March 4, 1924. 1,485,727

M. L. SINDEBAND

VOLTAGE BOOSTING OR BUCKING SYSTEM

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Fig. 1

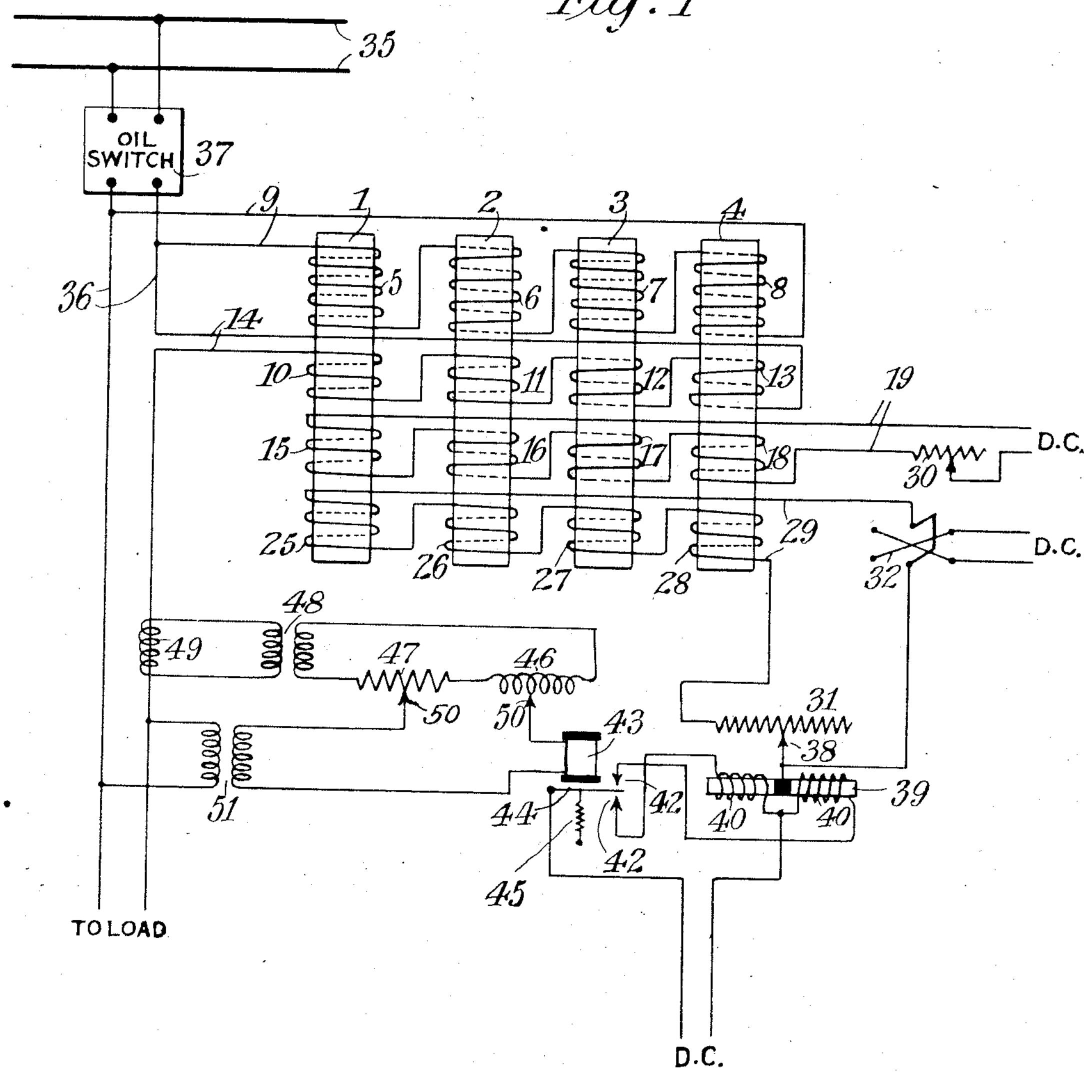

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Fig. 2

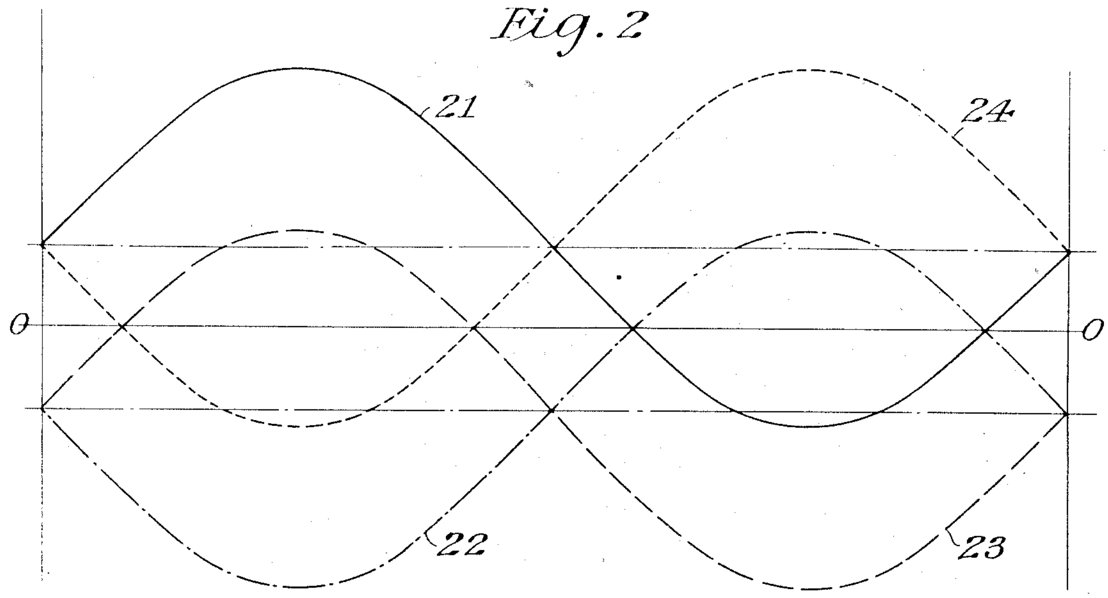
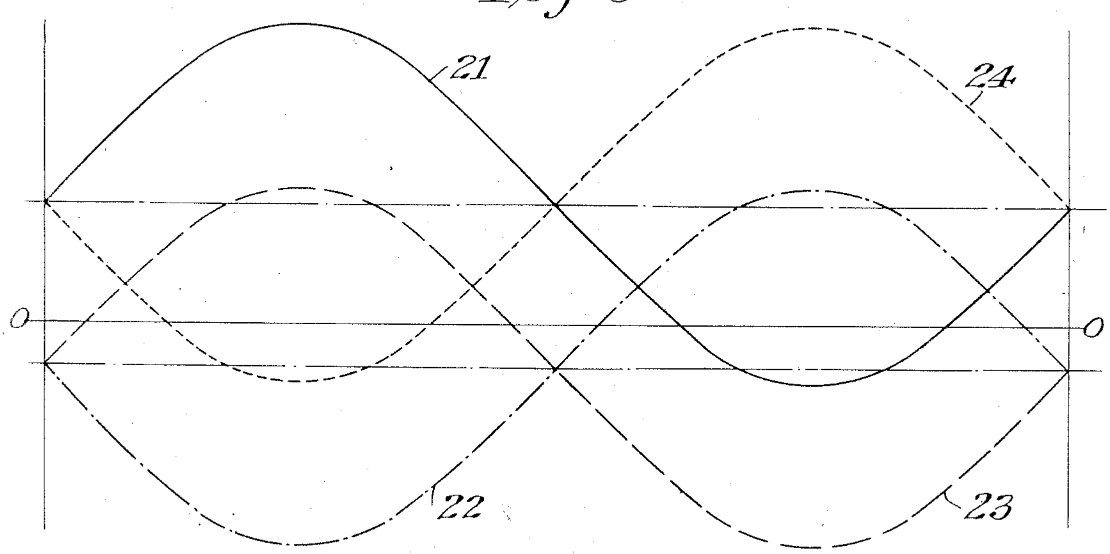


Fig. 3



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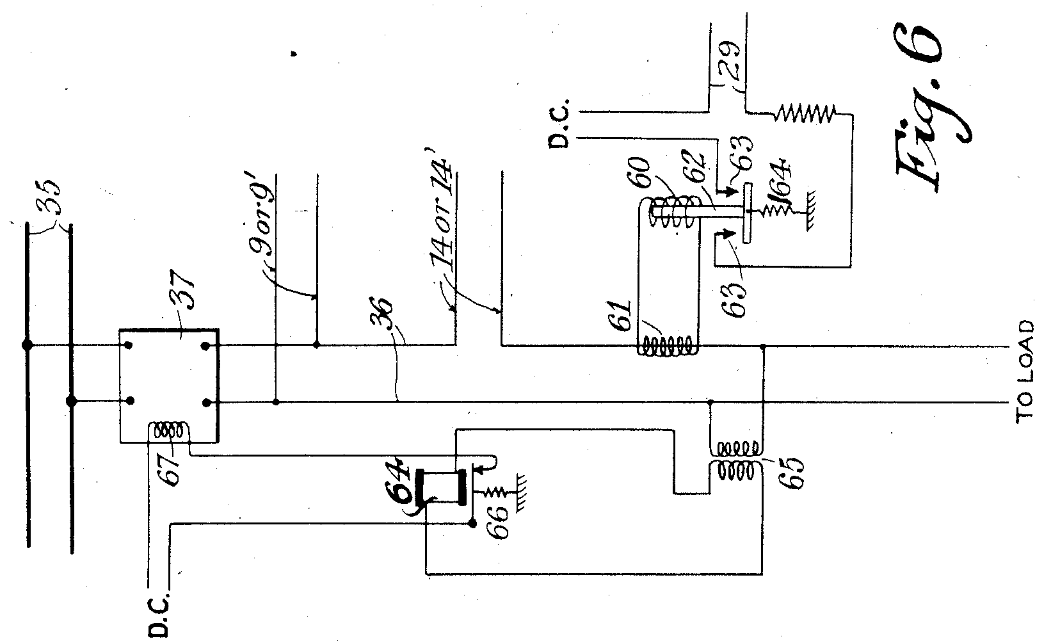

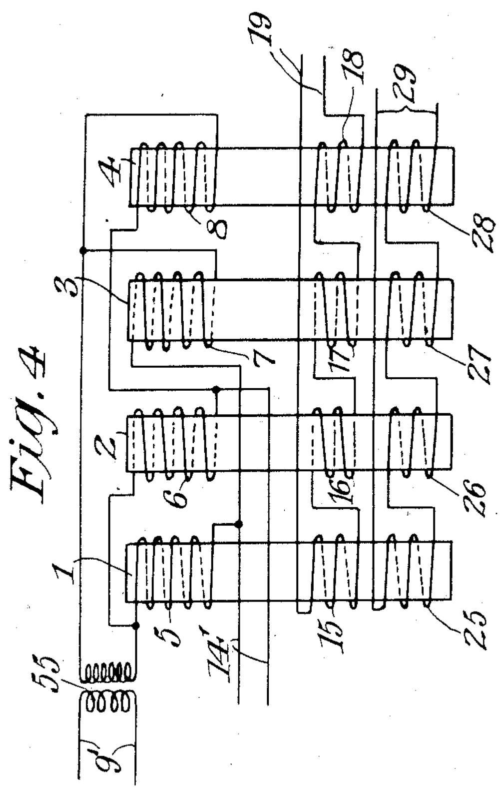

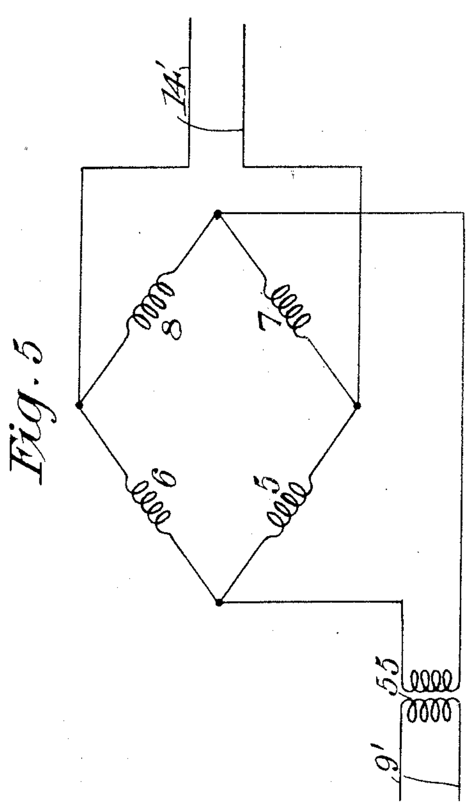

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Patented Mar. 4, 1924. **1,485,727**

UNITED STATES PATENT OFFICE.

MAURICE L. SINDEBAND, OF NEW YORK, N. Y., ASSIGNOR TO GENERAL ELECTRIC COMPANY, A CORPORATION OF NEW YORK.

VOLTAGE BOOSTING OR BUCKING SYSTEM.

Application filed September 20, 1920. Serial No. 411,479.

To all whom it may concern:

Be it known that I, MAURICE L. SINDEBAND, a citizen of the United States, residing at New York, county and State of New York, have invented certain new and useful Improvements in Voltage Boosting or Bucking Systems, of which the following is a full, clear, and exact description.

This invention relates to feeder regulators. More specifically it relates to feeder regulators of the alternating current type and has for one of its principal objects to provide a static regulator.

It is known to those skilled in the art that the voltage at the load end of feeders varies with the magnitude of the load due to variation in the potential drop on the feeders. In order to compensate for this drop and to maintain the voltage at the load substantially constant it is common to employ a regulator capable of impressing a positive (boosting) or negative (crushing or bucking) E. M. F. on that at the input end of the feeder. In A. C. systems it has been proposed to effect this result by connecting the primary of a static transformer across the feeder and the secondary in series with one of the feeders. In such a system the necessary variation of the additive E. M. F. would be accomplished by cutting out or adding turns to the secondary by means of suitable switch-controlled taps. The objections to this method of control are well recognized by skilled workers in the art and therefore need not be enumerated. Another proposed system is somewhat the same as the last mentioned one except that the desired variation in additive E. M. F. is effected by varying the mutually inductive relationship of the primary and secondary. This has been effected by shifting the relative portions of the primary and secondary cores by means of a motor controlled by a contact making voltmeter. Among other objections to this induction regulator are the following: In order to attain the desired range of boost or buck a large number of moving parts are required and the apparatus is large and expensive.

One of the principal objects of the present invention is to provide a feeder regulator of the static type which is free from the objections found in the above mentioned and other prior systems and which possesses a wide boosting and bucking range but is comparatively inexpensive both from the standpoint of initial cost and the cost in maintaining thoroughly reliable and efficient operation. Other important objects and advantages will appear in view of the following disclosure. My invention is capable of assuming various forms, some of which will be hereinafter described and others omitted to avoid surplusage in illustration and description.

Referring to the drawings which illustrate what I now consider preferred forms of the invention:

Fig. 1 is a diagram illustrating one form of the invention.

Figs. 2 and 3 illustrate curves employed in explaining the operation of the system employed in Fig. 1.

Fig. 4 is a diagrammatic view illustrating a modification.

Fig. 5 is a diagram illustrating more clearly the connections of certain of the elements shown in Fig. 4.

Fig. 6 is a diagram illustrating a system in which the invention is employed to buck or crush the line voltage in case of short-circuit.

As the result of tests the system illustrated in Fig. 1 has been found both effective and efficient. This system comprises four cores 1, 2, 3 and 4 of magnetizable material, preferably silicon steel commonly employed in transformers, each of which is of substantially the same dimensions and possessing substantially the same characteristics as the others. I have shown open cores for clarity in illustration. Each of these cores is provided with a winding 5, 6, 7 and 8, there being the same number of turns in any winding as there is in any of the others. These windings are serially connected by means of conductors 9 and for convenience I shall hereinafter refer to the same as the A. C. excitation, or primary, winding. It will be noted that the direction of winding or connections are such that, on passage of current through the conductors 9, the instantaneous flux produced by the windings 5 and 7 will be relatively in the same sense but that produced by windings 6 and 8 will be in the opposite sense. Each of the cores 1, 2, 3 and 4 is provided with a secondary winding 10, 11, 12, 13, each of the last mentioned windings possessing the same number of turns as any of the others of these secondary windings. The windings 10, 11, 12 and 13 are serially connected by means of conductors 14 and for convenience I shall hereinafter refer to the same as the A. C. secondary or boosting or bucking winding. Attention is directed to the fact that the windings 10 and 11 are wound or connected in the same sense and windings 12 and 13 in a sense opposite to that of said windings 10 and 11. It will be apparent that, by virtue of the relative connections of the windings thus far described, if an alternating E. M. F. is impressed on conductors 9, there will be no E. M. F. across conductors 14, the reason being that the E. M. F. induced in two of the secondary windings is equal to but opposite to that induced in the other two so that a state of balance exists. By impressing suitable additional magneto motive forces on the cores this state of balance may be destroyed and an alternating E. M. F. may be produced across the conductors 14. And the magnitude and phase relationship of this E. M. F. with respect to the alternating E. M. F. across conductors 9 may be governed by proper control of the added E. M. F.'s which produce the unbalance. Before proceeding to describe the means whereby this result may be attained I wish to describe what I term a D. C. permanent excitation which is preferably provided to increase the efficiency of the device.

Each of the cores 1, 2, 3 and 4 is provided with windings 15, 16, 17 and 18, each shown as having the same number of turns as any of the others. These windings are serially connected by means of conductors 19 adapted to be energized from any suitable D. C. source. The coils 15 and 18 are connected and wound in the same sense but opposite to that in which coils 16 and 17 are wound and connected so that even though an alternating E. M. F. is impressed across leads 9 and a direct current is passed through leads 19 and coils 15 to 18, there will be no E. M. F. across the conductors 14. Without intending to be bound by the theory advanced, the action of the system, as thus far specifically described, may be explained as follows.

Referring to magnetic flux above the X-axis of the magnetization curve as positive and that below as negative and assuming that the direction of current flow in the circuit 19 is such as to cause the winding 15 to produce or tend to produce a positive flux in the core, it will be seen that the winding 18 will produce or tend to produce a positive flux and the windings 16 and 17 negative fluxes in their respective cores. Particular attention is now directed to Fig. 2 in which the line O—O represents zero flux, values above this line—positive flux, and values below—negative flux. Distance along the X-axis represents time. The curve 21 represents the flux in the core 1 and it will be noted that this curve, instead of being symmetrical with reference to the line O—O, is displaced above the said line O—O due to the excitation produced by the winding 15. The flux curve 24 of the core 4 is of the same shape as the curve 21 but is displaced in phase therefrom due to the opposite relationship of winding 8 with respect to winding 5. The flux wave 22 of the core 2 is parallel to the curve 24 but displaced below the line O—O to the same extent that said curve 24 is displaced above said line O—O. The explanation of this opposite displacement of curves 22 and 24 is that the coils 16 and 18 are relatively reversed. For a similar reason the flux curve 23 of the core 3 is parallel to the curve 21 but displaced below the axis O—O by the same amount that said curve 21 is displaced above said axis. Bearing in mind that the flux in core 1 is at any and all times equal and opposite to that in core 2 and that secondary coils 10 and 11 are connected in the same sense it will be apparent that the E. M. F. induced in coil 10 will be equal but opposite to that induced in coil 11 so that these two E. M. F.'s will balance out. Similarly the E. M. F.'s induced in coils 12 and 13 will balance out so that the E. M. F. across leads 14 will be zero.

In order to effect an unbalance and to cause an alternating E. M. F. to result in circuit 14, i. e., in the secondary or boosting or bucking winding, means such as that illustrated in Fig. 1 may be employed, such means being constructed substantially as follows. The cores 1, 2, 3 and 4 are each provided with windings 25, 26, 27 and 28 respectively, serially connected in a circuit 29 so as to tend to produce fluxes in the same sense when current is passed through said circuit 29. Preferably the coils 25, 26, 27 and 28 all have the same number of turns. While either A. C. or D. C. may be employed in the circuit 29, I shall describe a system in which D. C. is employed in this circuit as the explanation of the operation is greatly facilitated. Suppose that the direction of direct current flow in the circuit 29 is such that the magnetizing effect of coils 15 and 25 is cumulative. The magnetizing effect of coils 16 and 26 is then differential; coils 17 and 27—differential and coils 18 and 28—cumulative. The effect of this variable excitation winding 25 to 28 is to shift all of the curves 21, 22, 23, and 24 upwardly (with respect to the line O—O of Fig. 2) to an extent depending on the magnitude of the current flowing in circuit 29. Such a condition is indicated in Fig. 3. Referring to the last mentioned figure it will be seen that the curve 22 is closer to the axis O—O than the curve 21. Similarly the curve 23 is closer to the said axis O—O than the curve 24. Or to state the result in another way the cores 1 and 2 (or 4 and 3) are not only being worked at opposite ranges with respect to the O point of the magnetization curve but at ranges displaced differently with respect to said zero point in a strictly numerical sense. In any event the induced E. M. F.'s in windings 10 and 11 no longer balance out but there is a resultant alternating E. M. F. Similarly, the induced E. M. F.'s in windings 12 and 13 no longer balance out but there is a resultant E. M. F. These two resultant E. M. F.'s are combined to produce an alternating E. M. F. in the circuit 14. While the curves 21 to 24 are shown in Fig. 3 as sine curves of equal amplitude each with respect to its own axis, it should be borne in mind that they are so shown merely for the sake of simplicity in illustration and explanation. The actual curves would be otherwise due to the fact that the cores 1 and 4 are being worked at points spaced a greater distance from the zero point of the magnetization curve than those at which the cores 2 and 3 are being worked.

At this point I wish to point out that one of the principal functions of the windings 15 to 18 is to cause the corresponding cores to be worked in a flux cycle displaced from the zero point of the magnetization curve thereby increasing the sensitivity and efficiency of operation of the system. While these coils might be omitted and the corresponding above mentioned function accomplished by the unbalance-creating windings 25 to 28 I prefer to utilize two independent sets of windings as greater efficiency and range of operation is thereby accomplished. The degree of displacement effected by coils 15 to 18 may be selected at will by proper adjustment of a current-varying means such as a variable resistance 30 connected in series with the circuit 19. The numerical value of the unbalance created by the windings 25 to 28 and consequently the magnitude of the resultant induced E. M. F. in circuit 14 may be selectively controlled by current varying means such as a variable resistance 31 in series with the circuit 29. Furthermore, as will hereinafter appear, the voltage at 14 may be caused to boost or buck the line voltage by throwing the pole-changing switch 32 to one or the other of its two closed positions.

In Fig. 1 I have shown one form of connections of the invention as applied to a single phase feeder circuit. The feeders 36 are connected to the A. C. supply bus 35 through an oil switch 37. The conductors 9, 9 are each connected to a corresponding one of the conductors 36 while the windings 10 to 13 are connected in series with one side of the feeder circuit. Current may be supplied to the circuits 19 and 29 by one or more suitable D. C. sources. From the foregoing description it will be appreciated that the voltage at 14 may be made boosting or bucking, with respect to the main voltage, by proper throw of the switch 32. Furthermore the magnitude of this boosting or bucking E. M. F. may be controlled by adjustment of the resistance 31. While these two factors may both be controlled automatically in response to the voltage at or adjacent the load end of the feeder I have, to avoid surplusage in description and illustration, shown only automatic means for controlling the magnitude of the boosting or bucking voltage in accordance with feeder voltage at the load end. One form of such means is shown in Fig. 1 and may be constructed substantially as follows.

The contact arm 38 of the current-controlling resistance 31 is connected to the cores 39, 39 of solenoids 40, 40 to be actuated thereby in opposite directions. Each of said solenoids is connected at one end to a corresponding one of the contacts 42, 42 of a contact-making voltmeter or relay 43. The other terminals of said solenoids 40 are connected to a suitable, preferably low voltage, A. C. or D. C. source whose other terminal is connected to the movable element 44 of the device 43. While the device 43 may be controlled by the voltage at the load end of the feeder by means of separate voltage leads running to that point substantially the same result may be obtained by the means illustrated in Fig. 1 which is preferable in some respects. An inductance 46 is connected in series with a resistance 47 and the secondary of a transformer 48 inductively coupled to the feeder by means of a current or series transformer 49. The adjustable contacts 50, 50 are connected, one to one terminal of the device 43 and the other to one terminal of the secondary of a potential transformer 51 whose primary is connected across the feeder circuit. The other terminals of the last mentioned secondary and device 43 are connected to each other. The connections are such that the difference of potential across slides 50—50, due to the flow of current through the inductance 46 and resistance 47, is opposed to the E. M. F. impressed on these slides by the transformer 51. And the design and connections are such that the difference of these two potentials, or in other words the voltage impressed upon the device 43, is at all times proportional to the voltage at the load end of the feeder circuit.

The operation of the system shown in Fig. 1 may be summarized as follows, assuming that the switch 32 is in such position that the voltage at 14 is a boosting voltage. If the voltage at the load end of the feeder circuit is higher than the predetermined value which it is desired to maintain the device 43 overcomes the pull of the spring, or other biasing means, 45, and causes energization of the proper one of solenoids 40, 40 to increase the effective resistance in the circuit 29 which causes a reduction in the current flowing in the last mentioned circuit. The resultant boosting voltage induced in the windings 10 to 13 is thereby decreased and the voltage at the load end of the feeder circuit is consequently decreased. On the other hand, if the voltage at the load end of the feeder circuit is too low the spring 45 overcomes the pull of the device 43 to cause resistance to be cut out of circuit 29 causing an increase in the boosting voltage and consequently a rise in voltage at the load end of the feeder. It will therefore be seen that my invention is admirably adapted to maintain, automatically, a substantially constant E. M. F. or voltage at the load end of a feeder system. Furthermore, by proper manipulation of the connections the invention may be employed to buck or crush as well as to boost so that a wide range of effective use is obtainable. Moreover by providing additional elements the invention may be applied to polyphase systems as well as single phase systems.

My invention is susceptible to modification in various respects. For example, the arrangement shown in Fig. 4 may be adapted, which in actual tests has been found to be efficient and effective. Calling attention to the last mentioned figure the elements 1, 2, 3, 4, 15 to 19 inclusive, and 25 to 29, inclusive, will at once be recognized, in view of the above description, and need not be described in detail. The windings 10 to 13, inclusive, are omitted in this form of the invention and the connections of the windings 5 to 8, inclusive, are modified. The windings 5 and 7 are connected in series with each other across the secondary of a transformer 55, the said windings 5 and 7 being reversed, one with respect to the other as shown. The windings 6 and 8 are also connected in series with each other across the secondary of the transformer, these windings also being reversed, one with respect to the other. One of a pair of conductors 14′ is connected to the conductor which connects windings 5 and 7 and the other of said conductors 14′ is connected to the conductor which connects the windings 6 and 8. The primary of the transformer 55 is connected to conductors 9′ which correspond to the conductors 9 in Fig. 1 and the conductors 14′, 19 and 29 in Fig. 4 correspond to the conductors 14, 19 and 29 in Fig. 1, the remainder of the elements of the system being omitted to avoid needless repetition.

The coils 5 to 8 connected as shown in Fig. 4 form a Wheatstone bridge as is shown more clearly in Fig. 5 which illustrates the connections of said coils more clearly. When an alternating E. M. F. is impressed across the conductors 9′, and a direct current caused to flow through the circuit 19 but no current is flowing in the circuit 29, the inductances of windings 5, 6, 7 and 8 are all equal so that there will be no difference of potential across the conductors 14′. In other words, a state of balance will exist. If, however, a current is caused to flow through the circuit 29 the inductance of the coils 5 and 8 will increase and that of coils 6 and 7 will decrease, or vice versa, depending on the direction of flow of the current in said circuit 29 with respect to the direction of current flow in the circuit 19. In either case the balance will be destroyed and there will be a difference of potential across the conductors 14 whose magnitude will depend upon the strength of current in the circuit 29 and which will be either boosting or bucking, with respect to the main line voltage, depending upon the above mentioned relative direction of current flow in said circuit 29. The operation of a complete system embodying the modification illustrated in Figs. 4 and 5 will be understood in view of the foregoing description in connection with Fig. 1.

The invention may also be employed to buck or crush the voltage on a feeder when a short circuit occurs on the latter, thereby reducing the KVA that the oil circuit-breaking switch is required to rupture. The size of the latter may thus be reduced, effecting a large saving. One form of system embodying this feature of the invention is illustrated in Fig. 6 in which the elements 35, 37, 9 (or 9′), 14 (or 14′), 36 and 29 will be recognized in view of the preceding disclosure. I have not illustrated the cores 1 to 4 and their windings in Fig. 6 as it will suffice to say that if the type shown in Fig. 1 is employed the windings 5 to 8 are connected to the conductors 9, the windings 10 to 13 to the conductors 14, and the windings 25 to 28 to the conductors 29, while, if the type shown in Fig. 4 is employed, the windings 5 to 8 are connected to the conductors 9′ and 14′, and the windings 25 to 28 to the conductors 29, and in either case the windings 15 to 18 (if employed) are connected as shown in Fig. 1. A solenoid 60 is connected across the secondary of a series or current transformer 61 coupled to one side of the feeder circuit. When normal current is flowing in the feeder circuit 36 the pull of the solenoid 60 is insufficient to overcome the opposing pull of the spring 164 on the core 62. However, on abnormal flow of current in the feeder circuit, as in a case of a short circuit, the solenoid 60 pulls the core 62 into a position in which the contacts 63, 63 are bridged thereby causing energization of the circuit 29 to cause a bucking voltage to be impressed at conductors 14 (or 14′). A low voltage relay 64 is shown coupled across the feeder circuit through a potential transformer 65. The pull of relay 64 upon its armature is sufficient to overcome the opposing pull of the spring 66 to hold the said armature disengaged from the back contact of the relay when the voltage across the feeder circuit is normal. However, when the voltage across the feeder circuit drops below a predetermined amount (as for example when the bucking voltage is impressed as above described) the relay 64 releases its armature which thereupon closes on its back contact and causes the energization of the tripping coil 67 of the oil switch 37.

Recapitulating, the operation of the system shown in Fig. 6 may be set forth as follows. When a short circuit occurs on the feeder circuit the solenoid 60 attracts its core and bridges the contacts 63. The circuit 29 is thereby energized to cause a bucking voltage to be impressed across conductors 14 (or 14′). The feeder voltage is thereby reduced and when it has dropped to a predetermined value (depending upon the capacity of oil switch 37 which it is desired to employ) the relay 64 releases its armature. The tripping coil 67 is then energized and the coil switch 37 opens automatically to break the feeder circuit.

In accordance with the provisions of the patent statutes, I have herein described the principle of operation of my invention, together with the apparatus which I now consider to represent the best embodiments thereof, but I desire to have it understood that the apparatus disclosed is only illustrative and that the invention can be carried out by other means. Also while it is designed to use the various features and elements in the combinations and relations described, some of these may be altered and others omitted and some of the features of each modification may be embodied in the others without interfering with the more general results and effects outlined, and the invention extends to such use.

What I claim is:

1. A voltage regulating system comprising an alternating current circuit, a transformer having a core, a primary winding connected across said circuit and a secondary winding connected in series with said circuit, a second core, a winding on said core connected in series with said primary winding, means for producing a unidirectional magnetomotive force in each of said cores, and means for producing another unidirectional magnetomotive force in each of said cores whereby the resultant unidirectional magnetomotive force is increased in one of said cores and is decreased in the other one of said cores.

2. A voltage regulating system comprising an alternating current circuit, a plurality of transformers, each transformer having a core, a primary winding exicted in response to the voltage of said circuit and a secondary winding connected in series with said circuit, means for producing two unidirectional magnetomotive forces in each core, and means responsive to the voltage of said circuit for controlling said unidirectional magnetomotive force producing means to vary inversely the saturation of said cores.

3. A voltage regulating system comprising an alternating current circuit, a plurality of transformers, each transformer having a core, a primary winding connected across said circuit and a secondary winding connected in series with said circuit, means for producing a unidirectional magnetomotive force in each of said cores, means for producing another unidirectional magnetomotive force in each of said cores whereby the resultant magnetomotive force is increased in certain of the cores and is decreased in the other of said cores, and means responsive to the voltage of said circuit for controlling one of said unidirectional magnetomotive force producing means.

4. A voltage regulating system comprising in combination a transmission line, an even number of static transformers; each of said transformers being provided with a core of magnetizable material, a primary winding, a secondary winding, and a third and fourth winding; means for coupling said primaries across said line; means for coupling said secondaries in series with said line; means for energizing said third windings to control the flux density in said cores; and means comprising said fourth windings for controlling the resultant of the E. M. F.'s induced in said secondaries.

5. A voltage regulating system comprising in combination, a transmission line, an even number of static transformers; each of said transformers being provided with a core of magnetizable material, a primary winding, a secondary winding, and a third and fourth winding; means for coupling said primaries across said line; means for coupling said secondaries in series with said line; means for energizing said third windings to control the flux density in said cores; and means governed by the line voltage and comprising said fourth windings for controlling the resultant of the E. M. F.'s induced in said secondaries.

In testimony whereof I hereto affix my signature.

MAURICE L. SINDEBAND.