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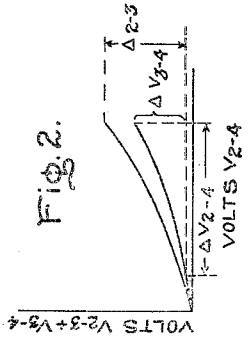
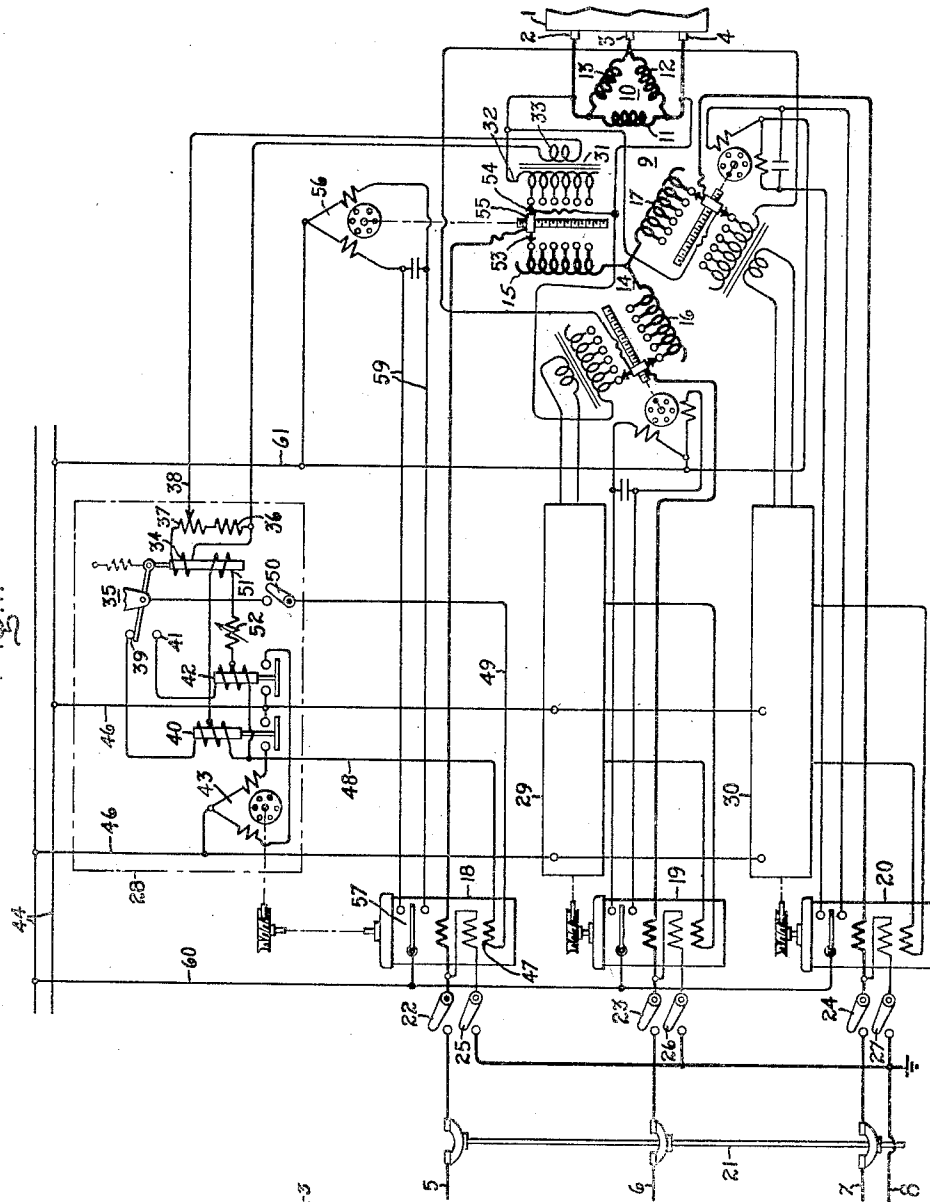
R. A. PRIOR

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ELECTRICAL REGULATING SYSTEM

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Fig. 1.



Inventor:
Roger A. Prior,
by *Crest Britton*
his Attorney.

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ELECTRICAL REGULATING SYSTEM

Roger A. Prior, Pittsfield, Mass., assignor to General Electric Company, a corporation of New York

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9 Claims. (Cl. 323—43.5)

The invention relates to electrical regulating systems and more particularly to improvements in automatic alternating current voltage regulating systems.

In polyphase, usually three phase, electric furnaces it is desirable to be able to control selectively over a substantial range the voltage of any phase, that is to say the voltage between any pair of electrodes, entirely independently of the voltage of the other phases, or in other words the voltages between all the other pairs of electrodes. The reasons for this are the desirability of selectively controlling the heating of different areas of the furnace wall and the desirability of being able to shift the center of heat in the furnace so as to control the heating in various parts of the melt. While the embodiment of the invention which is at present preferred represents the solution of a problem which arose in connection with the independent control of the phase voltages of a polyphase arc furnace, the invention, in its broader aspects and in certain subcombinations thereof, is not so limited.

Arc furnaces are usually supplied with current by a three phase furnace transformer arrangement, this being either three single phase transformers or a single three phase transformer, the two arrangements being equivalent so far as the present invention is concerned. It is preferred practice to connect the secondary phase windings of the furnace transformer in mesh or delta because it is desirable to run the furnace electrically ungrounded and the transformer secondary and furnace supply bus currents for given electrode currents are smaller with a delta connection than with a star or Y connection. The latter consideration is important because of the large currents involved in electric arc furnaces. If now the primary phase windings of the furnace transformer are also delta connected, excessively high circulating currents will flow in both the primary and secondary deltas if their phase voltages are unbalanced. Likewise, if the primary phase windings of the furnace transformer are Y connected with a grounded neutral, excessive circulating currents will flow if the phase voltages are unbalanced. It is, therefore, necessary to have the primary phase windings of the furnace transformer Y connected and to operate it with an isolated or ungrounded neutral in order to eliminate excessive circulating currents. However, with an ungrounded or isolated neutral, the neutral voltage will shift when the phase voltages are unbalanced so that control will be lost when it is attempted to operate with different phase voltages. Furthermore, it is characteristic of a delta connection that if one of the phase voltages is changed, the change affects both of the other phase voltages so that it is impossible to change one phase voltage independently of the others except by a number of successive cut and try adjustments of the voltages of all of the phases until the new voltage relationship is established.

In accordance with the present preferred form of the invention, the problems of excessive circulating current and neutral voltage shift are solved by connecting single phase induction voltage regulators in the supply lines to

the primary windings of the furnace transformer and Y connecting the primary or exciting windings of the induction voltage regulators and connecting the neutral point of this Y connection to the neutral of the power supply system, which is usually but not necessarily grounded. The problem of how to adjust each phase voltage of the furnace independently of the other phase voltages in a single operation is solved by a novel automatic control circuit in which each induction voltage regulator responds to the voltage of the phase of the secondary winding of the furnace transformer with which it is associated.

The regulating system also has additional novel features among which are a novel intercontrol between voltage adjusting means on the furnace transformer and the control of the associated induction voltage regulators so as to maintain at all times proper response or action of the primary voltage adjusting or voltage setting means for each of the phases.

An object of the invention is to provide a new and improved electrical regulating system.

Another object of the invention is to provide a new and improved automatic voltage regulating system.

An additional object of the invention is to provide a novel control system for polyphase electrical loads whereby the voltage of any phase may be adjusted at will over a wide range entirely independently of the voltage of the other phases.

A further object of the invention is to provide a new and improved control circuit for induction voltage regulators.

The invention will be better understood from the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

In the drawing, Fig. 1 is a diagrammatical representation of a preferred embodiment of the invention and Fig. 2 is a voltage diagram for explaining one of the features of the invention.

Referring now to the drawing, and more particularly to Fig. 1, there is shown an electric load 1 in the form of a three phase furnace having electrodes 2, 3, and 4. This furnace is supplied with power from the line conductors 5, 6, and 7 of a three phase power supply system which also has a neutral conductor 8. The voltage of the supply system is stepped down and the current is stepped up by means of a furnace transformer arrangement indicated generally at 9. As has previously been indicated, this may either be three single phase furnace transformers or a single three phase furnace transformer and solely for the sake of simplicity of description, it will be treated as a single three phase transformer having a delta connected secondary winding 10 provided with phase windings 11, 12, and 13 and having a Y connected primary winding 14 provided with tapped phase windings 15, 16, and 17. Connected between supply line conductor 5 and primary phase winding 15 is an induction voltage regulator 18; connected between the supply line conductor 6 and the primary phase winding 16 of the furnace transformer is another single phase induction regulator 19, and connected between the supply system conductor 7 and the primary phase winding 17 of the furnace transformer is a third induction voltage regulator 20.

Interruption of current supply to the furnace 1 is controlled by a three phase circuit breaker 21 while separate disconnecting switches 22, 23, and 24 are provided between the induction voltage regulators and their associated supply lines. The induction voltage regulators, as is well known, each have a series variable voltage winding shown in heavy lines and a shunt or exciting winding shown in lighter lines, the latter being normally connected to the system neutral 8 by individual disconnecting

switches 25, 26 and 27 so that these exciting windings are normally Y connected with a grounded neutral.

Most of the controls for the induction voltage regulator 18 are shown in the box 28 and it will be understood that corresponding controls are in the box 29 for induction voltage regulator 19 and in the box 30 for induction voltage regulator 20. As the controls for the induction voltage regulator and the tap changer in each of the three phases are the same, they will only be described in detail in connection with the topmost phase as viewed in the drawing, that is to say, for induction voltage regulator 18 and for the primary phase winding 15 of the furnace transformer whose associated secondary phase winding is indicated at 11 for providing the voltage between the furnace electrodes 2 and 4.

Induction voltage regulator 18 is connected to respond to the voltage of secondary phase winding 11 of the furnace transformer, that is to say, it is connected to respond to the voltage between the electrodes 2 and 4 of the furnace by means of a control potential transformer 31 having a multitapped primary winding 32 connected across the secondary phase winding 11 and having a secondary winding 33 connected to energize an operating coil 34 for a voltage regulating relay 35. However, this is not a direct connection because a ballast resistor 36 and a potentiometer rheostat 37 are series connected with the operating coil 34 while one terminal of the secondary winding 33 of the control potential transformer is connected to a movable manually adjustable slider contact 38 on the potentiometer rheostat. This slider contact 38 is the master manually operable adjuster for the voltage setting of the secondary phase winding 11 of the furnace transformer. The voltage regulating relay 35 has a raise contact 39 for controlling an auxiliary raise relay 40 and it has a voltage lowering main control contact 41 for controlling an auxiliary lowering relay 42. These relays control the direction of operation of a motor 43 for driving induction voltage regulator 18, the operating current for the motor 43 being obtained from a relatively low voltage auxiliary supply circuit 44 by way of conductors 46.

The current supply for the raising and lowering auxiliary relays 40 and 42 is derived from an auxiliary winding 47 on the induction voltage regulator 18, one terminal thereof being connected by a conductor 48 to a common terminal of the operating windings of the raising and lowering auxiliary relays 40 and 42 and the other terminal of the auxiliary winding 47 being connected by the conductor 49 through a manual-auto selector switch 50 to a common contact or the contact beam of the voltage regulating relay 35.

Adjacent to the main operating coil 34 of the voltage regulating relay 35 is a holding coil 51 which is connected by way of a series rheostat 52 to corresponding intermediate points on the operating windings of the auxiliary raising and lowering relays 40 and 42.

The power connections to the primary phase winding 15 of the transformer are made by way of a tap changer 53 and the energizing connections of the primary winding 32 of the control potential transformer 31 are made by way of a tap changer 54. These two tap changers are interlocked by a common operating member 55 so as to be operable simultaneously and so as to vary inversely the respective ratios of a phase 11, 15, of the furnace transformer and its corresponding control potential transformer 31. The tap spacings in the two sets of taps correspond percentage-wise to each other so that the change in ratio of the control potential transformer 31 resulting from a tap change is the same as, but inverse to, the change in ratio of the furnace transformer that results from a tap change. As will be explained more fully hereafter, it is this feature which makes it possible to obtain the same proportional control for any given adjustment of the master potentiometer slider contact 38 regardless of the position of the tap changer 53.

The common operating member 55 for the tap changers

53 and 54 may be operated through any suitable mechanism by a reversible motor 56 whose direction of operation is controlled by a reversing switch 57 shown on the regulator 18. The motor 56 and the switch 57 are interconnected by means of conductors 59 and operating current for the motor 56 is obtained through conductors 60 and 61 from the auxiliary supply circuit 44. The reversing switch 57 may either be manually operable or it may be a set of conventional limit switches built into the induction voltage regulator 18 so that the appropriate circuit for the motor 56 will automatically be closed whenever the induction voltage regulator reaches a limit of its travel so as to cause operation of the tap changer on the furnace transformer.

For the sake of simplicity, the usual protective limit switches in induction voltage regulators for deenergizing their operating motors when they reach either end of their limit of travel have been omitted but it will, of course, be understood that in actual practice, it is desirable to have them in the circuit. However, the switch 57 when operating as a limit switch will provide a certain amount of protection because of its control of the furnace tap changer. As soon as the furnace tap changer makes a tap change, the secondary voltage, of course, is changed and induction voltage regulator will, therefore, respond and back off thus opening the limit switch and stopping the furnace transformer ratio adjuster.

It will be observed that the induction regulators and the furnace transformers are both variable ratio transformers and that one of each are concatenated in each phase of the system in the sense that the output of each induction voltage regulator is connected to the input of a different phase of the furnace transformer. It will also be noted that the induction voltage regulators are smoothly variable ratio transformers whereas the tap changing furnace transformer is a step by step variable ratio transformer. There is thus a vernier type of voltage controlling action in the system in that the load or output voltage of the overall system is varied smoothly by the induction voltage regulators over a range corresponding roughly to a tap change or step of the furnace transformer and that the regulating action of the induction voltage regulators may be used over and over again for each different step or tap position of the tap changer for the furnace transformer.

The operation of the illustrated embodiment of the invention is as follows:

Assume that the three phase supply line 5-6-7 is energized by any suitable source of current supply (not shown), that the three phase circuit breaker 21 is closed, and that the disconnecting switches 22, 23, 24, 25, 26, and 27 are closed and that the manual-auto selector switch 50 is closed. Assume further that the voltage of the secondary phase 11 of the furnace transformer 9 is at the desired value. Under these conditions, the voltage regulating relay 35 will be balanced in an intermediate position so that the auxiliary relays 40 and 42 will be deenergized and consequently, the operating motor 43 for the induction regulator 18 will be deenergized. If now it is desired to vary the voltage of the phase 11 independently of the voltages of the phases 12 and 13 of the secondary winding 10 of the furnace transformer arrangement 9, the slider 38 on the potentiometer rheostat 37 is moved in the appropriate direction. This will momentarily unbalance the voltage regulating relay 35 causing it to complete a circuit through its raise contact 39 or its lower contact 41 in which case either the raise auxiliary relay 40 or the lower auxiliary relay 42 will be energized from the auxiliary winding 47, thereby completing an operating circuit for the motor 43 which latter circuit is energized by the auxiliary supply circuit 44. The induction regulator will therefore change the voltage applied to the primary phase 15 of the furnace transformer until the voltage of the secondary phase 11 reaches

series with the primary winding of said transformer and having an exciting winding, a voltage regulating relay for said induction voltage regulator, a control potential transformer for energizing said voltage regulating relay in accordance with the voltage of the secondary winding of said transformer, a potentiometer connected between said potential transformer and said voltage regulating relay for controlling the voltage setting of said relay, said control potential transformer also having a multitapped primary winding, separate tap changing means associated with the taps of each of said primary windings, and common operating means for said tap changer for causing corresponding but inversely related changes in ratio of said transformer and said control potential transformer.

5. In combination, a main transformer having a multitapper primary winding and a secondary winding, an induction voltage regulator having a series winding connected in series with the primary winding of said main transformer, said induction voltage regulator having an exciting winding and an auxiliary winding inductively coupled thereto, means including a voltage regulating relay for controlling the operation of the induction voltage regulator, a potential transformer for energizing said voltage regulating relay in proportion to the voltage of the secondary winding of said main transformer, a holding coil and said voltage regulating relay and means including said auxiliary winding on said induction voltage regulator for energizing said holding coil in response to a controlling action by said voltage regulating relay.

6. In combination, a three phase transformer system having a Y connected primary winding with an isolated neutral and a delta connected secondary winding, three single phase induction voltage regulators each having a variable voltage winding connected in series with a different phase winding of said primary winding, each regulator having an exciting winding connected to its associated variable voltage winding at the end thereof, electrically remote from said primary winding, said exciting windings having a common neutral connection, each regulator also having an auxiliary winding inductively coupled to its exciting winding, a voltage regulating relay for each induction voltage regulator, each regulating relay having a main control coil, each regulating relay also having a control coil and separate "raise" and "lower" control contacts, auxiliary relay means associated with each voltage regulating relay having separate operating coils provided with a common terminal which is connected to one end of the auxiliary winding on the associated induction regulator, the other end of said auxiliary winding being selectively connectable to said operating coils by way of said raise and lower contacts respectively, said holding coil being connected between the intermediate points on said operating coils, and means for energizing each main control coil from a phase voltage of said secondary winding which is in phase with the voltage of the auxiliary winding of the induction regulator with which it is associated.

7. In combination, a furnace transformer having a secondary winding for connection to an electric furnace and having a primary winding which is provided with a tap changer, an induction voltage regulator connected to control the voltage of the primary winding of said furnace transformer, an operating motor for said regulator, a voltage regulating relay for said regulator for controlling the direction of operation of its motor, a control potential transformer having a primary winding connected across the secondary winding of said furnace transformer and having a secondary winding connected to energize said

voltage regulating means, means including a rheostat interposed between said voltage regulating relay and the secondary winding of said control potential transformer for adjusting the voltage setting of said voltage regulating relay, a separate tap changer for the primary winding of said control potential transformer, the taps on the primary winding of said furnace transformer corresponding percentage wise to the taps on the primary winding of the control potential transformer, and means for interlocking and inversely coordinating the tap changer for the primary winding of the furnace transformer with the tap changer of the control potential transformer.

8. In combination, a three phase furnace transformer having a delta connected secondary winding provided with three terminals adapted to be connected respectively to the three electrodes of a three phase arc furnace and having an isolated neutral star connected primary winding each of whose phase is provided with a tap changer, three star connected single phase induction voltage regulators having a solidly connected neutral, each of said regulators having an output terminal directly connected to a different one of said tap changers and having an input terminal for connection to a different phase conductor of a three phase power supply circuit, a separate operating motor associated with each regulator, a separate voltage regulating relay associated with each regulator for controlling the direction of operation of its motor, three single phase control potential transformers whose primary windings are respectively connected between different pairs of output terminals of the delta connected secondary winding of said furnace transformer and whose secondary windings are connected respectively to energize the voltage regulating relay of the regulator which is connected to the corresponding primary winding of said furnace transformer, means including a potentiometer rheostat interposed between each voltage regulating relay and its associated control potential transformer secondary winding, a separate tap changer for the primary winding for each control potential transformer, the taps on the primary phase windings of a star connected furnace transformer corresponding percentagewise to the taps on the primary winding of the control potential transformer, and means interlocking and inversely coordinating the tap changer for the primary phase windings of the furnace transformer with the tap changer of the control potential transformer for the induction voltage regulator in the corresponding phase.

9. In an electric circuit, a first variable ratio transformer concatenated with a second variable ratio transformer so that energy normally flows from the first through the second, control means responsive to changes in the output voltage of the second transformer for varying the ratio of the first transformer so as to maintain said output voltage at a pre-determined value, said control means comprising a variable ratio potential control transformer, adjustable means movable through a given range for varying the magnitude of said pre-determined value, and additional means for varying the respective ratios of said potential control transformer and said second transformer in an inversely proportional relationship so that any percentage change in position of said adjustable means will cause the same percentage change in said predetermined value regardless of the ratio of said second transformer.

References Cited in the file of this patent

UNITED STATES PATENTS

1,780,032 Moody ----- Oct. 28, 1930

the predetermined value determined by the setting of the slider 38. When that value is reached, the voltage regulating relay 35 will again balance and the induction voltage regulator will come to rest.

It will be observed that only one auxiliary relay can be energized at a time and that the polarity of the voltage introduced in the circuit of the holding coil 51 of the voltage regulating relay will be in one direction when one auxiliary relay is energized and will be in the reverse direction when the other auxiliary relay is energized. Consequently, the holding coil 51 aids the main operating coil 34 in one case and opposes its action in the other case and the direction of winding of the holding coil 51 or its connections are so selected that when the raise auxiliary relay 40 is energized, the holding coil 51 opposes the main control coil 34 thus tending to hold the raise contacts firmly together whereas the reverse holding coil effect takes place during a lowering action of the regulator. However, the relative phase of the energizations of the main control coil 34 and the holding coil 51 is ultimately controlled by the sources of energization of these two coils which are respectively the control potential transformer 31 and the auxiliary winding 47 and it will be seen that the voltage of the primary winding of the control potential transformer 31 is substantially in phase with the voltage of the auxiliary winding 47.

Ordinarily, changing the voltage of one of the phases of a delta connection automatically changes the voltages of the other two phases so that these voltages are interdependent rather than independent. Thus, for example Fig. 2 shows how for a given incremental change in voltage between electrodes 2 and 4 indicated by ΔV_{2-4} , there will be an accompanying incremental change in voltage between electrodes 2 and 3 indicated by ΔV_{2-3} , and a smaller incremental change in voltage between electrodes 3 and 4 indicated by ΔV_{3-4} . However, with the present system, any incipient change in voltage between electrodes 3 and 4 resulting from the change in voltage setting between electrodes 2 and 4 will be checked by the automatic control 29 for the regulator 19 and, likewise, any incipient change in voltage between electrodes 2 and 3 caused by the change in voltage setting between electrodes 2 and 4 will be responded to and checked by the automatic control 30 for the regulator 20, it being, of course, understood that controls 29 and 30 correspond to control 28 for regulator 18.

If the induction voltage regulator 18 approaches a limit of its regulating range because of a sufficiently wide adjustment of the slider 38 of the potentiometer 37, then a tap change may be made on the primary winding 15. This, of course, produces a step-like change in voltage of the secondary phase 11 and, at the same time, produces a corresponding step-like change in the ratio of the control potential transformer 31. Because of the inversely proportional relationship between the respective ratio changes of the control potential transformer and the furnace transformer, the tap changing operation will not change the output voltage of the secondary winding 33 of the control potential transformer, so that the response of the system to the setting of the slider 38 will be the same as it was before the tap changing. That is to say, if the slider, for example, is in the middle of its range of adjustment, then the voltage regulating relay 35 will balance at a secondary phase voltage of the furnace transformer corresponding to the particular tap position of the tap changer 53 for the primary winding 15 when the regulator 18 is in its neutral position, and this relationship will be preserved for any position of the tap changers so long as the slider 38 is in the middle of its range of operation. If the slider is moved to produce a 3 percent increase or decrease in secondary voltage of the furnace transformer, then the same percentage change in voltage will be obtained with the same position of the slider 38 for any position of the tap changers.

The operation of the tap changers 53 and 54 can be made automatically in response to the induction voltage regulator 18 reaching the appropriate limit of its regulating range by energizing the operating motor 56 of the tap changers 53 and 54 from the auxiliary supply circuit 44 through a limit switch 57 on the regulator 18.

While I have shown electrodes 2-4 as being connected external to the closed delta 10, it is apparent that the delta 10 could equally well be closed at the electrodes. This alternative connection would desirably limit the circulating current flowing within the delta but would not materially affect the operating characteristics of the automatic regulating system.

While I have shown a particular embodiment of my invention, it will be understood, of course, that I do not wish to be limited thereto since many modifications may be made, and I, therefore, contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

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

1. In an electric circuit, a first variable ratio transformer concatenated with a second variable ratio transformer so that energy normally flows from the first through the second, means responsive to changes in the output voltage of the second transformer for varying the ratio of the first transformer so as to maintain said output voltage at a predetermined value, adjustable means movable through a given range for varying the magnitude of said predetermined value, and means responsive to a change in ratio of said second transformer for so varying the setting of said means responsive to the output voltage of said second transformer that any percentage change in position of said adjustable means will cause the same percentage change in said predetermined value regardless of the ratio of said second transformer.

2. In an electric power circuit, a transformer whose ratio is smoothly variable so concatenated with a transformer whose ratio is variable in steps that power normally flows from the smoothly variable ratio transformer to the step by step variable ratio transformer, means responsive to the output voltage of the smoothly variable ratio transformer for varying the ratio of the smoothly variable ratio transformer so as to maintain said output voltage at a predetermined value, adjustable means movable through a given range for varying said predetermined values and means responsive to a change in ratio of said step by step variable ratio transformer for so varying the setting of said means responsive to said output voltage that any percentage change in position of said adjustable means will cause the same percentage change in said predetermined value regardless of the ratio of said step by step variable ratio transformer.

3. In combination, an induction voltage regulator having main input terminals for connection to a source of power current and main output terminals, a transformer having main input terminals connected to the main output terminals of said induction regulator and main output terminals for connection to a load, a tap changer for varying the ratio of said transformer, means responsive to the voltage difference of the main output terminals of said transformer for operating said induction voltage regulator so as to maintain said voltage difference at a predetermined value, adjustable means movable through a given range for varying the magnitude of said predetermined value, and means operated by the tap changer of said transformer for so varying the setting of said means responsive to the voltage difference of the output terminals of said transformer that any percentage change in position of said adjustable means will cause the same percentage change in said predetermined value regardless of the position of said tap changer.

4. In combination, a transformer having a multitapped primary winding and a secondary winding, an induction voltage regulator having a series winding connected in