causing the rectifier output to be regulated independent of the voltage of said direct current circuit upon reestablishment of the alternating current supply.

7. In a regulator system, a direct current load circuit, an alternating current supply circuit, means comprising a grid controlled rectifier connected to supply rectified current to said load circuit, means comprising a phase shifting bridge circuit for varying the potential impressed on the grid of said rectifier, a resistance arm in said phase shifting circuit including a vacuum tube having a grid whose bias determines the extent to which the phase shifting circuit functions to vary the potential impressed on the grid of said rectifier, a potentiometer connected across said load circuit which is subject to voltage variations experienced by the load circuit and means including an amplifier for amplifying the voltage variations of said potentiometer and impressing corresponding biasing potentials on the grid of said vacuum tube whereby the potentials impressed upon the grid of said rectifier and therefore the output of said rectifier are varied in accordance with the voltage of said load circuit.

8. In a regulator system, a direct current load circuit, an alternating current supply circuit, means comprising a grid controlled rectifier connected to supply rectified current to said load circuit, means for regulating the output of said rectifier in accordance with voltage variations of said load circuit, said means including a phase shifting bridge circuit having the plate-cathode resistance of a vacuum tube included in one arm thereof, a potentiometer connected across said load circuit which is subject to voltage variations experienced by the load circuit, a screen grid amplifier tube for amplifying the voltage variations of said potentiometer and impressing corresponding potentials on the grid of said vacuum tube and a connection from the screen of said amplifier tube to a point on said potentiometer whereby said screen is supplied with a substantially constant grid voltage.

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