S. E. JOHANNESEN.

METHOD AND MEANS OF VOLTAGE CONTROL.

APPLICATION FILED JAN. 3, 1913.

1,225,639.

Patented May 8, 1917.

4 SHEETS—SHEET 1.

Fig. 2.

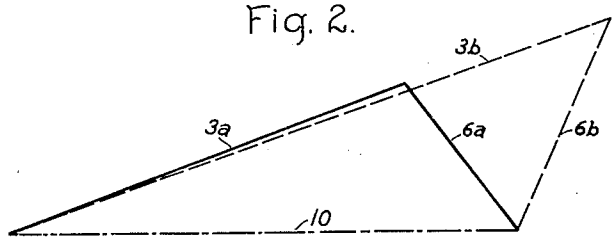


Fig. 1.

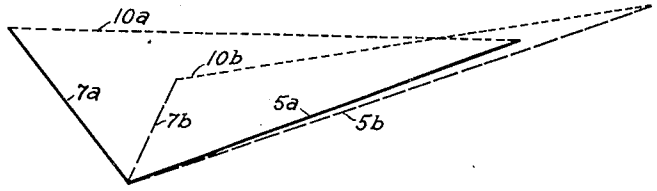
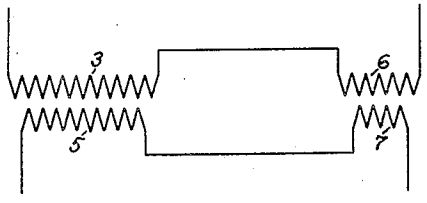


Fig. 3.



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4 SHEETS—SHEET 2.

Fig. 7.

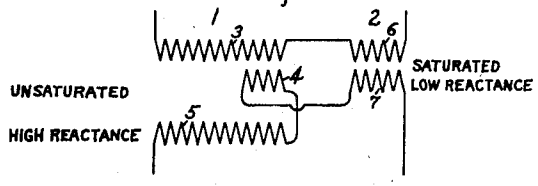


Fig. 9.

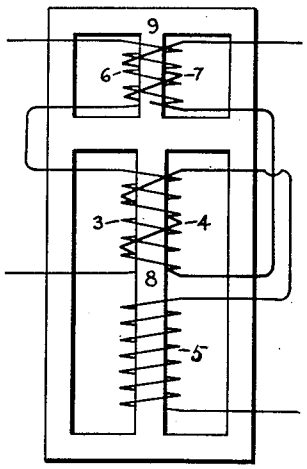


Fig. 5.

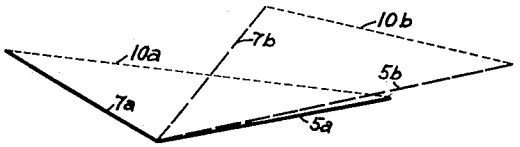


Fig. 4.

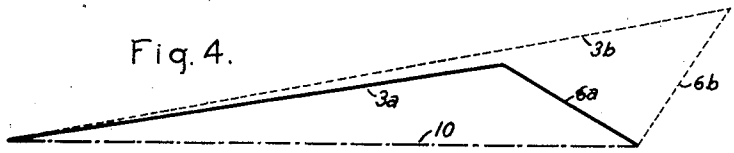


Fig. 6.

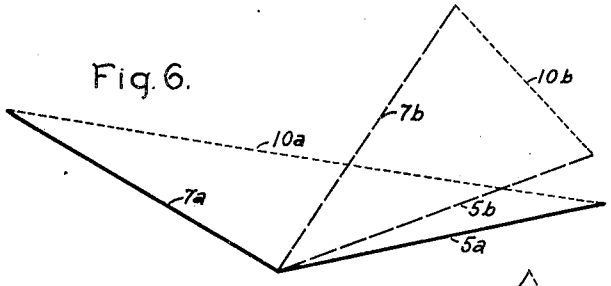
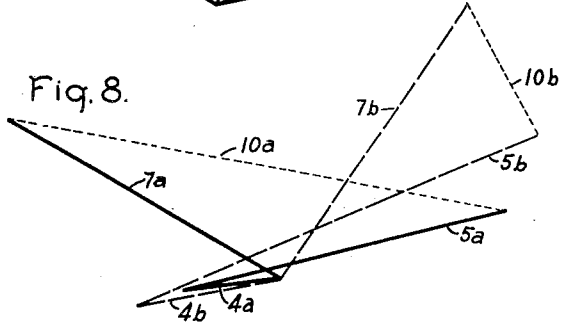


Fig. 8.



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4 SHEETS—SHEET 3.

Fig. 10.

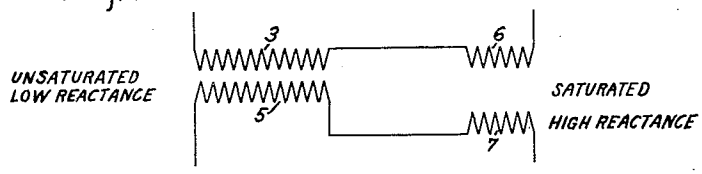


Fig. 11.

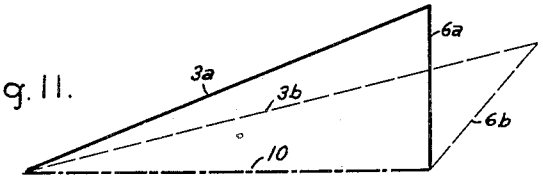


Fig. 12.

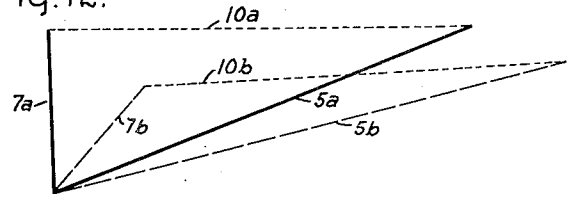
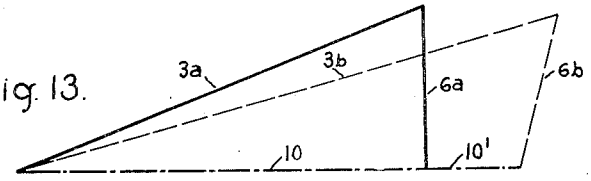


Fig. 13.



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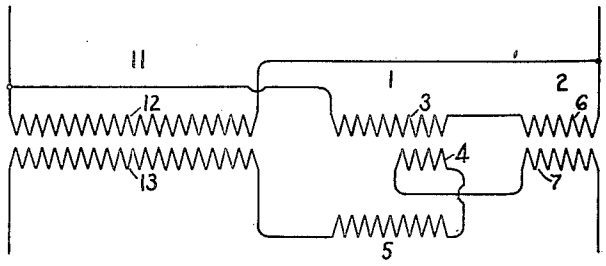
APPLICATION FILED JAN. 3, 1913.

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4 SHEETS—SHEET 4.

Fig. 14.



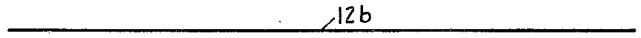


Fig. 15.

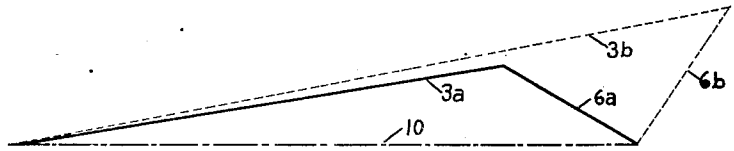
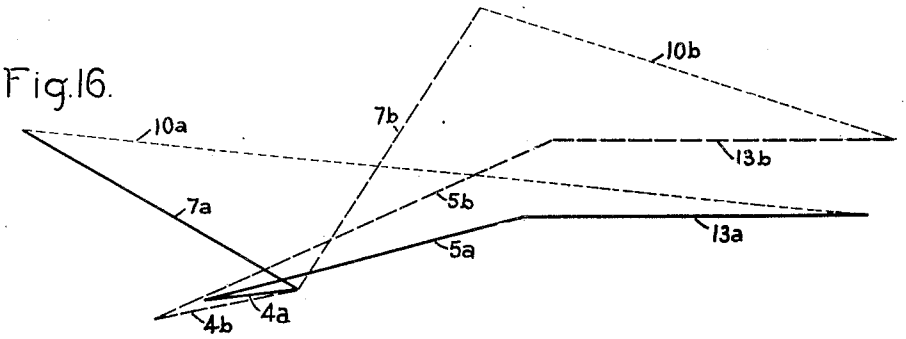


Fig. 16.



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UNITED STATES PATENT OFFICE.

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METHOD AND MEANS OF VOLTAGE CONTROL.

1,225,639. Specification of Letters Patent. Patented May 8, 1917.

Application filed January 3, 1913. Serial No. 740,003.

To all whom it may concern:

Be it known that I, SVEND E. JOHANNESEN, a citizen of the United States, residing at Pittsfield, county of Berkshire, State of Massachusetts, have invented certain new and useful Improvements in Methods and Means of Voltage Control, of which the following is a specification.

My invention relates to the controlling of the voltage impressed on a circuit, and the objects of my invention are to provide a method and means of controlling the voltage on a circuit, more particularly automatically controlling the voltage on a circuit in any predetermined desired manner irrespective of the load changes. More particularly still, my invention also relates to the production of a constant current transformer with no moving parts.

My method broadly comprises the controlling of the resultant electromotive force impressed on a local circuit by both controlling the valve of one or more of the component electromotive forces, and independently thereof controlling the phase relations of the components relatively to each other. Following this method, I am enabled to provide a constant current transformer without moving parts, in this transformer varying the phase relations of the component electromotive forces which are induced in a plurality of secondaries located on a plurality of core portions operating at different degrees of saturation, and controlling the values of the components of the resultant electromotive force by reactance or otherwise. It will be apparent from the further description that my invention is not limited to this single use.

My invention is described in detail hereinafter reference being made to the accompanying drawings which form a part of this specification. Figures 1 and 2 are vector diagrams to which reference is made in the broad description of my invention. Fig. 3 illustrates diagrammatically transformer connections. Figs. 4 and 6 are vector diagrams to which reference is made in describing a modification of my broad invention to obtain constant current from a transformer without moving parts. Fig. 5 is a vector diagram of use in the description of my invention. Fig. 7 is a diagrammatical representation of transformer connections involving a preferred form of my invention to obtain constant current. Fig. 8 is a vector diagram referring to the operation of the construction of Fig. 7. Fig. 9 is a diagrammatical illustration of a single construction employing the connections of Fig. 7. Figs. 10 and 14 are diagrammatical representations of transformer connections involving other modifications of my broad invention. Figs. 11, 12, 13, 15 and 16 are vector diagrams to which reference is made in describing modifications and specific applications of my broad invention.

I have in this specification described my method as carried out by a transformer since the method may be simply described with relation to a transformer inherently regulating.

In order that my invention may be clearly understood, I shall first describe a device known prior to my invention. Prior to my invention it was suggested that the voltage impressed on a circuit could be controlled as the load varied by means of a transformer (see Fig. 3), having a primary winding 3 located on an unsaturated core and a primary winding 6 located on a core saturated at all operating values of current. The secondary windings 5 and 7 respectively, were however, of inconsiderable reactance. Referring to Figs. 4 and 5: 10 in Fig. 4 may be regarded as representing the voltage impressed on the terminals of the primaries 3 and 6 in series; this voltage we may assume was impressed by a constant potential source. The electromotive forces in the two primaries were out of phase by design (one core being saturated by the exciting current) and are represented in Fig. 4 by the lines 3_a and 6_a respectively, at, say, open circuit on the secondary side. Now, providing the ratios of transformation were so chosen, the voltages in the secondaries 5 and 7 were as I have represented them at 5_a and 7_a respectively in Fig. 5; the secondary voltages may be regarded for the purpose of

this description as remaining, under varying load, 180° displaced from the primary voltages inducing them and therefore the lines 5_a and 7_a in Fig. 5 have been drawn approximately parallel to the lines 3_a and 6_a respectively in Fig. 4. The resultant secondary voltage, that impressed on the secondary circuit, is represented by the line connecting the free ends of 5_a and 7_a, the line 10_a. As the load comes on the secondary circuit, the primary winding 3 tends to take a larger and larger proportion of the voltage, its core remaining unsaturated and the core of the primary 6 being saturated at all degrees of load, with a result that the electromotive force in the primary 6 of necessity changes its phase considerably but its value but little; at some state of increased load the electromotive force distribution in the primaries 3 and 6 may be represented by the lines 3_b and 6_b respectively (Fig. 4). The secondary voltages are now represented by 7_b and 5_b (Fig. 5), 7_b having substantially the same value as 7_a and 5_b being greater than 5_a, resulting in 10_b impressed on the secondary circuit. It will be seen that the resultant voltage, 10_a—10_b, impressed on the load circuit has been varied, in this case lowered, as the load has been put on the secondary. The change in value of 5_a—5_b may be said to be in effect incidental and to have been regarded as an effect bound to occur and to be taken into account in determining the amount of phase change necessary to produce the desired result. All this was known prior to my invention, and I do not purport to cover any such structure or operation in the claims appended hereto. It will be observed that the range of variation was limited due to the facts that there was but one factor varied intentionally, the phase of the component electromotive forces 7_a—7_b and 5_a—5_b, and that at least one incidental change occurred over which no control could be exercised and which it was necessary to compensate for. Now a greater range of and more satisfactory voltage control may be obtained by introducing one or more variable factors to control the values of the components of the total impressed electromotive force, or some of them, whether they are produced by transformers or otherwise. Thus the components may be controlled in phase, as was done heretofore, while additional control over the values of the components may be exercised.

I shall first assume that I desire to decrease the voltage as the load on the system increases. The broad method I employ may be described with reference to Fig. 1: I here utilize two component electromotive forces and at some certain degree of load have adjusted their values and relative phases to those represented by 5_a and 7_a, resulting in the impression on the load circuit of the desired electromotive force 10_a. Now as the load increases, I propose to control the values of the component electromotive forces and their phase relation, as may be most favorable to the case in hand. Thus in this particular case for the second degree of load assumed, I desire a voltage on the system of the value represented by 10_b, and to obtain this I reduce the value of 7_a to 7_b, increase 5_a to 5_b and bring the components nearer into phase opposition. Now this method may be easily carried out by means of a transformer having two cores or core portions and located thereon respectively two primary windings in series and two secondary windings in series as shown in Fig. 3. Fig. 2 may represent the electromotive forces in the primaries. 10 is the electromotive force impressed on the terminals of the primaries in series. The secondary voltages of course bear a substantially fixed phase relation to their inducing primary voltages (for the purpose of this explanation this relation will again be assumed to be exactly 180°) and hence the angle between them may be made to be of any desired value at any certain degree of load, by exciting the cores or core portions to different degrees of saturation. I have assumed the open circuit reactance values given to the windings 3 and 6 of the transformer of Fig. 3 are such as to produce the angle shown between 5_a and 7_a of Fig. 1 at some degree of load, the electromotive force distribution in the primaries 3 and 6 for this first degree of load assumed being represented by 3_a and 6_a respectively (Fig. 2). Now as the load changes the phase relation between the two components of the secondary electromotive force will change because of the change which occurs in phase relation between the electromotive forces in the two primaries. Thus at the second degree of load assumed for Fig. 1, the electromotive force distribution in the primaries is represented by 3_b and 6_b (Fig. 2), the electromotive forces in 3 and 6 respectively. Different ratios of transformation in the two transformers or transformer portions may be used to aid, tending either to increase or decrease, this phase change in a manner well understood. Both of these electromotive forces have been assumed as increased in value tending to result in an increase in each of the components on the secondary side as occurred in one instance in Fig. 5. I would control these components, however, and this I prefer to do by giving the secondary windings the proper leakage reactance values. In the case illustrated, Fig. 1, these values are such that 5_a has been allowed to increase to 5_b and 7_a has been decreased to 7_b. These changes in value are not in this case proportional to the

changes in value of the primary voltages and are entirely controllable by the leakage reactances. Therefore, by properly changing the phase relation between the components by running the cores at different degrees of saturation and by properly changing their values by leakage reactance, the resultant voltage impressed on the circuit has been changed from 10_a to 10_b as the load increased.

Now it may not in all cases be desirable to change the values of both or either of the components with the change in load. The design and apparatus in some cases may be simplified by holding the values of both components constant, changing merely their phase relations, or in other cases by holding the value of one component constant, controlling the phase relations and the value of the other component. Either component may be held substantially constant in value, as well as allowed or caused to change in value only as desired, by giving the windings the proper leakage reactances. Also at least one component may be held at a substantially constant value by other means later described. In still other cases the design and apparatus may be simplified by giving one component a suitable value at one degree of load and allowing its value to remain constant or to change with load changes, as it may, compensating therefor and obtaining the proper voltage by controlling the phase relations and the value of another component. Some of these cases will now be described more in detail.

In applying my method of control to a transformer construction to obtain a constant current transformer without moving parts, I prefer that the two components remain substantially constant in value and that the principal change be in phase relation. See Figs. 4, 6 and 7. When a transformer is employed, one of the components of the secondary voltage may easily be held approximately constant by mounting the secondary winding producing it on a substantially saturated core. As illustrated in Fig. 7, I prefer in the case of a constant current transformer to provide two primary windings 3 and 6, parts of what I call the main and auxiliary transformers 1 and 2 respectively, the winding 6 surrounding a core or core portion practically completely saturated at no load, the core or core portion surrounded by the winding 3 being unsaturated at practically all degrees of load. The secondary 7 is of negligible leakage reactance and is located on the saturated core; the secondary 5 is of high leakage reactance and is on the unsaturated core. (The winding 4 will be omitted from consideration at this time). Fig. 4 may represent the electromotive force distribution in the primaries and Fig. 6 that in the secondaries at some degrees of load. 3_a and 6_a represent the electromotive forces in the primaries 3 and 6 respectively, say at no load, 10 being the electromotive force impressed on the primary terminals. At some certain degree of load the electromotive force distribution is as represented by 3_b and 6_b; 3_a—3_b has changed in value considerably while 6_a—6_b has remained practically constant (the winding producing it being located on a saturated core), but the change in phase between the two is considerable. On the secondary side at no load the electromotive forces in 5 and 7 are respectively 5_a and 7_a (Fig. 6), the angle between the two being determined as before explained by the angle between 3_a and 6_a, which in its turn was determined by the relative open circuit reactances of 3 and 6. As the load changes, 7_a changes in phase with 6_a—6_b to 7_b, remaining substantially constant in value, since 6_a—6_b remains substantially constant. 5_a likewise changes to 5_b in phase, its value, however, remaining nearly constant on account of the leakage reactance of the winding 5 which has been given the proper value to produce this result. The open circuit reactances of the windings 3 and 6 I prefer to so relate that the phase change between the components substantially entirely takes care of the voltage to give constant current to the load no matter what the resistance value of the load may be. A slight change in the value of one or both components is, however, I have found, sometimes desirable. In a particular instance, where the impressed voltage was about 3200 and the current desired on the secondary side about .5 amp., the ratios of transformation in the main transformer of 2:1 and in the auxiliary transformer of 1:2 were considered well suited, the reactance being sufficient to maintain the secondary component voltages substantially equal at all loads. By using different ratios of transformation the relation between the values of the secondary voltage is rendered somewhat independent of the relation between the numbers of turns of the two primary windings, and the two primary windings may be given the proper number of turns respectively, to obtain the desired phase relations with substantially no regard as to the secondary voltages desired. This it will be apparent from the earlier part of this description, is not the only way my method may be applied to obtain constant current with transformers, but is but one modification of my invention suitable for producing this result.

I have found further that in the case of transformers at least, the use of a main differential secondary winding 4 (see Fig. 7) is beneficial. This winding is in close

inductive relation to the primary winding 3. Fig. 8 may represent the secondary voltage distribution at the degrees of load assumed before and represented on the primary side in Fig. 4. In Fig. 8 the electromotive force in the main auxiliary secondary winding 4 is represented at the two degrees of load respectively by the lines 4_a and 4_b; the remaining lines of this figure bear the same characters as do the lines in Fig. 6 previously described and represent the same factors. When this main differential secondary winding 4 is used, I prefer to calculate the various factors so that the vector sum of the main secondary electromotive force 5_a plus the main differential secondary electromotive force 4_a is substantially equal to the vector sum of the auxiliary secondary electromotive force 7_a plus the main differential secondary electromotive force 4_a at no load, and so design the whole that these two resultants may be as nearly in phase as it is convenient to make them at no load. The main differential secondary 4 gives a dampening effect when the load is changed. The final regulation without this coil is just as good as with it, but on the sudden variation of the load to a relatively great extent without the coil, the electromotive force impressed on the load for a small fraction of a second may have a different value from that finally assumed.

Fig. 9 illustrates diagrammatically a possible transformer construction involving the connections more diagrammatically illustrated in Fig. 7. On the core portion 8, which is of sufficient cross sectional area to operate at all loads substantially below saturation, is located the primary winding 3, closely inductively related to which is the main differential secondary winding 4. On another part of this same core portion 8 is the main secondary winding 5, its location at some distance from its primary 3 giving it the required leakage reactance. On another core portion 9, which may be of smaller cross sectional area in order that it may be practically saturated as required, is the auxiliary primary 6 and the auxiliary secondary 7, closely inductively related.

To obtain constant voltage, either at the secondary terminals or at some distant point on the secondary circuit, I prefer, in the case of a transformer, to use the construction illustrated in Fig. 10. The latter case of constant potential at some distant point will now be described. The secondary winding 7, provided with the required leakage reactance, is located on a practically completely saturated core, while the secondary 5, without appreciable leakage reactance, is on the unsaturated core. The primaries 6 and 3 are located on the same cores as the secondaries 7 and 5 respectively. Fig. 11 is the primary potential vector diagram. The secondary potential vector diagram Fig. 12, however, shows how the component $5_a—5_b$ is allowed to increase in value with increase in load without hindrance, while $7_a—7_b$ is decreased in value with increase in load. The result desired of course, is an increase in electromotive force impressed on the terminals of the circuit, from 10_a to 10_b and this adaptation of my method I consider to be preferable in this case. In using this adaptation I prefer that the electro-motive force in the primary winding 6 be displaced substantially 90° from the impressed electromotive force 10 at no load. Thus at no load, 6_a should be substantially 90° from 10, which accounts for the angular differences between Figs. 4 and 11.

Constant potential may also be obtained from variable potential on the primaries by utilizing my method, as for example, from a series connected transformer (see Fig. 13). As the voltage impressed on the primaries changes from 10 to 10′, the voltage distribution therein changes from 3_a and 6_a to 3_b and 6_b. Constant potential may obviously be obtained by leakage reactances in the secondaries which properly change the values of the secondary electromotive forces induced.

Thus far I have applied my invention to obtain a range of voltage from a predetermined maximum through to zero. When the load variation is more or less limited and such a wide range of change is not required, the apparatus involving my invention, as before described, may be only of sufficient capacity to provide for the range of voltage required. Any suitable primary or secondary source of energy may be used in the load circuit for supplying a constant voltage, and the variable resultant, the resultant of the variable components, may either add to or subtract from the voltage of the additional source. By thus coupling a small voltage controlling means with another source of power, a higher power factor may generally be obtained than can be obtained by deriving the entire power through the voltage controlling means. Fig. 14 shows an ordinary power transformer 11 coupled, the primaries in parallel and the secondaries in series, with the voltage controlling means of Fig. 7; this is one means for carrying out this part of my invention. The power transformer 11 may provide most of the power supplied to the load circuit while the transformers 1 and 2 may either add to or subtract from the voltage of the transformer 11 the proper amount necessary to vary the voltage on the load circuit with load changes as desired. For the purposes of this explanation we may regard the resultant of the electromotive forces of trans-

formers 1 and 2 as adding to the voltage of 11. Fig. 15 may be regarded as representing the electromotive force distribution in the primaries at no load and at some certain degree of load. 12_b is the electromotive force impressed on the primary winding 12, constant at all loads and equal to and in phase with 10. It will be noted that the other part of this figure is similar to Fig. 4. The secondaries being in series the vector diagram thereof, Fig. 16, is similar to Fig. 8 with the constant voltages 13_a and 13_b of the secondary 13 added. The resultant voltages impressed on the secondary circuits are represented as heretofore by 10_a and 10_b. Obviously the addition of a constant voltage source and a variable voltage source is not limited solely to the attainment of constant current.

While I have described my method as carried out by means of transformer constructions, it will be understood to those skilled in the art that this is merely one convenient construction for rendering the control entirely automatic and that it is not limited in its application to such constructions, or even to inherent control. Other constructions may be designed embodying the method in their operation and hence I do not consider myself limited, as far as the method is concerned, to any particular one.

In the preceding description it has been assumed for simplicity's sake that the secondary voltage in a transformer is at all times displaced exactly 180° from the primary voltage inducing it. This is of course not absolutely accurate, but the phase relations are well understood and determinable, and, it will be understood, will need to be considered in accurate designing. Also, the secondaries, being in series and of different reactances, may have their electromotive forces affected in phase thereby; no notice has been taken in the above description of this, which while it may also need to be taken into account in design, likewise does not affect the general theory as laid down above.

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

1. The method of controlling the resultant voltage impressed on a circuit having a load connected thereto which consists in providing electromotive forces inducing other electromotive forces in the load circuit by means of said first mentioned electromotive forces, and changing the relative phase relation of the first mentioned electromotive forces and the ratio of transformation between one of said induced electromotive forces and its inducing electromotive force as the load changes.

2. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces, which consists in maintaining the values of the component electromotive forces substantially constant and varying the relative phase relation between two of the components to compensate for tendencies toward change of current.

3. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces, which consists in maintaining two of such component electromotive forces substantially equal in value and varying their phase relation to compensate for tendencies toward change of current.

4. The method of maintaining constant the current produced by a plurality of component electromotive forces in a circuit having a load connected thereto, which consists in partially regulating the voltage by varying the phase angle between two components and partially by controlling the relation of the values of the components as the load changes to compensate for tendencies toward change of current.

5. The method of maintaining constant the current produced by a plurality of component electromotive forces in a circuit having a load connected thereto, which consists in providing electromotive forces, inducing electromotive forces in the load circuit by means of the first mentioned electromotive forces and changing the relative phase relation of the first mentioned electromotive forces and the ratio of transformation between one of said induced electromotive forces and its inducing electromotive force as the load changes to compensate for tendencies toward change of current.

6. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces, which consists in providing electromotive forces, inducing other electromotive forces in the load circuit by means of the first mentioned electromotive forces, and subjecting one of said induced electromotive forces to the effect of an impedance and changing the relative phase relation of the first mentioned electromotive forces to compensate for tendencies toward change of current.

7. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces, which consists in providing electromotive forces, inducing other electromotive forces in the load circuit by means of the first mentioned electromotive forces, and maintaining the values of said induced electromotive forces substantially equal to each other and changing the relative phase relation of the first mentioned electromotive forces to compensate for tendencies toward change of current.

8. The method of controlling the resultant voltage impressed on a circuit which consists in providing electromotive forces and changing their relative phase relations, inducing two electromotive forces in the load circuit by means of one of the first mentioned electromotive forces, inducing another electromotive force in the load circuit by means of another of the first mentioned electromotive forces and changing the ratio of transformation between one of the two electromotive forces induced by the single electromotive force and that single inducing electromotive force.

9. The method of controlling the resultant voltage impressed on a circuit, which consists in providing not less than three electromotive forces, changing the phase relation between two of said electromotive forces and the third, and changing the value of one of those two electromotive forces relative to the value of the third, inducing other electromotive forces in the load circuit by means of the first mentioned electromotive forces and changing the ratio of transformation between one of the inducing electromotive forces of changing value and the electromotive force induced thereby.

10. The combination of a plurality of transformer windings, one set of said windings being provided with a saturated core and the secondary of another set of said windings being provided with considerable reactance, the secondaries being connected in series.

11. The combination of a plurality of secondary transformer windings connected in series, one of said windings being provided with a saturated core, another of said windings being provided with considerable reactance and a third secondary winding being connected to the first mentioned two.

12. The combination of a plurality of secondary transformer windings connected in series, one of said windings being provided with a saturated core, another of said windings being provided with considerable reactance and a third secondary winding being connected in opposition to the first mentioned two.

13. The combination of a plurality of transformers having their primary windings connected in series and their secondary windings connected in series, one of said transformers being provided with a core substantially saturated by its magnetizing current and another transformer having considerable reactance in its secondary winding.

14. The combination of a plurality of transformers having their primary windings connected in series and their secondary windings connected in series, one of said transformers being provided with a core substantially saturated by its magnetizing current and another transformer having considerable reactance in one portion of its secondary windings, another portion of its secondary winding being in close inductive relation to the primary winding.

15. The combination of a plurality of transformers having their primary windings connected in series and their secondary windings connected in series, one of said transformers being provided with a core substantially saturated by its magnetizing current and another transformer having considerable reactance in one portion of its secondary windings, another portion of its secondary windings being in close inductive relation to its primary winding and being connected in opposition to the first mentioned portion.

16. The combination with means for supplying energy to a circuit, of a plurality of transformers having their secondary windings connected in series with each other and said means, the core of one of said transformers being substantially saturated by its magnetizing current and the secondary winding of one of said transformers having considerable reactance.

17. The method of controlling the resultant voltage impressed by the secondary windings of a transformer on a circuit having a load connected thereto, which consists in impressing electromotive forces on the primary windings of said transformer, inherently changing their relative phase relation, and inherently changing the ratio of transformation as the load changes.

18. The method of controlling the resultant voltage impressed on a circuit by the secondary windings of a transformer which consists in impressing electromotive forces on the primary windings of said transformer and inherently changing their relative phase relation and subjecting one of the induced electromotive forces to the effects of an impedance inherent in the transformer.

19. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces impressed on the circuit by the secondary windings of a transformer which consists in impressing electromotive forces on the primary windings of said transformer, inherently changing their relative phase relation, and inherently changing the ratio of transformation between one of the induced electromotive forces and its inducing electromotive force to compensate for load changes.

20. The method of maintaining constant the current produced in a circuit by a plurality of component electromotive forces impressed on the circuit by the secondary windings of a transformer which consists in impressing electromotive forces on the pri-

mary windings of a transformer, inducing other electromotive forces in the secondary windings by means of said first mentioned electromotive forces, inherently in the transformer maintaining the values of said induced electromotive forces substantially equal to each other and inherently changing the phase relation of the electromotive forces of the primary windings to compensate for load changes.

In witness whereof, I have hereunto set my hand this 30th day of Dec., 1912.

SVEND E. JOHANNESEN.

Witnesses:

FLOYD R. FINCH,

HENRY C. SCHWECKE.