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VOLTAGE REGULATION

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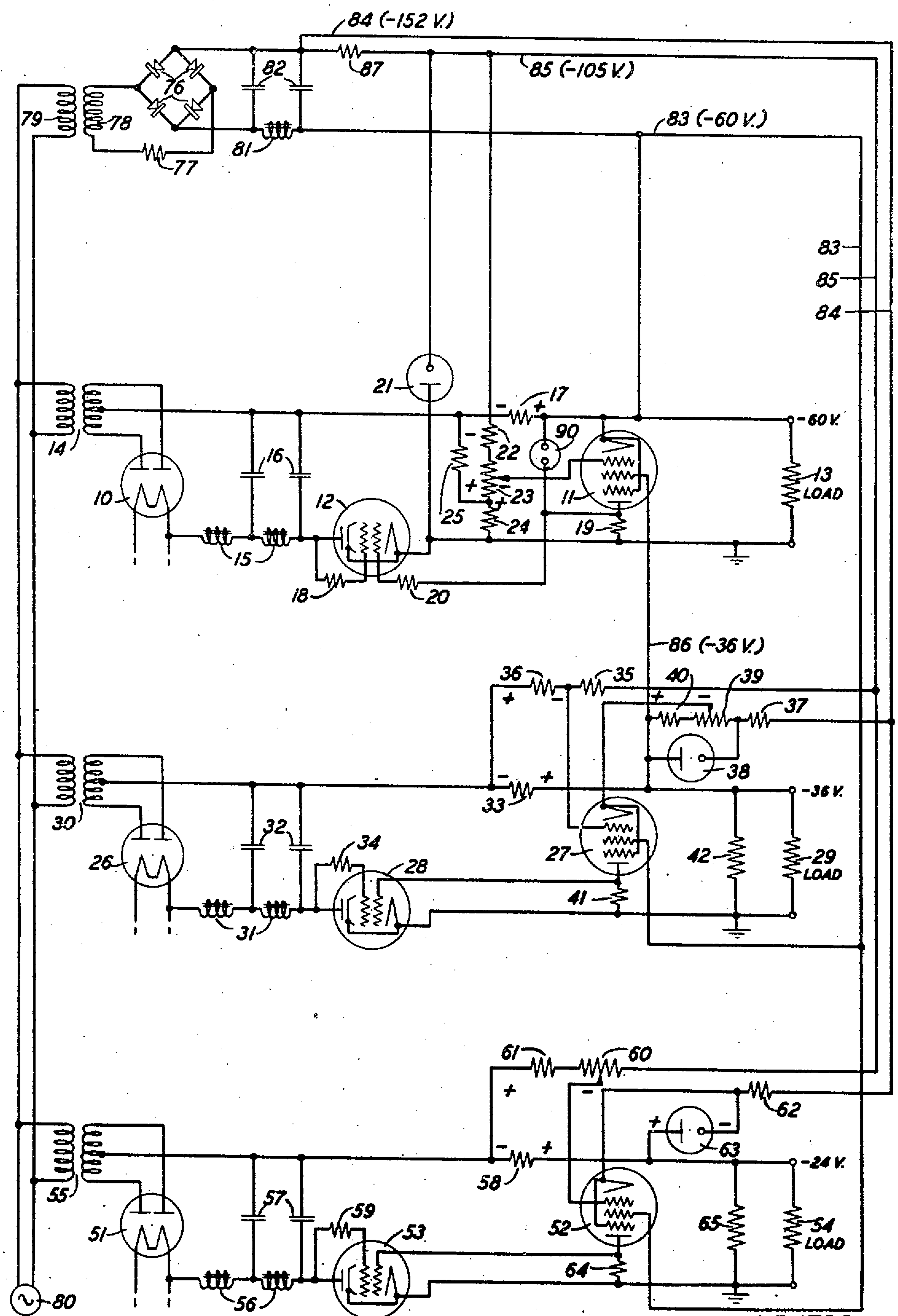

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VOLTAGE REGULATION

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This invention relates to voltage regulation and particularly to apparatus for regulating the direct current supplied to a load to maintain the load voltage substantially constant at a desired value.

An object of the invention is to provide improved regulated rectifying apparatus for supplying direct current to a load.

There has been used heretofore regulated rectifying apparatus employing a space discharge rectifying device upon the control grid-cathode circuit of which is impressed a control voltage for controlling the amplitude of the rectified current supplied to a load to maintain the load voltage substantially constant. Another type of known regulated rectifying apparatus employs a space discharge device in series with the load with respect to the rectifier output, a voltage being impressed upon the control grid-cathode circuit of the space discharge device for controlling the space current and therefore the current supplied to the load. In such apparatus the control grid-cathode voltage applied to the series space discharge device may be obtained from the output of an electronic amplifier upon the input of which a control voltage is impressed. The control voltage of such arrangements may have a plurality of components. There may be used, for example, two component voltages, one being a direct voltage proportional to the load voltage and the other being a substantially constant voltage in opposed relationship to the first. The resultant voltage is therefore a direct voltage of small amplitude and having variations corresponding to load voltage changes, the magnitude of this voltage being suitable for application to the grid-cathode circuit of an electronic amplifier or of a grid controlled rectifying device. It has been the practice, in order to avoid the necessity of using batteries, to derive the constant voltage component, or the so-called reference standard voltage, from a circuit comprising a cold cathode, gas-filled voltage stabilizing tube energized from the rectified voltage source and having the property of changing its resistance in response to current changes therethrough so as to maintain substantially constant the voltage drop across the tube.

In designing the regulated rectifiers shown and described herein, the difficulty was encountered that the voltage across the load is less than the breakdown voltage of the voltage stabilizing, cold cathode tube used for supplying the reference standard voltage. There was encountered the further problem of obtaining a sufficiently

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high voltage in the anode-cathode circuit of an amplifier tube to cause the anode-cathode resistance of the regulator tube which is controlled from the amplifier output to vary over a wide range in response to load voltage changes, for example. These and other problems have been solved in accordance with the present invention.

In accordance with a specific embodiment of the invention shown and described herein for the purpose of illustration, there are provided a plurality of regulated rectifiers for simultaneously supplying current to different loads respectively and for maintaining substantially constant at desired values the voltages across said loads respectively. Each regulated rectifier is of the type employing a series regulator tube the resistance of which is varied under control of the output voltage of an electronic amplifier. The control voltage impressed upon the input control grid-cathode circuit of the amplifier has three component unidirectional voltages, a first component varying with load voltage changes, a second component being a substantially constant reference standard voltage having a polarity which is in opposition to the first component voltage, and a third component which varies with load current. The first and third component voltages have such polarities, respectively, that when the resistance of the load is fixed, a change in load voltage due to a line voltage change, for example, causes the voltage changes of the first and third components to be in opposition but the changes of the first voltage component are predominantly large. However, when the load resistance is changed, the resulting voltage changes of the first and third components are in aiding relationship in the control grid-cathode circuit of the amplifier tube. The second component voltage is derived by means of a voltage stabilizing device to which is applied a voltage larger than the output voltage of the rectifier which supplies current to the load, the additional voltage required being supplied by an auxiliary rectifying apparatus.

The single figure of the accompanying drawing is a schematic view of regulated rectifying apparatus embodying the invention.

Referring to the drawing, there are provided three regulated rectifiers each for supplying direct current to a load and for maintaining each of the load voltages substantially constant. One of these regulated rectifiers comprises a full wave rectifier tube 10, a triple grid amplifier tube 11 and a beam power series regulator tube 12 for supplying direct current to a load 13 the potential of one terminal of which is 60 volts negative with respect to its other terminal which is grounded. A second regulated rectifier comprising a full wave rectifier tube 26, a triple grid amplifier tube 27, and a beam power series regulator tube 28 supplies direct current to a load 29 the polarity of one terminal of which is 36 volts negative with respect to its other terminal which is grounded. The third regulated rectifier, comprising a full wave rectifier tube 51, a triple grid amplifier tube 52, and a beam power series regulator tube 53, supplies direct current to a load 54 the polarity of one terminal of which is 24 volts negative with respect to its other terminal which is grounded.

There is also provided an auxiliary rectifier made up of varistors 76 connected in a bridge circuit two opposed vertices of which are connected through a 2700-ohm resistor 77 to the terminals of secondary winding 78 of a transformer the primary winding 79 of which is connected to a 110-volt alternating current supply source 80. The conjugate vertices of the bridge rectifier 76 are connected to the input terminals of a ripple filter comprising a series reactance coil 81 and shunt condensers 82. The lead 83 connected to the positive output terminal of the filter 81, 82 is directly connected to the —60-volt terminal of the load 13. The voltage across the output terminals of filter 81, 82 is about 92 volts so that the lead 84 connected to the negative filter terminal is 152 volts negative with respect to ground. Lead 85 is connected through a 2700-ohm resistor 87 to the negative terminal of filter 81, 82, the operating voltage drop across resistor 87 being such that the potential of lead 85 is 105 volts negative with respect to ground.

Considering further the —60-volt regulated rectifier, the two anodes of rectifier tube 10 are connected respectively to the end terminals of the secondary winding of a transformer 14 the primary winding of which is connected to the supply source 80. The rectifier output terminals going to a mid-tap of the secondary winding of transformer 14 and to the cathode of rectifier tube 10 respectively are connected to the input terminals of a ripple filter comprising series reactance coils 15 and shunt condensers 16. The negative output terminal of the filter is connected through a series load compounding resistor 17 of 160 ohms to the negative terminal of load 13. The positive filter output terminal is connected through the space current or anode-cathode path of the series regulator tube 12 to the grounded positive load terminal. The anode and screen grid of tube 12 are connected through a 30-ohm resistor 18. The cathode of amplifier tube 11 is connected to the negative load terminal and the anode of the tube is connected through 0.5-megohm resistor 19 to ground. The screen grid of tube 11 is given a potential of 24 volts positive with respect to the cathode by connecting it to lead 86 going to an output terminal of the regulated rectifier comprising tube 26, the potential of lead 86 being 36 volts negative with respect to ground. The anode of tube 11 is connected through 2000-ohm resistor 20 to the control grid of tube 12 so that the voltage drop across resistor 19 is impressed upon the control grid-cathode circuit of tube 12 to control its anode-cathode resistance. There is provided a voltage stabilizing, cold cathode tube 21 having one terminal connected to lead 85 and its other terminal grounded for maintaining the lead 85 at a potential of —105 volts with respect to ground. A potential dividing circuit is connected across the terminals of voltage stabilizing tube 21, said circuit comprising 62,000-ohm resistor 22, 0.1-megohm potentiometer 23, and 500-ohm resistor 24 in series. One terminal of a 10,000-ohm resistor 25 is connected to the negative output terminal of filter 15, 16 and the other terminal of resistor 25 is connected to the common terminal of potentiometer 23 and resistor 24. The two-electrode, gas-filled tube 90 in a path connecting the anode and cathode of tube 11 is provided to prevent the load voltage from rising to an excessive value. If the tube 11 should fail to pass space current through resistor 19 and as a result cause zero grid-cathode voltage to be applied to tube 12, the load voltage would be increased to an excessive value. However, when the load voltage is increased to 110 volts, tube 90 breaks down to cause current to flow through resistor 19, thereby applying a negative bias to the grid of tube 12 to limit the load current and voltage.

Considering the operation of the —60-volt regulated rectifier, it will be noted that there are three component voltages in a series circuit connecting the control grid and cathode of amplifier tube 11. One of the components is the voltage drop of about 13 volts across the load compounding resistor 17, this voltage varying with load current. A second component is the voltage drop of about 67 volts across resistor 25, this voltage varying with load voltage. The third component is a portion of the substantially constant voltage across voltage stabilizing tube 21, that is, the voltage drop of about 55 volts across the portion of potentiometer 23 between the common terminal of the potentiometer and resistor 24 and the variable potentiometer connection going to the control grid of tube 11. The voltage drop across resistor 17 and the voltage drop across the portion of potentiometer 23 in the circuit are aiding with respect to each other and opposed to the voltage drop across resistor 25 so that the resultant potential of the control grid with respect to the cathode is about one volt negative. When an increase in load voltage occurs, due to a voltage increase of source 80, for example, the resistance of the load being fixed, the voltage drop across resistor 17 and that across resistor 25 each increases, the increase of voltage across resistor 25 being larger. As a result the control grid becomes relatively more positive or less negative with respect to the cathode to cause the space current of tube 11 flowing through resistor 19 to increase. Therefore the control grid of regulator tube 12 becomes relatively more negative with respect to its cathode to cause the anode-cathode resistance of the tube to increase and thus reduce the current flowing through load 13 to restore the load voltage to its normal operating value. When the resistance of the load is reduced, for example, the load current increases and the load voltage decreases. As a result the voltage drop across resistor 17 increases while that across resistor 25 decreases. The voltage drops across resistors 17 and 25 being in opposition, the increase of voltage drop across resistor 17 and the decrease of voltage drop across resistor 25 cause the grid of tube 11 to become relatively more negative with respect to the cathode by an amount equal to the sum of the two voltage changes. The control grid of regulator tube 12 thus becomes less negative with respect to the cathode to cause the load voltage to increase to its normal value. The load voltage may be brought to a desired normal value by adjusting the variable contact of potentiometer 23 to change the reference standard voltage component in the grid-cathode circuit of amplifier tube 11.

Considering the −36-volt regulated rectifier, the two anodes of rectifier tube 26 are connected respectively to the end terminals of the secondary winding of a transformer 30, the primary winding of which is connected to the supply source 80. The rectifier output terminals going to a mid-tap of the secondary winding of transformer 30 and to the cathode of rectifier tube 26, respectively, are connected to the input terminals of a ripple filter comprising series reactance coils 31 and shunt condensers 32. The negative output terminal of the filter is connected through a series load compounding resistor 33 of 86 ohms to the negative terminal of load 29. The positive filter output terminal is connected through the space current path of the series regulator tube 28 to the grounded positive load terminal. The anode and screen grid of tube 28 are connected through a 30-ohm resistor 34. Resistor 35 of 7,500 ohms and resistor 36 of 0.1 megohm are in a path connecting the lead 85 and the negative output terminal of filter 31, 32, the common terminal of resistors 35 and 36 being connected to the control grid of amplifier tube 27. A 2,700-ohm resistor 37 and a cold cathode voltage stabilizing tube 38 in series are in a path connecting lead 84 to the negative load terminal. Across the cold cathode tube 38 are connected in series a 5,000-ohm potentiometer 39 and an 18,000-ohm resistor 40, the cathode of tube 27 being connected to the adjustable contact of potentiometer 39. The anode of tube 27 is connected through a 0.5-megohm resistor 41 to ground. A 1,500-ohm resistor 42 or so-called dummy load is connected across the load 29. The potential of the screen grid of tube 27 is made 40 volts positive with respect to the tube cathode by connecting it to the lead 83. The anode of amplifier tube 27 is connected to the control grid of regulator tube 28.

The amplifier tube 27, in order to provide voltage changes of sufficient magnitude across resistor 41 for controlling the regulator tube 28 to vary its anode-cathode resistance over a sufficiently large range, requires a larger voltage than the 36-volt regulated load voltage in its anode-cathode circuit. Therefore a voltage equal to the sum of the load voltage and the major portion of the substantially constant voltage across the voltage stabilizing tube 38 is impressed upon the anode-cathode circuit of tube 27, this voltage being about 100 volts. The resistors 35, 36 and 33 and the load 29 are in series path connecting the −105-volt lead 85 to ground. The voltage drop across resistor 35 is about 3 volts so that the control grid potential of tube 27 is about −102 volts with respect to ground or −2 volts with respect to the cathode since the cathode potential with respect to ground is about −100 volts. The voltage drop across load compounding resistor 33 is also small, it being about 2 volts. Therefore, since the potential of lead 85 remains substantially constant at −105 volts with respect to ground due to the action of the voltage stabilizing tube 21, the voltage across resistor 36 varies in response to load voltage changes, the voltage drop across resistor 36 increasing in response to a decrease in load voltage and decreasing in response to a rise in load voltage. The voltage in the control grid-cathode path of tube 27 thus has three components,

namely, the voltage drop across resistor 36 having variations corresponding to load voltage changes, the voltage drop across the load compounding resistor 33 which varies with load current and the substantially constant reference standard voltage across resistor 40 and a portion of resistor 39 in series, the voltage drops across resistors 36 and 33 being in aiding relationship and the voltage drop across the resistor 40 and a portion of resistor 39 being opposed to the voltage drops across resistors 36 and 33 to give a suitable operating control grid-cathode voltage for tube 27.

If the load voltage rises due to an increase of line voltage, for example, the voltage drop across resistor 33 increases while that across resistor 36 decreases and, since the latter voltage change is much larger than that across resistor 33, the grid of tube 27 is made relatively more positive or less negative with respect to the cathode and, as a result, the voltage drop across resistor 41 is increased due to the increased space current of tube 27. Therefore, the control grid of regulator tube 28 becomes relatively more negative with respect to its cathode to cause the load current and voltage to be reduced. If the load is increased, that is, the load resistance is decreased, while the line voltage is fixed, the voltage drop across resistor 33 is increased and the voltage drop across resistor 36 is increased due to a decrease in load voltage. The control grid of tube 27 is therefore made relatively more negative with respect to its cathode to decrease the space current of the tube and to make the control grid of tube 28 relatively less negative with respect to its cathode, thus reducing the resistance of the anode-cathode path of tube 28. Increased load current is thus caused to flow to restore the load voltage to its normal value. The load voltage may be set at a desired normal value by adjusting the movable contact of potentiometer 39 to change the potential of the cathode of tube 27 with respect to ground, that is, by changing the reference standard voltage.

The −24-volt regulated rectifier is somewhat like the −36-volt regulated rectifier. The two anodes of the full wave rectifier tube 51 are connected to the end terminals of the secondary winding of transformer 55 the primary winding of which is supplied with alternating current from source 80. The rectifier output terminals are connected to the input of a filter comprising series reactance coils 56 and shunt condensers 57. The negative output terminal of the filter is connected through a series load compounding resistor 58 of 43 ohms to the negative terminal of load 54. The positive filter output terminal is connected through the space current path of regulator tube 53 to the grounded positive load terminal. The anode and screen grid of tube 53 are connected through a 30-ohm resistor 59. Potentiometer 60 of 0.1 megohm and resistor 61 of 0.3 megohm are in a path connecting the lead 85 and the negative output terminal of filter 56, 57. The adjustable contact of potentiometer 60 is connected to the control grid of tube 52 and its setting may be changed to adjust the load voltage to a desired value. A 3,900-ohm resistor 62 and cold cathode, gas-filled voltage stabilizing tube 63 in series are in a path connecting lead 84 to the negative load terminal, the cathode of tube 52 being connected to the common terminal of resistor 62 and cold cathode tube 63. The anode current path of tube 52 is completed through 0.5-

megohm resistor 64 connecting the anode of tube 52 to ground. A dummy load resistor 65 of 1,500 ohms is connected across the load 54.

In this regulated rectifier, the voltage impressed upon the anode-cathode path of tube 52 is the sum of the substantially constant voltage across voltage stabilizing tube 63 and the load voltage, making the potential at the cathode about −99 volts with respect to ground. The control grid of tube 52 is about 101 volts negative with respect to ground and thus at a suitable operating potential of about −2 volts with respect to the cathode. The component voltages in the grid-cathode circuit of tube 52 are the voltage drop across resistor 61 and a portion of resistor 60 which varies in response to load voltage changes, the voltage drop across resistor 58 which varies in accordance with load current changes and the substantially constant voltage drop across the voltage stabilizing tube 63. The voltage across tube 63 is opposed to each of the other two component voltages.

When an increase in load voltage occurs, the voltage across resistor 61 and a portion of potentiometer 60 is reduced to make the control grid of tube 52 relatively less negative. The control grid of tube 53 is thus made more negative relative to its cathode to cause the load voltage to be restored to its normal operated value. An increase in load causes the voltage drop across resistor 58 to increase making the grid of tube 52 relatively more negative with respect to its cathode and the grid of tube 53 relatively less negative with respect to its cathode, thus causing the load voltage to be increased to its normal operating value.

What is claimed is:

1. Means for regulating the voltage across a load to which is supplied current from a direct current source comprising space discharge means having an anode, a cathode and a control electrode, auxiliary rectifying means for producing an output voltage, voltage stabilizing means the resistance of which changes in response to current changes therethrough at a rate to maintain substantially constant the voltage across said stabilizing means, a current path connected across said load comprising in series a resistor, said auxiliary rectifier and said voltage stabilizing means, the voltage of said direct current source and the voltage of said auxiliary rectifying means being in aiding relationship in said path so that the voltage across said voltage stabilizing means is greater than the voltage across said load and greater than the output voltage of said auxiliary rectifying means, and means for controlling the potential of said control electrode with respect to said cathode for causing load voltage changes to be minimized, said last-mentioned means comprising a circuit connecting said control electrode and cathode including a voltage which varies in response to load voltage changes and in opposition thereto a portion at least of the voltage across said voltage stabilizing means.

2. Means for regulating the voltage across a load to which is supplied current from a direct current source comprising a space discharge means having an anode, a cathode and a control electrode, auxiliary rectifying means for producing an output voltage, voltage stabilizing means the resistance of which changes in response to current changes therethrough at a rate to maintain substantially constant the voltage across said stabilizing means, a current path connected across said load comprising in series a resistor, said auxiliary rectifier and said voltage stabilizing means, the voltage of said direct current source and the voltage of said auxiliary rectifying means being in aiding relationship in said path so that the voltage across said voltage stabilizing means is greater than the voltage across said load and greater than the output voltage of said auxiliary rectifying means, voltage dividing resistance means connected across said voltage stabilizing means and means for controlling the potential of said control electrode with respect to said cathode for causing load voltage changes to be minimized, said last-mentioned means comprising a circuit connecting said control electrode and cathode and including a voltage proportional to the load voltage and in opposition thereto a portion of the voltage across said voltage dividing means.

3. Means for regulating the voltage across a load to which is supplied current from a direct current source comprising space discharge means having an anode, a cathode and a control electrode, auxiliary rectifying means for producing an output voltage, voltage stabilizing means the resistance of which changes in response to current changes therethrough at a rate to maintain substantially constant the voltage across said stabilizing means, a current path connected across said load comprising in series a resistor, said auxiliary rectifier and said voltage stabilizing means, the voltage of said direct current source and the voltage of said auxiliary rectifying means being in aiding relationship in said path so that the voltage across said voltage stabilizing means is greater than the voltage across said load and greater than the output voltage of said auxiliary rectifying means, means for connecting said cathode to one of said load terminals, means for connecting said anode to the other load terminal and a circuit connecting said cathode and said control electrode having therein the voltage across said load and in opposition to said load voltage at least a portion of the voltage across said voltage stabilizing means.

4. Means for regulating the voltage across a load to which is supplied current from a direct current source comprising a regulator space discharge device having an anode, a cathode and a control electrode and having its space current path in series with said load with respect to said direct current source, a load compounding resistor in series with said load with respect to said direct current source, a first current path connected across said load including the space current path of an amplifier space discharge device having an anode, a cathode and a control electrode, a second current path connected across said load comprising in series an auxiliary rectifier, a resistor and a voltage stabilizing device the resistance of which changes in response to current changes therethrough at a rate to maintain substantially constant the voltage across said stabilizing device, a circuit connecting the cathode and control electrode of said amplifier space discharge device having therein in series a first voltage component which varies with the voltage drop across said load compounding resistor, a second voltage component which varies with the load voltage and a third voltage component which is a portion at least of the voltage across said voltage stabilizing device and means for impressing upon the control electrode of said regulator space discharge device with respect to its cathode a voltage which varies with the anode potential changes of said amplifier space discharge device.

5. A combination in accordance with claim 4 in which the polarity of said second component voltage is in opposition to the polarity of said third component voltage.

6. A combination in accordance with claim 4 in which the polarity of said second component voltage is in opposition to the polarity of said first and third component voltages.

7. A combination in accordance with claim 4 in which the cathode of said amplifier space discharge device is connected to the negative load terminal through a path comprising said voltage stabilizing device.

8. Means for regulating the voltage across a load to which is supplied rectified alternating current from a source comprising electronic means having an input control grid-cathode circuit upon which a control voltage is impressed and an output anode-cathode circuit through which load current flows for causing the amplitude of said load current to be controlled in response to variations of said control voltage, auxiliary rectifying means for producing an output voltage, voltage stabilizing means the resistance of which varies in response to current changes therethrough at a rate to cause the voltage across said voltage stabilizing means to remain substantially constant and a current path connected in shunt with said load with respect to said source comprising in series the output of said auxiliary rectifier, said voltage stabilizing means and a resistor, the output voltage of said auxiliary rectifier being in aiding relationship to the load voltage so that the sum of the voltage drop across said voltage stabilizing means and the voltage drop across said resistor is greater than said load voltage, said input control grid-cathode circuit including said resistor for causing load voltage variations to be impressed upon said control grid-cathode circuit, thereby controlling the load current to minimize said load voltage variations.

9. Means for regulating the voltage across a load to which is supplied current from a direct current source comprising a series regulator space discharge device having an anode, a cathode and a control electrode, the anode-cathode discharge path of which is in series with the load with respect to said direct current source, an amplifier space discharge device having an anode, a cathode and a control electrode, a voltage stabilizing device the resistance of which changes in response to change of current therethrough to maintain the voltage across said device substantially constant, a circuit comprising auxiliary rectifying means for supplying direct current to said voltage stabilizing device, a space current circuit connecting the anode and cathode of said amplifier discharge device having therein the voltage across said load and at least a portion of the voltage across said voltage stabilizing device in aiding relationship in said circuit, a second voltage stabilizing means to which current is supplied from said auxiliary rectifying means to set up a substantially constant voltage thereacross, a current path connected across said second voltage stabilizing means comprising in series said load and resistance means so that the voltage across said resistance means varies in response to load voltage changes, a circuit connecting the control grid and cathode of said amplifier space discharge device comprising said first voltage stabilizing device and at least a portion of said resistance means, the polarity of the voltage across said first voltage stabilizing means being in opposition to the voltage across said resistance means in said circuit, and means for impressing upon the control grid-cathode path of said regulator space discharge device a voltage derived from the anode-cathode path of said amplifier space discharge device for causing the load current to be controlled to maintain said load voltage substantially constant.

10. A voltage regulator for controlling the current supplied from a direct current source to a load to maintain the load voltage substantially constant comprising a regulator electronic device having an anode, a cathode and a control electrode, the anode-cathode resistance of which may be varied for controlling the current supplied to said load, an amplifier having an output circuit connected to the control electrode-cathode circuit of said regulator electronic device for controlling the anode-cathode resistance of said device in accordance with the output voltage of said amplifier, said amplifier comprising a second electronic device having an anode, a cathode and a control electrode, a circuit connecting the anode and cathode of said second electronic device having therein a voltage larger than the load voltage for causing anode current to flow in said circuit, and a circuit connecting the control electrode and cathode of said second electronic device having therein two opposed component voltages one of said component voltages varying in accordance with load voltage changes and the other of said component voltages varying in accordance with load current changes.

11. Means for regulating the voltage across a load to which is supplied rectified alternating current from a source comprising electronic means having an input control grid-cathode circuit upon which a control voltage is impressed and an output anode-cathode circuit through which load current flows for causing the amplitude of said load current to be controlled in response to variations of said control voltage, auxiliary rectifying means for producing an output voltage, voltage stabilizing means the resistance of which varies in response to current changes therethrough at a rate to cause the voltage across said voltage stabilizing means to remain substantially constant, and a current path connected in shunt with said load with respect to said source comprising in series the output of said auxiliary rectifier, said voltage stabilizing means and a resistor, the output voltage of said auxiliary rectifier being so related to said load voltage that the sum of the voltage drop across said voltage stabilizing means and the voltage drop across said resistor is greater than said load voltage, said input control grid-cathode circuit including said resistor for causing load voltage variations to be impressed upon said control grid-cathode circuit, thereby controlling the load current to minimize load voltage variations.

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