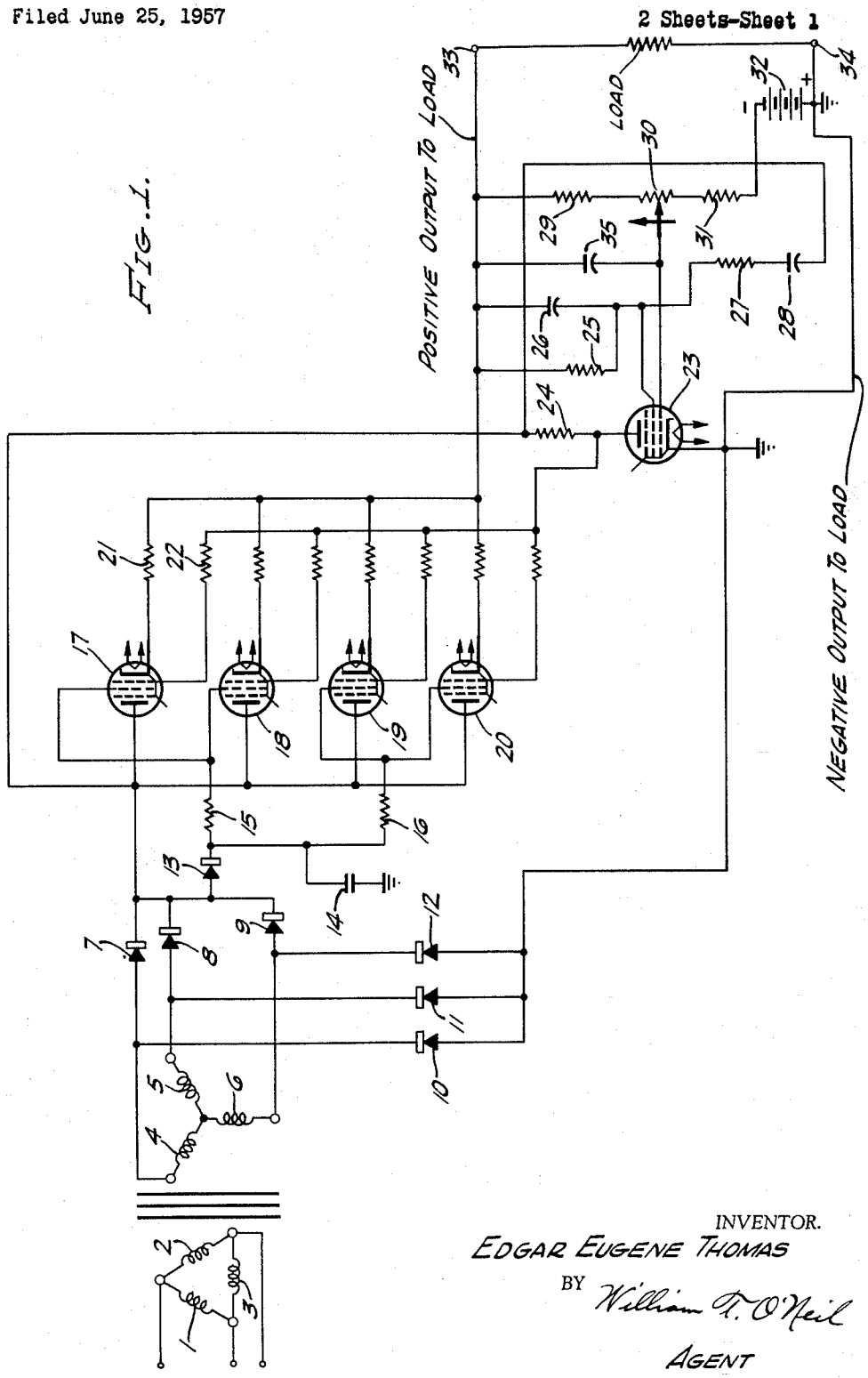
Oct. 17, 1961 E. E. THOMAS 3,005,143

ELECTRONICALLY REGULATED POWER SUPPLY

Filed June 25, 1957 2 Sheets-Sheet 1

FIG. 1.



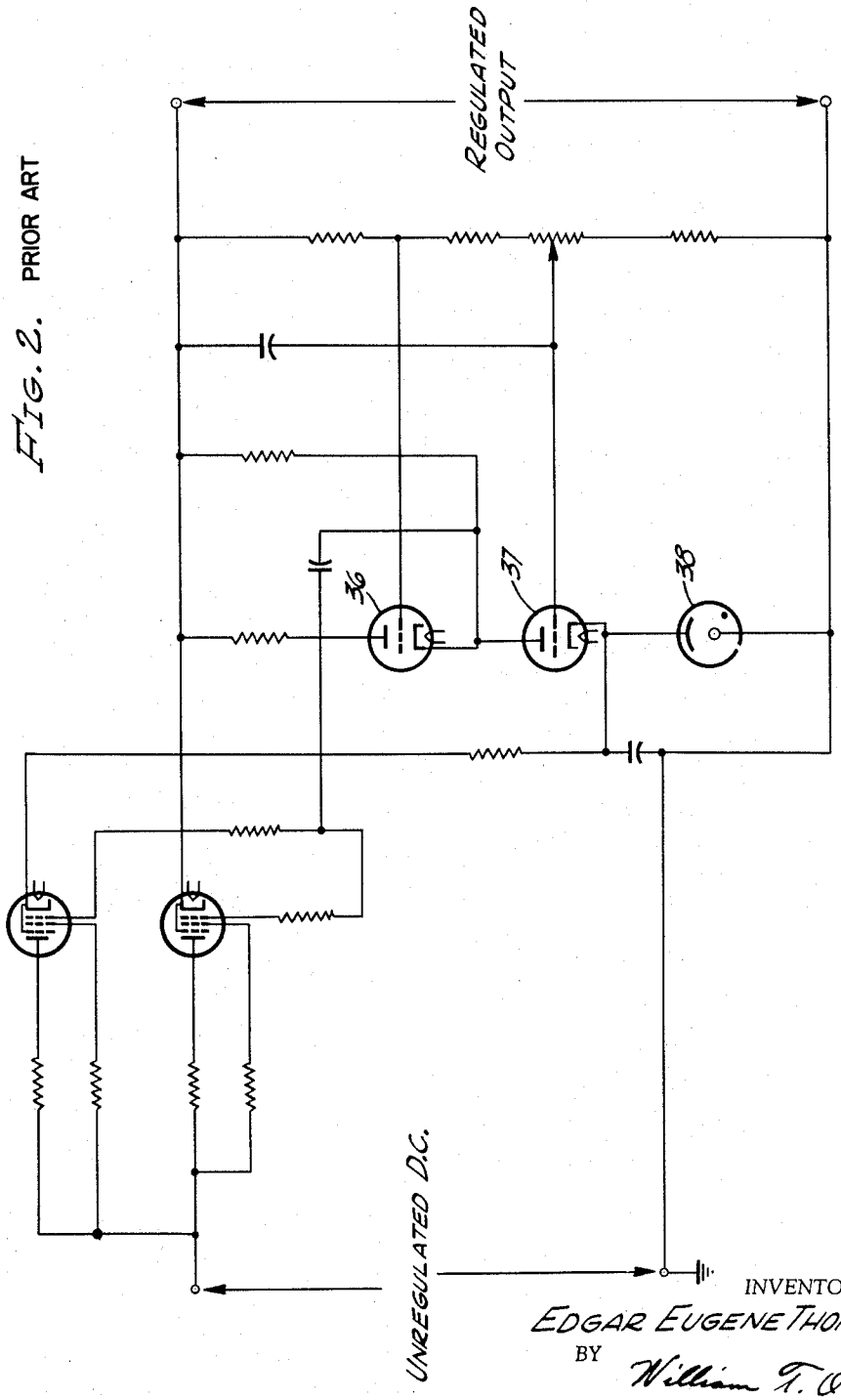
INVENTOR.
EDGAR EUGENE THOMAS
BY William T. O'Neil
AGENT

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FIG. 2. PRIOR ART



INVENTOR.
EDGAR EUGENE THOMAS
BY William T. O'Neil
AGENT

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3,005,143 ELECTRONICALLY REGULATED POWER SUPPLY

Edgar Eugene Thomas, Whittier, Calif., assignor to Gilfillan Bros., Inc., Los Angeles, Calif., a corporation of California

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12 Claims. (Cl. 321—18)

This invention relates to electronic regulated power supplies of the type ordinarily used as a source for supplying direct current to electronic equipment or other applications where it is desired that the terminal voltage of the said source be relatively constant. The principal object of the invention is the provision of this regulated or constant voltage through the use of an improved regulator circuit which substantially enhances the economy of construction of the said regulator by reducing the amount of power which is inherently lost or dissipated in the regulator circuit itself. The advantages of the invention in its many applications will be evident to those skilled in the art. The prior art in electronic regulators is delineated in considerable detail in most textbooks and handbooks commonly employed in the field of electronic engineering. These textbooks include "Radio Engineers Handbook" by Frederick Emmons Terman, published by McGraw-Hill Book Company; "Reference Data for Radio Engineers," published by International Telephone & Telegraph Corp., 67 Broad Street, New York 4, New York, and printed in the United States by American Book Company, Stratford Press, Inc., New York; and in vacuum tube manufacturers technical data as published by companies such as the General Electric Co., Schenectady, New York, Radio Corporation of America, and Sylvania Electric Products, Inc., Emporium, Pennsylvania.

In addition there are many prior art United States and foreign patents descriptive of this art. Following are a few pertinent U.S. patents:

Vance, Re. 21,749
Norgaard, 2,219,195
White, 2,268,790

Patent No. Re. 21,749 to Vance fully discusses the operation of the basic series regulator type of electronically regulated power supply. Vance shows a series regulator vacuum tube such as **29** on his FIGURE 1 and other vacuum tubes for controlling the operation for this series regulator tube by controlling the potential of its control grid **77** in accordance with sensed variations in the voltage across the load **23**. Although Vance shows only a triode regulator tube, it is well known that one or a plurality of tetrode, pentode, or "beam power" tubes can be substituted for the triode regulator tube. The advantage of substituting one of these multigrid type tubes instead of a triode in this application is concerned with the inherently lower effective electron beam resistance thereby obtainable. Since the operation of the series regulator tube might be compared to the operation of a series hand operated variable resistor located between a source and a load, and used to adjust a load voltage, the lowest value to which the equivalent resistance of the vacuum tube series regulator tube can be adjusted will determine the minimum amount of electric power which it is necessary to dissipate across the series regulator tube. In the comparison given above it should be noted that a hand operated variable resistor might normally be expected to be adjustable to essentially zero resistance. However, by their nature, vacuum tubes and many other electric discharge devices as a class exhibit irreducible minimums of series resistance which must be considered in the design of series regulated electronic power supplies. Since, as indicated

above, it is desirable from the point of view of power efficiency and economy of parts and components such as rectifiers, power transformers, etc., that the use of multigrid series regulator tubes often becomes desirable.

FIGURE 1 is a circuit diagram of a complete rectifier and regulator arrangement according to the present invention.

FIGURE 2 illustrates prior art.

One of the important design problems which presents itself when multigrid tubes are used thusly is the problem of obtaining a suitable screen grid voltage source. Often a screen grid is simply tied to the anode of a series regulator tube allowing for the inclusion of small value resistor for the purpose of limiting current through the screen grid. FIGURE 2 of this patent application shows a circuit in which this type of screen grid connection is employed. This circuit was obtained from the publications of the "Engineering Data Service" of Sylvania Electric Products, Inc., Radio Tube Division, showing the employment of the Type 6308 which is a cold cathode glow discharge diode for use as a voltage reference tube **38** as shown, although not directly related to the subject invention. The entire FIGURE 2 of this application is in fact shown for prior art purposes only to illustrate one type of screen grid series regulator tube connection currently employed, and over which it is the accomplished purpose of the instant invention to afford a substantial improvement.

In addition to the prior art discussed above, it should be pointed out that the use of a fixed potential derived from some separate source such as another power supply is known to have been used to supply screen grid voltage to series regulator tubes. There are several significant disadvantages to such a system however. In addition to the fact that considerable additional circuitry and complication is occasioned, a constant screen voltage has the important disadvantage of inflexibility. When a heavy load current is being drawn through the said screen grid regulator tube, the anode voltage tends to be reduced due to transformer, rectifier, and filter component voltage drops ahead of the regulator tube itself. The result of this can well be a disproportionately great screen current due to the well known screen grid characteristic causing excessive screen currents to be drawn when the anode voltage falls below some critical value compared to the said screen grid potential. The effect of this phenomenon is likely to be a limitation on the maximum load carrying capability of the screen grid regulator tube because of excessive screen grid power dissipation, thereby cancelling perhaps the most significant advantage of using a screen grid type tube as a series regulator. This fact is probably the most important consideration explaining the widespread use of triode-connected screen grid type tubes as series regulators in regulated power supplies.

Referring now to FIGURE 1, the operation of the circuit of the invention will be explained. As this explanation proceeds, it will be obvious to those skilled in the art what further advantages over the prior art accrue in view of the simplicity and effectiveness of the circuit of this invention.

The major portion of the components as shown in FIGURE 1 perform functions comparable to their counterparts in FIGURE 2. Although the amplifier tube **23** in FIGURE 1 takes the place of the two tube cascode connected amplifier comprising tubes **36** and **37** in FIGURE 2, this fact is of no significance in the present invention, it being possible as a design choice to use the said cascode amplifier circuit of FIGURE 2 in place of amplifier tube **23** in FIGURE 1.

In FIGURE 1, a complete rectifier and regulator arrangement is shown. The transformer windings **1**, **2** and **3** represent the primaries of a three-phase transformer

arrangement, and windings 4, 5 and 6 are the related secondary windings. This arrangement contemplates the use of a three-phase power input source. Rectifier diodes 7, 8, 9, 10, 11 and 12 are connected in a standard three-phase rectifier bridge, the negative terminal of which is the common junction of rectifiers 10, 11 and 12, a positive terminal being the common juncture of rectifier diodes 7, 8 and 9. It will be readily understood, of course, that this invention is in no way limited to the rectifier and transformer configuration employed, and any well known single phase or polyphase arrangement could also have been used. Since the unfiltered output of the three-phase rectifier bridge as shown is a pulsating direct current, the value of which never falls below an appreciable fraction of its peak value, no filter choke or capacitor is employed in the circuit of FIGURE 1. It would normally be required, however, that at least a capacitive filter, with or without a filter choke, would be used with a single phase arrangement. It will be noted that four series regulator tubes, 17, 18, 19 and 20, of the screen grid type are used in parallel, their anodes being connected together and supplied from the positive terminal of the rectifier bridge. It is felt that the operation of amplifier 23 and its associated anode resistor 24, together with the voltage sensing and adjusting network 29, 30 and 31, is so well known and sufficiently thoroughly explained in the technical literature, including the references hereinbefore mentioned, that a detailed description is unnecessary. The voltage reference battery 32 is, of course, only one of many types of voltage reference devices suitable for this application. Referring to FIGURE 2, another type of voltage reference, the glow tube 38 was used, and a similar configuration could equally well have been used in the arrangement of FIGURE 1. This adaptation would be obvious to anyone skilled in the art. Capacitor 28, resistor 27, and resistor 25 and capacitor 26 are associated in a well known manner with the screen grid supply of discharge device 23 and with the introduction of residual output ripple voltage thereon. The effect of this ripple voltage introduction is the reduction of the amount of rectifier ripple appearing across the output terminals 33 and 34. Capacitor 35 also affords an important function in this regard in that it injects residual ripple from lead 33 onto the control grid of discharge device 23, thereby aiding in the further reduction of output ripple. It will be noted that the output taken from the anode of discharge device 23 is fed to each series regulator tube, 17, 18, 19 and 20 control grid in parallel through individual series resistors, as for example, 22. Since no one of these series regulator tubes 17, 18, 19 and 20 is permitted to draw grid current (i.e. operate in a positive grid region) no current flows through 22 or the corresponding grid series resistors for 18, 19 and 20. The only purpose of these series resistors is to reduce the tendency for parasitic oscillation to develop in the paralleled series regulator tubes.

Returning to the positive terminal of the diode rectifier bridge, that is the common juncture of diode rectifiers 7, 8 and 9, it will be noted that the anode of an additional diode rectifier 13 is connected thereto. The cathode terminal of 13 is by-passed to ground by capacitor 14 and also connected to the screen grids of 17 and 18 through series resistor 15 and to the screen grids of 19 and 20 through series resistor 16. The waveform at the anode of 13 depends on the nature of the rectifier circuit ahead of it. For a three-phase rectifier, as illustrated in FIGURE 1, it has already been pointed out that the pulsating D.C. voltage always remains a substantial fraction of the peak value. In other words, it does not fall to zero instantaneously at any point during the cycle as might be expected with certain single phase rectifier configurations. Since the smoothed value of any pulsating D.C. waveform is necessarily less than the peak value, a screen grid voltage for the series regulator tubes 17, 18, 19 and 20, which is higher than the average anode voltage of these same series regulator tubes, can be obtained by peak rectification of the same pulsating D.C. waveform. The function of capacitor 14 is to store the near peak value thus obtained and supply this to the series regulator tube screen grids through series resistors 15 and 16, and to give smoothing of the screen grid voltage thus obtained.

For the circuit of FIGURE 1, suitable resistor and capacitor values and tube types are listed, based on the assumption of a 400 cycle three-phase power source as follows:

Capacitor 14	0.68 microfarad.
Resistors 15 and 16	100 ohms.
Tubes 17, 18, 19 and 20	Type 5902.

as manufactured by General Electric Company and other vacuum tube suppliers. The above values except for capacitor 14, which would be larger than 0.68 microfarad, are also suitable for 60 cycle single phase rectifier versions of the equipment.

Cathode output resistors for each of the series regulator tubes 17, 18, 19 and 20, such as, for example, 21, serve the purpose of equalizing the amount of load drawn by each regulator tube by introducing degeneration in each of 17, 18, 19 and 20 individually. A suitable value for 21 and its counterpart for tubes 18, 19 and 20 is 22 ohms. The function of resistors 15 and 16 is primarily that of screen current limiting under extreme conditions. As stated before, it is well known that low plate voltage on a series regulator tube of the screen grid type can result in excessive screen grid current necessitating some limiting resistance as 15 and 16. It should be pointed out, however, that need for these resistors is not the same as was discussed in connection with the prior art fixed screen grid voltage arrangement since there is an action in the circuit of the present invention which minimizes this excessive screen grid current effect. It will be noted that the same factors which tend to decrease the series regulator tube anode voltage, as a result of the voltage regulation characteristics of the rectifier, transformer, etc., also operates to reduce the potential across capacitor 14. In this manner screen voltage for 17, 18, 19 and 20 is reduced in proportion to the reduction of plate voltage, thereby substantially reducing the tendency of the screen grids to draw excessive current and thereby dissipate excessive power.

All rectifier diodes shown in FIGURE 1 can be of the semi-conductor type as shown, but could be vacuum tubes as a design choice. In either event the considerations affecting electrical ratings of these diodes are well known.

Modifications and variations falling within the scope and spirit of this invention will suggest themselves to those skilled in the art, accordingly it is not intended that the scope of this invention be limited to the embodiment shown.

What is claimed is:

1. A system of the character described comprising the combination of: a polyphase alternating current power source; a first rectifying device of a polyphase type connected to said power source and thereby producing pulsating direct current the minimum instantaneous amplitude of which is greater than zero; an electrical load connected so as to utilize electric power from said first rectifying device; a regulator circuit interposed between said load and said rectifying device, said regulator circuit operating by means of an inverse feedback loop responsive to the voltage across said load to produce substantially constant voltage across said load regardless of variations of current in said load and variations of voltage from said alternating current power source, said regulator circuit including at least one multigrid vacuum tube connected as a series regulator tube with its control grid responsive to said feedback loops; and ancillary rectifying and filtering means operating from said pulsating direct current and connected to supply screen grid voltage of higher magnitude than the average value of said pulsating direct current to said series regulator tube.

2. The invention described in claim 1 in which said ancillary rectifying means includes at least one rectifying diode and said filtering means includes a capacitor connected so as to by-pass the cathode of said rectifying diode.

3. In an electrically regulated direct current power supply including at least first rectifying means producing pulsating direct current the instantaneous peak amplitude of which is always greater than zero, and a regulator circuit employing at least one series multigrid vacuum tube regulator having an output and having an input connected to said pulsating direct current, the combination of: inverse feedback means adapted to supply compensatory voltage to the control grid of said multigrid vacuum tube in response to variations in the voltage at said output; second rectifying means and capacitive storage means operating in cooperation and connected to peak rectify from said pulsating direct current and store the output of said second rectifying means thereby developing a second direct current voltage approximately equal to the peak value of said pulsating direct current; and means supplying said second direct current voltage to the screen grid of said multigrid regulator tube.

4. A system of the character described comprising the combination of: a polyphase alternating current power source; a first polyphase rectifying device connected to said power source and producing pulsating direct current voltage having an instantaneous value always greater than zero; an electrical load connected so as to utilize electric power from said first rectifying device; a regulator circuit interposed between said load and said rectifying device, said regulator circuit operating to produce substantially constant voltage across said load regardless of variations of current in said load and variations of voltage from said alternating current power source, said regulator circuit including at least one vacuum tube connected as a series regulator tube, said vacuum tube having at least an anode, electron emitting means, a control grid, and a screen grid; an inverse feedback circuit responsive to the voltage across said load and adapted to energize said control grid in a manner so as to make substantially constant said voltage across said load; and ancillary rectifying and filtering means receiving pulsating direct current from said first rectifying device and operating to produce a direct current voltage having substantially less ripple than present in the said pulsating direct current voltage from said first rectifying device, said ancillary rectifying and filtering means being connected to supply screen grid potential to said series regulator tube.

5. The invention set forth in claim 4 further characterized in that said ancillary rectifying and filtering means includes a rectifying diode with its anode connected to receive said pulsating direct current voltage from said first rectifying device and with its cathode by-passed to a point of fixed potential and with its cathode further connected to supply screen grid voltage to said vacuum tube connected as a series regulator tube.

6. In a voltage regulating electrical power supply, the combination comprising; an alternating current power source; a first rectifying means connected to said power source and producing pulsating direct current voltage the minimum instantaneous amplitude of which is greater than zero; an output permitting an electrical load to be connected thereto so as to utilize electric power from said first rectifying means; a regulator circuit interposed between said output and said rectifying device, said regulator circuit including at least a first vacuum tube having at least an anode, electron emitting means, a control grid, and a screen grid, and being connected as a series regulator tube whereby current drawn at said output passes through said anode and said electron emitting means; and means for sensing variations in the voltage across said output and controlling the control grid voltage of said series regulator tube in accordance with said variations thereby to compensate for said output voltage variations; a second rectifying and filtering means receiving pulsating direct current from said first rectifying device and operating to supply a second direct current voltage having an average value greater than said pulsating direct current voltage and substantially less ripple than present in the said pulsating direct current voltage from said first rectifying device, said second rectifying and filtering means being connected to supply said second direct current voltage as a screen grid potential to said series regulator tube.

7. In a voltage regulator circuit of the series type in which at least one vacuum tube having at least anode, cathode, control grid and screen grid elements is disposed with anode-cathode space current path in series with the current path between a source and a load, whereby said anode is supplied rectified but unregulated positive polarity voltage from said source, said source has a predetermined internal impedance, a ripple component having a peak amplitude substantially less than the average value of said unregulated positive polarity voltage is present on said unregulated positive polarity voltage; and said cathode provides an output voltage, the combination comprising: means including a degenerative feedback path responsive to said output voltage for supplying and automatically adjusting a potential to said control grid in a manner tending to stabilize said output voltage; means for supplying electric power to said screen grid, said means including ancillary rectifying means connected between said source and said screen grid; and means associated with said screen grid for storing electric charge whereby the voltage applied to said screen grid has a higher average value than said source of unregulated voltage, and said voltage applied to said screen grid tends to decrease as increasing load current decreases the average voltage supplied by said source due to said predetermined internal impedance.

8. In a voltage regulator circuit wherein at least one vacuum tube having at least anode, cathode, control grid, and screen grid elements is connected to operate as a series regulator with its anode-cathode space current path disposed between the positive terminal of a source of rectified but unregulated voltage the value of which, including ripple component, never falls below an appreciable fraction of its peak value and the positive terminal of a load, the combination comprising: means for sampling a predetermined fraction of the voltage at said cathode and adjusting the potential of said control grid in a sense tending to cancel variations in said voltage at said cathodes; means including an ancillary rectifier connected between said source and said screen grid for supplying electric voltage and current to said screen grid; and filter means operative in cooperation with said ancillary rectifier thereby to obtain and apply to said screen grid, a voltage of higher direct current value than the voltage of said source.

9. The invention set forth in claim 8 in which said filter means includes a capacitor connected between said screen grid and a point of substantially more negative potential than is applied to said screen grid.

10. In a voltage regulating electrical power supply, the combination comprising: an alternating current power source; a first rectifying means connected to said power source and producing pulsating direct current voltage the minimum instantaneous amplitude of which is a substantial fraction of the instantaneous peak amplitude; an electrical load connected so as to utilize electric power from said first rectifying means; a regulator circuit interposed between said electrical load and said rectifying device, said regulator circuit including at least a first vacuum tube having at least an anode, electron emitting means, a control grid, and a screen grid, and having its electron emitting means and its anode connected as a series regulator; means for sensing variations in the voltage across

said electrical load and controlling the control grid voltage of said series regulator tube in accordance with an inverse function of said variations thereby to compensate for said output load voltage variations; a second rectifying and filtering means receiving pulsating direct current from said first rectifying means and operating to supply a second direct current voltage having substantially less ripple and a higher average value than present in the said pulsating direct current voltage from said first rectifying means, said second rectifying and filtering means being connected to supply screen grid potential to said series regulator tube.

11. The invention defined in claim 10 further defined in that said alternating current power source is three phase, said first rectifying means is of a three phase type, and said second direct current voltage is defined as decreasing as a function of voltage drop in said power source as current in said load increases, thereby to obtain the advantage of relatively high voltage on said screen grid without causing excessive power dissipation in said screen grid as said current in said load increases.

12. A system of the character described comprising the combination of: an alternating current power source; first means connected to said alternating current power source and including a rectifying circuit for producing a pulsating direct current supply the minimum instantaneous voltage amplitude of which is greater than zero; a pair of output terminals arranged to provide for connection of a load to utilize direct current electric power from said first means; a regulator circuit interposed in the circuit between said first means and said output terminals for regulating the voltage at said output terminals against variations in said load and said power source, said regulator circuit including at least one vacuum tube having at least control and screen grids and being connected as a series regulator tube; means including a voltage reference for comparing said voltage at said output terminals with said voltage reference to derive an error signal and means for applying said error signal to said control grid in the proper sense to cause said vacuum tube to compensate and thereby regulate said voltage at said output terminals; and ancillary rectifying and filtering means connected to said screen grid and operating from said pulsating direct current supply thereby to provide a higher voltage to said screen grid than the average voltage of said pulsating direct current supply, said screen grid voltage also thereby automatically decreasing in response to decrease of said pulsating direct current voltage.

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