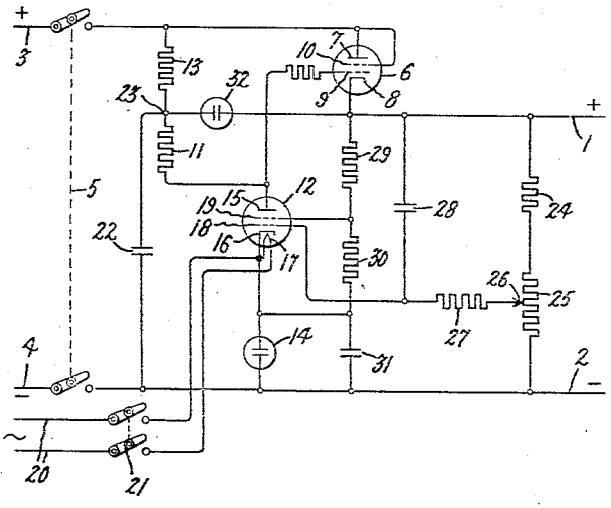
April 13, 1943. W. A. FORD ET AL 2,316,577

ELECTRONIC REGULATOR

Filed July 4, 1942



Inventors:
Warren A. Ford,
Philip C. Michel,
by Harry E. Dunham
Their Attorney.

Patented Apr. 13, 1943 2,316,577

UNITED STATES PATENT OFFICE

2,316,577

ELECTRONIC REGULATOR

Warren A. Ford and Philip C. Michel, Schenectady, N. Y., assignors to General Electric Company, a corporation of New York

Application July 4, 1942, Serial No. 449,750

9 Claims. (Cl. 171—312)

Our invention relates to electric regulators and more particularly to regulators employing electronic discharge devices.

Electric regulators employing electronic discharge devices are frequently employed to maintain a load voltage or an output voltage at a substantially constant value. Many of the prior art arrangements have subjected the amplifier portion of the regulator to an excessive range of voltages, thereby not only injuring the electronic discharge devices but also sacrificing the precision of control obtained. In accordance with the teachings of our invention described hereinafter, we provide a new and improved electric regulator wherein a greater precision of operation is offered than that afforded by the prior art arrangements, and which also provides protection for the electronic discharge devices during operation and starting.

It is an object of our invention to provide a new and improved electric regulator.

It is another object of our invention to provide a new and improved electronic voltage regulator for maintaining the voltage of an output circuit at a substantially constant or fixed value.

It is a further object of our invention to provide a new and improved electronic voltage regulator for supplying direct current to an output circuit from a direct current supply circuit, and wherein the electronic amplifying device employed therein is protected during the starting and normal operating conditions.

It is a still further object of our invention to provide a new and improved electronic voltage regulator wherein the electronic discharge device used as the amplifier is controlled to maintain its anode voltage at a fixed increment above the potential of the positive conductor of the output circuit, thereby limiting the duty to which the amplifier electronic discharge device is subjected and also serving to increase the precision of operation of the regulator.

Briefly stated, in the illustrated embodiment of our invention we provide an electronic voltage regulator for supplying a substantially constant voltage to a direct current output circuit from a direct current supply circuit. A variable impedance electronic discharge device is connected between the positive conductors of the supply circuit and the output circuit, and a second electronic discharge device or an amplifier is employed for controlling the potential of the grid of the variable impedance device. Means responsive to an electrical condition, such as the output voltage, control the conductivity of the amplifier, and the range of anode voltage applied to the amplifier is limited by means of a constant voltage device such as a glow discharge valve connected in circuit between the positive terminal of the output circuit and the anode of the amplifying discharge device.

For a better understanding of our invention, reference may be had to the following description taken in connection with the accompanying drawing, and its scope will be pointed out in the appended claims. The single figure of the drawing diagrammatically illustrates an embodiment of our invention as applied to an electronic regulator for a direct current circuit.

Referring now more particularly to the single figure of the drawing, our invention is there illustrated as applied to an electronic regulator for controlling an electrical condition such as the voltage of a direct current load or output circuit comprising a positive conductor 1 and a negative conductor 2. The regulator may be energized from a suitable source of direct current comprising a positive conductor 3 and a negative conductor 4. The supply circuit may, in turn, be energized from a rectifier which is energized from an alternating current supply circuit (not shown). A suitable circuit controlling means, such as a switch 5, may be connected between the supply circuit and the regulator.

Between the positive conductors 1 and 3 of the output circuit and the supply circuit, we provide a variable impedance electronic discharge device 6, of the high vacuum type, comprising an anode 7, a cathode 8 and a control means such as a control grid 9. If desired, the device 6 may be provided with a screen grid 10 which is connected to the anode 7.

In order to control the conductivity of the electronic discharge device 6 and to control an electrical condition, such as the voltage, of the output circuit, we provide a circuit which may be energized from the supply circuit and which includes an impedance element, such as a resistance 11, through which are transmitted variable amounts of unidirectional current by means of a second electronic discharge device 12 which serves as an amplifier responsive to the electrical condition which is being regulated. The impedance element 11 and the electronic discharge device 12 are connected across the supply circuit through serially connected elements, such as a resistance 13 and a constant voltage device such as a glow discharge valve 14. The glow discharge valve 14 serves to maintain the cathode of elec-

tric discharge device 12 at a fixed potential above that of the negative conductors 2 or 4.

Electronic discharge device 12 is preferably of the high vacuum type comprising an anode 15, a cathode 16, means for heating the cathode 16 such as a filamentary heating element 17, and control means for controlling the conductivity such as a control grid 18 and a screen grid 19.

The filamentary heating element 17 of electronic discharge device 12 may be energized from a suitable source of current, such as an alternating current circuit 20, through a switch 21.

We provide damping or filtering means connected across a portion of the amplifier circuit which may include a capacitance 22 connected between the common juncture 23 of resistances 11 and 13 and the negative conductor 2 or 4.

As a means for controlling the conductivity of electronic discharge device 12 and, hence, for controlling the conductivity of discharge device 6 in response to an electrical condition of either the supply circuit or the output circuit, we provide means for impressing on the grids 18 and 19 potentials responsive to that electrical condition. In order to illustrate our invention, we provide means for controlling the conductivity of discharge device 12 in response to the output voltage in a manner to maintain the output voltage substantially constant. This means may comprise a voltage divider including resistances 24 and 25, the latter of which is provided with an adjustable contact 26 which is connected to grid 18 through a current limiting resistance 27. Damping or filtering means, such as a capacitance 28, may be connected between the positive terminal 1 of the output circuit and grid 18. The contact 26 serves as a means for adjusting the magnitude of the output voltage which is maintained by the regulator. Where it is also desired to vary the potential of the screen grid 19 in response to the magnitude of the output voltage, we also may employ a second voltage divider including resistances 29 and 30 and a capacitance 31 connected across the output circuit. Resistances 29 and 30 also constitute elements of a voltage divider which include the glow discharge valve 14, so that the potential of the cathode 16 is maintained at a constant value above that of the negative conductor 2 or 4. Capacitance 31 also serves as a damping or filtering means under dynamic load conditions, thereby assisting the system in maintaining the potential of cathode 16 at a constant or fixed value.

We provide means for maintaining the anode voltage of the amplifying discharge device 12 within a predetermined range of values during normal operation and during the starting operation. More particularly, we provide means for assuring that the anode 15 of the electronic discharge device 12 is not subjected to excessive voltages during the starting operation, or during normal operation, where the system is adjusted to supply relatively low or small output voltages determined by the setting of adjustable contact 26. This means is also arranged so that the anode voltage supplied to electronic discharge device 12 may become sufficiently great to permit the desired or normal output voltage regulation.

In order to control or regulate the anode voltage supplied to the electronic discharge device 12, we provide a constant voltage means, such as a glow discharge device or valve 32, connected between the positive terminal 1 of the output circuit and the circuit connected to anode 15. We have found that this control is effectively accomplished by connecting the glow discharge valve 32 to the resistance 11 or to the common juncture 23 of resistances 11 and 13. The glow discharge valve 32 upon being rendered conducting maintains across its terminals a substantially constant voltage and, hence, regulates the voltage supplied to the anode 15 to maintain it at a substantially fixed potential increment above the potential of the output conductor 1. This arrangement enables the amplifying electronic discharge device 12 to perform about the same operating point, regardless of the output control provided by adjustment of resistance 25, and avoids the danger of arcing-over of the discharge device 12 before the temperature of the cathode 16 assumes a safe operating temperature or the normally required electron emitting temperature.

The operation of the embodiment of our invention will be explained by considering the system when it is arranged to maintain the voltage of the output circuit at a substantially constant value under varying load conditions, or when the voltage of the supply circuit varies throughout appreciable limits. The potential of the positive output conductor 1 is determined by the conductivity of electronic discharge device 6 which operates as a variable impedance device or means. As the potential of the grid 9 is rendered more negative with respect to the cathode 8, the effective impedance of the discharge device increases thereby lowering the potential of conductor 1; and, conversely, as the potential of the grid 9 is made less negative the effective impedance of discharge device 6 decreases and the potential of the positive conductor 1 is raised.

The amplifier portion of the regulator varies the potential of control grid 9 in response to variations in the output voltage, thereby serving to restore the output voltage to the desired value under variable load voltage and variable supply voltage conditions. This regulatory operation is effected by means of the electronic discharge device 12, the conductivity of which is varied in response to the output voltage. As the output voltage tends to increase above the desired value, the conductivity of or the current conducted by the electronic discharge device 12 increases, thereby increasing the current transmitted through resistance 11 and rendering grid 9 more negative. Consequently an increase in the impedance of the discharge device 6 is effected thereby restoring the potential of conductor 1 to the desired value. If the voltage of the output circuit tends to decrease, the reverse operation takes place wherein the conductivity of the electronic discharge device 12 is decreased to raise the potential of grid 9 of discharge device 6.

The glow discharge valve 32, which is connected between the positive conductor 1 and the circuit including the anode 15 of electronic discharge device 12, limits the range of anode voltage which is supplied. More particularly, the glow discharge valve 32 maintains the potential of the anode 15 at a fixed increment above the potential of the positive conductor 1 over the desired range of the output voltage. For example, under minimum voltage conditions, that is where the contact 26 is adjusted so that the regulator maintains a relatively low output voltage, the glow discharge valve 32 limits the anode voltage applied to discharge device 12 to a fixed increment above the potential of conductor 1. This enables the discharge device 12 to perform about the same operating point of its characteristic regardless of the output voltage setting.

The glow discharge valve 32 also performs a protective operation during the starting of the system. For example, if the switch 5 is closed to energize the regulator prior to the time the cathode 16 has assumed a safe operating temperature, the glow discharge valve 32 limits the voltage applied to the anode 15, thereby limiting the current which the discharge device 12 is required to conduct and consequently avoiding or substantially decreasing the danger or reverse conduction of current between the cathode 16 and anode 15.

While we have shown and described our invention as applied to a particular system of connections and as embodying various devices diagrammatically shown, it will be obvious to those skilled in the art that changes and modifications may be made without departing from our invention, and we, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of our invention.

What we claim as new and desire to secure by Letters Patent of the United States is:

1. In combination, a direct current supply circuit comprising positive and negative terminals, a direct current output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and comprising a grid, an impedance element, a second electronic discharge device connected in circuit with said impedance element for transmitting variable amounts of current therethrough and for controlling the potential of said grid, said second discharge device comprising an anode, a cathode and control means, means responsive to an electrical condition of one of the first mentioned circuits for controlling the potential of said control means, and means connected in circuit between the positive terminal of said output circuit and said anode for maintaining the potential thereof at a fixed increment above the potential of the positive output terminal.

2. In combination, a direct current supply circuit, an output circuit having positive and negative terminals, a variable impedance electronic discharge device having a control grid and being connected between said circuits for controlling an electrical condition of said output circuit, an impedance element, means for transmitting variable amounts of current through said impedance element for controlling the potential of said grid and comprising a second electronic discharge device, means responsive to said electrical condition for controlling the conductivity of said second electronic discharge device, and means connected in circuit with the positive terminal of said output circuit and the anode of said second discharge device for limiting the range of variation of the anode voltage.

3. In combination, a direct current supply circuit comprising positive and negative terminals, a direct current output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and comprising a grid, means for controlling the potential of said grid including a circuit energized from said supply circuit and including in series relation an impedance element, a second electronic discharge device and a glow discharge valve, said second discharge device including an anode, a cathode and control means, means for controlling the potential of said control means in response to a predetermined electrical condition of said output circuit, and means for limiting the voltage of said anode comprising a second glow discharge valve connected between the positive terminal of said output circuit and said impedance element.

4. In combination, a direct current supply circuit comprising positive and negative terminals, a direct current output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and comprising a grid, an impedance element, a second electronic discharge device connected in circuit with said impedance element for transmitting variable amounts of current therethrough and for controlling the potential of said grid, said second discharge device comprising an anode, a cathode and control means, means responsive to the voltage of said output circuit for controlling the potential of said control means, and constant voltage means connected between the positive terminal of said output circuit and said impedance element for limiting the range of voltage applied to said second discharge device.

5. In combination, a direct current supply circuit including positive and negative terminals, a direct current output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit, said discharge device having a grid, an impedance element, means for transmitting variable amounts of unidirectional current through said impedance element to control the potential of said grid and comprising a second electronic discharge device having an anode, a cathode and control means, voltage responsive means connected to said output circuit for controlling the potential of said control means, and a glow discharge valve connected between the positive terminal of said output circuit and the anode circuit of said second discharge device for limiting the maximum positive voltage applied to said anode for relatively small voltages applied to said output circuit.

6. In combination, a direct current supply circuit having positive and negative terminals, an output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and including a control grid, means for controlling the potential of said grid comprising an impedance element and a second electronic discharge device energized from said supply circuit and having an anode, a cathode and control means, means responsive to the voltage of said output circuit for controlling the potential of said control means, and constant voltage means connected between the positive terminal of said output circuit and said impedance element to limit the range of variation of the voltage applied to said anode.

7. In combination, a direct current supply circuit having positive and negative terminals, a direct current load circuit having positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said load circuit and comprising a grid, an impedance element, a second electronic discharge device for transmitting variable amounts of unidirectional

current through said impedance element from said supply circuit and for controlling the potential of said grid, said second electronic discharge device having an anode, a cathode and control means, means comprising a voltage divider connected across said load circuit for impressing on said control means an adjustable component of voltage to determine the magnitude of the voltage which is impressed across said load circuit, and constant voltage means connected between said impedance element and the positive terminal of said load circuit to limit the maximum value of positive voltage impressed on said anode for relatively small output voltage settings of said voltage divider.

8. In combination, a direct current supply circuit having positive and negative terminals, a direct current output circuit having positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and having a control grid, an impedance element, a second electronic discharge device for transmitting variable amounts of current through said impedance element and for controlling the potential of said grid, said second electronic discharge device having an anode, a cathode, means for heating said cathode and control means, means responsive to an electrical condition of one of the first mentioned circuits for controlling the potential of said control means, means for energizing the cathode heating means, and means for limiting the maximum voltage applied to said anode comprising a glow discharge valve connected in circuit between the positive terminal of said output circuit and said anode.

9. In combination, a direct current supply circuit including positive and negative terminals, a direct current output circuit including positive and negative terminals, a variable impedance electronic discharge device connected between the positive terminals of said supply circuit and said output circuit and including a control grid, an impedance element, a second electronic discharge device for transmitting variable amounts of current through said impedance element and for controlling the potential of said grid, said second electronic discharge device having an anode, a cathode, means for heating said cathode and control means, means for effecting energization of said supply circuit, means for effecting energization of the cathode heating means, means responsive to an electrical condition of one of the first mentioned circuits for controlling the potential of said control means, and means for limiting the maximum voltage applied to said anode comprising a glow discharge valve connected in circuit between the positive terminal of said output circuit and said anode.

WARREN A. FORD.
PHILIP C. MICHEL.