Dec. 22, 1942. L. E. STILPHEN 2,306,000

VOLTAGE REGULATOR

Filed Aug. 15, 1941 2 Sheets-Sheet 1

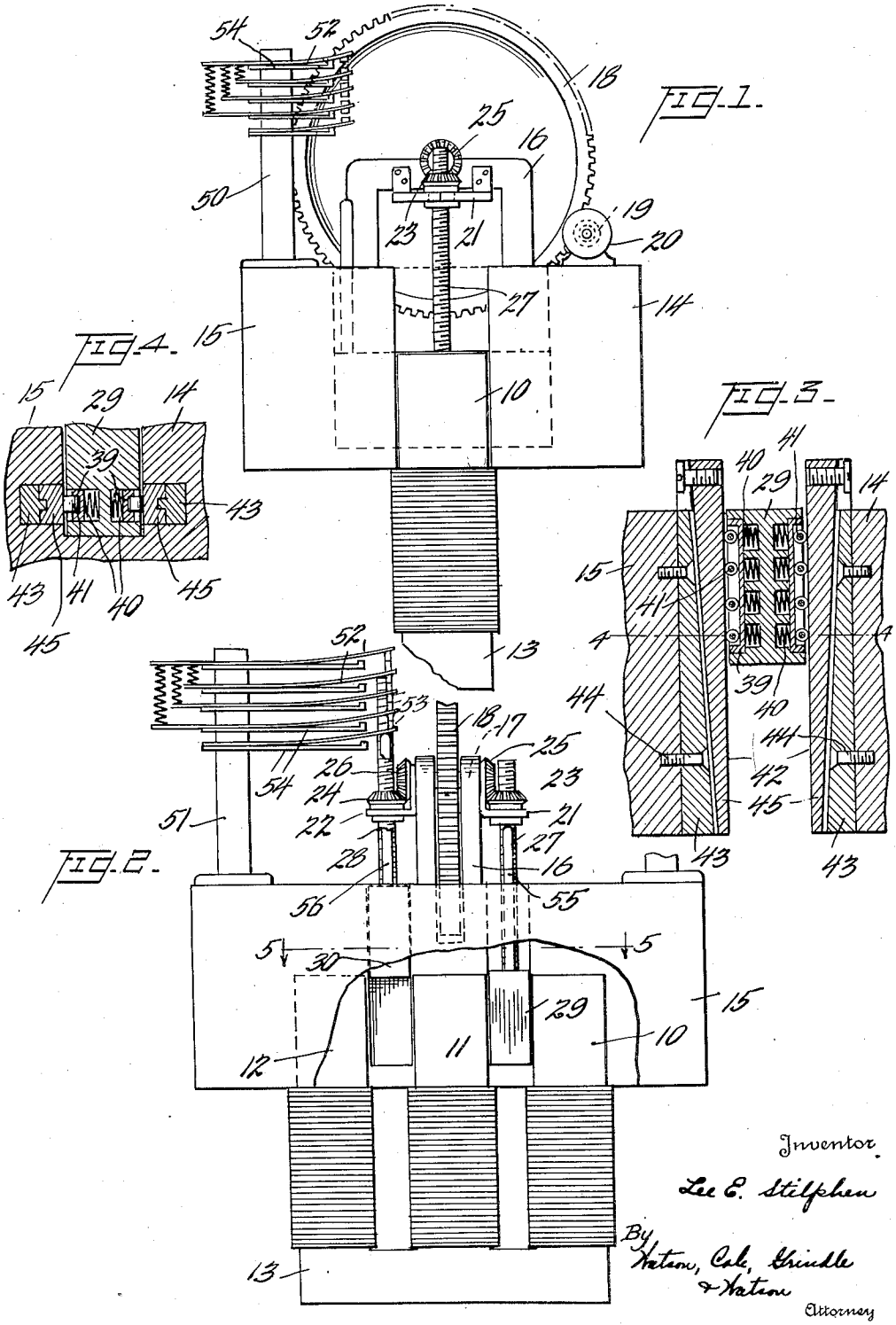

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FIG. 5.

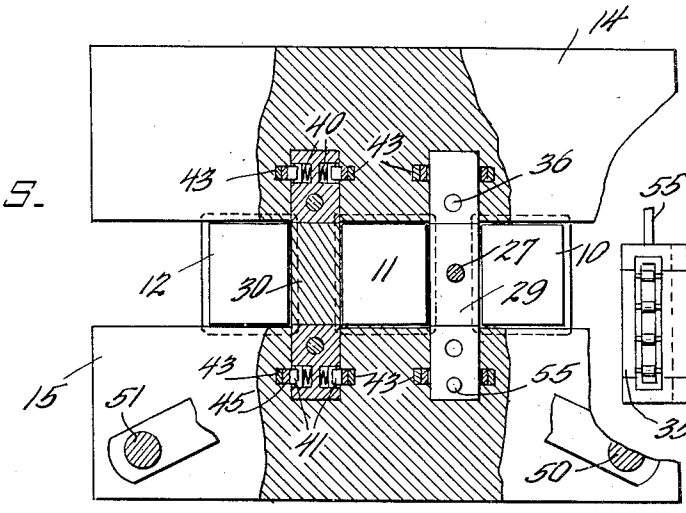


FIG. 6.

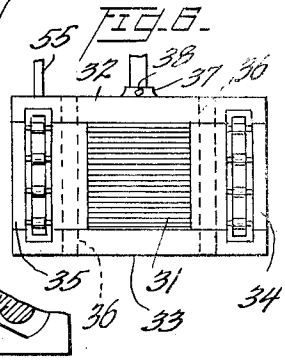
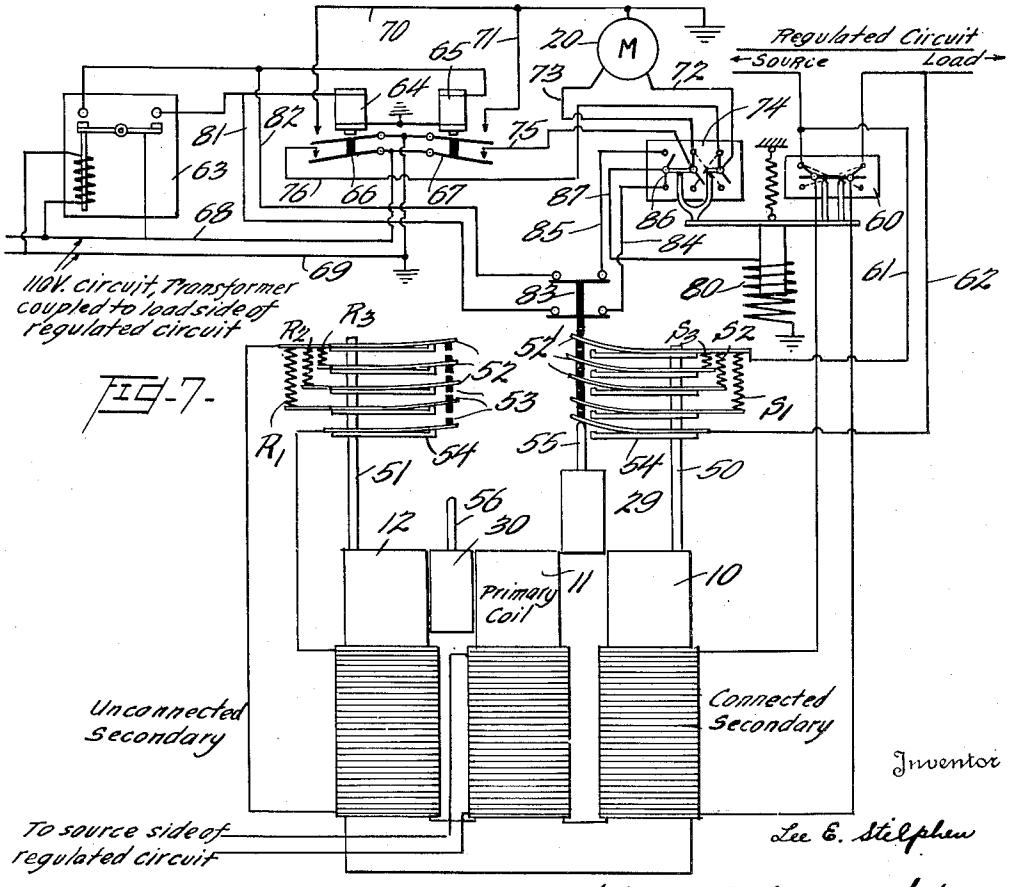


FIG. 7.



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UNITED STATES PATENT OFFICE

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VOLTAGE REGULATOR

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11 Claims. (Cl. 171—119)

This invention relates to voltage regulators for alternating current load circuits, and more particularly to a voltage regulator which may be referred to as of the "reluctance" type as distinguished from the common "induction" and "compensator" types of voltage regulators.

One object of the present invention is the provision of a reluctance type voltage regulator of simple but rugged construction, and which is especially economical to manufacture, because of its simple design and because no irregular core stampings are required. A further object is the provision of a voltage regulator of the type in question, of such design that the extent of regulation is as great as that of the induction type regulator, which has not been the case with previous regulators operating on the principle of varying the reductance of one or more magnetic circuits. Another object is the provision of a simple and efficient automatic control for the moving core-pieces of the regulator.

Previous voltage regulators of the reluctance type have sought to effect the regulation of load circuits by varying the reluctance of one or more magnetic circuits linked by the primary and secondary coils of a transformer, but such previous voltage regulators have been more or less unsatisfactory due to the designs adopted. In one such design, movable core-pieces are employed for shunting the magnetic circuit linked by one or the other of two opposing secondary coils. The degree of regulation thus obtained is relatively small, since, in such devices, a permanent iron path is provided for the flux in each magnetic circuit, and the amount by which the flux may be varied by shunting a portion of the circuit is relatively limited. As compared with this prior device, the voltage regulator of the present invention operates in such a way as to diminish the magnetic flux in one of the secondary circuits while increasing the flux in the opposing secondary circuit, thus insuring a much greater range of effect for a given size of device.

Other voltage regulators heretofore proposed have sought to vary the reluctance in two opposed secondary magnetic circuits by means of a single movable core-piece, pivoted so as to be movable toward the air gap of one magnetic circuit and away from the air gap of the other. This design is defective in that, even in its maximum position in one direction, the movable core-piece does not provide for substantial elimination of the air gap, for reducing the reluctance of the associated magnetic circuit to its lowest possible value. In the device of the present invention, two movable core-pieces are provided, and are supported for equal and opposite movements into and out of the respective air gaps of two magnetic circuits in such a way that in its position of maximum regulation, one of the core-pieces is disposed entirely within its associated air gap, substantially closing the same, while the other movable core-piece lies wholly without the air gap with which it is associated.

An important feature of the present invention resides in the fact that the two secondary coils are arranged in such a manner that only one of them is connected into the regulated circuit, the other being entirely independent thereof, whereby the resistance of the regulated circuit is reduced. The coil which is not connected in the regulated circuit is arranged to be short-circuited on itself when the regulator is in bucking or boosting position, thus providing a path of high reluctance for the magnetic flux in the associated magnetic circuit and forcing a large proportion of the flux through the magnetic circuit linking the connected coil, thus increasing the amount of regulation obtainable, and to be open when the device is in neutral condition, thus effecting an economy in the power input to the regulator, and also preventing the over-heating or burning out of the unconnected coil.

According to this arrangement, the secondary coil which is in the regulated circuit, which will be called the "connected coil," is arranged to be connected in either direction, so that the E. M. F. induced therein will either assist or oppose the E. M. F. of the regulated circuit, as conditions may require, and automatic means are provided for effecting the necessary switching operations. Similarly, automatic means are provided for moving the two movable core-pieces as circumstances may require, and for partially or entirely short-circuiting them in accordance with the mode of operation to be described.

A further feature of the present invention lies in the provision of novel bearing means by reason of which the movable core-pieces may be easily moved in and out of their respective magnetic circuits, while being positively restrained from lateral movements due to magnetic attraction.

Other and further objects, features and advantages of the present invention will be apparent to one skilled in the art from the following description taken in connection with the accompanying drawings in which:

Figure 1 is an elevational view of a voltage reg-

ulator constructed in accordance with the present invention;

Figure 2 is a second elevational view, at right angles to Figure 1;

Figure 3 is a vertical section illustrating the bearings for the movable core-pieces;

Figure 4 is a horizontal section on line 4—4 of Figure 3;

Figure 5 is a horizontal section on line 5—5 of Figure 2;

Figure 6 is an elevation of one of the movable core-pieces with its associated non-magnetic framework and anti-friction bearings; and

Figure 7 is a diagrammatic view of the device and its associated electrical circuits.

In order to facilitate an understanding of the invention, reference is made to the embodiments thereof shown in the accompanying drawings and detailed descriptive language is employed. It will nevertheless be understood that no limitation of the invention is thereby intended and that various changes and alterations are contemplated such as would ordinarily occur to one skilled in the art to which the invention relates.

Referring to Figures 1 and 2, the magnetic core of the voltage regulator comprises three vertically extending branches 10, 11 and 12, magnetically connected at their lower ends through a common magnetic member 13. The members 10, 11, 12 and 13 may be made up of a plurality of relatively thin laminations, in the usual manner, and the vertical branches 10, 11 and 12 may be secured to the horizontal member 13 in any suitable manner. The upper ends of the branches 10, 11 and 12 are secured in spaced relation by means of a non-magnetic structure comprising blocks 14 and 15 rigidly fastened together by bolts or other suitable means, the blocks 14 and 15 also serving to support bearings for the moving core-pieces to be described. Surmounting and extending between the blocks 14 and 15 is a yoke 16, on which is journalled a shaft 17 carrying a large spur gear 18, which meshes with a pinion 19 secured on the shaft of a small motor 20. The yoke 16 carries brackets 21 and 22, disposed on opposite sides thereof, which support and guide bevel gears 23 and 24 (Figure 2), which engage the bevel gears 25 and 26, respectively, secured on the shaft 17.

The gears 23 and 24 are internally threaded, to engage the threaded plungers 27 and 28, each of which supports, at its lower end, a movable iron core-piece 29, 30 respectively, for movement into and out of the gaps provided between the members 10, 11 and 12 of the magnetic circuit. The core-pieces 29 and 30, as shown in Figure 6, comprise a pile of iron laminations 31 held in a non-magnetic frame comprising horizontal members 32, 33 and vertical members 34, 35, held together by bolts 36. The upper horizontal member 32 is provided with a recessed boss 37 to receive the lower end of its associated rod 27 or 28, as the case may be, to which it is secured by a screw 38.

The special bearings provided for the moving core-pieces comprise trough-shaped members 39 set into each lateral face of the non-magnetic frame adjacent each end thereof, the members 39 being urged outwardly by springs 40. Each trough member 39 carries a plurality of rollers 41, retained therein in any suitable manner, at spaced intervals. The non-magnetic blocks 14 and 15 of the stationary structure, which are suitably recessed to receive the frames of the movable core-pieces, are provided with facings 42 (Figure 3) providing bearing surfaces for engagement with the rollers 41, each such facing comprising a wedge-shaped fixed member 43, secured within a slot, formed in the block, by means of screw 44, and an adjustable wedge-shaped member 45 which may be adjusted vertically to vary the distance between opposed facings. The screws 46, which extend through slots in the upper ends of members 43 and into threaded engagement with members 45, serve to secure the members 45 in adjusted position. By this means the movable core-pieces may be accurately aligned in their respective gaps, and maintained in position despite the powerful magnetic attraction acting laterally, while at the same time they may be moved vertically with a minimum of friction.

Referring now to Figures 2 and 6 it will be seen that the fixed, non-magnetic structure carries, adjacent each movable core-piece, an insulated post 50, 51 each of which supports a plurality of spring contact arms 52, each carrying appropriate contact points 53. The posts 50, 51 also carry rigid supporting members or stop arms 54, one for each spring contact arm 52, to limit downward movement thereof. Secured to the upper surface of the non-magnetic frame of each moving core-piece is a plunger 55, 56, which is disposed so that as the core-piece starts to rise, the plunger 55 or 56, as the case may be, will engage the lowermost contact arm 52 of the associated series, and raise it into contact with the next one, this process being repeated as the core-piece rises until, as shown in Figure 2, all of the contact arms are in engagement when the core-piece reaches its uppermost position.

Referring now to Figure 7, it will be seen that the central leg 11 of the magnetic circuit is surrounded by a primary coil, connected into the circuit to be regulated on that side next the source. The leg 10 is provided with a secondary coil which is connected into the regulated circuit through a reversing switch 60, as seen at the upper right. Thus, the E. M. F. induced in the connected secondary may either assist or oppose the primary E. M. F., depending on the condition of the switch 60, which in turn will depend on the needs of the load circuit.

Surrounding the third leg 12 of the magnetic circuit is a secondary coil which is not connected at any time to the regulated circuit, and which is normally opened at the spring contact arms 52, as seen in Figure 7. However, when the core-piece 30 rises, in the movement of the apparatus to bucking or boosting position, the plunger 56 will cause the associated contact arms 52 successively to engage, closing the unconnected secondary first through a relatively large resistance R_1, then placing a smaller resistance R_2 in shunt with R_1, and lastly placing a low resistance R_3 in shunt with the others, thus gradually short-circuiting the unconnected secondary on itself.

In a similar manner, the plunger 55, when the core-piece 29 rises, successively actuates the contact arms with which it is associated, connecting the conductors 61, 62 through successively smaller resistances S_1, S_2 and S_3 and thus gradually shunting out the connected secondary coil as the core-piece 29 reaches its uppermost or "neutral" position. At this time, of course, the opposite core-piece 30, which moves counter to the core-piece 29, will be in its lowest position and the unconnected coil will be in open circuit.

The control circuit for the regulator comprises

a contact-making voltmeter 63 controlling a pair of relays 64, 65 which operate switches 66, 67 in the feed circuit to the motor 20. The motor is fed from any suitable source, but for the sake of simplicity it is shown, in the present case, as connected to the 110 v. circuit 68, 69 through the switch (alternatively) 66 or 67, conductor 70 or 71, conductor 72 or 73, reversing switch 74, and conductor 75 or 76. The voltmeter 63, which is the ultimate control element, must of course respond to conditions on the regulated load circuit, and thus the circuit 68, 69, across which the voltmeter is connected, must derive from the load circuit, being connected thereto through a step-down transformer if the load circuit is at a high potential. It will be understood without further explanation that the voltmeter 63 will respond to variations in the potential of the load circuit to energize one or the other of the relays 64, 65, according to the direction of variation of the load circuit potential from normal, and that the motor will thus be connected across its feed circuit in one direction or the other, to correspond to the needs of the load circuit.

The voltmeter 63 also controls a switch-operating relay 80, through conductor 81 or 82 (alternatively), switch 83, conductor 84 or 85, switch 86, and conductor 87. Thus, when the core-piece 29 reaches uppermost position, closing switch 83, the relay 80 is actuated, operating reversing switches 60 and 74, and switch 86. This causes the reversal of the motor 20, which will thus move the core-piece 29 downwardly again, and also the reversal of the connected secondary coil.

The operation of the voltage regulator is as follows: Assuming the line voltage to be normal, and the device in neutral position, additional load is connected, as a result of which the line voltage falls. The voltmeter 63 will close the motor circuit at switch 67 and, if the switches 60 and 74 are not in proper condition, will also actuate the relay 80 to reverse them. If switches 60 and 74 are in proper condition (i. e., in "boost" position) the relay circuit will be open at the switch 86, and relay 80 will not be actuated.

Thus, with the connected secondary in the line in the proper direction, the motor will operate to lower the core-piece 29 until the line voltage is raised sufficiently to open the control circuit at the voltmeter. During this operation the core-piece 30 rises, and the associated coil gradually short-circuits, thus retarding the flow of flux through the leg 12 and increasing the flow through the leg 10, linking the connected secondary.

Now, assuming load is removed and the line voltage rises, the motor circuit will be closed in the reverse direction by the voltmeter, and the core-piece 29 will rise, lessening the voltage induced in the connected secondary. If the line voltage has risen sufficiently, the core-piece 29 will reach its uppermost position, when the relay 80 will be actuated, reversing the motor and the connected secondary, and the device will move into "buck" position. Since the relay 80 can only operate when its circuit is closed both at the voltmeter and at the switch 86, the switches 60 and 74 will always be in proper condition to supply the needs of the load circuit.

From the foregoing description it will be understood that the switch 60 can only operate at times when the connected secondary is shunted by conductors 61, 62 and the spring contact arms 52', hence the regulated circuit is maintained at all times, and there is substantially no load on the switch 60 when it operates. Since only one of the secondary coils is ever in the regulated circuit, and since it is shunted when the device is in neutral condition, the resistance of the circuit is not increased as in the case of devices in which opposed secondary coils are connected in circuit at all times. When the device is in neutral condition, a low reluctance magnetic circuit is provided through the core-piece 30 and leg 12, since the unconnected secondary coil is open at the contacts 53, while when the device is bucking or boosting, the core-piece 30 is raised and the unconnected coil is short-circuited, forcing a major portion of the flux through the core-piece 29 and leg 10, linking the connected coil. For these reasons it will be seen that the present invention provides a voltage regulator of high efficiency and possessing many advantages over those previously known.

Having thus described the invention, what is claimed as new and desired to be secured by Letters Patent is:

1. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, a secondary coil linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctance thereof, reversible switch means for connecting said secondary coil in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil.

2. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, a secondary coil linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctance thereof, reversible switch means for connecting said secondary coil in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means for shunting said last-mentioned coil during said switching operation, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil.

3. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, a secondary coil linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctance thereof, reversible switch means for connecting said secondary coil in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means under control of its associated movable core-piece for shunting said last-mentioned coil during said switching operation, and means responsive to variations in the voltage of said regulated circuit for initiating action of

said motor means and for controlling the direction of connection of said series coil.

4. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, secondary coils each linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctances thereof, reversible switch means for connecting one of said secondary coils in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means for shunting said last-mentioned coil during said switching operation, said movable core-piece associated with said series coil being substantially removed from its magnetic circuit and said other movable core-piece being substantially wholly within its magnetic circuit during said switching operation, means for opening the electric circuit through said other secondary coil when its associated core-piece is wholly within its magnetic circuit and for closing said electric circuit as said core-piece moves out of its magnetic circuit, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil.

5. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, secondary coils each linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctances thereof, reversible switch means for connecting one of said secondary coils in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means for shunting said last-mentioned coil during said switching operation, said movable core-piece associated with said series coil being substantially removed from its magnetic circuit and said other movable core-piece being substantially wholly within its magnetic circuit during said switching operation, means associated with said second movable core-piece for opening the electric circuit through its associated secondary coil when said core-piece is wholly within its magnetic circuit and for closing said electric circuit as said core-piece moves out of its magnetic circuit, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil.

6. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, secondary coils each linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctances thereof, reversible switch means for connecting one of said secondary coils in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means under control of its associated movable core-piece for shunting said last-mentioned coil during said switching operation, said movable core-piece associated with said series coil being substantially removed from its magnetic circuit and said other movable core-piece being substantially wholly within its magnetic circuit during said switching operation, means associated with said second movable core-piece for opening the electric circuit through its associated secondary coil when said core-piece is wholly within its magnetic circuit and for closing said electric circuit as said core-piece moves out of its magnetic circuit, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil.

7. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, secondary coils each linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctances thereof, reversible switch means for connecting one of said secondary coils in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means for shunting said last-mentioned coil during said switching operation, said movable core-piece associated with said series coil being substantially removed from its magnetic circuit and said other movable core-piece being substantially wholly within its magnetic circuit during said switching operation, means associated with said second movable core-piece for opening the electric circuit through its associated secondary coil when said core-piece is wholly within its magnetic circuit and for closing said electric circuit as said core-piece moves out of its magnetic circuit, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil, said last means comprising contact-making means adapted to close the circuit to said motor in either direction, as required.

8. In a voltage regulator for alternating current circuits, in combination, a core affording a pair of magnetic circuits, a primary coil linking both said circuits and connected across the circuit to be regulated, secondary coils each linking one of said magnetic circuits, a pair of movable core-pieces, reversible motor means for moving said core-pieces into and out of said respective magnetic circuits to vary the reluctances thereof, reversible switch means for connecting one of said secondary coils in series with said circuit to be regulated alternatively in bucking or boosting relation thereto, means for shunting said last-mentioned coil during said switch operation, said movable core-piece associated with said series coil being substantially removed from its magnetic circuit and said other movable core-piece being substantially wholly within its magnetic circuit during said switching operation, means associated with said second movable core-piece for opening the electric circuit through its associated secondary coil when said core-piece is wholly within its magnetic circuit and for closing said electric circuit as said core-piece moves out of its magnetic circuit, and means responsive to variations in the voltage of said regulated circuit for initiating action of said motor means and for controlling the direction of connection of said series coil. said last means comprising con-

tact-making means adapted to close the circuit to said motor in either direction, as required, and also to energize the circuit controlling said reversible switch means.

9. In a control circuit for voltage regulators as defined in claim 1, a reversing switch for said motor, a relay circuit for actuating said switch and also said reversing switch for said series coil, and switch means actuated by the movable core-piece associated with said series coil for controlling said relay circuit whereby the latter can be closed only when said core-piece is in its position of greatest reluctance.

10. In a control circuit for voltage regulators as defined in claim 1, a reversing switch for said motor, a relay circuit for actuating said switch and also said reversing switch for said series coil, switch means actuated by the movable core-piece associated with said series coil for controlling said relay circuit whereby the latter can be closed only when said core-piece is in its position of greatest reluctance, and means actuated by said core-piece for shunting said series coil when said core-piece is in its position of greatest reluctance.

11. In a control circuit for voltage regulators as defined in claim 1, a reversing switch for said motor, a relay circuit for actuating said switch and also said reversing switch for said series coil, switch means actuated by the movable core-piece associated with said series coil for controlling said relay circuit whereby the latter can be closed only when said core-piece is in its position of greatest reluctance, and switch means in said relay circuit and associated with said motor reversing switch for controlling said relay circuit so that the latter may not be closed when the motor reversing switch is in the proper position as indicated by the needs of the regulated circuit.

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