March 27, 1956 E. O. JOHNSON 2,740,089

GAS TUBE VOLTAGE REGULATOR

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Fig. 1.

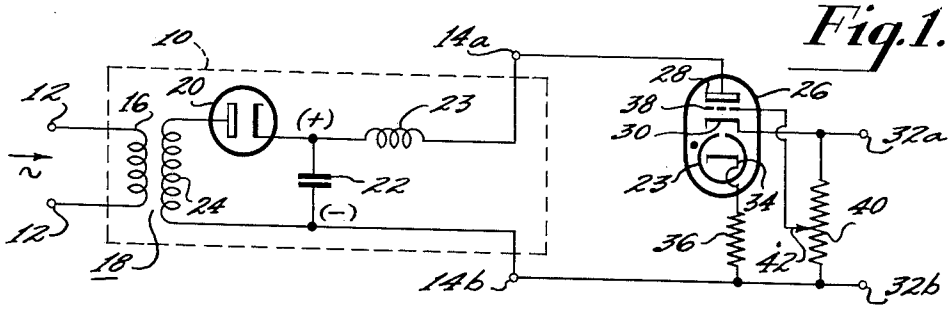
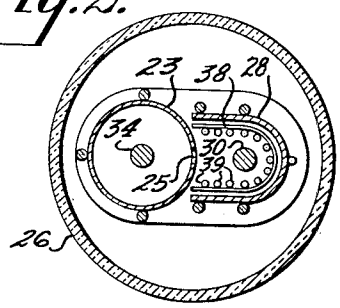


Fig. 2.



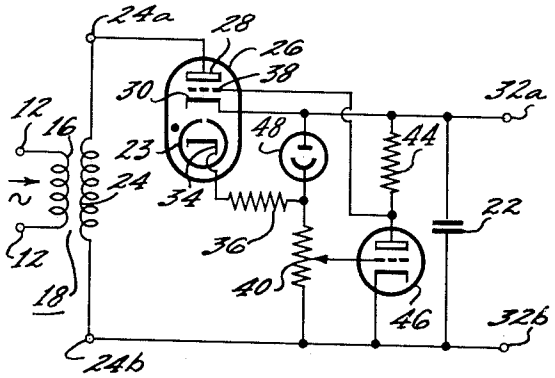
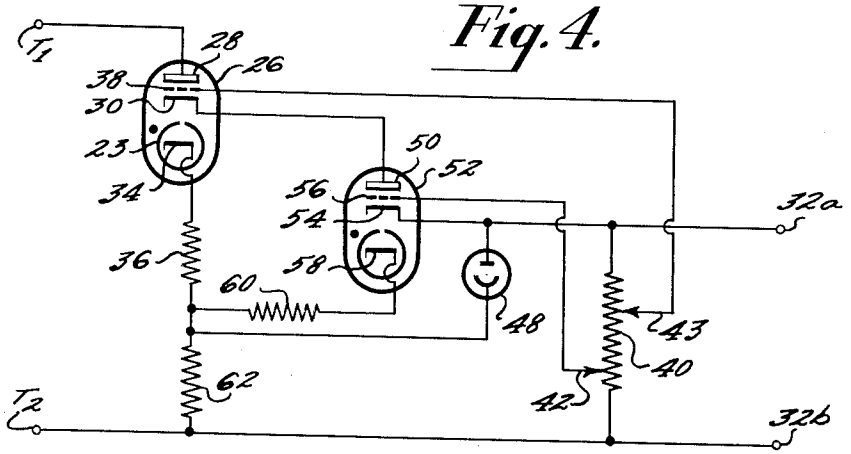


Fig. 3.

Fig. 4.



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GAS TUBE VOLTAGE REGULATOR

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8 Claims. (Cl. 323—22)

This invention relates to improvements in electrical power supply systems, and particularly to power supply systems utilizing gas filled electron tubes.

In electrical apparatus requiring unidirectional operating voltage, it is customary to provide a so-called power supply system for converting alternating voltage from a commercial outlet to unidirectional voltage.

Frequently, the operating characteristics of a given electrical apparatus require that the unidirectional operating voltage supplied thereto be kept relatively constant, or "regulated," notwithstanding changes in the source voltage or in the load on the power supply. Regulated power supplies frequently include a grid-controlled vacuum tube connected between the power supply rectifier and the load, with the impedance of the tube being varied in accordance with the voltage furnished to the load.

Regulated power supplies of this type have definite disadvantages. Since vacuum tubes inherently are relatively high impedance devices, they cannot pass large amounts of current to the load without substantial voltage losses. Even for a load requiring only, say, 100 milliamperes of current, it is not unusual to find as many as four large triode tubes connected in parallel in a regulating system.

Furthermore, a grid-controlled vacuum tube has characteristics that make it unsuitable for use as a rectifier. Therefore, conventional regulated power supply systems ordinarily have separate rectifier and regulating tubes.

All of the above mentioned deficiencies of prior art regulated power supply systems add to the complexity, cost, size and weight thereof.

It is a general object of the present invention to provide a power supply system having relatively high current handling capability, good regulating characteristics, and unusual operating efficiency.

A further object of the invention is to provide a system for supplying regulated unidirectional voltage to a load from a variable voltage source with a minimum of voltage loss.

Another object of the invention is to provide a power supply system wherein the functions of alternating voltage rectification and unidirectional voltage regulation are accomplished simultaneously.

In accordance with the invention, the foregoing and other related objects and advantages are obtained in a system utilizing a gaseous electron tube either as a variable impedance element or as a combined variable impedance element and rectifier. The gaseous electron tube utilized in accordance with the invention is of the type wherein separate potentials are used to provide the ionization needed for space charge neutralization and to provide the field needed for drawing current through the ionized gas. As will be pointed out more fully hereinafter, a system of this type can handle unusually large amounts of current and with very low voltage loss.

A more complete understanding of the invention can be had by reference to the following descriptions of illustrative embodiments thereof, when considered in connection with the accompanying drawing, wherein:

Fig. 1 is a schematic diagram of a power supply system having a regulator embodying the present invention,

Fig. 2 is a sectional view of a gas filled electron tube such as may be used in the circuit of Fig. 1,

Fig. 3 illustrates a combined regulator and rectifier arranged in accordance with the invention, and

Fig. 4 illustrates a modified arrangement of a regulator embodying the principles of the invention.

Referring to the drawing, there is shown in Fig. 1 a power supply system having a regulator arranged in accordance with the present invention. The power supply of Fig. 1 includes a rectifying network **10** for converting alternating voltage, applied to the input terminals **12** thereof, into unidirectional voltage at a second pair of terminals **14***a*, **14***b*. The primary winding **16** of a transformer **18** is connected to the terminals **12**, and a rectifier tube **20** is connected in series with a storage capacitor **22** across the secondary winding **24** of the transformer **18**.

The rectifying network **10** is conventional in form. When alternating voltage is applied to the terminals **12**, the rectifier **20** will conduct current on alternate half cycles, developing a unidirectional voltage of polarity as indicated across the capacitor **22**. If desired, a filter choke **23** can be connected between the rectifier tube **20** and the positive output terminal **14***a* of the rectifying network.

If a load device were to be connected across the terminals **14***a*, **14***b*, it is possible that the voltage at these terminals might vary, due either to a change in the input voltage or to a change in the load. In order to compensate for such changes in accordance with the invention, a gaseous electron tube **26** has its anode **28** connected to the positive terminal **14***a*, and its principal cathode **30** connected to the output terminal **32***a*. Thus, the space path between the electrodes **28**, **30** of the tube **26** is in series between the terminals **14***a* and **32***a*.

The gas tube **26** of Fig. 1 also is provided with an auxiliary cathode **34** from which current can flow either to the main cathode **30**, or to the anode **28**, or both. This current from the auxiliary cathode **34** is relied on to ionize the gas in the tube **26**, and will be referred to hereinafter as the ionizing current. The ionizing current circuit is completed by connecting the auxiliary cathode **34** to the negative terminal **14***b* through a current limiting resistor **36**.

The structural details of a typical tube such as the tube **26** are given hereinafter. A tube of this type is described more fully and claimed in the copending application of the present inventor, Serial No. 185,745, filed September 20, 1950, and assigned to the assignee of the present invention.

In the embodiment of the invention presently being described, the voltage supplied to the output terminal **32***a* from the positive terminal **14***a* of the voltage source **10** is regulated by varying the impedance (and, hence, the voltage drop) between the anode **28** and the main cathode **30** in the tube **26**. This impedance can be regulated by applying a suitable control voltage to a control electrode **38** disposed between the anode **28** and the main cathode **30**. One suitable source of such control voltage may comprise a potentiometer **40** connected between the output terminals **32***a*, **32***b*, and having a movable tap **42** which is connected to the control electrode **38** in the tube **26**.

As is explained in the above-mentioned copending application, if the function of ionizing the gas in a gas filled electron tube is separated from the function of passing work circuit current between the main tube electrodes, it becomes possible to control the work circuit

current in a number of different ways, one of which by means of the control electrode 38.

Consider, for example, the tube shown in cross section in Fig. 2. In Fig. 2, a gas tight envelope 26 is provided with a cathode 30. A U-shaped control electrode or grid 38 and a U-shaped anode 28 partially surround the cathode 30. The grid 38 comprises a plurality of parallel wires 39 which are supported in spaced relation. The anode 28 may be a sheet metal element.

Opposite the open ends of the grid 38 and the anode 28 there is mounted a cylindrical focusing electrode 23 provided with an elongated slot 25 facing the open ends of the grid and anode structures. An auxiliary cathode 34 is mounted coaxially within the focusing electrode 23.

A tube having a structure such as that shown in Fig. 2 can be operated as follows:

If a voltage greater than that required to ionize gas in the tube 26 is applied between the auxiliary cathode 34 and the anode 28, a current will flow which will ionize the gas in the tube. As a result, a highly conductive mixture or "plasma" of ions and electrons will be created within the tube envelope. The focusing electrode 23 is effective to concentrate the ionizing current, making it possible to obtain high plasma densities with very small amounts of current or power. With the tube gas ionized to create plasma in the manner just described, it becomes possible to pass a relatively high current between the main cathode and the main anode with a voltage drop which may be of the order of 0.1 volt or less. Furthermore, it also becomes possible to control this main cathode-anode current by means of a control electrode disposed in the space path as shown.

With a tube of this type connected in a power supply system in the manner shown in Fig. 1, certain important advantages can be obtained. First, as compared with a voltage regulating system wherein a conventional vacuum tube is utilized as a variable impedance element, the voltage loss across the regulatory impedance will be very small. Furthermore, currents far in excess of those which can be passed through a conventional vacuum tube will flow readily through the conducting plasma in the gas tube, so that the current handling capabilities of the power supply system need not be limited by the inclusion of the regulator.

The system shown in Fig. 1 will operate in the following manner:

Assume that the voltage between the terminals 14*a*, 14*b* tends to increase. This, in turn, will cause an increase in the voltage across the potentiometer 40, as measured at the main cathode 30 of the gas tube 26. The voltage also will increase at the control electrode 38. However, since the voltage at the main cathode 30 will increase more than the control electrode voltage, the net effect will be to make the control electrode 38 more negative with respect to the cathode 30. As a result, there will be an increase in the effective impedance between the main cathode 30 and the anode 28, accompanied by an increase in the voltage drop between these electrodes 28, 30. This increase in voltage drop will tend to offset the original voltage change at the terminals 14*a*, 14*b*, and will tend to maintain the voltage between the output terminals 32*a*, 32*b* essentially constant.

It has been found that changes in the ionizing current in a tube of the type shown in Figs. 1 and 2 will cause a corresponding change in the work circuit current. In the case of the regulating arrangement shown in Fig. 1, this change will be opposed to the desired regulatory action. That is, if the voltage between the auxiliary cathode 34 and the main electrodes 28, 30 were to increase, as in the example just given, a greater amount of ionizing current would flow, reducing the effective impedance between the anode 28 and the main cathode 30. This would tend to offset the regulatory effect of the previously described change in control electrode voltage. If, in a given case, the effect of ionizing current changes cannot be tolerated, the arrangement shown in Fig. 3 can be adopted, wherein two expedients are shown for improving the regulating action. Fig. 3 also illustrates a further important feature of the invention; namely, the combination of rectifying and regulatory action.

In the system shown in Fig. 3, the rectifying network 10 of Fig. 1 has been eliminated. The tube anode 28 is connected directly to one terminal 24*a* of the transformer secondary winding 24, while the main cathode 30 is connected to the other secondary winding terminal 24*b* through the capacitor 22. Thus, the work circuit of the gas tube 26 will supply rectified current to charge the capacitor 22.

The voltage across the capacitor 22 in Fig. 3 will be regulated by a control voltage applied to the control electrode 38 from an amplifying circuit. This amplifying circuit includes a resistor 44 connected in series with a conventional amplifier 46 across the capacitor 22. A control voltage for the amplifier tube will be obtained from a potentiometer 40 which is connected in series with a conventional gas regulator tube 48 across the capacitor 22. The auxiliary cathode 34 of the gas tube 26 is connected through a current limiting resistor 36 to the junction of the regulator 48 and the potentiometer 40.

The regulatory action of the tube 26 in the circuit of Fig. 3 will be superior to that obtained with the system shown in Fig. 1 for two reasons. First, the regulator tube 48 will help to maintain substantially constant voltage and, hence, substantially constant ionizing current between the auxiliary cathode 34 and the main electrodes 28, 30. This will tend to prevent the adverse effect of ionizing current changes previously referred to. Second, an amplified control voltage will be applied to the control electrode 38. This amplified control voltage will aid in offsetting any adverse effect due to changes in the ionizing current.

Suppose, for example, that the voltage at the secondary winding terminals 24*a*, 24*b* increases. The voltage across the potentiometer 40 also will increase, causing the amplifier tube 46 to draw more current. This will increase the voltage drop across the resistor 44, making the gas tube control electrode 38 more negative with respect to the main cathode 30. Thereupon, the effective impedance between the gas tube anode 28 and the main cathode 30 will increase, offsetting the effect of the original voltage increase.

The circuits thus far described will provide regulatory compensation for voltage changes of several volts, and with a voltage loss in the regulator tube of no more than, say, 0.1 volt at the lowest source voltage. Also, currents of as much as one ampere can be handled readily in systems of the type described. However, the voltage between the gas tube anode 28 and the main cathode 30 should not exceed the ionizing potential of the tube gas. If this ionizing potential is exceeded, then an ionizing discharge may occur between the main cathode and the anode, and grid control of the work circuit current will be lost. If it is anticipated that the voltage may change by an amount greater than the ionizing potential of the tube gas, the main electrodes of two or more gas tubes can be connected in series between the voltage source and the load to insure that the voltage between the main tube electrodes of any one of the tubes will not exceed the ionizing potential of the gas.

Such an arrangement is shown in Fig. 4, wherein the anode 28 of a first gaseous electron tube 26 is connected to an input terminal T1, corresponding either to the terminal 14*a* of Fig. 1 or to the terminal 24*a* of Fig. 3. The cathode 30 of this first tube 26 is connected to the anode 50 of a second gas discharge tube 52. The cathode 54 of the second tube 52 is connected to the output terminal 32*a*, and the control electrodes 38, 56 of the tubes 26, 52 are connected to adjustable taps 42, 43 on a potentiometer 40. The auxiliary cathodes 34, 58 of the gas tubes 26, 52 are connected through current limiting

resistors **36**, **60** to the junction between a regulator tube **48** and a resistor **62** which are in series across the potentiometer **40**. Although not shown, an amplifier such as the amplifier **46** of Fig. 3 can be used in the circuit of Fig. 4.

In the circuit of Fig. 4, the regulating action of each of the tubes **26**, **52** will be substantially the same as has already been described in connection with Figs. 1 and 3. The principal difference is in the fact that the voltage drop between the input terminal **T1** and the output terminal **32***a* will be divided substantially equally between the two tubes **26**, **50**, making it possible to have a wider range of output voltage regulation but without adversely affecting the gas tube operation.

From the foregoing, it will be apparent that the present invention provides a regulating arrangement for power supply systems characterized by low voltage losses, high current handling capabilities, and excellent control characteristics.

What is claimed is:

1. In a system for converting alternating voltage to regulated unidirectional voltage wherein a gas tube having a plurality of electrodes is used as a variable resistance, an alternating voltage source, an impedance, a circuit connecting said impedance to said voltage source through the space path between a first pair of said electrodes, a control electrode between said first pair of said electrodes, a second circuit connecting said voltage source in series with the space path between a second pair of said electrodes, and a feedback circuit connected between said impedance and said control electrode to supply continuously between said control electrode and one of said first pair of said electrodes a voltage proportional to the voltage across said impedance, one of said electrodes being common to said first and second pairs of said electrodes.

2. In a voltage regulator system wherein a gas tube having a plurality of electrodes is used as a variable impedance, a voltage source, a load device, a circuit connecting said load device to said voltage source through the space path between a first pair of said electrodes, a second circuit connecting said voltage source between a second pair of said electrodes to generate a conductive ion-electron plasma in said tube in the area between said first pair of said electrodes, and means to control the voltage drop between said first pair of said electrodes continuously as a function of the voltage across said load device, said means including a voltage-feedback circuit connecting one of said first pair of said electrodes to another of said tube electrodes, one of said electrodes being common to said first and said second pairs of said electrodes.

3. In a system for supplying regulated unidirectional voltage wherein a gas tube having a plurality of electrodes is used as a variable resistance, a voltage source, an impedance, a circuit connecting said impedance to said voltage source through the space path between a first pair of said electrodes, a control electrode between said first pair of said electrodes, a second circuit connecting said voltage source across the space path between a second pair of said electrodes, and a feed-back circuit connected between said impedance and said control electrode to supply continuously between said control electrode and one of said first pair of said electrodes a voltage proportional to the voltage across said impedance, one of said electrodes being common to said first and said second pairs of said electrodes.

4. In a system for supplying regulated unidirectional voltage wherein a gas tube having a plurality of electrodes is used as a variable resistance, a pair of input terminals, a pair of output terminals, a circuit connecting one of said input terminals to one of said output terminals through the space path between a first pair of said electrodes, a connection between the other of said input and output terminals, a second circuit connecting said input terminals through the space bath between a second pair of said electrodes, and a feedback circuit connected between said one output terminal and said control electrode to supply continuously between said control electrode and one of said first pair of said electrodes a voltage proportional to the voltage across said output terminals, one of said electrodes being common to said first and said second pairs of said electrodes.

5. In a system for supplying regulated unidirectional voltage wherein a gaseous electron tube having a plurality of electrodes including an anode, a main cathode, and an auxiliary cathode is used as a variable resistance, a pair of input terminals, a pair of output terminals, a circuit connecting one of said input terminals to one of said output terminals through the space path between said anode and said main cathode, a connection between the other of said input and output terminals, means connecting said one output terminal to one of said electrodes to control the voltage between said one electrode and said main cathode continuously as a function of the voltage between said output terminals, and means connecting said main and auxiliary cathodes to maintain substantially constant voltage between said main and auxiliary cathodes.

6. A system as defined in claim 5 wherein said last named means comprises a gas regulator tube and a resistor connected in series between said output electrodes.

7. A system as defined in claim 5 wherein said first named means comprises a potentiometer connected in circuit between said output terminals, and a grid-controlled amplifier connecting said potentiometer to said one electrode.

8. In a voltage regulator system wherein a gas tube having a plurality of electrodes is used as a variable resistance, a voltage source, a load device, a circuit connecting said load device to said voltage source through the space path between a first pair of said electrodes, a second circuit connecting said voltage source between a second pair of said electrodes to generate a conductive ion-electron plasma in said tube in the area between said first pair of said electrodes, and means to control the voltage drop between said first pair of said electrodes continuously as a function of the voltage across said load device, said means including a voltage-feedback circuit connecting one of said first pair of said electrodes to said second circuit, one of said electrodes being common to said first and said second pairs of said electrodes.

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