

May 10, 1938.

C. D. BOCK

2,117,138

VOLTAGE REGULATOR

Filed June 22, 1936

2 Sheets-Sheet 1

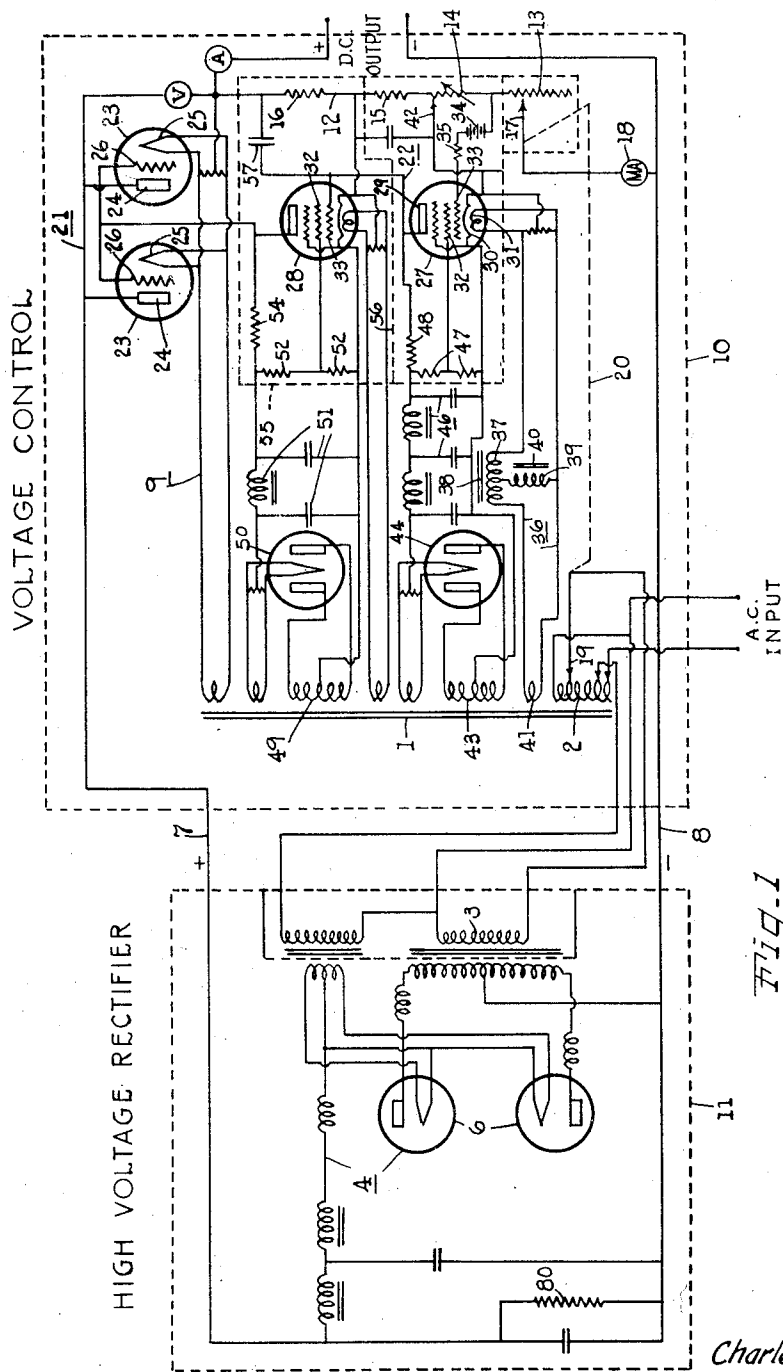


Fig. 1

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2 Sheets-Sheet 2

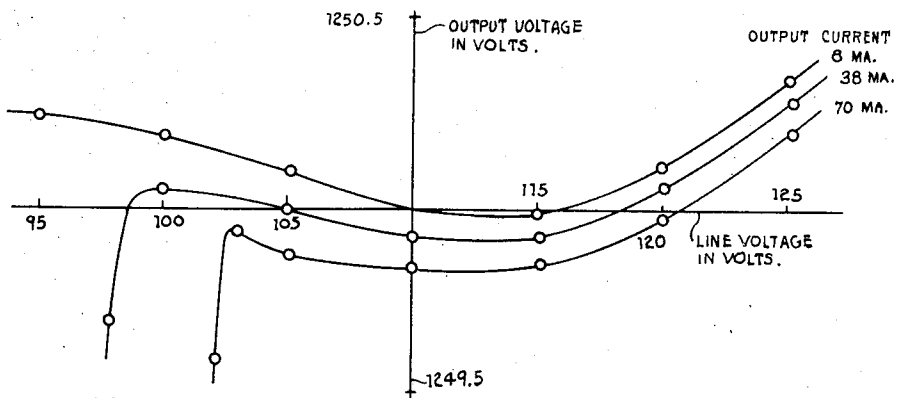


Fig-3

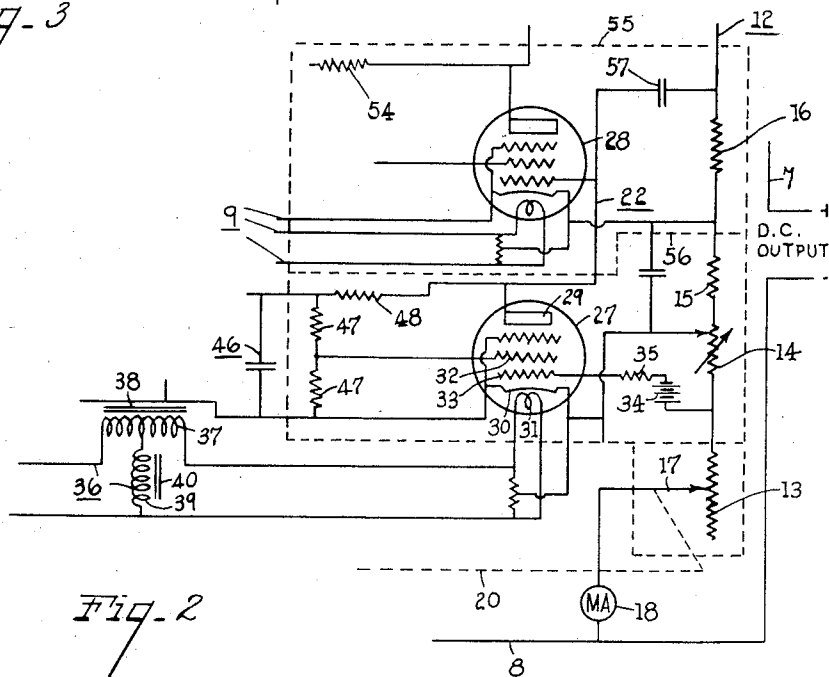


Fig. 2

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2,117,138

VOLTAGE REGULATOR

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Application June 22, 1936, Serial No. 86,639

18 Claims. (Cl. 171—312)

The main objects of this invention are:

First, to provide a voltage regulator which is especially well adapted for uses requiring as nearly perfect regulation as it is possible to obtain.

Second, to provide a high voltage source of constant potential from a conventional low voltage alternating current circuit, having desirable characteristics similar to but better than those of a standard high voltage storage battery.

Third, to provide a voltage regulator which is simple and economical in its parts and very efficient and effective in operation, the system being adjustable simply and quickly for any desired voltage.

Objects relating to details and economies of my invention will appear from the description to follow. The invention is defined and pointed out in the claims.

A structure which is a preferred embodiment of my invention is illustrated in the accompanying drawings, in which:

Fig. 1 is a fragmentary diagrammatic representation of a voltage regulator embodying features of my invention.

Fig. 2 is an enlarged fragmentary view similar to Fig. 1.

Fig. 3 is a graphical representation illustrating the operation of my voltage regulator.

In the illustrated embodiment of my invention, 1 is a transformer having a primary winding 2 energized by an alternating current supply of low voltage such as that used in conventional house circuits, in this case 110 volts. The tapped primary winding 2 of the transformer 1 acts as an autotransformer to control the voltage of the high voltage transformer 3 which supplies a rectifier 4. The tubes 6 of the rectifier are preferably of the type known as "866A", although for simpler models vacuum type rectifiers are preferred. The rectifier 4 is otherwise of conventional design and needs no further description here, rectifiers of this type being well known to those skilled in the art.

The output circuit of the high voltage rectifier 4 includes a positive conductor 7 and a negative conductor 8, the output circuit also including a load resistor 10. The voltage between the conductors 7 and 8 in the present example is in the order of 1250 volts, but it will be understood that my apparatus is efficient over a wide voltage range inasmuch as I have operated the device successfully with a voltage output in the order of 2500 volts. The conductors 7 and 8 pass through a voltage control unit or the voltage regulator 9, this unit being enclosed in a shield 10 to insulate

the same from the high voltage rectifier 4 which is also enclosed in a shield 11. I have separately shielded these two parts of the circuit in order to decrease certain tendencies toward interaction between the rectifier tubes and the sensitive voltage control.

Across the D. C. output lines 7 and 8, I connect a variable potentiometer 12 including a variable resistor 13, a variable resistor 14, a fixed resistor 15, and a fixed resistor 16. While I prefer to use resistors, it will be appreciated that other types of impedance elements may be used in the potentiometer circuit. The adjustable tap 17 of the potentiometer is connected to the negative conductor 8, there being a milliammeter 18 in this circuit.

The potentiometer tap 17 and the autotransformer tap 19 are mechanically connected by manually controlled means 20 for simultaneous adjustment. Interconnection of the taps 17 and 19 makes possible the simultaneous selection of the proper voltage and the automatic adjustment of the potentiometer to the proper impedance. This feature is important in simplifying the operation of the device.

In series circuit relation with the positive conductor 7 of the output circuit of the voltage rectifier, I connect vacuum tube impedance means 21. This vacuum tube impedance means is controlled to keep the potential of the output circuit constant in accordance with the setting of the manually controlled means 20, by vacuum tube amplifying means 22 acting to control the impedance means 21 in response to the voltage across the variable resistor 14. In the present example of my invention, the vacuum tube impedance means 21 comprises a pair of vacuum tubes 23 of the triode type, preferably of high mutual conductance, such as types "45," "50," "2A3," having an anode or plate 24, a cathode or filament 25, and a control grid or electrode 26. The electrodes of the tubes 23 are connected in parallel as shown, the control grids 26 being responsive to the output of the vacuum tube amplifying means 22. A standard battery may be inserted in the cathode lead, with some advantage in reducing the capacity of the circuit.

The vacuum tube amplifying means 22 comprises in the present preferred embodiment a first vacuum tube amplifier 27 and a second vacuum tube amplifier 28 of the pentode type. The amplifier 27 comprises an anode or plate 29, an indirectly heated cathode 30, a cathode heater 31, a screen grid 32, and a control grid 33. The tube preferably has an equipotential cathode to pre-

vent disturbance of the grid voltage by fluctuations in the heating current.

The control grid 33 is connected to one terminal of the variable resistor 14 by a circuit including a standard battery 34 and a resistor 35. No current is drawn from this battery in operation as it merely controls the potential of the control grid 33. The battery minimizes the importance of changes in the characteristics of tube 27 and increases the efficiency of the voltage control.

The temperature of the cathode heater 31 is held constant by means of the regulating transformers 36, the series section 37 being on a slightly open unsaturated iron core 38, and the shunt section 39 being on a closed saturated core 40. Thus, the cathode heater 31 is energized from the secondary winding 41 of the transformer 1, line voltage fluctuations of the A. C. output being prevented from affecting the constant temperature of the heater by virtue of the automatic action of the regulating transformers 36.

The indirectly heated cathode 30 of the tube 27 is connected to the other terminal of the variable resistor 14 at 42. Thus, changes in the output voltage of the high voltage rectifier change the voltage across the variable resistor 14, changing the grid potential of amplifier 27, which results in the functioning of the impedance means 21 to offset the voltage change by an equal and opposite voltage. The cathode and anode of the tube 27 are supplied with an operating potential from the secondary winding 43 of the transformer 1 by means including a vacuum tube rectifier 44 and filters 46, the rectifier 44 being preferably of the "80" type.

The cathode-anode circuit of the tube 27 includes a pair of resistors 47 and a third resistor 48 in series with the anode 29. The screen grid 32 of the tube is connected between the resistors 47, these resistors and the resistor 48 having such relative resistances that the cathode to plate potential of the tube is not affected by fluctuations of the operating voltage from the A. C. input. The screen and plate voltage changes are thus balanced off against each other by a proper selection of the resistances of resistors 47 and 48. This is best accomplished by trial and error, the resistances of the resistors being adjusted until changes in the plate voltage are balanced by changes in the screen voltage. Thus, the sensitivity of the tube 27 which is preferably of the "57" type is utilized without interference from fluctuations of the A. C. output.

In the present embodiment, the second amplifier tube 28 is similar to the first amplifier 27 and is supplied with an operating potential by similar means including the secondary winding 49, vacuum tube rectifier 50, and filters 51. The balancing of the plate and screen voltage changes is likewise accomplished by means of a pair of resistors 52 and a third resistor 54 in the plate-cathode circuit.

In connection with the elimination of the ripple in the output of the regulator, it is necessary to provide adequate shielding for the first amplifier tube 27 and the potentiometer 12. Also, due to the high gain of the amplifier and to imperfections in the resistor 12, not easily avoidable, fluctuations inherent in the tube appear larger than the theoretical residual ripple in the output. The most practical solution of these problems is to use tube 27 for direct current control only. I have achieved this result by means of condenser 51 which I connect from the positive end of the potentiometer 12 to the control

grid 33 of the second amplifier tube 28. Connected in this manner, the condenser 51 serves the double function of blocking off rapid fluctuations in the potential of grid 33 of tube 28 and simultaneously impressing upon tube 28 the proper potential for the correction of any alternating component in the regulated power output of the tubes 23.

The vacuum tube amplifying means 22 is shielded within the voltage control unit 10 by a shield 55, the amplifiers 27 and 28 being shielded from each other by a shield 56 disposed therebetween.

Referring to Fig. 3, I illustrate the voltage current relations of my voltage regulator, output voltage being plotted against line voltage. Attention is directed to the almost perfect regulation provided for various values of load current. The characteristics shown in the graph indicate that an increase of load of 30 milliamperes gives a drop in voltage of less than 1 part in 10,000. This is true up to 100 milliamperes, the maximum load for which the present embodiment was designed. The total change in voltage corresponding to a line change from 5% undervoltage to 5% overvoltage is about 1 part in 10,000, an achieved reduction of 1000 to 1, and an even better reduction factor for smaller changes since the relation is non-linear.

In operation, a voltage is selected somewhat greater than that desired by manipulating the manual control means 20. Fractional voltages are obtained by adjusting the variable resistor 14. The milliammeter 18 indicates the fraction of the above selected voltage at the output terminals. In this manner, any voltage within the range of the apparatus is available at a moment's notice. Otherwise, my voltage regulator is entirely automatic in operation and regulates the output of the rectifier to such an extent, both against fluctuations in the A. C. input and against voltage drop due to its own internal resistance, that it furnishes a far more constant voltage than any storage battery even in the best condition.

The direct current amplifier, in spite of its tremendous gain, about 250,000, is extremely stable, provided the circuits are well shielded, because of the inherent ability of my circuit to correct any variation in the current through the output potential divider. The fundamental action of the circuit is that of a correction device, the control voltage being obtained from a small increment in the current through the potentiometer. The voltage thus obtained is the proper voltage to prevent further change in the output voltage.

If I let G equal the gain of the amplifier, V_i equal input voltage, r_1 equal the resistance of the variable resistor 14, R_0 equal the resistance of potentiometer 12, i equal the current through R_0 , and V_0 equal the output voltage, then

$$\Delta V_i = G r_1 \Delta i = \left(G \frac{r_1}{R_0} + 1 \right) \Delta V_0$$

Correction

$$\frac{\Delta V_i}{\Delta V_0} = G \frac{r_1}{R_0} + 1$$

In view of the high gain of the amplifier, this factor can be made very large. However, two secondary effects make it impossible to achieve the expected constancy in the output voltage against line voltage changes. These are involved in the effects of the changes on the first control amplifier, its output voltage to the grid of tube 28 being affected by its control grid

voltage as is desired. It is changed also by variations in (1) its plate voltage, (2) its screen voltage, and (3) its cathode temperature.

Variations (1) and (2) are controlled by my use of a multiple grid tube in the circuit in which use is made of the fact that the effect of the variations in the screen grid potential on the output voltage of the tube are opposite to the effect of the variations of the plate potential. Hence, by adjusting the resistance values of resistors 47 until the proper fraction of the change in the input voltage is impressed on the screen grid, the variations of output voltage can be reduced to a small fraction of those of the input voltage. Account must be taken of the screen grid current through upper resistor 47, best considered as due to an additional resistor r_7 which may in certain cases be useful and the resistance of resistor 48 must be greater than a certain minimum value or the screen grid lead must be interchanged with the plate resistor lead in the voltage divider.

Letting MG_2 equal the amplification factor of the screen grid, r_4 equal the resistance of lower resistor 47, r_5 equal the resistance of upper resistor 47, r_6 the resistance of resistor 48, and Z_p equal the plate impedance of the tube, then

$$\Delta V_0 = \Delta V_i - \left(\frac{r_4}{r_4 + r_5} \right) \Delta V_i \frac{MG_2 r_5}{r_5 + Z_p} = 0$$

$$MG_2 \frac{r_5}{r_5 + Z_p} = \frac{r_4 + r_5}{r_4}$$

$$\frac{r_5}{r_4} = \frac{MG_2}{1 + \frac{Z_p}{r_5}} - 1$$

This expression is approximate, neglecting r_7 .

Writing for the gain of the screen grid, G_{G_2} , then

$$\frac{r_5}{r_4} = G_{G_2} - 1$$

The best method of determining the proper resistances of the resistors 47 is by trial, since non-linear analysis is needed to determine the actual characteristics. The circuit balances only a relatively short region of variation of the plate voltage due to the non-linearity of the tube, but the action turns out to satisfy the requirements in an excellent manner. My circuit furnishes any desired relative variation of amplifier output voltage when the proper resistances of resistors 47 and 48 are chosen. Use is made of this feature in this invention to correct out the final variations in the output voltage and thus give the perfection of bridge correction circuits without their difficulties of adjustment.

The cathode temperature changes could be balanced out with this bridge circuit, but because there is a considerable time lag between the change of cathode temperature and the line voltage change, there would exist a time of erroneous voltage. I prefer to use an auxiliary regulator circuit, as pointed out above, comprising a pair of magnetic cores, one saturated and the other unsaturated, such as the Rieber regulating transformer set. Since only the heating value of the current needs regulation, the wave distortion does not matter.

Another advantage of my circuit is its voltage regulation on variable currents. Besides offering very low resistance to the currents, it corrects for the voltage drop in the rectifier or other source of power. Its action can be most simply explained with the aid of mathematical symbols.

If, again, G is the voltage gain of the direct current amplifier and $R_i = Z_p + r$, the total internal resistance composed of the plate impedance of the output tubes, Z_p , and the resistance of the transformer, rectifier and filter system, r , the voltage drop is then $R_i \Delta i$ to be corrected out by the circuit. But I showed that

$$\Delta V_0 = \frac{R_0}{G r_1} \Delta V_i$$

approximately, since

$$1 < \frac{G r_1}{R_0}$$

and therefore

$$\Delta V_0 = \frac{R_0 R_i}{G r_1} \Delta i$$

The effective internal resistance is

$$\frac{\Delta V_0}{\Delta i} = \frac{R_0 R_i}{G r_1}$$

It is thus clear that the circuit corrects the voltage drop due to internal resistance in the same way that it corrects the variations due to line voltage changes. The regulation of the illustrated embodiment is about five hundred times better than that of a good rectifier filter circuit, actually .001 ohm per volt. Further, my rectifier gives considerable correction of the machine for any unfiltered ripple, an undesirable fault with certain prior schemes. Thus, my rectifier greatly decreases the cost of the filter circuit for a given purity of direct current.

As to the uses of my apparatus, I might mention the replacement of expensive rapidly depreciating equipment in the laboratory. My invention has been satisfactorily used to supply current to a large high voltage potential divider for a class in radio-activity, whose members simultaneously required variable voltages for their electrometers and ionization chambers. I use it to supply potential for a mass spectrometer. It has also been used with success for a precision counter of atomic disintegration particles, which allows distinction of the kinds of particle. In fact, I obtained accurate counts of a few alpha particles per minute in a background of hundreds of X-ray electrons per minute. It may also be used in accurate radio work, in gaseous discharges, and many other installations where high potential storage batteries are now used.

Attention is directed to the fact that the feature of balance referred to above is dependent on the quantitative setting of the resistors 47 and 48. It is the result obtained by the use of the proper relative values of these resistors which constitutes an important feature of the present invention. The circuit will not produce the desired results until the proper values of the resistors, as explained above, are chosen. The proper adjustment of these resistors is essential to the action of the whole device. The invention also contemplates controlled deviations from such balance.

My invention makes available a power source of high potential direct current sufficiently constant to fully supplant the storage battery sources used in most laboratories. Storage battery sources of high potential direct current are extremely costly both in initial investment and upkeep, and further, they depreciate rapidly even under the best of care. Single tube voltage regulators have been used in some laboratories, but these sources are not suitable for furnishing power comparable to ordinary storage batteries. The equivalent resistance of the systems of Johnson and Street at

Bartol Laboratory, published in the Journal of the Franklin Institute, 1932, was of the order of 30 ohms per volt, whereas good storage batteries have an internal resistance of less than 1 ohm per volt.

I developed my invention specifically to replace a storage battery high potential source of direct current. The invention has proved successful for one of the most exacting services of the battery source, that of counting ions in an ionization chamber by a method known as linear amplification, and has proved itself to be more satisfactory in every respect than a storage battery. A storage battery is generally used with protective resistances amounting to 1 ohm per volt. My new source of 2500 volts has an internal resistance better than the battery without the protective resistances.

My voltage regulator is automatically stable in operation and overcomes without any special stabilizing the chief difficulty with direct coupled amplifiers, suitable for amplification of direct currents. In fact with proper by-pass condensers in the circuit the amplifier may be used to amplify alternating currents. My circuit is so stable that more than two tubes can be used as shown, with corresponding improvements in control and regulation. If desired, the standard battery 34 may be omitted, but this will result in some loss in accuracy of control.

There are no restrictions on the type of tubes which may be used. The voltage gain tube may be a tetrode or a pentode. In general, tubes with a high voltage gain are chosen for the amplifier, tubes with a high mutual conductance being chosen for the impedance or regulating means 21. In my preferred embodiment, however, the amplifier comprises tubes having at least two grids to obtain compensation of line voltage fluctuations, a tetrode or pentode being best suited for this service. The second amplifier tube can be any sort of tube. However, with two amplifier tubes of the "57" type, I have obtained the phenomenal success mentioned above.

Considerable advantage is gained by the use of tubes with an equipotential cathode, since the grid voltage would otherwise be disturbed by fluctuations of the heating current. This is especially true of the first stage amplifier tube. The simplicity of operation of my apparatus is very important. The output voltage is controlled by two simple adjustments. While I contemplate the use of a single transformer with fixed primary voltage and a tapped high voltage secondary, the apparatus herein described is definitely preferable for the high voltage set-up. If desired, auxiliary transformers may be used to supply the rectifiers 49 and 50, as these extra units may be cheaper than the windings on the control transformer.

Of course, the regulating or impedance means 21 may be a single tube instead of a bank of tubes in parallel as shown. The second amplifier tube 28 does not require the balanced circuit described, although I prefer this arrangement. An amplifier omitting the second amplifier tube is contemplated and because of the balanced circuit would give nearly as good correction characteristics except that its current regulation would be much poorer. The standard battery and the leads to the resistor 14 are then both reversed to allow for the phase change in vacuum tube 28. Also, the resistor 35 which protects the standard battery 34 when warming up the tubes may be omitted if desired.

I consider the balancing circuit of the first amplifier tube to be the most important feature of my invention because on this circuit depends the perfection of operation of my device. This circuit is useful in other direct current amplifier applications as will be apparent to those skilled in the art.

If desired, a bridge of tubes may be used in place of the first amplifier 27 to eliminate the need for the control of the cathode temperature, but my present arrangement is more satisfactory from the standpoint of simplicity of adjustment because the regulator transformers can be adjusted permanently at the factory.

I have illustrated and described my improvements in an embodiment which I have found very practical. I have not attempted to illustrate or describe other embodiments or adaptations as it is believed this disclosure will enable those skilled in the art to embody or adapt my improvements as may be desired.

Having thus described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply of low voltage, a high voltage rectifier having a transformer energized from the tapped primary winding of said first transformer, a variable potentiometer including a variable resistor connected in parallel circuit relation with the output circuit of said high voltage rectifier, manually controlled means mechanically connecting said variable potentiometer and said first transformer for simultaneous adjustment, vacuum tube impedance means in series circuit relation with the output circuit of said high voltage rectifier, vacuum tube amplifying means acting to control said impedance means in response to the voltage across said variable resistor to keep the potential of said output circuit constant in accordance with the setting of said manually controlled means, and vacuum tube rectifying means and filters for supplying said vacuum tube impedance and amplifying means with operating power from the secondary windings of said first transformer.

2. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a high voltage rectifier having a transformer energized from the primary winding of said first transformer, a variable potentiometer including a variable resistor connected in parallel circuit relation with the output circuit of said high voltage rectifier, manually controlled means mechanically connecting said variable potentiometer and said first transformer for simultaneous adjustment, impedance means in series circuit relation with the output circuit of said high voltage rectifier, amplifying means acting to control said impedance means in response to the voltage across said variable resistor to keep the potential of said output circuit constant in accordance with the setting of said manually controlled means, and rectifying means and filters for supplying said impedance and amplifying means with operating power.

3. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a rectifier having a transformer energized from the primary winding of said first transformer, a variable poten-

tiometer including a variable resistor connected in parallel circuit relation with the output circuit of said rectifier, manually controlled means mechanically connecting said variable potentiometer and said first transformer for simultaneous adjustment, vacuum tube regulating means in series circuit relation with the output circuit of said rectifier, and vacuum tube amplifying means acting to control said regulating means in response to the voltage across said resistor to keep the potential of said output circuit constant.

4. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a rectifier having a transformer energized from the primary winding of said first transformer, a variable potentiometer including a resistor connected in parallel circuit relation with the output circuit of said rectifier, means mechanically connecting said variable potentiometer and first transformer for simultaneous adjustment, vacuum tube regulating means in the output circuit of said rectifier, and vacuum tube amplifying means acting to control said regulating means in response to the voltage across said resistor to keep the potential of said output circuit constant.

5. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a rectifier having a transformer energized from the primary winding of said first transformer, a variable potentiometer connected across the output circuit of said rectifier, manually controlled means mechanically connecting said variable potentiometer and first transformer for simultaneous adjustment, vacuum tube regulating means in the output circuit of said rectifier, vacuum tube amplifying means acting to control said regulating means in response to the voltage across said variable potentiometer to keep the potential of said output circuit constant in accordance with the setting of said manually controlled means, and vacuum tube rectifying means and filters for supplying said vacuum tube regulating and amplifying means with operating power from the secondary windings of said transformer.

6. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a tube rectifier having a transformer energized from the primary winding of said first transformer, a variable potentiometer connected across the output circuit of said rectifier, manually controlled means mechanically connecting said variable potentiometer and first transformer for simultaneous adjustment, regulating means in the output circuit of said rectifier, and amplifying means acting to control said regulating means in response to the voltage across said variable potentiometer to keep the potential of said output circuit constant in accordance with the setting of said manually controlled means, said potentiometer including a manually variable resistor.

7. A voltage regulator comprising a transformer having a primary winding and secondary windings, the primary winding being energized by an alternating current supply, a tube rectifier having a transformer energized from the primary winding of said first transformer, a variable potentiometer connected across the output circuit of said rectifier, manually controlled means me-

chanically connecting said variable potentiometer and first transformer for simultaneous adjustment, regulating means in the output circuit of said rectifier, and amplifying means acting to control said regulating means in response to the voltage across said variable potentiometer to keep the potential of said output circuit constant in accordance with the setting of said manually controlled means.

8. A voltage regulator comprising a variable potentiometer including a variable resistor in parallel circuit relation with a high voltage direct current source subject to fluctuations, a vacuum tube having an anode and a cathode in series circuit relation with said source, the vacuum tube having a control grid, and means acting to amplify the voltage across said variable resistor and operate said control grid in accordance therewith so that a tendency for the voltage to change is met by an equal and opposite voltage resisting the change, said means comprising a vacuum tube of the tetrode or pentode type having an anode, an equipotential cathode, a cathode heater, a screen grid, and a control grid, a circuit including a standard battery connecting said control grid to one terminal of said variable resistor, a circuit connecting said cathode to the other terminal of said resistor, means including a self-regulating transformer for energizing said cathode heater, and means including a rectifier and filter for supplying said cathode and anode with an operating voltage, the cathode-anode circuit comprising a pair of resistors between which is connected the screen grid, and a third resistor in series with the anode, said pair of resistors and third resistor having such relative resistances that the cathode-to-anode voltage of the tube is not affected by fluctuation of the operating voltage.

9. A voltage regulator comprising a variable potentiometer including a resistor in parallel circuit relation with a direct current source subject to fluctuations, a vacuum tube having an anode and a cathode in series circuit relation with said source, the vacuum tube having a control grid, and means acting to amplify the voltage across said resistor and operate said control grid in accordance therewith so that a tendency for the voltage to change is met by an equal and opposite voltage resisting the change, said means comprising a vacuum tube of the pentode type having an anode, an equipotential cathode, a cathode heater, a screen grid, and a control grid, a circuit including a standard battery connecting said control grid to one terminal of said resistor, a circuit connecting said cathode to the other terminal of said resistor, means for energizing said cathode heater, and means including a rectifier and filter for supplying said cathode and anode with an operating voltage, the cathode-anode circuit comprising a pair of resistors between which is connected the screen grid, and a third resistor in series with the anode, said pair of resistors and third resistor having such relative resistances that the tube is not affected by fluctuation of the operating voltage.

10. A voltage regulator comprising a variable potentiometer including a variable resistor in parallel circuit relation with a direct current source subject to fluctuations, a vacuum tube regulator in series circuit relation with said source, and means acting to amplify the voltage across said variable resistor and operate said regulator in accordance therewith so that the output voltage is kept constant, said means comprising a vacuum tube of the pentode type having an anode, 75

an equipotential cathode, a cathode heater, a screen grid, and a control grid, a circuit including a standard battery connecting said control grid to one terminal of said variable resistor, a circuit
 5 connecting said cathode to the other terminal of said resistor, means including a self-regulating transformer or transformer set for energizing said cathode heater, and means including a rectifier and filter for supplying said cathode and
 10 anode with an operating voltage, the cathode-anode circuit comprising a pair of resistors between which is connected the screen grid, and a third resistor in series with the anode, said pair of resistors and third resistor having such relative
 15 resistances that the tube is not affected by fluctuation of the operating voltage.

11. A voltage regulator comprising a potentiometer including a resistor in parallel circuit relation with a direct current source subject to
 20 fluctuations, a regulator in series circuit relation with said source, and means acting to amplify the voltage across said resistor and operate said regulator in accordance therewith so that the
 25 output voltage is kept constant, said means comprising a vacuum tube having an anode, an equipotential cathode, a screen grid, and a control grid, a circuit including a standard battery connecting said control grid to one terminal of said
 30 resistor, a circuit connecting said cathode to the other terminal of said resistor, and means including a rectifier and filter for supplying said cathode and anode with an operating voltage, the
 35 cathode-anode circuit comprising a pair of resistors between which is connected the screen grid, and a third resistor in series with the anode, said pair of resistors and third resistor having
 such relative resistances that the tube is not affected by fluctuation of the operating voltage.

12. A voltage regulator comprising a variable
 40 potentiometer including a variable resistor in parallel circuit relation with a high voltage direct current source subject to fluctuations, a voltage regulator operatively associated with
 45 said source, means acting to amplify the voltage across said variable resistor and operate said regulator in accordance therewith, said means comprising a vacuum tube of the pentode type having
 50 an anode, an equipotential cathode, a screen grid, and a control grid, the input circuit of said tube including said variable resistor, and means including a rectifier and filter for supplying said
 55 cathode and anode with an operating potential, the cathode-anode circuit comprising a pair of resistors between which is connected the screen grid, and a third resistor in series with the anode,
 said pair of resistors and third resistor having such relative resistances that the tube is not affected by fluctuation of the operating potential.

13. A voltage regulator comprising a variable
 60 potentiometer including a resistor in parallel circuit relation with a direct current source subject to fluctuations, a regulator operatively associated with said source, means acting to amplify the
 65 voltage across said variable resistor and operate said regulator in accordance therewith, said means comprising a vacuum tube having an anode, an equipotential cathode, a screen grid,
 70 and a control grid, the input circuit of said tube including said resistor, and means for supplying said cathode and anode with an operating potential, the cathode-anode circuit comprising a
 75 pair of resistors between which is connected the screen grid, and a third resistor in series with the anode, said pair of resistors and third resistor having such relative resistances that the

tube is not affected by fluctuation of the operating potential.

14. A voltage regulator including a transformer having a primary and a plurality of secondary
 5 windings, an alternating current supply energizing said primary winding, a rectifier connected with said primary winding, means for maintaining constant the output voltage of said rectifier,
 10 comprising a vacuum tube in circuit with said rectifier, a resistor in parallel circuit relation with the output terminals of said rectifier, means connected with the control grid of said tube to
 15 amplify the voltage across the resistor and operate the control grid whereby a tendency for the voltage to change is met by an opposite voltage
 20 resisting the change, comprising a further vacuum tube in circuit with said resistor, and means for supplying the cathode and anode of said last named tube with an operating voltage, said last
 named means including one of the secondary
 25 transformer windings and rectifying means between the same and the tube to be supplied.

15. A voltage regulator including a transformer having primary and secondary windings,
 25 a current supply energizing said primary winding, an output circuit connected to said primary winding, means for maintaining constant the output voltage of said circuit, comprising a vacuum
 30 tube having a control grid, a resistor in parallel circuit relation with the output terminals of said circuit, means connected with said control grid to amplify the voltage across the resistor and
 35 operate the control grid whereby a tendency for the voltage to change is met by an equal and opposite voltage resisting the change, comprising a further vacuum tube in circuit with said resistor,
 40 and means for supplying the anode of said last named tube with an operating voltage, said last named means including a secondary winding of said transformer and rectifying means
 45 between the same and the tube to be supplied.

16. A voltage regulator including a transformer having primary and secondary windings, a current
 50 supply energizing said primary winding, an output circuit connected to said primary winding, means for maintaining constant the output voltage of said circuit, comprising a resistor in parallel
 55 circuit relation with the output terminals of said circuit, means to amplify the voltage across the resistor, comprising a vacuum tube in circuit with said resistor, and means for supplying said
 60 tube with an operating voltage, said last named means including a secondary winding of said transformer.

17. In a voltage regulator for a direct voltage
 65 current source subject to fluctuations and connected with a variable load, a variable resistor including a potentiometer in parallel circuit relation with said source, means for amplifying the
 70 voltage across said resistor and for correcting rapid fluctuations in the current to be regulated without objectionable time lag, comprising a pair of vacuum tubes, and means for constituting said
 75 amplifying means a two-stage amplifier for slow fluctuations and a one-stage amplifier for fast
 fluctuations including a condenser for connecting the control grid of one of said tubes to one
 terminal of said potentiometer, and means including a standard battery for connecting the control grid of the other tube to the other terminal of said potentiometer.

18. In a voltage regulator for an electrical voltage source subject to fluctuations and connected
 75 with a variable load, variable resistance means in parallel circuit relation with said source, means

for amplifying the voltage across said resistance means and for correcting rapid fluctuations in the current to be regulated without objectionable time lag, comprising a pair of vacuum tubes, and means for constituting said amplifying means a two-stage amplifier for slow fluctuations and a one-stage amplifier for fast fluctuations includ-

ing a condenser for connecting the control grid of one of said tubes to one terminal of said resistance means, and means connecting the control grid of the other tube to the other terminal of said resistance means.

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