

April 27, 1937.

F. G. LOGAN

2,078,880

ELECTRIC CONTROLLING APPARATUS

Filed Feb. 9, 1935

6 Sheets-Sheet 1

FIG. 1

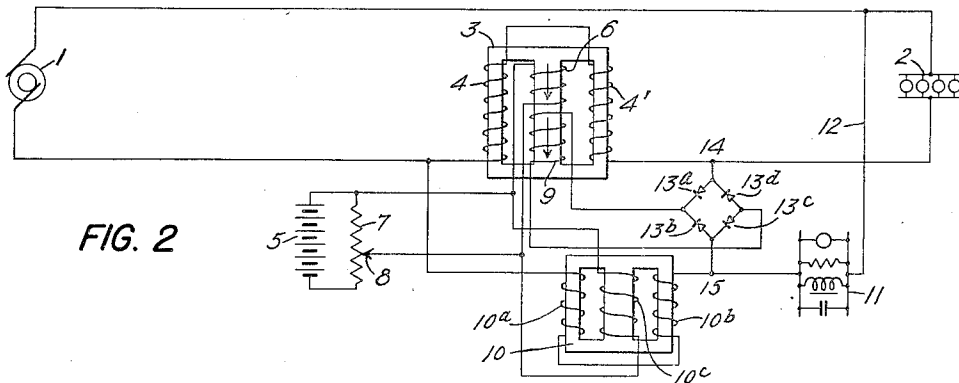
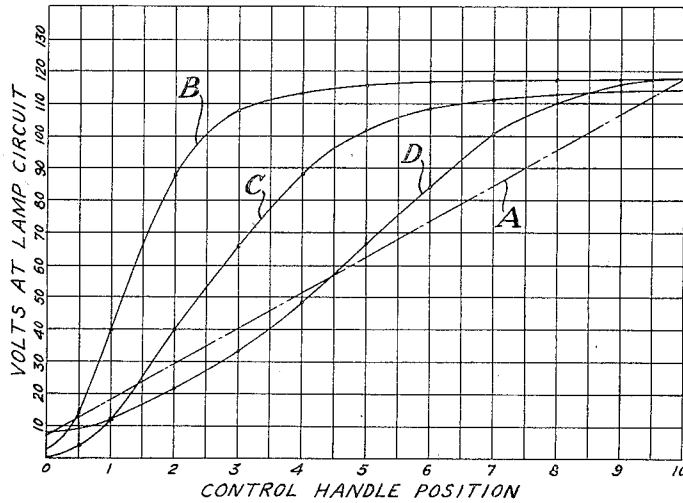


FIG. 2

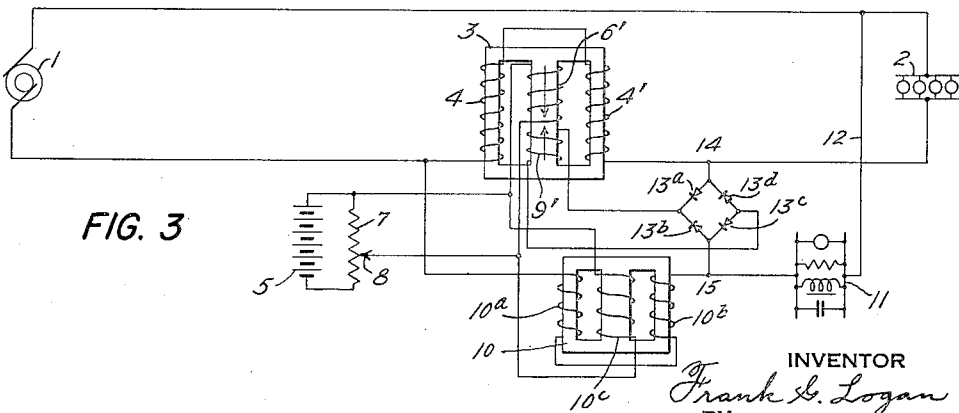


FIG. 3

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FIG. 6

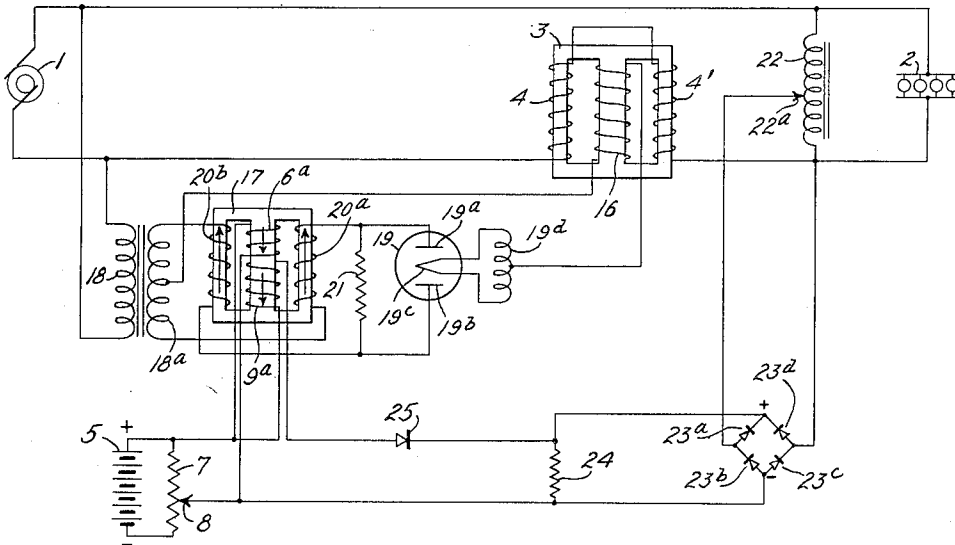
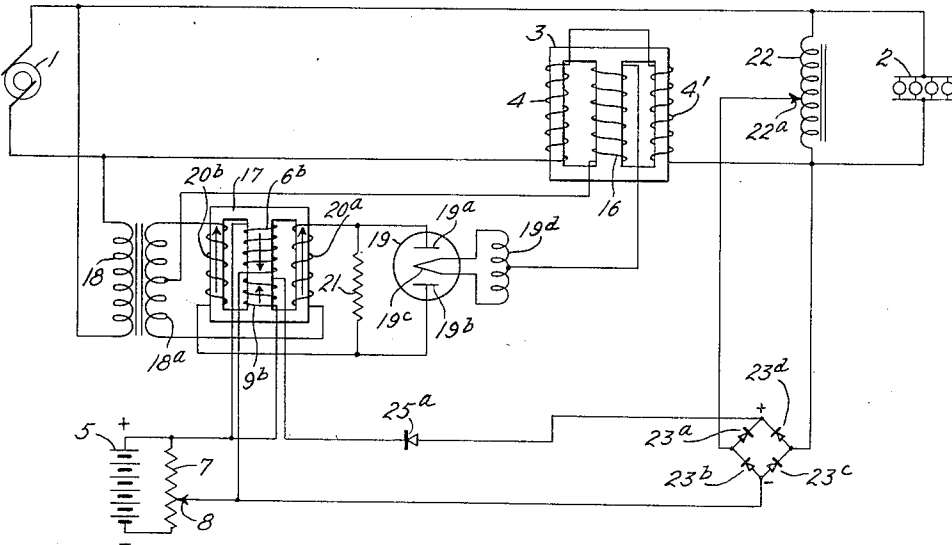


FIG. 7



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FIG. 8

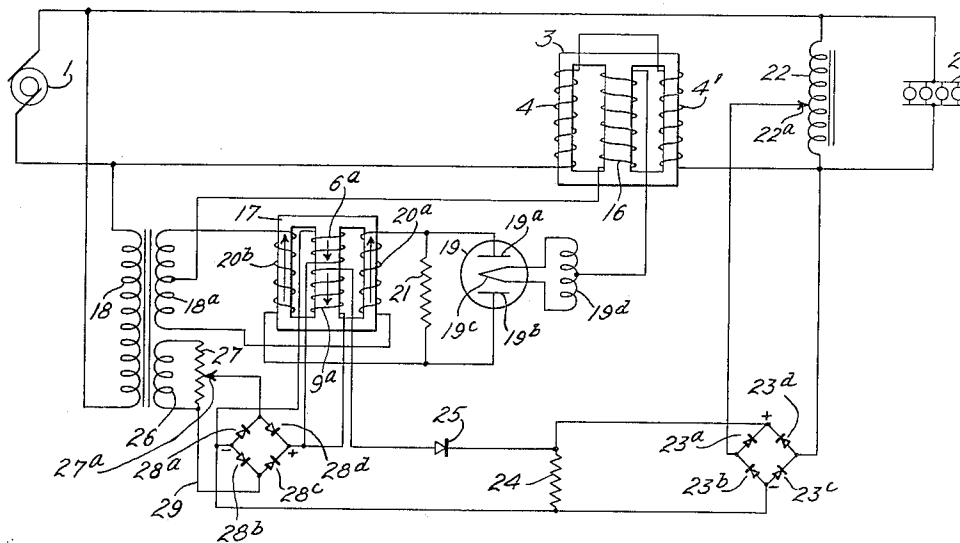
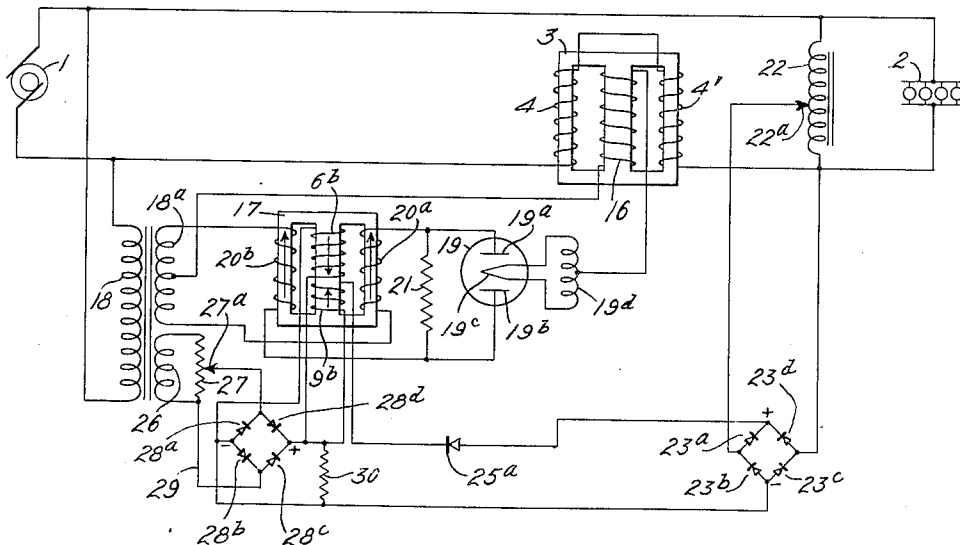


FIG. 9



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ELECTRIC CONTROLLING APPARATUS

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FIG. 10

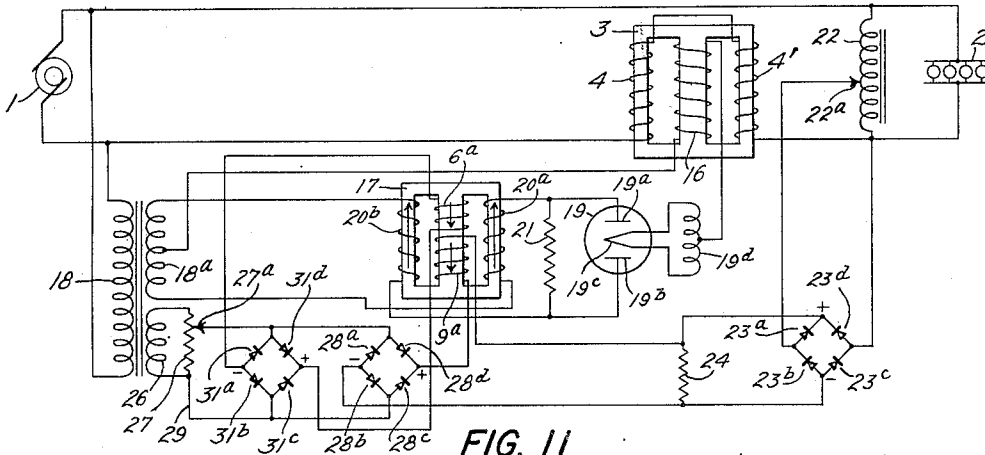


FIG. 11

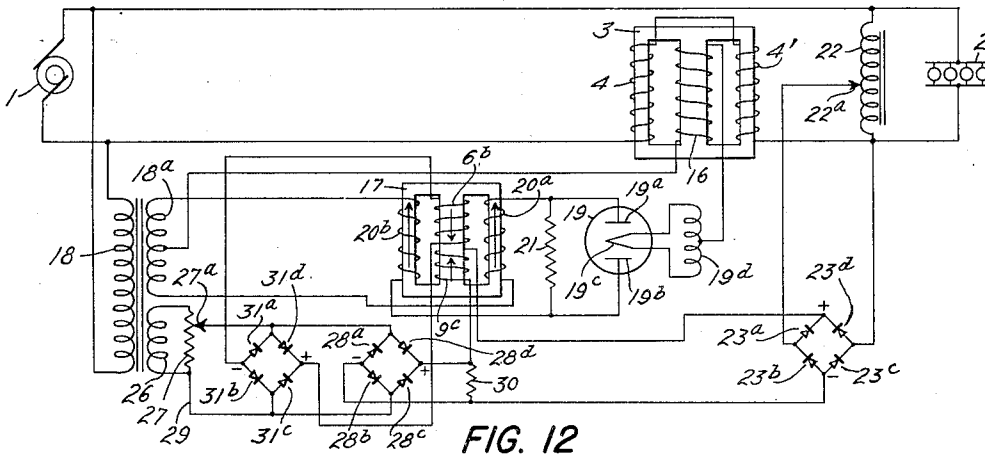
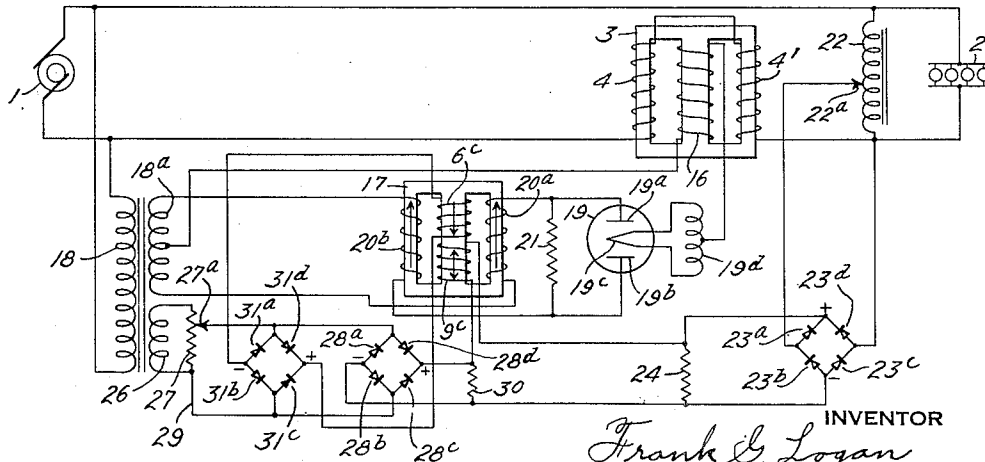


FIG. 12



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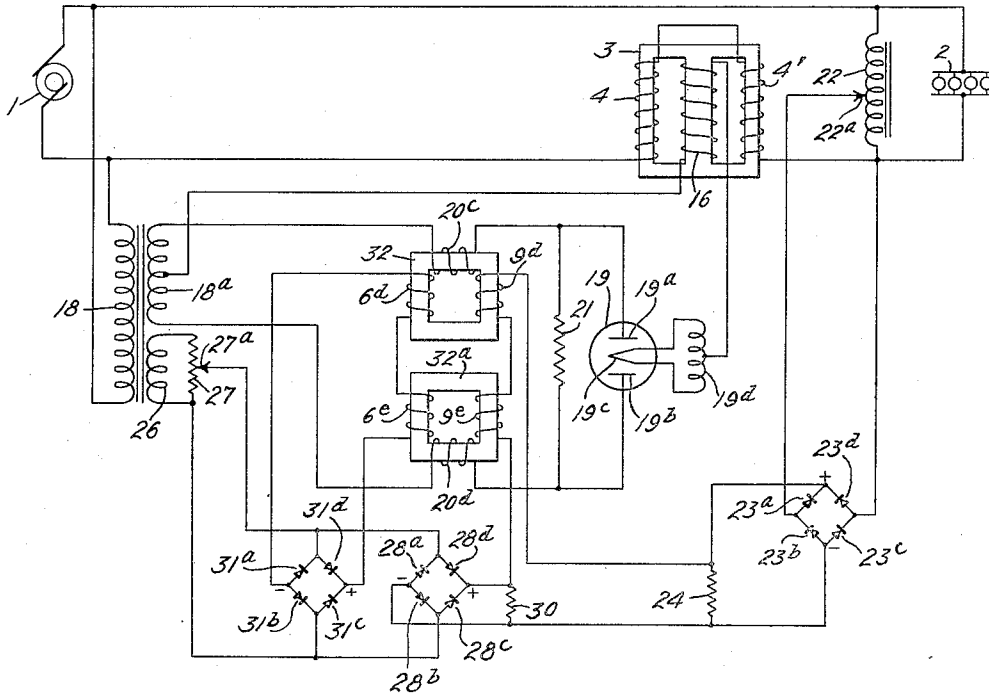
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FIG. 13



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2,078,880

ELECTRIC CONTROLLING APPARATUS

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Application February 9, 1935, Serial No. 5,719

29 Claims. (Cl. 171-242)

This invention is particularly applicable to the control of consumption circuits wherein the voltage applied thereto is varied over a wide range, such as in the case of dimmer control of lamp circuits for stage productions. Reactors are commonly used for effecting this variation of lamp circuit voltage wherein current from the alternating current source is passed through one or more windings on the reactor core in series with the lamp circuit. The lamp circuit voltage is adjusted to the desired different values by changing the value of a direct current passing through another winding on the reactor core. This results in changing the magnetic flux of the core and thus changes the reactance of the alternating current windings resulting in correspondingly changing the voltage applied to the lamp circuit. The value of the controlling direct current is changed by some adjustable means, such as a control handle or sliding contact. When the number of lamps connected to the consumption circuit, or the load, remains constant, the position of the control handle will always be the same for securing the same consumption circuit voltage or the same lamp brilliancy, assuming the voltage of the source to remain constant. When, however, the number of lamps connected to the consumption circuit, or load, is changed, the voltage applied to the consumption circuit becomes quite different for a given position of the control handle. Furthermore, under any lamp load, there results a considerable departure of the voltages applied to the consumption circuit along the range of adjustment, from the most desirable or ideal lamp voltage curve with reference to the successive steps of movement of the controlling handle. It thus follows that when the lamp load on one of these controlled circuits, or on any number of them is changed for obtaining different lighting effects, the operator finds that for corresponding positions of the controlling handle, the resulting lamp voltage and lamp brilliancy varies greatly. The operator is likewise unable to secure the ideal lamp voltage over the full range for any load. Where a multiplicity of these lamp circuits is to be variably utilized with different loads in different set-ups of sequential scenes, it is impossible for the operator to preset the controlling handle for each circuit to give the required voltage and lighting effect, owing to the practical difficulties of attempting to variably preadjust the position of the control handle for different lamp loads. Likewise with the usual control system, he cannot obtain the ideal lamp voltage curve under any load.

The main object of the present invention is to provide an improved method of control and automatic controlling means for securing the same lamp voltage, or consumption circuit voltage, or load condition, from each corresponding position of the control handle, regardless of the value of the load, or change in number of the lamps in circuit within the capacity range of the reactor. Another object is to attain the ideal lamp voltage curve, or a close approximation thereto, throughout the range of control for any load. Other objects are to accomplish these purposes efficiently and by means of apparatus which is comparatively simple, inexpensive and dependable with long continued use. Another object is to reduce the size and cost of the main controller which becomes permissible because the auxiliary controlling means secures automatic control of the minimum and maximum controlling current under all loads and thus avoids the necessity of extra size of the main controller otherwise required for obtaining desired results at the extremes of adjustment. Other objects and advantages will be understood from the following description and accompanying drawings.

Figure 1 is an explanatory chart; Fig. 2 is a diagram showing one embodiment of the invention; Fig. 3 is a similar diagram with a modified form of control; Fig. 4 is a diagram of another embodiment of the invention; Fig. 5 is a diagram similar to Fig. 4 with a modified form of control; Fig. 6 is a diagram of a different type of control embodying the invention and Fig. 7 is a diagram of a modified form thereof; Fig. 8 is a diagram of another embodiment and Fig. 9 a modified form thereof; Fig. 10 is a diagram of still another embodiment of the invention and Figs. 11 and 12 are diagrams of modified forms; and Fig. 13 is a diagram similar to Fig. 12 and in which separate cores are used in the auxiliary controlling reactor.

Referring to Fig. 1, the abscissae represent the position of the dimmer control handle and equal increments of saturating current and the ordinates represent the volts applied to the lamp circuit. The line A represents an example of an ideal lamp voltage curve, being shown as a straight line and giving the same increase in volts applied to the lamp circuit for each step of the control handle. This ideal curve may be different for particular cases but the line A may be assumed as the most desirable for the present case. The curve B shows the actual results obtained when the lamp load on the circuit was comparatively small and when using the customary reactor control system. Here the lamp

voltage is at about 100 volts when the control handle is in position $2\frac{1}{2}$. Thus in the more advanced handle positions there is practically no control of the lamps and there is altogether a too pronounced change of lamp voltage in the initial positions. The curve C shows the actual results obtained with twice the load of curve B. Curve C shows 100 volts is attained before position $\frac{1}{2}$ of the control handle is reached giving no practical control beyond that position. Likewise the control is too pronounced in the initial positions. The curve D shows the results obtained with the optimum lamp load and the circuits specially adjusted to give the best results for that load. Even then the lamp voltage change is too pronounced at the middle handle positions and too small in the outer positions. Obviously, with the widely different lamp voltage curves resulting from adjustment of the control handle under the different load conditions, the lighting effect is quite different for corresponding positions of the handle and cannot even obtain the ideal curve with the optimum load. By means of the present invention, the method of control and apparatus used results in bringing the lamp voltage curve under all load conditions to approximately coincide with the ideal lamp voltage curve for all positions of the control handle.

In carrying the present invention into effect, the method employed consists in utilizing or specially creating a selected reference lamp voltage for the different positions of the control handle, such as the line A of Fig. 1, and then causing the voltage applied to the consumption circuit to conform thereto, or very nearly thereto, by utilizing the difference between the reference voltage and lamp circuit voltage for yielding a resultant current which in turn controls suitable compensating means. This voltage or potential difference is comparatively slight in order to secure the desired compensating effect with the result that the lamp circuit voltage may be readily kept, in practice, within one or two volts of the reference voltage, or ideal lamp voltage, for all positions of the control handle, even under change of load.

One form of apparatus for practicing this invention is disclosed in Fig. 2 wherein the alternating current source 1, which may be any suitable source, supplies current to the consumption circuit 2, indicated as having a lamp load. A main controlling reactor is shown having a core 3 which is indicated for simplicity as of the three-legged type. On the outside legs are wound the usual alternating current windings 4, 4' in series with each other and with the load. Obviously, when the reactance of these windings is changed by control of the magnetic flux of the core, the voltage applied to the consumption circuit will be changed in a manner well understood by those skilled in the art. A source 5 of direct current supplies a winding 6 on the middle leg of the core 3 which may be termed a saturating winding. The source 5 may be any suitable source and may be derived from the alternating current source 1 but is shown as a battery for simplicity. A resistance 7 is connected across the direct current source and one terminal of the winding 6 is connected to the adjustable contact 8 engaging the resistance 7. In the usual reactor control system the winding 6 serves as the main controlling direct current winding, current therein being adjusted by the movable contact 8, corresponding to the control handle above referred to. As already explained in connection

with Fig. 1, the lamp circuit voltage will vary greatly, under different lamp loads, and widely depart from the ideal lamp voltage curve for corresponding positions of the control contact 8 unless some compensating means be employed.

In the present instance, the ampere-turns of the winding 6 are made considerably less than those of the usual direct current control winding of the reactor and is made so much less that at no time will the voltage applied to the consumption circuit in any position of the control handle 8, attain the values represented by the ideal lamp voltage curve. That is to say, the lamp voltage curve resulting from the use of winding 6 alone would, at all points, be below the ideal lamp voltage curve. In order to bring the lamp voltage up to the desired value for each position of the control handle, another uni-directional current winding 9 is shown added to the middle leg of the reactor core and is wound in such direction, as indicated by the arrows on the middle leg of the core, as to act cumulatively with the excitation of the winding 6. The current in the compensating winding 9 is dependent upon the amount which the lamp circuit voltage departs from the selected reference voltage curve which difference is always comparatively small.

In order to create the reference voltage so that it will be related to the consumption voltage to give the desired control of the lamp circuit voltage for all positions of the control handle, an auxiliary reactor 10 which may be comparatively small, is provided which in turn supplies a special reference load 11. The reactor 10 is shown as having a three-legged core for simplicity and as having the outside legs enveloped by alternating current windings 10a and 10b which are connected in series with each other and with the load 11 across the supply lines of the source 1. The middle leg of the core carries a direct current winding 10c which is connected in parallel with the winding 6 between the control handle 8 and the other side of the resistance 7. The reference load 11 is a fixed load and may be made up of such combination of resistive, inductive and capacitive devices, as will give the desired reference control voltage for making the consumption circuit voltage coincide with, or closely conform to, the desired circuit voltage curve for all positions of the control handle. The load 11 is of comparatively small value and a lamp, resistor, inductor and condenser is represented as a general indication of making up the load of such character as will give the desired reference voltage, the composition and adjustment of such load being arrived at in a manner well understood in the art. This reference load is formed not only to give a required voltage as a reference voltage to the consumption circuit voltage throughout the range of control, but also to give a desired phase relationship of its voltage to that of the consumption circuit.

In order to relate the reference voltage to the consumption circuit voltage and to utilize their difference for securing the desired controlling current in the winding 9 of the main reactor, one side of the load 11 is connected directly to one side of the consumption circuit by the lead 12 and the other side of the load 11 is connected to the other side of the consumption circuit through a full wave rectifier which will deliver a current to the winding 9 depending upon the potential and phase difference applied to the rectifier. Any suitable form of rectifier may be used but for

simplicity a copper-oxide rectifier 13a, 13b, 13c, 13d, is indicated connected respectively in each side of a bridge connection. The opposite apexes of the bridge are connected respectively to one side of the consumption circuit and to one side of the reference load so that the rectifier is subjected to the difference in potential between them. The other opposed apexes of the bridge are connected to the winding 9. It will be seen that when the line 14 of the consumption circuit has one polarity, current will pass therefrom through the rectifier 13a, winding 9 and through rectifier 13c to the line 15 of the reference load. When the polarity of the line 14 is reversed, current will pass from the line 15 through the rectifier 13b, winding 9 and through rectifier 13d, to line 14. Obviously, the magnitude of the current which will flow in the control winding 9 will depend upon the relative potentials of the points 14 and 15.

In understanding the operation, it should be remembered that if the control winding 6 were used without the cooperative effect of the winding 9, the voltage of the consumption circuit would always be such as to give a consumption circuit curve below the desired curve in all positions of the control handle 8; and the voltage of the reference load for all positions of the control handle will conform closely at all times to the ideal lamp circuit voltage. Let it be assumed that the handle 8 be placed in one of the intermediate positions. At that time the current in the winding 6 is not enough to sufficiently saturate the core 3 to bring the voltage of the lamp circuit up to the desired amount. Consequently, a potential difference exists between points 14 and 15 in the consumption circuit and the reference load which will cause a resultant controlling current to flow in the winding 9. As this current has a cumulative effect with that of the winding 6 on the saturating flux of the core 3, the voltage applied to the lamp circuit will be correspondingly increased. As the resistance of the compensating circuit, including the winding 9 and the rectifiers, may be made low, the current in the compensating winding 9 may be of such value as to increase the voltage applied to the consumption circuit to the required amount, or very close thereto, with only a slight difference in potential between the points 14 and 15; and aside from the average value of this potential difference, the phase difference of the circuits may likewise be utilized for securing the desired compensating effect by composition of the load 11 as regards inductance and capacity, as above explained. It will likewise be appreciated that any desired lamp voltage curve may be attained or very closely approached by proper composition of the load 11 by deriving a reference voltage curve which is properly related to the desired lamp voltage curve and which relation may take account of and off-set the losses which may occur in the compensating connections. It will be understood that what has been said as to one intermediate position of the control handle will likewise apply to all other positions thereof, owing to the fact that the compensating control always compensates to the degree necessary to bring the voltage at the consumption circuit under all loads up to the required lamp voltage, or a very close approach thereto, for every position of the control handle.

In Fig. 3, the apparatus and connections are the same as those described in Fig. 2, the same reference characters designating the corresponding parts, except that in Fig. 3 the winding 6'

has more ampere-turns than the winding 6 of Fig. 3 and the winding 9' of Fig. 3 has less ampere-turns than the winding 9 of Fig. 2 and is reversed as to the winding 6'. In the case of Fig. 3, instead of compensating on the principle of raising the voltage of the consumption circuit to the required consumption circuit voltage curve, as in Fig. 2, the excitation due to the winding 6' is made so large that if it acted alone, the voltage of the lamp circuit would be above the desired voltage for all positions of the control handle. The winding 9' being such as to always oppose the flux due to the winding 6' and carrying a controlling current dependent upon the difference between the voltage of the consumption circuit and of the reference circuit will result in reducing the saturation flux of the main reactor to such an amount as to bring the voltage at the consumption circuit down to the desired consumption circuit voltage; and this will occur in all positions of the control handle 8 giving the desired consumption voltage curve regardless of the load, as will be understood from the explanations made in Fig. 1.

Fig. 4 shows the invention in its application to the control of the consumption circuit voltage particularly adapted for instances where the consumption circuit load is comparatively large. In Fig. 4 the parts similarly designated correspond to the same parts in Fig. 2. In Fig. 4 there is only one controlling direct current winding 16 on the main reactor core 3, the current for which is derived from the alternating current source 1 and controlled through an auxiliary controlling reactor having a core 17. A transformer has a primary 18 connected to the source 1 and a secondary 18a which supplies current to a full wave rectifier 19 having anodes 19a and 19b and a cathode 19c. One terminal of the secondary 18a is connected to a winding 20b on one of the outside legs of the reactor core 17 and is in turn connected to the anode 19b. The other terminal of the secondary 18a is connected to a winding 20a on the other outside leg of the core 17 and in turn is connected to the other anode 19a. From a mid-point of the usual heating winding 19d for the cathode, a connection extends to one terminal of the winding 16 on the main reactor, the other terminal of the winding 16 being connected to a mid tap of the secondary 18a. The windings 20a and 20b are so wound on the legs of the core 17 that the flux thereof passes in a common direction through the middle leg of the core, as indicated by the arrows. The winding 6a on the middle leg 17 of the controlling reactor corresponds to the winding 6 of Fig. 2 and is connected between the handle 8 and one terminal of the resistance 7. The other winding 9a on the core 17 corresponds to the winding 9 on the core 3 of Fig. 2 and is connected to the rectifying means 13a-13d in the same way as in Fig. 2, the rectifying means being likewise connected to the points 14 and 15 of Fig. 4 in correspondence with the connections of Fig. 2 to the reference load and consumption circuit.

It will be appreciated from the explanations made in connection with Fig. 2 that adjustment of the control handle 8 will change the flux of the core 17 by change of current through the winding 6a which in turn will control the output of the rectifier 19 to the control winding 16 of the main reactor. But, as explained in connection with Fig. 2, the current supplied to the winding 16 due to the control winding 6a alone, is not sufficient to bring the voltage at the consumption

circuit 2 up to the desired voltage curve; and the winding 9a acting cumulatively with the winding 6a is depended upon to raise the output of the rectifier 19 to the required amount to bring the voltage at the consumption circuit to the desired values along the consumption circuit voltage curve for different positions of the control handle 8. This supplementary or compensating action by the winding 9a is, as already explained, due to utilization of the difference between the potentials of the points 14 and 15 of the consumption circuit and of the reference load. In the control system of Fig. 4, a comparatively small current through the winding 9a is sufficient to produce the required compensation and the results obtained in this form of control give a greater refinement of control and a closer approach of the consumption circuit voltage to that of the reference load voltage at all positions of the control handle 8.

In Fig. 5 the apparatus and connections are the same as those of Fig. 4. However, in Fig. 5 the winding 6b on the middle leg of the core 17 is given more ampere turns than the winding 6a of Fig. 4 and the winding 9b of Fig. 5 is reversed with reference to the winding 6b so that the flux of winding 9b opposes that of the winding 6b, as well as opposing the flux due to the windings 20a and 20b. Thus, in Fig. 5, like in Fig. 3, the controlling action due the winding 6b alone is so great as to bring the flux and the resulting voltage of the consumption circuit above the desired consumption circuit voltage for the different positions of the control handle 8, whereas the winding 9b is depended upon to bring the flux of the core 17 down sufficiently in its compensating action so that the current supplied to the winding 16 of the main reactor is of the proper amount to give the required consumption circuit voltage for all positions of the control handle 8.

In both Figs. 4 and 5 an auxiliary cooperating controlling device 21 is shown connected in shunt to the rectifier 9, being connected at points between the anode 19a and anode winding 20a and between the anode 19b and anode winding 20b. The device 21 may be a non-inductive resistance, an inductive coil, or an impedance device of any character to give the best cooperative results. It may advantageously be variable or adjustable but may be made of a fixed value selected to give desirable cooperation. The impedance device 21 aids in extending the range of control of the apparatus in the direction in which low voltage is applied to the consumption circuit and permits the auxiliary reactor controller to be made smaller than would otherwise be necessary.

This shunting impedance device is disclosed in various relationships to other apparatus and broadly claimed in my pending application, Serial No. 535,600, filed May 7, 1931. It serves to cause an auxiliary current to pass through the windings 20a and 20b during the alternate periods when those windings are inactive in supplying current to the consumption circuit. Considering the winding 20a, and assuming that this supplies current to the load in a given direction which we may call positive, then during the alternate inactive periods, the impedance device 21 will cause or permit a current, which may be of comparatively small amount, to pass through the winding 20a in the reverse direction. This will be understood because during the alternate periods when the winding 20a is inactive in supplying current to the load, the winding 20b will be active in supplying current to the load and,

by reason of the shunting impedance 21, a small part of the current supplied by the winding 20b will pass through this shunt and through the winding 20a back to the source in a direction, say negative, and opposite to that of the current through winding 20a when it is supplying current to the load. The conditions thus set up in the winding 20a and its core, as regards flux and energy conditions, tends to establish in greater or lesser degree, as determined by the value of the impedance 21, the conditions which would exist if the winding 20a and its core had not been subjected to inactive conditions as regards supply of energy to the output circuit. Consequently, when the winding 20a again becomes normally active, the amount of energy and current which this winding is permitted to deliver to the output circuit is correspondingly controlled and reduced. A similar condition exists with reference to the winding 20b and its core by the controlling effect of the impedance device 21 in causing a controlling current to be passed through the winding 20b in a direction opposite to that of the normal load current therethrough; and this opposite controlling current will pass through the winding 20b during the alternate inactive periods of the winding 20b. It has been found in practice that the controlling current due to the presence of the impedance device 21 may be made very small for obtaining the desired effect in the reduced control of the voltage applied to the consumption circuit. Thus, when the control handle 8 is moved in the direction to include a smaller amount of the resistance 7 and thereby supply a reduced current to the windings 6a or 6b, the shunting impedance 21 serves to give a cooperating amplifying effect in still further reducing the current supplied to the rectifier 9, giving the maximum cooperative effect at the lowest range of low voltage applied to the consumption circuit. When the handle 8 is moved to positions to include increasing amounts of the resistance 7, the cooperative effect of the shunting impedance 21 becomes less and less effective. At the higher values of load voltage, the impedance 21 continues to pass a reverse current alternately through the windings 20a and 20b; but the effect is then not material because the reactance of the windings 20a and 20b is then so low as to not be appreciably affected by the shunting current. For the very best results the impedance 21 should preferably be adjusted to have a comparatively low value at low values of the voltage applied to the consumption circuit in order to permit the shunting current to have its highest influence and then adjust it to have a comparatively high impedance at high values of voltage applied to the consumption circuit so that the shunting current would have a negligible value and effect. The adjustment of this impedance can be controlled by, and simultaneously with, the adjustment of the control handle 8; but for simplicity and considering the advantages obtained when using a fixed value of the impedance 21, the refinement of making the same adjustable would ordinarily be unnecessary. The fixed value would be arrived at by determining the amount of the shunting control current at the lowest value of the consumption circuit voltage to give the desired effect under that condition and yet make it sufficiently high to avoid any objectionable effect at the high values of consumption circuit voltage.

In Fig. 6, instead of creating a special reference voltage as a standard for determining the controlling effect, the standard of reference is taken

as that of the voltage between the control handle 8 and the other terminal of the resistance 7 included in the circuit. In utilizing this adjustable voltage as the standard, the refinement of control and capability of special adaptability is not as great as may be attained by the use of a specially made up load and creation of a special reference standard voltage, but is nevertheless of advantage as utilized herein by reason of its commercial practicability for some purposes. In applying the invention a voltage is derived from the consumption circuit voltage which reflects its change of voltage and which is properly related in comparative value and polarity to that of the standard voltage.

Thus in Fig. 6, wherein like reference characters indicate similar parts of Fig. 4, the voltage of the direct current source 8 is assumed to be less than that of the supply lines from source 1; and a direct current voltage is derived from the alternating current voltage of the consumption circuit which is properly functionally adapted to the variable standard voltage. Across the consumption circuit is connected an auto-transformer winding 22 having an adjustable contact 22a. After knowing the proper position of this contact or point of connection to the auto-transformer winding, this may be made a fixed connection. The leads from this point of connection and from one side of the consumption circuit are connected to opposed points of a rectifier of the above described bridge type having the rectifiers 23a, 23b, 23c, and 23d in the arms of the bridge, although any suitable form of rectifier may be used. The other two opposite points of the bridge form the plus and minus terminals for delivering a direct current voltage which will correspond at all times to any change in voltage of the consumption circuit. In the lead wire connecting terminals of like polarity, say positive, of the source 5 and of the rectifier, is connected the cumulatively acting winding 9a of the auxiliary controlling reactor. The negative terminal of the rectifier is connected to the movable contact 8 of the control handle. Thus the voltage of the source 8, as adjusted by the control handle, is opposed in the circuit of the winding 9a to the voltage of the rectifier which voltage corresponds to the changes of the consumption circuit voltage. It follows that if these opposed voltages differ, a resultant current passes through the winding 9a.

If the effect of the cumulative winding 9a be disregarded, the result would be that upon adjustment of the control handle 8, the resulting voltage applied to the consumption circuit would, for all adjusted positions, be below the ideal voltage curve. In order to secure the desired control, the direct current voltage delivered by the rectifier 23a—23d, must also be below the voltage of the source 5 as adjusted by the handle 8, even though this difference will be slight when the compensating effect of the winding 9a is considered. Under these assumptions, it follows that the cumulative winding 9a will carry a current from the source 5 through a comparatively high resistance by-pass 24 back to the control contact 8 and the source 5. This will, of course, result in raising the voltage of the consumption circuit for any adjusted position of the handle 8 to nearly correspond with the standard reference voltage as determined by the adjusted position of the control handle 8 which, in this particular embodiment, is the voltage between the control handle 8 and one side of the source 5, being the

positive side as indicated in the drawings. Thus, for any position of the control handle, the winding 9a will be subjected to such an amount of current as will cause the voltage applied to the consumption circuit to have an approximately constant ratio to the voltage as adjusted by the control handle 8. The by-pass resistance 24 is necessary owing to the fact that the compensating current in the winding 9a could not pass through the rectifier 23a—23d in the reverse direction. In the circuit of the winding 9a is also inserted a one way electric valve 25 of any suitable type so as to insure the current passing in the winding 9a in one direction only. If this valve were not present, a too rapid adjustment of the control handle 8 might otherwise cause the flow of a reverse current and interfere with the proper functioning of the apparatus owing to the fact that the time constant of the main reactor might differ widely from the time constant of the auxiliary controlling means or controlling reactor. For example, the main reactor controlling the consumption circuit is usually much slower in responding to the control than is the auxiliary controlling reactor.

The apparatus indicated in Fig. 7 is similar to that of Fig. 6 except the winding 6b of the auxiliary reactor has more ampere-turns than the winding 6a of Fig. 6, whereas the winding 9b of Fig. 7 has less ampere-turns than the winding 9a of Fig. 6. Likewise, the winding 9b is so wound or connected as to cause its magnetomotive force to oppose that of the winding 6b. Also, the one way electric valve 25a in the circuit of the winding 9b is reversed so as to insure that the current will flow only in one direction from the rectifier 23a—23d through the winding 9b to the source 5. In this case the by-pass resistance 24 is unnecessary. In this application of the invention, the ampere-turns of the winding 6b, as in Fig. 5, are of such values upon adjustment of the handle 8 that, disregarding the effect of the winding 9b, the voltage applied to the consumption circuit will always be higher than the desired ideal lamp voltage curve and always higher than the standard voltages imposed from the source 5 by the different positions of the handle 8. Likewise the voltages delivered by the rectifier 23a—23d will be higher than the imposed standard voltage disregarding the effect of the winding 9b and cause a current to pass through this winding to oppose the effect of the winding 6b and thus bring the voltages applied to the consumption circuit down to approximately coincide in proportional amounts with the standard voltage for all positions of the control handle 8.

Fig. 8 indicates apparatus similar to Fig. 6 as indicated by corresponding reference characters; but in Fig. 8 instead of utilizing a direct current source such as 5 for controlling the apparatus and as yielding the standard or pilot voltages, the control source is an alternating current source. For this purpose the transformer having the primary winding 18 is provided with an auxiliary secondary winding 26 which delivers current to the terminals of an adjustable resistance or inductance 27. An adjustable contact 27a engaging this resistance or inductance is connected to one terminal of a rectifier indicated of the bridge form and having rectifiers 28a, 28b, 28c, and 28d in the arms of the bridge. From the opposite point of the bridge connection of the contact 27a, a lead 29 extends to one terminal of the adjustable impedance device 27.

Thus an alternating current voltage, adjusted as desired, is imposed upon this rectifier giving a corresponding direct current output voltage at the points of the bridge marked plus and minus in the drawings. The winding 8a is connected across these terminals. Likewise, the winding 9a is connected in the circuit upon which is imposed the opposed voltages derived from the rectifier 23a—23d and of the rectifier 28a—28d. The operation is the same as that described with reference to Fig. 6, the output voltage of the rectifier 28a—28d corresponding to the standard or pilot voltage as imposed by adjustment of the contact 27a.

Fig. 9 is the same as Fig. 8 except it is modified to have the control winding 9b opposing the magnetomotive force of the winding 8b and cause the apparatus to operate on the principle of bringing the consumption circuit voltage down to be approximately the same as the standard reference voltage by the opposing action of the winding 9b of the auxiliary controller. This method of control is the same as that described with reference to Fig. 7. In Fig. 9, in view of using an alternating current source for the pilot voltage and using a rectifier for converting the same, a shunt path of a comparatively high resistance 30 is provided across the circuit of the rectifier 23a—23d so as to permit the current which is always supplied in one direction from the rectifier 23a—23d, through the one way valve 25a, to have a return path after passing through the winding 9b through the resistance 30 back to the rectifier 23a—23d.

Fig. 10 shows the same apparatus as that of Fig. 8 except an additional bridge connected type rectifier 31a, 31b, 31c, and 31d, is introduced for individually supplying current to the winding 6a of the auxiliary controlling reactor, the rectifier 31a—31d receiving its imposed voltage from the alternating source as controlled by the adjustable contact 27a. This provision of an independent supply for the control winding 6a gives a little better regulation than the form of Fig. 8 as less duty is imposed upon the rectifier 28a—28b; and it likewise insures that the current in winding 6a cannot be reversed, as might otherwise be caused by the difference in time constants of different portions of the apparatus. By the use of this auxiliary rectifier for supplying the winding 6a, the one way valve 25 would then ordinarily be unnecessary.

Fig. 11 indicates the same apparatus as Fig. 10 except that the ampere-turns of the windings 8b and 9b are so related and likewise their direction of turns that the operation is based upon the mode described with reference to Figs. 3, 5, 7, and 9. In the case of Fig. 11 the resistance 24 of Fig. 10 is omitted or transferred to form the resistance 30 connected across the line on the other side of the winding 9b so that the exciting current in this winding from the rectifier 23a—23d will find a path for its return thereto after passing through the winding 9b.

In Fig. 12 the apparatus is similar to that disclosed in Figs. 10 and 11 except that the ampere-turns of the windings 8c and 9c are modified in relation to each other so that instead of working on the principle of the previously described apparatus of raising the consumption circuit voltages up to the ideal lamp voltage or bringing them down from values above the ideal lamp voltages, there are enough turns in the control winding 8c to give the nearest values obtainable of the consumption circuit voltage to the standard voltage

and then either raise it or lower it to approximately coincide with the voltage selected as the standard by passing a current through the winding 9c in either one direction or in the reverse direction according to whether the consumption circuit voltage requires to be raised or lowered for a particular position of the control handle. Thus in Fig. 12 current may pass in either direction through the winding 9c depending upon whether the output voltage of the rectifier 23a—23d is higher or lower than the output voltage of the rectifier 28a—28d in order to bring the consumption voltage to the desired amount. In this case both the shunting resistances 24 and 30 are used so that one or the other may form a return path for the current to the rectifier that happens to be active in supplying current to the winding 9c. This method of control by reversal of current through the winding 9c could also be utilized by making corresponding changes in other disclosures of this application.

Fig. 13 is similar to Fig. 12 and is introduced as one example of how the auxiliary controlling reactor may be modified in the various disclosures hereof. Instead of using a single core, two separately acting cores 32, 32a are provided. These cores are shown of simple rectangular form. One arm of the core 32 carries the anode winding 20c and on one leg of the core 32a is mounted the other anode winding 20e. The control winding 6c of Fig. 12 is divided into two parts 6d and 6e and placed respectively on legs of the cores 32 and 32a and are connected in series with each other across output terminals of the rectifier 31a—31d. Similarly, the winding 9c of Fig. 12 is divided into two parts 9d and 9e which are placed respectively on other arms of the cores 32 and 32a and are connected in series with each other in the circuit of the opposed controlling voltages. Although Fig. 13 shows the adaptation of Fig. 12 to this form of division of the auxiliary controlling reactor, it is evident that the reactors of the other figures of the drawings may be similarly sub-divided and various other changes made in the forms of the cores and relationship of the windings.

It will be understood that the accompanying drawings and description disclose embodiments of this invention in simple forms of apparatus for the purpose of simplicity and ready understanding and that the structure of the various parts may be widely varied from the typical forms indicated. Likewise, the invention may be embodied in various modifications and relationship of the parts for particular installations and purposes without departing from the scope of the invention. It will also be appreciated that the form of the desired consumption circuit voltage curve may be made such as to suit the particular purposes and character of consumption circuit load by proper composition of the reference load as to its resistance, inductance and capacity, where a specially created reference voltage is utilized.

I claim:

1. Electric controlling apparatus comprising a consumption circuit, a reference voltage circuit, adjustable means for imposing on the reference voltage circuit a series of values of voltages over a wide range and for imposing on the consumption circuit a series of values of voltages below those imposed on the reference voltage circuit, and auxiliary means for raising the values of the voltages of the consumption circuit to approach those of the reference voltage circuit.

2. Electric controlling apparatus comprising a consumption circuit, a reactor having a controlling winding for changing the voltage of the consumption circuit over a series of values, and a second winding on said reactor acting in opposition to said controlling winding for reducing said series of values to a lower range of values.

3. The method of obtaining a series of voltages of different values applied to a consumption circuit which comprises imposing a series of values of voltages on the consumption circuit lower than the desired values, creating a series of desired reference voltages of different values, and raising the voltages of the consumption circuit to approach the respective reference voltages.

4. The combination of an alternating current circuit, an alternating current consumption circuit, a reactor having a winding in series between said circuits, a direct current winding on said reactor, means comprising an adjustable direct current source supplying current to said winding for varying the reactance of said reactor over a wide range and thereby varying the voltage of the consumption circuit over a wide range, means for deriving direct current voltages from the consumption circuit corresponding in values to change of the alternating current voltages of the consumption circuit, and a winding responsive to the differences between the voltages of said adjustable direct current source and the direct current voltages derived from the consumption circuit for bringing the voltages of the consumption circuit to relatively conform to those of said direct current source at each condition of adjustment.

5. An alternating current supply circuit, a consumption circuit supplied with alternating current from said supply circuit, a reactor having a winding in series between said circuits, adjustable means comprising a saturating winding on said reactor for changing the reactance of said reactor and the voltage of the consumption circuit over a wide range and for yielding a series of corresponding reference voltages as a standard, and auxiliary means comprising an additional winding on said reactor affected by the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively for causing the voltages of the consumption circuit to relatively conform to the series of reference voltages respectively.

6. Electric controlling apparatus comprising a consumption circuit, adjustable means comprising a reactor having a saturating winding for changing the voltage of the consumption circuit over a wide range and for creating a series of reference voltages over a wide range conforming to a series of desired values, and auxiliary electromagnetic means comprising an additional winding on said reactor for causing the voltage of the consumption circuit to relatively conform to that of the reference voltage throughout the range of control.

7. Electric controlling apparatus comprising a consumption circuit, means comprising a reactor having a saturating winding and an adjustable handle for changing the voltage of the consumption circuit over a wide range, auxiliary means controlled by the movement of said handle for creating a reference voltage over a wide range conforming to a series of desired values, and means comprising an additional winding on said reactor for causing the voltage of the consumption circuit to relatively approach and conform

to that of the reference voltage for each position of said handle.

8. Electric controlling apparatus comprising a consumption circuit, a reference load circuit, means comprising a reactor having a saturating winding for changing the voltages applied to said circuits, and auxiliary means comprising a winding on said reactor responsive to the relative departure of the voltages of the consumption circuit voltages from the reference load circuit voltages respectively for causing the voltage of the consumption circuit to relatively conform to that of the reference load circuit.

9. Electric controlling apparatus comprising a consumption circuit, a reference voltage circuit, adjustable means comprising a reactor having a saturating winding for imposing on the reference voltage circuit a series of values of voltages over a wide range and for imposing on the consumption circuit a series of values of voltages above desired values, and means comprising an additional winding on said reactor for reducing the values of the voltages of the consumption circuit to relatively conform to those of the reference voltage circuit.

10. An alternating current supply circuit, a consumption circuit supplied with alternating current from said supply circuit, a reactor having a winding in series between said circuits, adjustable means for affecting said reactor to apply a series of voltages to the consumption circuit below desired values, and to establish a series of reference voltages of desired values, and means comprising an additional winding on said reactor affected by the difference between the voltage of the consumption circuit and the corresponding reference voltage for increasing the voltages at the consumption circuit to the desired values.

11. An alternating current supply circuit, a consumption circuit supplied with alternating current from said supply circuit, a reactor having a winding in series between said circuits, adjustable means for affecting said reactor to apply a series of voltages to the consumption circuit above desired values, and means comprising an additional winding on said reactor for decreasing said voltages to the desired values.

12. The method of obtaining a series of voltages of different values applied to a consumption circuit which comprises imposing a series of values of voltages on the consumption circuit higher and lower in portions of the series than the desired values, creating a series of reference voltages, and lowering and raising the voltages of the consumption circuit in different portions of the series of voltages to conform relatively to the respective reference voltages.

13. Electric controlling apparatus comprising a consumption circuit, a reference circuit having a fixed load, a device for changing the voltage applied to the consumption circuit, a device for changing the voltage applied to the reference load circuit for imposing a series of desired voltages thereon, a common adjustable means for affecting both of said devices for effecting the change in said voltages, and auxiliary control means for adjusting the consumption circuit voltages to relatively conform respectively to the reference load voltages.

14. Electric controlling apparatus comprising a consumption circuit, a reactor for controlling the voltage applied to said circuit, adjustable means for controlling said reactor, a reference circuit having a fixed load, means controlled by said first named means for imposing on said

reference circuit a series of voltages of desired values, and additional means affected by the difference between the voltages of said circuits for controlling said reactor for bringing the voltages of the consumption circuit to relatively conform to those of the reference circuit respectively.

15. Electric controlling apparatus comprising a consumption circuit, means comprising a reactor having a saturating winding for changing the voltage applied to said circuit over a wide range and for forming a corresponding series of reference voltages as a standard, and means comprising an additional compensating winding on said reactor affected by the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively for causing the voltages of the consumption circuit to relatively conform to said series of reference voltages respectively.

16. An alternating current source, an alternating current consumption circuit, a direct current source, means for deriving a series of desired reference voltages from said direct current source and for varying over a wide range the voltage of said consumption circuit, means for deriving a direct current from said consumption circuit, and means responsive to difference in voltages between said reference voltages and the voltages derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively.

17. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a direct current source, means for deriving a series of desired reference voltages from said direct current source and for varying over a wide range the voltage of said consumption circuit, means for deriving a direct current from said consumption circuit, and means comprising a controlling winding responsive to difference in voltages between said reference voltages and the voltages derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively.

18. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current to said rectifier, a reactor having a winding connected in series between said means and said rectifier, means for deriving a direct current from said consumption circuit, means for deriving a series of desired direct current reference voltages, and means comprising a winding on said second named reactor responsive to the difference in voltages between said reference voltages and the voltages of the direct current derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively.

19. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current to said rectifier, a reactor having a winding connected in series between said means and said rectifier, means for deriving a

direct current from said consumption circuit, means for deriving a series of desired direct current reference voltages, means comprising a winding on said second named reactor responsive to the difference in voltages between said reference voltages and the voltages of the direct current derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively, and an impedance device connected in shunt between terminals of said rectifier.

20. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said consumption circuit, means for deriving a series of desired direct current reference voltages and for supplying current to said saturating winding on said last named reactor, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said reference voltages and the voltages of the direct current derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively.

21. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said consumption circuit, means for deriving a series of desired direct current reference voltages and for supplying current to said saturating winding on said last named reactor, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said reference voltages and the voltages of the direct current derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively, said additional winding acting cumulatively with said saturating winding on said last named reactor.

22. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said consumption circuit, means for deriving a series of desired direct current reference voltages and for supplying current to said saturating winding on said last named reactor, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said reference volt-

ages and the voltages of the direct current derived from said consumption circuit respectively for relatively conforming the voltages of the consumption circuit to said reference voltages respectively, said additional winding acting in opposition to said saturating winding on said last named reactor.

23. Electric controlling apparatus comprising a consumption circuit, means comprising a reactor having a saturating winding for changing the voltage applied to said circuit over a wide range and for forming a corresponding series of reference voltages as a standard, and means comprising an additional compensating winding on said reactor affected by the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively for causing the voltages of the consumption circuit to relatively conform to said series of reference voltages respectively, said additional winding acting cumulatively with said saturating winding.

24. Electric controlling apparatus comprising a consumption circuit, means comprising a reactor having a saturating winding for changing the voltage applied to said circuit over a wide range and for forming a corresponding series of reference voltages as a standard, and means comprising an additional compensating winding on said reactor affected by the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively for causing the voltages of the consumption circuit to relatively conform to said series of reference voltages respectively, said additional winding acting in opposition to said saturating winding.

25. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current derived from said source to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said source for exciting said saturating winding on said last named reactor and for varying the voltage thereof, means for deriving a direct current from said consumption circuit having a voltage corresponding thereto, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said variable direct current voltages derived from said source and the direct current voltages derived from said consumption circuit for relatively conforming the voltages of the consumption circuit to said variable voltages derived from said source.

26. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current derived from said source to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said source for exciting said saturating winding on said last named reactor and for varying the volt-

age thereof, means for deriving a direct current from said consumption circuit having a voltage corresponding thereto, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said variable direct current voltages derived from said source and the direct current voltages derived from said consumption circuit for relatively conforming the voltages of the consumption circuit to said variable voltages derived from said source, said additional winding acting cumulatively with said saturating winding on said last named reactor.

27. An alternating current source, an alternating current consumption circuit, a reactor having a winding in series between said source and said circuit, a saturating winding on said reactor, a rectifier for supplying current to said saturating winding, means for supplying alternating current derived from said source to said rectifier, a reactor having a winding connected in series between said means and said rectifier, a saturating winding on said last named reactor, means for deriving a direct current from said source for exciting said saturating winding on said last named reactor and for varying the voltage thereof, means for deriving a direct current from said consumption circuit having a voltage corresponding thereto, and means comprising an additional winding on said last named reactor responsive to the difference in voltages between said variable direct current voltages derived from said source and the direct current voltages derived from said consumption circuit for relatively conforming the voltages of the consumption circuit to said variable voltages derived from said source, said additional winding acting in opposition to said saturating winding on said last named reactor.

28. Electric controlling apparatus comprising a consumption circuit, adjustable means comprising a reactor having a saturating winding for changing the voltage of the consumption circuit over a wide range and for creating a series of reference voltages over a wide range conforming to a series of desired values, means responsive to the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively, and an additional winding on said reactor controlled by said last named means for causing the voltage of the consumption circuit to relatively conform to that of the reference voltage throughout the range of control.

29. Electric controlling apparatus comprising a consumption circuit, means comprising a reactor having a saturating winding and an adjustable handle for changing the voltage of the consumption circuit over a wide range, auxiliary means controlled by the movement of said handle for creating a reference voltage over a wide range conforming to a series of desired values, means responsive to the relative departure of the voltages of the consumption circuit from said series of reference voltages respectively, and an additional winding on said reactor controlled by said last named means for causing the voltage of the consumption circuit to relatively conform to that of the reference voltage for each position of said handle.

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