March 16, 1937. A. A. EMMERLING 2,074,145

ELECTRIC CIRCUIT CONTROL MEANS

Filed July 10, 1935

Fig. 1.

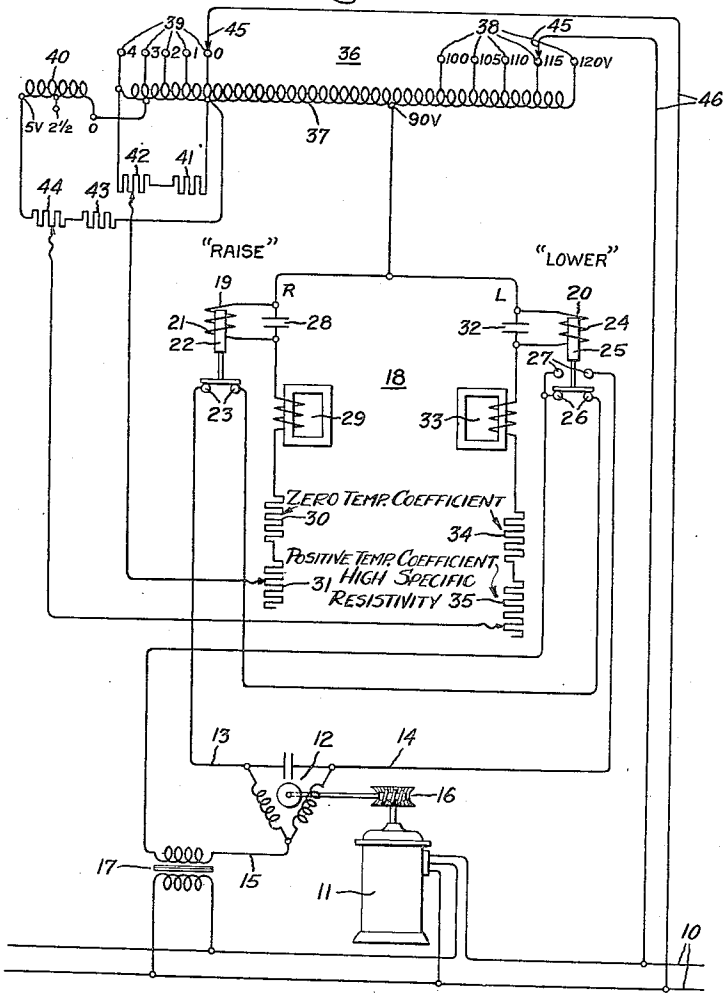


Fig. 2.

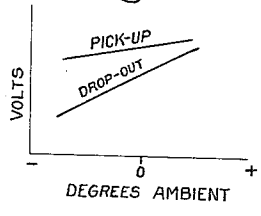
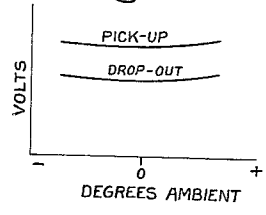


Fig. 3.



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ELECTRIC CIRCUIT CONTROL MEANS

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Application July 10, 1935, Serial No. 30,629

24 Claims. (Cl. 171—119)

My invention relates to electric circuit control means and more particularly to alternating current circuit control means employing circuits of the resonant type having non-linear volt-ampere characteristics.

In the control and regulation of electric circuits and dynamo-electric machines various arrangements of non-linear resonant circuits comprising a saturable inductance and a capacitance have been proposed or used heretofore but such arrangements have required careful design and factory adjustment of the non-linear circuit in order to have the critical voltage of the non-linear resonant circuit correspond to a particular value of the quantity to be regulated or controlled. Means have been provided in the non-linear resonant circuit per se whereby the critical response on a continuous increasing energization, i. e. the "resonant voltage", or the critical response on a continuous decreasing energization, i. e., the "dissonant voltage", could be varied, so that the non-linear resonant circuit could be adjusted and adapted for different selected values of the quantity to be controlled or regulated. However, in the application of electric circuit control means of this type it has been found that recalibration and adaptation of the non-linear circuit or circuits for the different conditions and range of voltage values met with in practice is difficult for the average user to make. It has also been found that changes in ambient temperature affect the resonant and dissonant voltage values of the non-linear resonant circuits so that the critical values as well as the difference between these critical voltage values may change in an undesirable manner causing inaccuracy of response or hunting during the operation of the control or regulating apparatus.

It is an object of my invention to provide a new and improved electric circuit control means comprising a non-linear resonant circuit.

It is another object of my invention to provide a new and improved electric circuit control means utilizing a non-linear resonant circuit wherein the non-linear resonant circuit may be initially adjusted accurately for its most sensitive condition and simply and readily adapted without significantly changing the calibration of the non-linear circuit per se for use on different circuits having a rated voltage differing from the critical response voltages of the non-linear resonant circuit.

It is another object of my invention to provide a new and improved electric circuit control means utilizing a non-linear resonant circuit whereby greater sensitivity and precision of operation is obtained for a relatively broad range of values of the quantity to be maintained constant.

It is another object of my invention to provide a new and improved electric circuit control means utilizing a non-linear resonant circuit which shall be substantially free of changes or errors due to variations in temperature.

It is another object of my invention to provide a new and improved non-linear resonant circuit which shall have a substantially constant difference between resonant and dissonant voltages thereof within its intended range of operation.

It is a further object of my invention to provide a new and improved non-linear resonant circuit which shall not only have a substantially constant difference between the resonant and dissonant voltage values thereof but also have a substantially constant value for the resonant and dissonant voltage values within the intended range of operation of the non-linear resonant circuit.

In accordance with one feature of my invention, instead of connecting the non-linear resonant circuit directly to the circuit to be controlled, or through voltage adjusting means which involves large resistance losses and causes a relatively large change in the impedance of the non-linear circuit per se for recalibration, as has been the practice heretofore, I provide an improved voltage adjusting means between the non-linear circuit and the circuit to be controlled so that within the range of adjustment of the voltage adjusting means the non-linear circuit may be energized by a substantially fixed voltage for any value of voltage desired to be maintained or controlled without making a significant change in the impedance of the non-linear circuit. I have found that transforming means in which the major adjustments are made between the controlled circuit and the primary circuit of the transforming means without changing the number of turns of the secondary circuit included in the non-linear circuit, gives satisfactory results in practice. In accordance with another feature of my invention, temperature corrective means are provided in the non-linear circuit so as to maintain the critical voltages thereof substantially independent of changes in ambient temperature. According to the broader aspects of this last-mentioned feature of my invention, I use in the non-linear circuit resistance elements of selected value and temperature coefficient of resistance so as to maintain the difference between the resonant and dissonant voltages of the non-linear circuit substantially constant throughout the changes in ambient temperature to which the non-linear circuit may be subjected. Where greater exactness of control is desired, I proportion the value and temperature coefficient of resistance of the respective resistance elements of the non-linear circuit so as to maintain the resonant and dissonant voltages substantially constant throughout the changes in ambient temperature to which the non-linear circuit may be subjected. While my invention is generally

applicable to non-linear resonant circuit control means, an embodiment of my invention, by way of illustration, has been shown in a voltage regulating system wherein a pair of non-linear resonant circuits, respectively calibrated for a high degree of non-linearity, are connected to a circuit to be controlled through an adjustable autotransformer. Voltage controlling means in the regulated circuit are controlled by apparatus controlled by the non-linear circuits to effect an increase in the voltage of the controlled circuit when one non-linear circuit is dissonant and to effect a decrease in the voltage of the controlled circuit when the other non-linear circuit is resonant.

My 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 diagrammatic illustration of one embodiment of my invention in a contact-making control relay mechanism for an electric regulating system, and Figs. 2 and 3 are explanatory diagrams for explaining the temperature compensating feature of my invention.

Referring to Fig. 1 of the drawing, I have shown my invention as embodied in a contact-making relay arrangement of the type employed for motor-actuated or contactor-operated voltage regulators. The circuit 10 represents diagrammatically an electric circuit, such as a feeder circuit, the voltage of which at the utilization point or some other selected point on the circuit is to be maintained constant or controlled within selected limits of variation. A regulator 11 which is to be taken as illustrative of any desired type of motor-actuated or contactor-operated type of regulator, such as a rheostatic regulator, tap-changing regulator, induction regulator, etc., is diagrammatically represented as a single phase induction regulator connected in the circuit 10 in the well known manner and arranged for operation by any convenient electric means shown as a reversible motor 12. For purposes of simplicity in illustration, the motor 12 is shown as a well known capacitor motor having two directions of rotation controlling circuits 13 and 14 and a return conductor 15. The motor 12 is arranged to operate the movable element of regulator 11 through suitable gearing 16 and is connected to be energized from any convenient circuit and as illustrated from the circuit 10 through a transformer 17. The return conductor 15 is permanently connected to one side of the secondary winding of transformer 17 while the conductors 13 and 14 are arranged to be selectively connected to the other side of the secondary winding of transformer 17 in accordance with the operation of circuit control means 18.

The circuit control means 18 includes a pair of relays 19 and 20 which may be selected from any one of a variety of known forms, but preferably of a form in which the movement of the armature of the relay has a minimum effect on the calibration of the non-linear circuit. The relay 19 is shown in a simple diagrammatic form as comprising a solenoid 21 and a core member 22 for closing a pair of contacts 23 when its solenoid is deenergized below a predetermined value. Similarly, relay 20 is shown as comprising a solenoid 24 and a core member 25 for closing a pair of contacts 26 when its solenoid is deenergized below a predetermined value and for simultaneously opening contacts 26 and closing a pair of contacts 27 when its solenoid is energized above a predetermined value. The contacts 23 of relay 19 when closed complete the circuit including conductors 13 and 15 if contacts 26 of relay 20 are closed for operating the motor 12 in a direction to raise the voltage of circuit 10 and hence relay 19 may be referred to as the "raise" relay. The contacts 27 of relay 20 when closed complete the circuit including conductors 14 and 15 for operating the motor 12 in a direction to lower the voltage of circuit 10 and hence relay 20 may be referred to as the "lower" relay. It will thus be observed that the "lower" relay must be in the drop-out position in order to complete the "raise" control circuit. This arrangement provides an electrical interlock so as to prevent closing of both motor control circuits at the same time.

Relays 19 and 20 are each controlled by a different non-linear resonant circuit indicated generally by R and L respectively. The non-linear resonant circuit R, for controlling the "raise" relay 19, is shown as a series type of circuit comprising a capacitance 28, a saturable inductance 29, a fixed resistance element 30 and an adjustable resistance element 31. The solenoid 19 is connected to be energized in accordance with the voltage across the capacitance 28. The non-linear resonant circuit L, for controlling the "lower" relay 20, is similarly shown as a series type of circuit comprising a capacitance 32, a saturable inductance 33, a fixed resistance element 34 and an adjustable resistance element 35.

In accordance with one feature of my invention, I connect the non-linear resonant circuits R and L to the circuit to be controlled, that is, the circuit 10, through means indicated generally by the numeral 36 and referred to generally hereinafter, as voltage adjusting means. In order to understand more clearly the function and importance of the voltage adjusting means 36 in electric circuit control means of this type, it seems expedient to discuss briefly some of the characteristics of the non-linear resonant circuit pertinent to the use of the voltage adjusting means.

It is generally known that if a circuit comprising a series connected resistance, capacitance and saturable inductance is properly dimensioned, it will exhibit for a gradually increasing voltage of constant frequency, an effective current which is not proportional to voltage but which changes critically at a certain voltage heretofore referred to as the "resonant" voltage. For relay applications it is convenient to refer to the "resonant" voltage as the "pick-up" voltage. Similarly, when the voltage applied to the same circuit is gradually decreased from a value above the "resonant" voltage, it will be observed that the effective current changes critically at a certain voltage heretofore referred to as the "dissonant" voltage. For relay applications it is convenient to refer to the "dissonant" voltage as the "drop-out" voltage. For a given capacitance and inductance the non-linear properties of the circuit increase as the series resistance decreases but there is a critical value beyond which a hysteresis effect appears. In other words, there is a difference between the "resonant" and "dissonant" voltages of the circuit which in relay practice may be referred to as the "holding effect". This is a convenient operating characteristic for relay purposes but it is not desirable to make the "holding effect" too great, otherwise too great a change in the regulated quantity will be effected and cause hunting of the regulator.

On the other hand, if the resistance of the circuit is increased above the critical value of resistance for maximum non-linear response, the non-linear properties of the circuit decrease and the circuit loses its unique property of effecting a large and abrupt change in current for a small change in voltage. The resistance of the circuit thus determines the degree of non-linearity of the circuit and also the "dissonant" voltage but it has some practical effect on the "resonant" voltage in applications requiring close limits of control. The "resonant" voltage also has a slight dependence on the capacitance for general applications but this dependence on capacitance becomes of more importance in applications requiring close limits of control. This change in capacitance effect will be considered in connection with the temperature compensating aspect of my invention. The "resonant" or "pick-up" voltage of the non-linear resonant circuit depends primarily upon the characteristics of the saturable reactor but as previously noted it is influenced to a certain degree by a change in resistance and capacitance.

In voltage regulating systems it is common practice to hold on the feeder or circuit to be regulated some selected voltage such as 115 volts. Under such conditions it is common practice to require a band of several volts between operating voltages of the "raise" and "lower" relays in order to prevent too frequent operation of the mechanism. This band may for example be 3 volts. The relay mechanism must then operate at 113.5 volts to raise the voltage and at 116.5 volts to lower the voltage. It is also desirable to have some "holding effect" on each relay, for example 0.5 volt, to insure positive operation of the mechanism. In order to fulfill the assumed conditions of operation the "raise" relay must pick up at 114 volts (113.5+0.5) and drop out at 113.5 volts. The "lower" relay must pick up at 116.5 volts and drop out at 116 volts (116.5—0.5).

To meet these rather exacting assumed conditions, which however are well within the requirements of commercial practice, it is not a difficult task to design and adjust under laboratory conditions a set of non-linear resonant circuits and relays for the particular assumed conditions. However, in practice it is often necessary to provide for regulation over a range of voltages, i. e., to hold any voltage for example from 110 volts to 130 volts. When the non-linear circuits are connected directly to the circuit to be controlled, or through a resistor variable on the non-linear circuit side or a fixed ratio transforming means, as has been the practice heretofore, each non-linear circuit must be adjusted or recalibrated for each different condition. With a given capacitor, an adjustable saturable reactor and a variable resistor this is possible, but difficult, for the average user.

Now in accordance with one feature of my invention I take a given pair of non-linear circuits designed to operate at a nominal voltage preferably of the same order of magnitude as the voltage of the circuit to be controlled and carefully adjust each circuit with laboratory instruments and under laboratory conditions to find that correlation of the impedances of the respective circuit elements of each non-linear resonant circuit which will give the maximum non-linearity with the proper "holding" effect. For example, in one regulating equipment under construction I found that one non-linear circuit with a given capacitance and saturable inductance approached maximum conditions of non-linearity and proper "holding" effect with a resistance that gave a "resonant" or "pick-up" voltage of 94 volts while the other circuit exhibiting similar conditions had a "resonant" or "pick-up" voltage of 98 volts.

For purposes of explanation, it will be assumed that I use the non-linear circuit with a "pick-up" voltage of 94 volts for controlling the "raise" circuit designated as R and the non-linear circuit with a pick-up voltage of 98 volts for controlling the "lower" circuit designated as L. It will further be assumed that these non-linear circuits are to be used on a circuit to hold any voltage from 100 volts to 120 volts and that the particular voltage to be held is 115 volts. The voltage adjusting means **36** as illustrated comprises an auto-transformer winding **37** with taps **38** at the high voltage end and taps **39** at the low voltage end. By way of example, the taps **38** at the high voltage end are marked in intervals of 5 volts from 100 to 120, and the taps at the low voltage end are marked in intervals of 1 volt from 0 to 4. In addition to the main winding **37**, I provide an additional winding **40** which may conveniently be referred to as a "floating" winding. This winding may be connected in additive or subtractive relation with the main winding **37** depending upon the critical voltage of the non-linear circuit to be energized therefrom. It will occur to those skilled in the art that the "floating" winding **40** may be connected at either end of the main winding or at some intermediate point without departing from my invention in its broader aspects, since one function of this winding is to make it possible to adapt the second non-linear circuit with a given critical voltage to the conditions imposed by the connection of the first non-linear circuit. For the embodiment of my invention as illustrated in Fig. 1, it was found suitable to connect the winding **40** in additive relation at the low voltage end of the main winding **37**.

In general with the floating winding **40** connected at the low voltage end of transformer **37** one end of each non-linear circuit R and L is connected to an appropriate fixed tap or taps at the high voltage end of winding **37**.

For the assumed critical values of the non-linear circuits, the circuits R and L are connected at one end to a 90 volt fixed tap in the winding **37**. Across the low voltage tapped section of transformer **37** I connect in series relation a fixed resistor **41** and an adjustable resistor **42**. The other side of non-linear circuit R is connected to adjustable resistor **42**. The floating winding **40** has one terminal connected in a fixed manner to an appropriate tap on the low voltage section of transformer **37** and with the assumed conditions to the tap marked 3 volts. From the zero tap of the low voltage section to an appropriate tap, under the assumed conditions to the end terminal of the floating winding in additive relation, a fixed resistor **43** and an adjustable resistor **44** are connected in series relation. The other side of the non-linear circuit L is connected to the adjustable resistor **44**. The resistors **42** and **44** are provided to enable an accurate selection of the pick-up voltages of the relays, i. e., the band of regulation. The adjustable resistors **31** and **35** in the non-linear circuits R and L are to provide for accurate adjustment of the holding effect which has been assumed to be 0.5 volt. The transformer **37** is connected to be energized from the circuit to be

controlled through adjustable connections 45 and conductors 46. The adjustable connections 45 should always be connected to the auto-transformer taps having the rating nearest the voltage to be held. Under the assumed conditions the adjustable connections 45 would be connected to the 115 and 0 taps, respectively.

It will thus be observed that for a given non-linear circuit the voltage adjusting means permits connecting the non-linear circuit for energization in accordance with that value of voltage most closely approaching its most critical voltage without restricting the range of voltages for which the regulating circuit is adapted. Thus the non-linear circuit always operates under a substantially fixed voltage irrespective of the value of the voltage to be held. Furthermore, the critical voltages at which the non-linear circuits pick up need not be different or in the same order as the nominal pick-up values of voltages which are selected to maintain a given voltage. For example, if non-linear circuit R had a pick-up voltage of 94 volts, the non-linear circuit L might also have the same or a lower pick-up voltage by appropriate connection of the floating winding 40. For the assumed values the non-linear circuit R has been connected so that when the voltage of circuit 10 is 114 volts, with the 115 voltage taps selected, 94 volts, or the pick-up voltage, is impressed on circuit R. If the floating winding 40 were connected so as to be subtractive then when the voltage of circuit 10 was 116.5 volts the pick-up voltage for the non-linear circuit L would be 88 volts, i. e., 93 volts less 5 volts of the floating winding so as to have circuit L pick up relay 20 at a controlled circuit voltage of 116.5.

The operation of the illustrated arrangement under the conditions assumed for the voltage to be held, namely, 115 volts, with a band of 3 volts, and a holding effect, 0.5 volt, is as follows: With the auto-transformer energized from circuit 10 through taps 115 and 0 the following adjustments are first made. The rheostats 42 and 44, the band selecting rheostats, are first turned to include all the resistance in the circuit and the holding effect rheostats 31 and 35 are moved to their mid-position. The source voltage applied to the auto-transformer is adjusted to 114 volts and by adjusting the rheostat 42 the "raise" relay 19 is made to pick up. The source voltage is then reduced until the relay drops out. If the drop-out voltage is lower than 113.5 the rheostat 31 is changed to increase the resistance and thereby decrease the holding effect to the desired value. Conversely, if the drop-out voltage is higher than 113.5 volts the rheostat 31 is changed to decrease the resistance and thereby increase the holding effect. Adjustment of the "lower" relay to pick up at 116.5 volts and drop out at 116 volts is made in the same manner using rheostats 44 and 35. By similar adjustments any other voltage within the range of the voltage adjusting means 36 may be made.

With the circuit adjusted in the manner outlined and the voltage of circuit 10 at 115 volts, the "raise" relay 19 is in its upper or energized position and the "lower" relay is in its lower or deenergized position. Under these conditions the motor 12 is not energized and is thereby stationary and the movable element of the regulator is likewise stationary. Now assume the voltage falls to the drop-out value for the "raise" relay, i. e., 113.5 volts under the assumed conditions, the contacts 23 are closed (contact 26 being closed) and motor 12 is operated through conductors 13 and 15 in a direction to increase the voltage of circuit 10. As soon as the voltage of circuit 10 reaches 114 volts, the relay 19 again picks up, the motor 12 is deenergized, and the regulator brings the regulated voltage up to the nominal value of 115 volts. On the other hand if the voltage of circuit 10 continues to rise and reaches the value of 116.5 volts, the pick-up voltage for relay 20, the relay 20 closes its contacts 27, at the same time opening its contacts 26 in the raise control circuit, and closes the "lower" control circuit 14, 15 so as to operate motor 12 in a direction to decrease the voltage of circuit 10. As soon as the voltage of circuit 10 drops to 116 volts the relay 20 opens its contacts 27 and thereby the "lower" control circuit of the motor and closes contacts 26 in the "raise" control circuit.

With the circuit requirements as described above, it will be clear that it is important to keep the holding effect, i. e., the difference between the pick-up voltage and the drop-out voltage, of each non-linear circuit constant. If the drop-out value becomes too nearly equal to the pick-up value, the relay tends to hunt since it picks up and drops out at substantially the same voltage. Furthermore, as a greater refinement from the point of view of accuracy of the value of the voltage to be held, it is desirable to have the pick-up and drop-out voltages of each relay remain constant in value throughout the usual operating range of the equipment.

In Fig. 2 I have shown illustrative pick-up and drop-out curves for the usual uncompensated non-linear resonant circuit for different ambient temperature conditions. These curves are plotted with volts as ordinate and degrees ambient temperature above and below zero temperature as abscissae. In accordance with the previous explanation of the dependence of the pick-up and drop-out voltages on the resistance of the circuit, it will be observed that for the usual copper conductor circuit of positive temperature coefficient the pick-up voltage tends to increase slightly with increase of temperature, whereas the drop-out increases at a much greater rate tending to approach the condition of zero difference or zero holding effect. This follows from the general theory of the non-linear resonant circuit since the circuit with resistance elements of positive temperature coefficient increases the resistance with an increase of the ambient temperature and thereby increases the drop-out voltage and decreases the holding effect. In order to appreciate fully the effect of this variation in critical voltages, it must be kept in mind we are dealing with a difference voltage of the order of ½ to ¾ of a volt. I have also found that many capacitors even though selected for use in non-linear resonant circuits exhibit a sufficient change in capacitance under variations in ambient temperature to affect adversely the values of pick-up and drop-out and also the difference between these values. Since the pick-up value of the non-linear circuit is determined primarily by the characteristics of the inductance element any change in the characteristics of the inductance element independent of current, such as ambient temperature, also adversely affects the pick-up value and hence the holding effect.

In accordance with this aspect of my invention, I so proportion the total critical resistance

of the non-linear resonant circuit between resistance elements of zero temperature coefficient of resistance and positive temperature coefficient of resistance as to maintain the holding effect of each non-linear circuit constant throughout the range of temperatures to which the circuit may be subjected. By proper selection of the value and temperature coefficient of resistance of the respective resistance elements of the non-linear circuit, I have not only been able to maintain the holding effect substantially constant but have also been able to maintain the pick-up values and the drop-out values, each substantially constant over a range of ambient temperatures of the order of 60° C. It is important to note that the temperature compensation is made not only with reference to the resistance elements of the circuit but also with reference to the changes occasioned by the temperature effects on the capacitance and inductance of the circuit.

In Fig. 3 I have shown illustrative pick-up and drop-out curves of a non-linear circuit compensated in accordance with my invention. These curves are plotted between volts as ordinates and degrees ambient temperature above and below zero as abscissae.

In accordance with my investigations, I have found that in a particular non-linear resonant circuit requiring a critical total resistance of 580 ohms, including 80 ohms in the saturable inductance, if the resistance element per se of 500 ohms is proportioned so as to have one portion of 370 ohms of negligible or zero temperature coefficient of resistance and the other portion of 130 ohms of positive temperature coefficient of resistance of the same order of magnitude as copper, the non-linear circuit will exhibit a substantially constant holding effect and substantially constant pick-up and drop-out voltages over a range of ambient temperatures from −30° C. to +30° C. My investigations have indicated that in the usual non-linear resonant circuit for use on low voltage circuits of the order of 100 to 200 volts, the resistance element of negligible or zero temperature coefficient of resistance should be of the order of ⅔ of the total resistance of the non-linear circuit and the remaining resistance of positive temperature coefficient of resistance including the usual copper wire inductance should be of the order of ⅓ of the total resistance. Certain well known resistance alloys such as manganin, or copper-nickel alloys, such as the alloys known to the trade as "Advance", "Copel" and "Ideal" are suitable for the resistance element of negligible or zero temperature coefficient of resistance. I have found that a copper-nickel alloy composed of 55 per cent copper and 45 per cent nickel corresponding to "Copel" and having a temperature coefficient accepted in the trade as zero gives very satisfactory results. Although resistance material of copper or other metals having a positive temperature coefficient of resistance of the same order of magnitude as copper are suitable for the other external resistance element, I find it is preferable to use a material with a relatively high resistivity compared to copper. I have found that a material known to the trade as "Lucero" composed of roughly 65 per cent nickel and 30 per cent copper with a temperature coefficient of resistance of roughly ⅔ that of copper (between −30° C. to +30° C.) and a resistivity roughly 25 times as great gives very satisfactory results.

While I have shown and described a particular embodiment of my invention, it will occur to those skilled in the art that various changes and modifications may be made without departing from my invention and I, therefore, aim in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of my invention.

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

1. In combination, an electric circuit, a non-linear resonant circuit, and voltage adjusting means interconnecting said circuits and adjustable so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same connections between said non-linear circuit and said voltage adjusting means.

2. In combination, an electric circuit, a non-linear resonant circuit, transforming means having a primary circuit connected to said electric circuit and a secondary circuit connected to said non-linear circuit, and means for adjusting said transforming means so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same number of turns of said secondary circuit included in circuit with said non-linear circuit.

3. In combination, an electric circuit, a non-linear resonant circuit, an auto-transformer interposed between said circuits, said auto-transformer being provided with taps at each end of the winding thereof, and adjustable connections between said taps and said electric circuit, said non-linear circuit being connected to said auto-transformer so as to include the same number of turns of said transformer independently of the position of said adjustable connections.

4. In combination, an electric circuit, a plurality of non-linear resonant circuits, transforming means having a primary circuit connected to said electric circuit and a secondary circuit connected to said non-linear circuits, each of said non-linear circuits being connected to said transforming means so as to include respectively a different fixed number of turns of said transforming means, and means for adjusting said primary circuit so as to impress substantially a constant voltage on each of said non-linear circuits for a plurality of different values of voltage of said electric circuit.

5. In combination, an electric circuit, a pair of non-linear resonant circuits, an auto-transformer interposed between said electric circuit and said non-linear circuits, said transformer having a main winding provided with taps at each end, adjustable connections between said taps and said electric circuit, one of said non-linear circuits being connected to include turns of said main winding only, and an additional winding on said transformer having one terminal connected to said main winding, the other of said non-linear circuits being connected to include turns of said main winding and said additional winding.

6. In combination, an electric circuit, a pair of non-linear resonant circuits, an auto-transformer interposed between said electric circuit and said non-linear circuits, said transformer having a main winding provided with taps at each end, adjustable connections between said taps and said electric circuit, an additional winding having one terminal connected to a point corresponding to one of the taps at the low voltage end of said

main winding, a resistance element connected across a portion of said main winding at said low voltage end, and a resistance element connected to a point in said auxiliary winding and a point at the low voltage end of said main winding, one terminal of each of said non-linear circuits being connected to a point at the high voltage end of said main winding and the remaining terminals being connected respectively to a different one of said resistance elements.

7. In combination, an electric circuit, a pair of non-linear resonant circuits each comprising in series relation a capacitance, a saturable inductance, a fixed resistor and a variable resistor, an auto-transformer interposed between said electric circuit and said non-linear circuits, said transformer having a main winding provided with taps at each end, adjustable connections between said taps and said electric circuit, an additional winding connectable for cumulative or differential action with said main winding with one terminal connected to a point corresponding to one of the taps at the low voltage end of said main winding, a resistance having an adjustable portion connected across the tapped portion at the low voltage end of said main winding, a resistance having an adjustable portion connected across a portion of said main winding at said low voltage end and to a point of said auxiliary winding, one terminal of each of said non-linear circuits being connected to a common point at the high voltage end of said main winding and the remaining terminals being connected respectively to a different one of said adjustable resistance portions connected across said main and auxiliary windings of said auto-transformer.

8. In combination, an electric circuit, means for controlling an electrical condition of said circuit, a non-linear resonant circuit for controlling said means, and voltage adjusting means interconnecting said circuits and adjustable so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same connections between said non-linear circuit and said voltage adjusting means.

9. In combination, an electric circuit, means for controlling an electrical condition of said circuit, a non-linear resonant circuit for controlling said means, transforming means having a primary circuit connected to said electric circuit and a secondary circuit connected to said non-linear circuit, and means for adjusting said transforming means so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same number of turns of said secondary circuit included in circuit with said non-linear circuit.

10. In combination, an electric circuit, means for controlling an electrical condition of said circuit, a non-linear resonant circuit for controlling said means, an auto-transformer interposed between said circuits, said auto-transformer being provided with taps at each end of the winding thereof, and adjustable connections between said taps and said electric circuit, said non-linear circuit being connected to said auto-transformer so as to include the same number of turns of said transformer independently of the position of said adjustable connections.

11. In combination, an electric circuit, means for controlling an electrical condition of said circuit, a pair of non-linear resonant circuits for controlling said means, an auto-transformer interposed between said electric circuit and said non-linear circuits, said transformer having a main winding provided with taps at each end, adjustable connections between said taps and said electric circuit, an additional winding having one terminal connected to a point corresponding to one of the taps at the low voltage end of said main winding, a resistance element connected across a portion of said main winding at said low voltage end, and a resistance element connected to a point in said auxiliary winding and a point at the low voltage end of said main winding, one terminal of each of said non-linear circuits being connected to a point at the high voltage end of said main winding and the remaining terminals being connected respectively to a different one of said resistance elements.

12. In combination, an electric circuit, means comprising an electric motor for controlling the voltage of said circuit, a pair of relays each comprising a winding and a pair of contacts for controlling said electric motor, one of said relays having a second pair of contacts in series relation with said pair of contacts of the other relay, two non-linear resonant circuits each comprising in series relation a capacitance, a saturable inductance and a resistance, the said non-linear circuits being arranged to have respectively an abrupt change of current for a different value of the voltage of said electric circuit, the windings of said relays being connected respectively to be responsive to the voltage of a capacitance in a different one of said non-linear circuits, means including said resistance in the respective non-linear circuits for changing the dissonant voltage of each of said non-linear circuits to adjust the drop-out voltage of the relay associated therewith, an auto-transformer interposed between said electric circuit and said non-linear circuits, said transformer having a main winding provided with taps at the high voltage and low voltage ends respectively, adjustable connections between said taps and said electric circuit, an additional winding having one terminal connected to a point corresponding to one of the taps at the low voltage end of said main winding, an adjustable resistance element connected across a portion of said main winding at said low voltage end, an adjustable resistance element connected to a point in said auxiliary winding and a point at the low voltage end of said main winding, one-terminal of each of said non-linear circuits being connected to a common point at the high voltage end of said main winding and the remaining terminals being connected respectively to a different one of said adjustable resistance elements.

13. In combination, an electric circuit controlling device having two energizing circuits, a pair of relays each comprising a winding for selectively controlling the energization of said energizing circuits, two non-linear resonant circuits respectively connected to energize a different one of said relay windings, and electrical interlocking means between said relays for preventing simultaneous energization of said energizing circuits.

14. In combination, an electric motor having two energizing circuits for selectively determining the direction of rotation of said motor, a pair of relays each comprising a winding and a pair of contacts for selectively controlling the energization of said energizing circuits, two non-linear resonant circuits respectively connected to

energize a different one of said relay windings, the pair of contacts of one of said relays being connected in series relation with one of said energizing circuits and the pair of contacts of the other of said relays being connected in series relation with the other of said energizing circuits, and an additional pair of contacts for said other relay connected in series relation with the contacts of said one relay, one of said energizing circuits of said motor being completed through a pair of contacts on each of said relays when said relays are in the same corresponding operating positions.

15. In combination, an electric circuit, means for controlling the voltage of said circuit, an electric motor for controlling said voltage controlling means, a voltage increasing relay having a pair of contacts for causing operation of said motor in a direction to increase the voltage of said circuit when the energization of said relay is below a predetermined value, a voltage decreasing relay having a pair of contacts for causing a reversal of the direction of rotation of said motor to decrease the voltage of said circuit when the energization of said last-mentioned relay is above a predetermined value, a non-linear resonant circuit for controlling the energization of said voltage increasing relay, a non-linear resonant circuit for controlling the energization of said voltage decreasing relay, both of said non-linear circuits being connected to be energized from said electric circuit, and an additional pair of contacts controlled by said voltage decreasing relay and connected in series relation with the contacts of said voltage increasing relay in circuit closing position when said voltage decreasing relay is energized below a predetermined value.

16. A non-linear resonant circuit comprising a capacitance, a saturable inductance and a resistance, a portion of the total effective resistance of said circuit comprising a resistance element of negligible temperature coefficient of resistance.

17. A non-linear resonant circuit comprising a capacitance, a saturable inductance and a resistance, the greater portion of the total effective resistance of said circuit comprising a resistance element of negligible temperature coefficient of resistance.

18. A non-linear resonant circuit comprising a capacitance, a saturable inductance and a resistance including a resistance element of positive temperature coefficient of resistance, a portion of the total effective resistance of said non-linear circuit being of negligible temperature coefficient of resistance and of such a value as to maintain substantially constant the difference between the resonant and dissonant voltages of said non-linear circuit with variations in ambient temperature.

19. A non-linear resonant circuit comprising a capacitance, a saturable inductance, and a resistance including a resistance element of positive temperature coefficient of resistance, a portion of the total effective resistance of said non-linear circuit being of negligible temperature coefficient of resistance and of such a value as to maintain substantially constant the resonant and dissonant voltages respectively of said non-linear circuit throughout variations in ambient temperature.

20. In a non-linear resonant circuit, a capacitor, a closed core saturable inductor having a copper winding, a resistor having a positive temperature coefficient of resistance of the same order of magnitude as that of copper at 20° C. and a resistivity substantially higher than that of copper at 20° C., and a second resistor having a temperature coefficient of resistance of substantially zero and a value constituting a substantial portion of the total effective resistance of said non-linear circuit.

21. In a non-linear resonant circuit, a capacitor, a closed core saturable inductor having a copper winding, a resistor composed of a resistance alloy of substantially 65 per cent nickel and 30 per cent copper, and a second resistor composed of a resistance alloy of substantially 45 per cent nickel and 55 per cent copper, said second resistor having a value substantially equal to two-thirds of the total resistance of said non-linear circuit.

22. In combination, an electric circuit, a non-linear resonant circuit comprising a capacitance, a saturable inductance, and a resistance, a portion of the total resistance of said non-linear circuit being of negligible temperature coefficient of resistance and of such a value as to maintain the difference between the resonant and dissonant voltages of said non-linear circuit substantially constant, and voltage adjusting means interconnecting said circuits and adjustable so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same connections between said non-linear circuit and said voltage adjusting means.

23. In combination, an electric circuit, a non-linear resonant circuit comprising a capacitance, a saturable inductance and a resistance, a portion of the total resistance of said non-linear circuit being of negligible temperature coefficient of resistance and of such a value as to maintain substantially constant the resonant and dissonant voltages respectively of said non-linear circuit, transforming means having a primary circuit connected to said electric circuit and a secondary circuit connected to said non-linear circuit, and means for adjusting said primary circuit so as to impress substantially the same voltage on said non-linear circuit for a plurality of different values of voltage of said electric circuit with the same number of turns of said secondary circuit included in circuit with said non-linear circuit.

24. In combination, an electric circuit, a plurality of non-linear resonant circuits each comprising a capacitance, a saturable inductance and a resistance, a portion of the total resistance of each of said non-linear circuits being of negligible temperature coefficient of resistance and of such a value relative to the total critical resistance of each of said non-linear circuits as to maintain the difference between the resonant and dissonant voltages thereof substantially constant, transforming means having a primary circuit connected to said electric circuit and a secondary circuit connected to said non-linear circuits, each of said non-linear circuits being connected to said transforming means so as to include respectively a different fixed number of turns of said transforming means, means for adjusting said primary circuit so as to impress a substantially constant voltage on each of said non-linear circuits for a plurality of different values of voltage of said electric circuit, means for independently varying the resonant voltage of each of said non-linear circuits, and means for independently varying the dissonant voltage of each of said non-linear circuits.

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