

Aug. 4, 1959

J. F. O'DONNELL ET AL

2,898,514

VOLTAGE CONTROL SYSTEM

Filed March 13, 1956

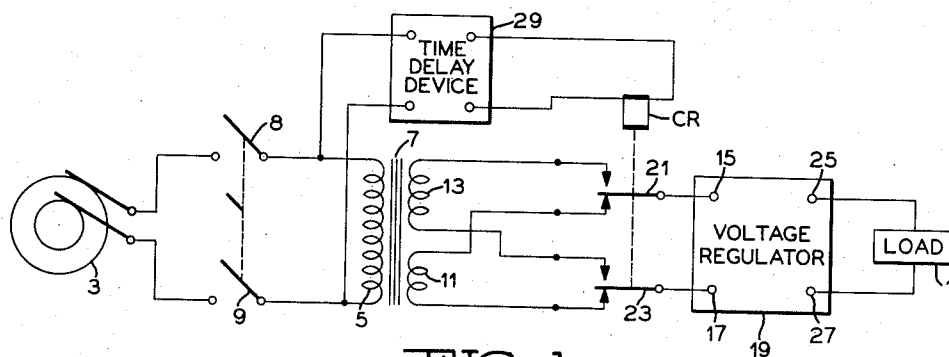


FIG. 1

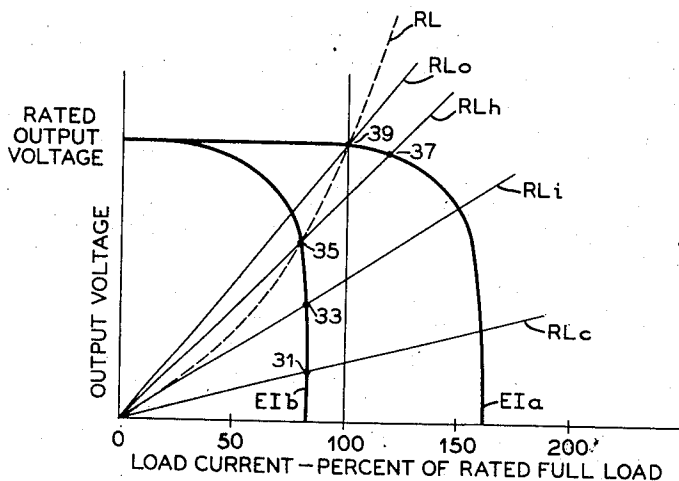


FIG. 2

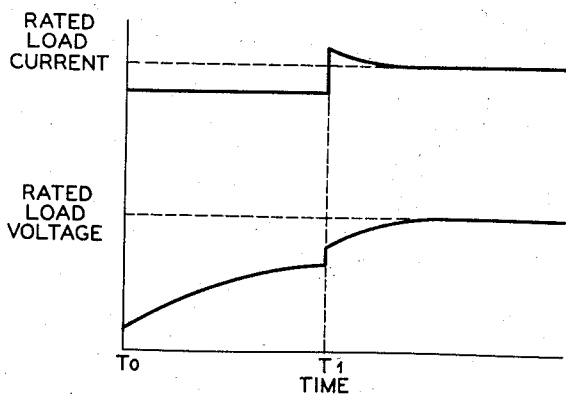


FIG. 3

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VOLTAGE CONTROL SYSTEM

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Application March 13, 1956, Serial No. 571,183

8 Claims. (Cl. 315—106)

This invention relates to voltage control systems, and particularly to a voltage control system adapted to supply power to a load having an impedance which varies from a relatively low initial value to some higher value as a result of energization. More particularly, the present invention is directed to an improved voltage control system for governing the supply of power to the filaments, or cathode heaters, of electron discharge devices.

The energization of a relatively large number of electron discharge devices, such as the vacuum tubes employed as functional units in an electronic computer, for example, presents a difficult problem from the voltage control standpoint. When the load is first energized, the so-called "cold resistance" thereof is relatively low, representing, for example, only one-seventh of the so-called "hot resistance" which exists after the filaments are heated to their normal operating temperature at rated voltage and current. Moreover, when such a load is in its normal operating condition, the voltage must be carefully controlled since it is well known that over-voltages are deleterious to vacuum tube filaments or heaters, and undervoltages will not, of course, supply sufficient power for proper emission.

It has heretofore been proposed to provide suitable means for limiting the inrush current to tube heaters by the use of suitable limiting impedances, or by the use of a multi-tap transformer, with suitable switching means for switching the limiting impedance out of the supply circuit, or for changing the transformer taps as the tubes warm up. Such arrangements are open to the general objection that the transition requires more than two steps if it is to take place relatively smoothly and without exceeding the maximum permissible input current, so that the switching apparatus is relatively complex.

Continuously variable transformers or limiting impedances have also been employed in this capacity, but these devices are relatively expensive, and the motor drives used to operate them automatically are relatively complex and costly.

Considering the problem of maintaining a substantially constant operating voltage for vacuum tube heaters or filaments, numerous types of voltage regulators, well known in the art, have been employed for this purpose.

It is an object of the present invention to provide an improved voltage control system for a load which provides inrush current limitation to a load which increases in impedance after energization, and which maintains a substantially constant voltage across the load after the load reaches its normal operating impedance value.

Another object of the invention is to provide a voltage control system employing a voltage regulator having a drooping voltage-versus-current operating characteristic to limit the inrush current to a load having a low initial impedance which changes to some higher operating impedance, at which value the voltage supplied thereto is maintained substantially constant.

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A further object of the invention is to provide a voltage control system for governing the supply of energy to the heaters or filaments of electron discharge devices in which a voltage regulator having a drooping voltage-versus-current characteristic is employed both as an inrush current limiter and a voltage regulator.

Other objects of the invention will be pointed out in the following description and claims and illustrated in the accompanying drawings, which disclose, by way of examples, the principle of the invention and the best mode, which has been contemplated, of applying that principle.

In the drawings:

Fig. 1 is a schematic circuit diagram of a voltage control system in accordance with a preferred embodiment of the invention.

Figs. 2 and 3 are graphs illustrating the operation of the arrangement shown in Fig. 1.

Referring now to Fig. 1, there is shown in simplified form an arrangement for controlling the voltage supplied to a load 1 from a suitable source of energy such as the alternator 3. Power is supplied from the alternator 3 to the primary winding 5 of a transformer 7 when the contacts 8 and 9 of a control switch are closed. A first secondary winding 11 or a second secondary winding 13 are connected to input terminals 15 and 17 of a voltage regulator 19 in accordance with the position of contacts 21 and 23 of a control relay CR. The output terminals 25 and 27 of regulator 19 are connected to the load 1. Relay CR is energized by power supplied from the alternator when the switch SW is closed, after the expiration of a suitable time interval determined by a time delay device 29.

Before explaining the operation of the arrangement shown in Fig. 1, it is necessary to consider the voltage-versus-current characteristics of the voltage regulator 19, and the impedance characteristics of the load 1, which are depicted graphically in Fig. 2.

Considering first the voltage regulator 19, the actual form or construction of the regulator is immaterial to the present invention, the only necessary requirement being that the voltage-versus-current characteristic of the regulator must be of the general form illustrated by the curves EIa and EIb of Fig. 2. Curve EIa shows that with nominal or rated input voltage the output voltage of the regulator remains substantially constant for all values of output current up to 100 percent of rated full load, after which the voltage drops off rather sharply so that for relatively large overload currents, the output voltage drops to zero. Curve EIb illustrates the relation of the output voltage and current for an input voltage substantially less than rated or nominal input voltage, for example, 50 percent of rated input voltage, wherein the output voltage remains substantially constant for currents up to 40 or 50 percent of full load current, and then drops off sharply so that the output voltage is reduced to zero for load currents of the order of 80 percent of full load value. The values given are only approximate and illustrative, and other limits may be as readily established, the only important feature being the relatively sharp drop in the curve after full load current is exceeded.

It will be obvious to those skilled in the art that many types of voltage regulators may be designed to have such characteristics of output voltage-versus-current, and accordingly it is deemed unnecessary to show any specific structure for the voltage regulator 19.

Considering now the impedance characteristics of the load 1, the dashed line RL of Fig. 2 illustrates the changing impedance characteristics of the load. Since a preferred use of the invention is to control the power sup-

plied to vacuum tube heaters, the curve RL illustrates the manner in which the voltage and current vary in a load such as one or more vacuum tube heaters, as a result of the change of resistance with heating. Since the resistance change with respect to temperature is non-linear, the characteristic curve RL is curved as shown. A series of straight lines designated by the reference characters RLc, RL_i, RL_h and RL_o are projected values of the characteristic curve RL taken at different points, and represent the load impedance for different conditions of time, in this particular instance. For example, the line RLc represents the impedance of the load 1 at the time of initial energization, any point along the line representing the ratio of E divided by I. Likewise the impedance at successively later intervals of time following energization is represented by the lines RL_i, RL_h and RL_o, in the order given. It will be seen therefore that the load to be supplied by the system according to this invention is one which changes its impedance from a relatively low initial value when first energized to some higher value or series of values following energization, and which maintains a relatively stable impedance value at any predetermined level of energization after having reached that value. Thus the arrangement is especially adapted for controlling the energy to vacuum tube heaters, which exhibit this type of impedance characteristic, but is not limited to this application.

Having thus considered the characteristics of the regulator 19 and the load 1, the operation of the invention as illustrated in Fig. 1 will now be described.

When the switch is closed, its contacts 8 and 9 complete the circuit for supplying power from the source 3 to the primary winding 5 of transformer 7. Relay CR is released at this time, and will remain released until the expiration of a predetermined time delay introduced by time delay device 29. The details of the time delay device are not shown since it may take any one of a number of forms well known in the art, and its detailed construction forms no part of the present invention. Suffice to say that the control relay CR is energized only after a predetermined time interval has elapsed following the closing of switch SW.

Energy is supplied at this time from the secondary winding 11 of transformer 7 over the unoperated contacts 21 and 23 of relay CR to input terminals 15 and 17 of voltage regulator 10. The parts are constructed and arranged so that the voltage at terminals 15 and 17 at this time is some value substantially less than the nominal or rated input voltage, so that the voltage regulator output voltage at terminals 25 and 27 is expressed by curve EIb of Fig. 2.

With the load 1 at its initial or low impedance value, as shown by the line RLc of Fig. 2, the initial operating voltage and current established at the closing of switch SW is determined by the intersection 31 of the plots. It can be seen that the voltage is relatively low and that the current is limited to a value of the order of approximately 80 percent of rated full load.

In the particular case where the load 1 is the heater or filament circuit of one or more vacuum tubes, the value RLc would represent the impedance of the load with the heaters cold. In similar fashion, the values RL_i, RL_h and RL_o would represent points selected along the curve RL as the impedance increases from its initial cold value, through an intermediate value, a hot value and finally to an operating value at rated voltage and current.

As the impedance of the load increases following initial energization, the voltage will rise along curve EIb, from point 31, through point 33, to some point 35, in some predetermined time interval determined by the nature of the load. For example, in the case of vacuum tube heaters, the time required for the impedance to change from RLc to RL_h may be of the order of 25 seconds.

It can be seen from curve EIb that during the rise in

voltage from point 31 to point 35, the current to the load will remain substantially constant and less than the full load value.

After the expiration of the predetermined time interval, corresponding to the delay time of time delay device 29, the relay CR is energized and its contacts transfer the input connection of voltage regulator 19 from secondary winding 11 to secondary winding 13 of transformer 7. The parts are proportioned and arranged so that the supply of energy to regulator 19 from secondary winding 13 will cause the output of regulator 19 to follow the curve EIa of Fig. 2.

With the resistance of the load at this time represented by the line RL_h of the graph, it will be seen that the voltage and current will immediately jump to the intersection of curve EIa and line RL_h, designated by the reference character 37. At this point, the current is slightly over the rated full load current, but is not excessive. The output voltage will be increased from its previous value to some value slightly lower than rated output voltage.

The voltage will now build up slowly to rated output voltage, and the current will decrease to its rated full load value, defined by the intersection of curve EIa and line RL_o, point 39, which can be said to be the normal operating point of the system.

Following the arrival of the system at its stable operating point, the voltage regulator then operates in its normal manner to maintain the output voltage constant despite fluctuations in the voltage supplied to the input of the regulator.

Upon shut down all parts are restored to their original condition, as initially described, and subsequent restarting will follow the operation described above.

The operation of the system in providing a slow build up of load voltage without excessive overload current is depicted graphically in Fig. 3, in which the variations of load current and voltage are plotted against time. When the control switch is closed, at time T₀, the voltage and current immediately assume certain values, each substantially less than rated. The voltage then increases gradually until the expiration of the time delay interval at time T₁, while the current remains substantially constant at some value less than its full load value. At time T₁, the voltage jumps to some increased value, still less than rated value and the current jumps to some value greater than full load value. The voltage then builds up slowly to its rated value, and the current decreases to its full load value, after which the voltage and current are maintained substantially constant.

A number of variations in the arrangement of the system are possible. For example, the control of the voltage supplied to the input of regulator 19 may involve more than two steps, as herein shown and described. Various arrangements for supplying the different input voltages are possible, such as, for example, the use of an autotransformer for transformer 7 rather than a transformer having separate secondary windings.

From the foregoing, it will be seen that a voltage control system according to the invention advantageously employs the drooping voltage-versus-current characteristic of a conventional voltage regulator to govern the supply of power to a load having an impedance which changes following energization. The arrangement is economical and uncomplicated and does not interfere with the normal function of the regulator.

While there have been shown and described and pointed out the fundamental novel features of the invention as applied to a preferred embodiment, it will be understood that various omissions and substitutions and changes in the form and details of the device illustrated and in its operation may be made by those skilled in the art, without departing from the spirit of the invention. It is the intention, therefore, to be limited only as indicated by the scope of the following claims.

What is claimed is:

1. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values and then decreases sharply to zero voltage for values of output current substantially in excess of full load, means for connecting said load to said voltage regulator output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, at least one other source of energy having a nominal voltage substantially less than said predetermined normal value of said regulator input voltage, and means for sequentially connecting said sources of energy to the input terminals of said voltage regulator.

2. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output-current relation in which for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, a second source of energy having a nominal voltage substantially less than said predetermined normal value of regulator input voltage, and means for sequentially connecting said sources of energy to the input terminals of said voltage regulator.

3. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, a second source of energy having a nominal voltage substantially less than said predetermined normal value of regulator input voltage, means for initially connecting said second source of energy to said input terminals of said voltage regulator for initial energization of said load, and means for subsequently disconnecting said second source of energy and connecting said first source of energy to said input terminals of said voltage regulator for normal and continued energization of said load.

4. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator

output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, a second source of energy having a nominal voltage substantially less than said predetermined normal value of regulator input voltage, means for initially connecting said second source of energy to said input terminals of said voltage regulator for initial energization of said load, and means effective after the elapse of a predetermined time interval following the initial energization of said load for disconnecting said second source of energy and connecting said first source of energy to said input terminals of said voltage regulator for normal and continued energization of said load.

5. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, a second source of energy having a nominal voltage substantially one-half of the value of said predetermined normal value of regulator input voltage, means for initially connecting said second source of energy to said input terminals of said voltage regulator for initial energization of said load, and means operative after a predetermined time interval following the initial energization of said load for disconnecting said second source and connecting said first source to the input terminals of said voltage regulator for normal and continued energization of said load.

6. A voltage control system for governing the power supplied to a load comprising the emission-producing elements of at least one electron discharge device, comprising, in combination, voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of input voltage, the output voltage remains constant at the rated normal voltage for said load for values of output current from zero to full load value, and thereafter decreases sharply to zero voltage for current values substantially greater than the rated full load current for said load, means for connecting said load to said voltage regulator output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of input voltage, a second source of energy having a nominal voltage equal to substantially one-half the value of said predetermined normal value of input voltage, a control relay, means including contacts of said control relay for sequentially connecting the input terminals of said voltage regulator to said first and said second source of energy, means including a time delay device for operating said relay at the expiration of a predetermined time interval following the initial energization of said load, control means effective to govern said initial energization.

7. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising voltage regulating means having input and output terminals and characterized by an output voltage-versus-output current relation in which, for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator

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output terminals, a first source of energy having a nominal voltage equal to said predetermined normal value of regulator input voltage, a second source of energy having a nominal voltage substantially one-half of the value of said predetermined normal value of regulator input voltage, means for initially connecting said second source of energy to said input terminals of said voltage regulator for initial energization of said load, and means operative after a predetermined time interval following the initial energization of said load for disconnecting said second source and connecting said first source to the input terminals of said voltage regulator for normal and continued energization of said load, said last-named means comprising time delay switching means provided with transfer contacts which transfer the connection of the input of said regulator means from said second source to said first source at the expiration of said predetermined time interval.

8. A voltage control system for governing the power supplied to a load having an impedance which increases from a first to a second value following energization, comprising, in combination, a voltage regulator having input and output terminals and characterized by an output voltage versus output current relation in which for a predetermined normal value of regulator input voltage, the regulator output voltage remains substantially constant for values of output current between zero and full load

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values, and then decreases sharply to zero voltage for values of current substantially in excess of full load, means for connecting said load to said voltage regulator output terminals, a source of energy, transforming means for deriving from said source energy at a first voltage value substantially less than said normal voltage and at a second voltage equal to said normal voltage, control means for connecting said source of energy to said transforming means, switching means effective in a first condition to connect the input of said regulator to said transforming means to energize said regulator at said first voltage value and effective in a second condition to connect the input of said regulator to said transforming means to energize said regulator at said second voltage value, and means governed by said control means to initially establish said switching means in said first condition and after a predetermined time interval to establish said switching means in said second condition.

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