May 8, 1951 J. A. GULOW 2,551,943

VARIABLE TAP TRANSFORMER SYSTEM

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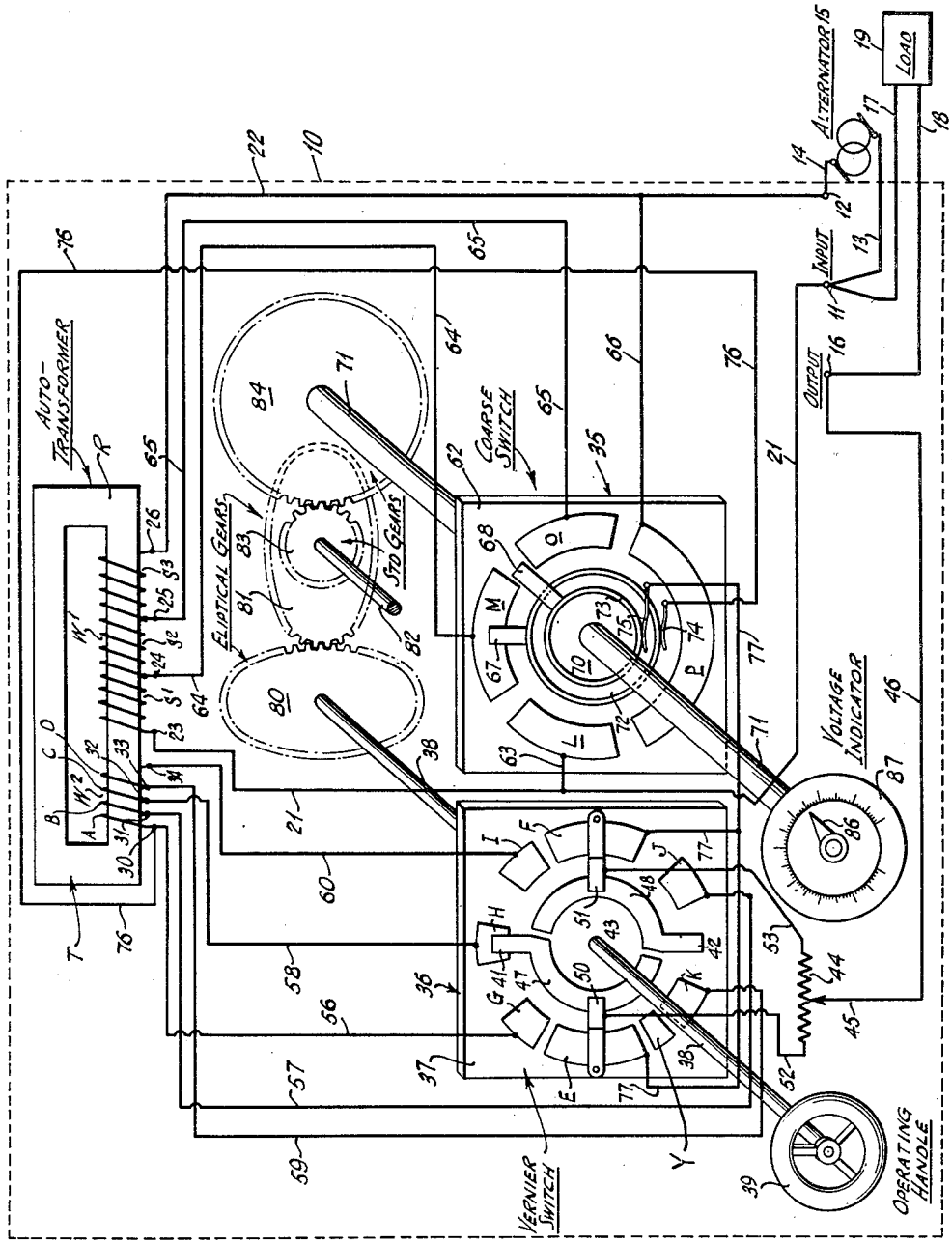


Fig. 1.

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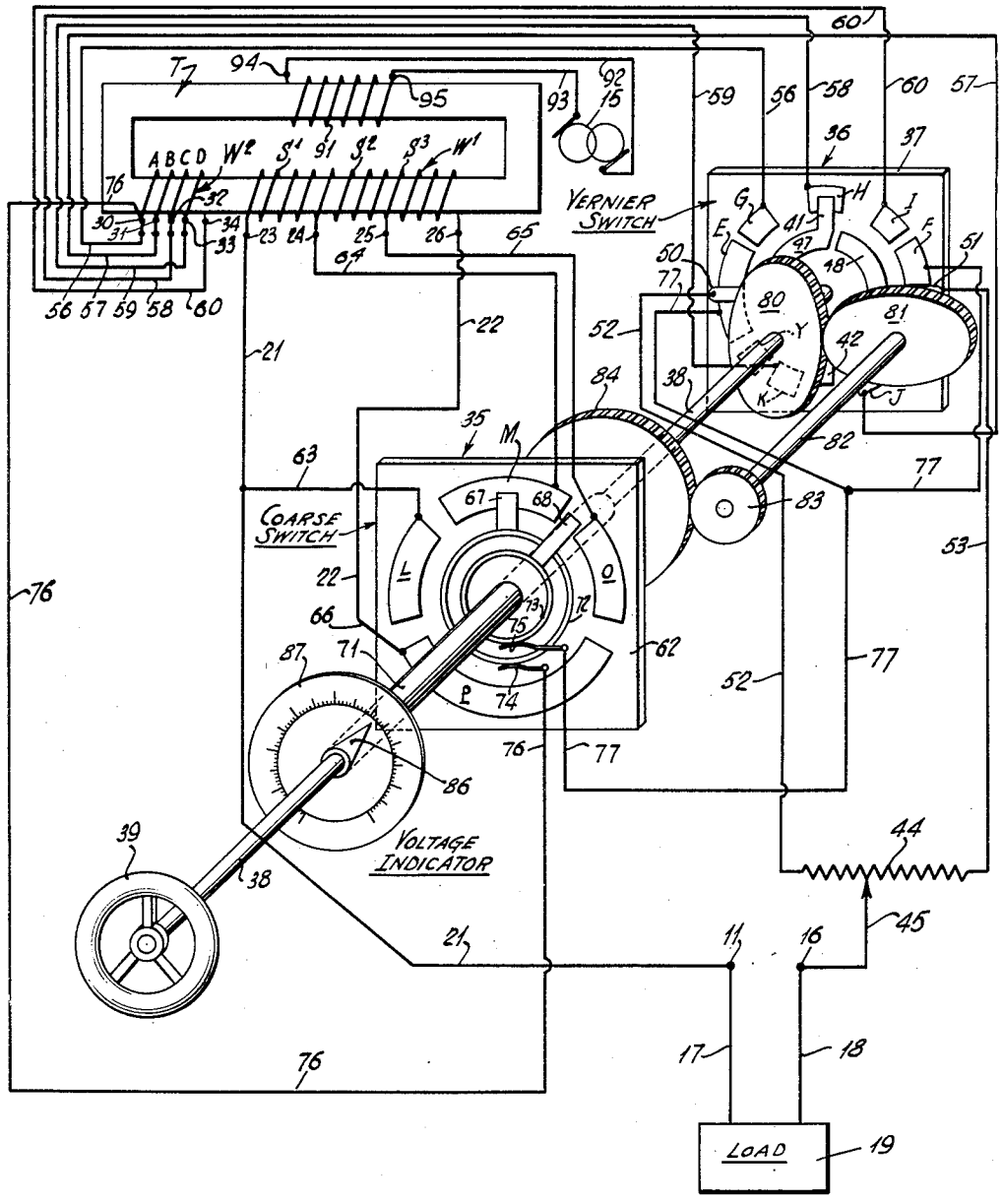


Fig. 2.

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VARIABLE TAP TRANSFORMER SYSTEM

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Application April 19, 1945, Serial No. 589,167

4 Claims. (Cl. 323—43.5)

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This invention relates to an apparatus for providing at will a variable voltage, such as may be required for laboratory, test and other purposes, and, more particularly, this invention relates to an apparatus capable of providing a wide range of change of alternating potential.

One of the objects of this invention is to provide a compact, efficient, and practical apparatus for selectively providing, in suitable increments, a wide range of change of voltage. Another object is to provide an apparatus of the just-mentioned character particularly adapted to furnish alternating potential, of suitable frequency, and selectively variable in suitable increments or steps. Another object is to provide a suitably variable potential from a source of substantially fixed potential by way of switching means coacting with the source or sources of relatively fixed potential so that commutation is facilitated, relatively movable circuit controlling parts or cantacts are protected against detrimental sparking or loading, greater compactness, and less bulk in the conductive parts of the switching means is possible, and other advantages are achieved.

More particularly, another object is to provide a coacting transformer and switching system whereby greater compactness and lesser bulk may be achieved, both as to the transformer means and the switching means employed, to provide the desired range of variability of alternating potential. Another object is to so interrelate, in such a system, the transformer means and the switching means as to permit the employment of a simpler, smaller, and more compact transformer structure, thus also diminishing iron losses and improving efficiency, while at the same time achieving improved commutation by the switching means and in a manner to permit the employment, in the switching means, of metallic conductive switching parts that are of small mass within the range of normal load current at the selected voltage.

Another object is to provide a practical and compact multiple switching means for successively adding small increments of potential from the selected source and then successively adding such small increments to successively added large increments from the selected source, with the multiple switching means mechanically coupled for suitable commutation of one from the other and so coacting with each other and with the source or sources of potential that destructive commutation or sparking at the switching

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means does not take place and unintentional or abnormal loading of conductive parts of the switching means is avoided. Another object is to carry out this last-mentioned object by achieving inherently variable rate of drive of one switching means from another and in relation to the available increments of the source or sources of potential so as, in turn, to permit the employment of shorter lengths of conductive parts in the switching means themselves.

Other objects are, in general, to provide an improved apparatus capable of converting a relatively fixed potential into a selectively variable potential, and to provide such an apparatus that will be practical and simple to manufacture, easy to manipulate, and efficient and long-lasting in action. Other objects will be in part obvious or in part pointed out hereinafter.

The invention, accordingly, consists in the features of construction, combination of elements, and arrangements of parts all as will be exemplified in the structure to be hereinafter described, and the scope of the application of which will be indicated in the following claims.

In the accompanying drawings, in which are shown, by way of illustration, several possible embodiments of this invention:

Fig. 1 is a schematic and diagrammatic representation of a transformer and switching arrangement for achieving a selectively variable potential from a source of relatively fixed potential, and

Fig. 2 is a diagrammatic and schematic representation of a modified form of system and apparatus to illustrate how my invention may be employed where electrical isolation of the system and apparatus from the initial source of potential is desired, and to illustrate also how the multiple switching means may be arranged for greater compactness than in the arrangement of Fig. 1.

Similar reference characters refer to similar parts throughout the several views of the drawings.

Referring, first, to Fig. 1, the apparatus may be embodied or mounted to form a single compact unit, indicated generally by the reference character 10, which may represent a suitable base, or mounting, or casing on or within which the various parts are mounted in any suitable way, and in that embodiment let it be assumed that a variable potential is to be obtained from any suitable extraneous source of relatively fixed potential, such as an existing power circuit or a generator. I, therefore, prefer to provide a pair

of terminals 11 and 12 to which connection may be made in any suitable way, as by conductors 13 and 14, to such a source of relatively fixed potential, which is diagrammatically indicated at 15, and I provide also two terminals by which connection may be made to lead or supply the variable potential to whatever load or device it is to energize, and, conveniently, I use one of the terminals 11, 12 and a terminal 16 for this latter purpose. Accordingly, conductors 17 and 18 may be connected to the terminals 11 and 16 to supply the load 19 with the selectively variable, alternating potential.

Included in the apparatus is a transformer, generally indicated by the reference character T, having preferably a shell type of core R and windings W^1 and W^2, of which winding W^1 is constructed to function at the voltage applied to the terminals 11, 12 by the source 15—illustratively 110 volts—and, by conductors 21 and 22, its terminals 23 and 26 are connected to apparatus terminals 11, 12. Winding W^1 is subdivided into a suitable number of equal sections, illustratively three, by suitable taps that are connected to terminals 24 and 25. When energized, winding W^1 can function as the primary winding, with respect to which W^2 is the secondary winding, and the latter is preferably constructed to have induced in it a voltage equal to the voltage of any one of the equal sections S^1, S^2, and S^3 of the winding W^1. Thus the total number of turns of winding W^2 is equal to the number of turns in each of the equal sections of winding W^1.

Secondary winding W^2 is, in turn, subdivided into the desired number of preferably equal sections or increments—illustratively four sections A, B, C, and D—by suitable taps or terminals 30, 31, 32, 33, and 34.

The taps or terminals 23 to 26 of winding W^1 are connected to contact segments of a rotary switch structure, generally indicated by the reference character 35, and the terminals or taps 30 to 34 are connected to contact segments of another rotary switch structure, generally indicated by the reference character 36, the two switches being suitably coupled together for timed actuation of one by the other, preferably in the manner later described. These switches are so arranged and are made to coact with one another in such a way that there may be made available, at the output terminals 16—11, a voltage that is variable throughout a range from a fraction of the voltage of a section of winding W^2 up to the voltage of the winding W^2, plus the voltage of as many sections of the winding W^1 as may be desired.

Switch 36 preferably comprises a suitable number of contact members, being in number equal to the number of taps from winding W^2, plus two, and they are preferably metallic—illustratively in the form of flat arcuate plates arranged in a circle, being suitably mounted upon a suitable insulating plate or base, indicated at 37; they may be proportioned and spaced from each other substantially as indicated in the drawing, for a four-sectioned winding W^2, and they comprise contacts E and F which are positioned in diametric opposition and are of relatively substantial arcuate extent, leaving substantially equal upper and lower arcuate spaces between their respective ends; in the upper arcuate spaces are positioned three contact plates G, H, and I, and in the lower arcuate spaces are positioned two contact plates J and K. Relative arcuate lengths and spacings are substantially as shown in the drawing.

Through the mounting plate 37 extends a shaft 38, rotatably supported in any suitable bearings (not shown), the shaft being provided at its forward end with suitable means, such as a hand wheel 39, by which its rotational movements may be controlled. Shaft 38, in turn, actuates two diametrically opposed brushes 41 and 42 which are adapted to engage the above-mentioned contact plates E to K, and they may be mounted in any suitable manner to be driven by the shaft 38. Thus there may be provided a hub 43 of insulating material, suitably secured to the shaft 38 and carrying the brushes 41 and 42. The brushes 41 and 42 are connected to the respective ends of a suitable voltage divider, which conveniently takes the form of a resistance 44 and which is provided with a tap 45, usually positioned at the midpoint of the resistance 44 but preferably shiftable or adjustable along its length for purposes later described, the tap 45 being in turn connected, by conductor 46, to the output terminal 16. In order to maintain this connection of the brushes 41 and 42 to the resistance 44 for the various rotary positions that the brushes may assume, the brushes 41 and 42 are connected electrically to, or formed integrally with, arcuate contacts 47 and 48, respectively, each being of an effective arcuate extent of substantially 180 degrees and being conveniently secured to the hub 43, thus also forming the mounting onto the hub 43 of the brushes 41 and 42 themselves. As indicated in the drawing, the contact segments 47 and 48 are electrically insulated from each other and, with their faces lying in the same plane, and electrical contact with them during their rotary movements may be effected by brushes 50 and 51, to which the resistance 44 is connected by conductors 52 and 53. Brushes 50 and 51 are conveniently carried insulatingly by the main mounting plate 37, to which they are secured in any suitable manner, on their respective outer ends, it being noted that they are constructed to be of sufficient length to bridge over the fixed contact plates E and F from which they are spaced, being suitably bent for that purpose, so as to permit the brushes 41 and 42 to ride in under them without contacting them.

The end terminal 30 of winding W^2 is connected to contact plate G by conductor 56; tap 31 is connected to contact J by a conductor 57, tap 32 is connected to contact H by conductor 58, tap 33 is connected by conductor 59 to contact K, and the end tap 34 is connected by conductor 60 to contact I.

The above-described arrangement of plate contacts for switch 36 is suitable where winding W^2 comprises four sections, and is illustrative; where more sections, and hence more taps, are provided for winding W^2, the number of plate contacts is increased according to the just-described illustrative arrangement.

As for switch 35, that is, in general, constructed and arranged successively to add sections S^1, S^2, etc., of the winding W^1 to the winding W^2, or such fractions of it or its voltage as are made effective by the switch 36; switch 36 might thus be termed a "fine" or vernier switch, and switch 35 might be termed the "coarse" switch. Switch 35 comprises a suitable support, such as a plate 62 of insulating material, having mounted thereon arcuate contact plates, four in number where the winding W^1 has three sections and, hence, has four taps; these contact plates com-

prise plates L, M, and O respectively connected by conductors 63—21, 64, and 65 to the taps 23, 24, and 25, and a contact plate P which is connected by conductor 66 to conductor 22, and hence to tap 26 of winding W^1. These plates, in relative arcuate extent or length may be substantially as indicated in the drawing.

Two contact brushes 67 and 68 are supported in any suitable way, as by a hub 70 of insulating material, on a shaft 71 which extends through the supporting plate 62 and which is provided with suitable bearings (not shown) for rotatably supporting it in parallelism with the shaft 38 of the vernier switch 36 and laterally displaced therefrom, as to the right, as shown in Fig. 1. The brushes 67, 68 are angularly displaced substantially as indicated, are insulated from each other in any suitable manner—as by the structure of the insulating hub 70—and they are in electrical connection, respectively, with slip rings 72 and 73 coaxially carried by the hub 70, and by the latter insulated from each other. Brushes 74 and 75, supported in any suitable way on or by the insulating support 62, bear against the slip rings 72 and 73, respectively, so that electrical connection with the brushes 67 and 68 may be maintained, regardless of what position the latter assume and also during rotary movement thereof.

Brush 74 is connected by conductor 76 to tap 30 of winding W^2, and brush 75 is connected by conductor 77 to contact plates E and F of switch 36.

Suitable means are provided to coordinate the rotary motion of the shaft of one of the switches to the shaft of the other switch, and this is preferably achieved so as to provide the desired ratio of drive between the two shafts and preferably, also, to achieve periodic variations in that ratio of drive. In Fig. 1 an illustrative driving connection between the two shafts 38 and 71 is shown, and it may comprise two elliptical gears 80 and 81, with a gear ratio of 1 to 1, one of the gears being mounted on the shaft 38 and the other upon an intermediate idler shaft 82; gear 81 drives a spur gear 83, conveniently coaxially mounted with it on idler shaft 82, and, meshing with the spur gear 83, is a gear 84 secured to the shaft 71 of the other switch. On the forward end of shaft 38 is mounted, as above described, the hand wheel 39 for manually controlling the interconnected switches, and on shaft 71 may be mounted a pointer or indicator 86 to be rotated by the shaft 71 relative to a suitably graduated dial 87 so as to indicate visually and directly the voltage which the apparatus makes available across the output terminals 11—16 within the range of the apparatus.

In the starting or initial position of the parts, corresponding to which the indicator 86 and dial 87 would show minimum possible or zero voltage, brush 41 rests on contact G and brush 42 is between contacts F and J; brushes 67 and 68 are both in engagement with plate contact L. No voltage is, therefore, applied across the output terminals 11—16.

The first increment of clockwise rotation of shaft 38, however, brings brush 42 into engagement with contact J, while brush 41 maintains contact with contact G, due to the relative positions and arcuate lengths of these parts; and brushes 67 and 68 remain in contact with contact L. With brushes 41 and 42 on contacts G and J, respectively, section A of secondary winding W^2 is impressed across the resistance 44, and any fraction of its voltage, depending upon the position of tap 45, may thus be impressed across the output terminals 16 and 11. The corresponding circuit arrangement is from tap 30, conductor 56, contact G, brush 41, contact 47, brush 50, conductor 52, resistance 44, conductor 53, brush 51, contact 48, brush 42, contact J, conductor 57, to the other tap or terminal 31 of section A of winding W^2. A conductor 76, as above described, leads from the first tap 30 of winding W^2 to brush 74, which, through slip ring 72, brush 67, contact L, conductor 63, and conductor 21, impresses the potential of tap 30 on output terminal 11; by means of the voltage divider 44—45, any desired fraction of the voltage of section A of winding W^2 may be impressed upon the other output terminal 16, so that there is applied to the load 19 a voltage variable from zero to the voltage of section A, according to the position of the tap 45 relative to the resistance 44. For each stage or succeeding stage, a corresponding splitting or variation of added voltage may be achieved, but, for convenience in the ensuing description, it will be assumed that the tap 45 is in midposition relative to the resistance 44, though it will be understood that the above-described variation may be, nevertheless, achieved at each such succeeding step.

If, for example, the voltage of section A is one volt, the last above-described setting of the parts impresses a voltage of 0.5 volts across the terminals 16 and 11.

The next increment of rotary movement leaves brushes 67, 68 still on contact L, for they still partake of very small angular movement; while brush 41 assumes a position between contacts G and H, and brush 42 engages contact J. Tap 30 remains connected to terminal 11 through the engagement of brush 67 with contact L of coarse switch 35, while output terminal 16 is now connected to tap 31 through a circuit that runs from terminal 16, conductor 46, tap 45, the right-hand portion of resistance 44, conductor 53, brush 51, contact 48, brush 42, contact J, conductor 57, to tap 31, and thus the full voltage of section A is applied to the output terminals, through the right-hand portion of resistance 44.

The next increment of rotary motion brings brush 41 to engage contact H, brush 42 remaining in engagement with contact J, brushes 67 and 68 of the coarse switch being still in engagement with contact L. This rearrangement, achieved by switch 36, places section B of winding W^2 across the resistance 44, thus adding half its voltage (tap 45 assumed to be at the mid-point) to terminal 16, terminal 11 being maintained by coarse switch 35 connected to tap 30.

The connection of section B just described extends from tap 31, conductor 57, contact J, brush 42, contact 48, brush 51, conductor 53, resistance 44, conductor 52, brush 50, contact 47, brush 41, contact H, conductor 58, to tap 32.

The next increment of rotary motion maintains brush 41 in engagement with contact H and moves brush 42 into the space between contacts J and K of the vernier switch 36, and brush 67 of the coarse switch 35 still maintains contact with contact L, but brush 68 is moved into the space between contacts L and M. Thereby tap 30 remains connected to output terminal 11, and output terminal 16 becomes connected to tap 32 through a portion of the resistance 44, and thereby the voltage across the terminals 11 and 16 is again increased by an appropriate increment. The resultant connec-

tion of terminal 16 may be traced from the latter, thence conductor 46, tap 45, left-hand portion of resistance 44, conductor 52, brush 50, contact 47, brush 41, contact H, conductor 58, to tap 32.

The next increment of movement finds brushes 41 and 42 in contact with contacts H and K, respectively, thus bridging resistance 44 across section C (taps 32—33), the mid-position of tap 45 increasing the voltage potential added across terminals 16 and 11 by half the voltage of section C, terminal 11 remaining connected to tap 33, since brush 67 is still in engagement with contact L and brush 68 is about to engage contact plate M.

The next increment of rotary movement brings brush 41 between contacts H and I, brush 42 maintaining contact with contact K, whereby tap 33 of section C is connected to terminal 16 through a portion of resistance 44, the circuit extending through conductor 46, tap 45, resistance 44, conductor 53, brush 51, contact 48, brush 42, contact K, conductor 59, to tap 33, terminal 11 continuing to be connected to tap 30, since brush 67 is still on contact L, though brush 68 has now made engagement with contact M.

The next increment of rotary motion of switch 36 brings brush 41 on contact I, brush 42 still maintaining engagement with contact K, brushes 67 and 68 of switch 35 engaging contacts L and M, respectively. Section D of taps 33 and 34 is thus connected by conductors 59 and 60 across the resistance 44, and an added increment of voltage becomes applied to output terminal 16, according to the position of tap 45 along the resistance R.

The next increment of motion brings brush 42 into the space between contacts K and E, brush 41 engaging contact I and the brushes 67 and 68 of the coarse switch 35 contacting contacts L and M, respectively. As a result a full voltage increase, represented by the voltage of section D, is now applied to output terminal 16 through the left-hand portion of resistance 44, the circuit extending from tap 34, conductor 60, contact I, brush 41, contact 47, brush 50, conductor 52, resistance 44, tap 45, conductor 46, to output terminal 16, and thus the full voltage of all of the sections of secondary winding W^2 is applied to the output terminals 11 and 16, and, hence, to the load 19—all in successive step-by-step increments which, if the tap 45 remains at the mid-point of resistance 44, are each in an amount equal to half of the voltage of a section of the winding W^2; however, for any of these increments, variation or change may be achieved by varying the setting of the tap 45. Moreover, for each shift or change resulting from an increment of rotary movement of the switch 36, there is dependable control of current flow as the switch achieves a shift or change in circuit connections, for there is dependable control of the current undergoing commutation, due to the coactions and presence of the resistance 44, which, as will be seen from the above, is in its entirety or in part always associated with a circuit being interrupted or made. Thus, for example, the resistance 44 is either shunted across a selected section of the winding W^2 or disconnected therefrom, and thus represents a definite load. Moreover, that shunt relationship is shifted in either direction—that is, according to connection or disconnection—in relation to a preceding or succeeding circuit arrangement in which a portion (half, if tap 45 is at the mid-point) of the resistance 44 is always included in the load circuit and can thus function as a current-limiting resistance to effect limitation upon current values affected by the commutating action of the two switch structures.

Such coactions make it possible to avoid many of the disadvantages of known types of transformer-tap-changing switch constructions and, moreover, contribute toward permitting the use of smaller, and hence more compact, conductive parts of both the vernier switch and the coarse switch; for example, I am enabled to use solid silver contact elements in small and compact form, with unusually high capacity, the commutation control above described contributing also toward longer life of the moving switch parts.

Recurring to the operation of the switch mechanism, the engagement of brush 68 of coarse switch 35 with contact M is effective to connect the opposed long contacts E and F of vernier switch 36 to tap 24 of the primary winding W^1, the circuit extending from tap 24, conductor 64, contact M, brush 68, slip ring 73, brush 75, and, by conductor 77, to contacts E and F. Contacts E and F are thus at the same potential; contact I, being connected by conductor 60 to tap 34, is at the same potential as contacts E and F, winding W^2 and section S^1 being of the same voltage or number of turns. Hence the spacing between contacts I and F can be relatively small—small enough so that the brush 41 can bridge the gap between the two and engage both of them in movement from the one to the other. A similar relationship of close spacing exists between contacts G and E, which, at the outset, are at the same potential—contact G being connected to tap 30 through conductor 56 and contact E being connected by conductor 77, brush 75, slip ring 73, brush 68, contact L, conductor 63, and conductor 21, to tap 23 of the primary winding W^1, taps 30 and 23 being at the same potential; this latter relationship exists at the start of the cycle of operations, as will now be understood.

The next increment of movement brings brushes 41 and 42 into engagement with contacts E and F, respectively, thus bridging the resistance 44 across these contacts through conductors 52 and 53, and during the travel of the brushes 41 and 42 along the contacts E and F, respectively, the rate of drive of shaft 71—and, hence, of brushes 67 and 68—is increased, the longer radius portions of gear 80 being now operative upon portions of shorter radius on the gear 81, so that brush 67 is quickly moved off contact L in the coarse switch and brought onto contact M with which brush 68 is still in engagement. This increased rate of drive of the brush parts in the coarse switch permits of greater spacing between the contacts of coarse switch 35 and permits, also, the use of brushes of greater current-carrying capacity; thereby, also, contacts on the vernier switch 36 can be of shorter arcuate length and the structure can be made more compact, and, more particularly, contacts E and F can be made shorter and the other contacts of vernier switch 36 made longer.

With the parts in the positions just described, all of the brushes are at the potential of tap 24 of winding W^1, but, as the rotational movements continue, brush 50 bridges contacts G and E, and brush 51 enters the space between contacts F and J, brushes 67 and 68 of the coarse switch being still on contact M. The voltage across output terminals 16 and 11 is still the same as before, being equal to the full voltage of winding W^2, but

that voltage is supplied by the entire section S^1 of primary winding W^1. Thus terminal 23 of section S^1 is connected, through conductor 21 to output terminal 11, while tap 24 (the other terminal of section S^1) is connected to output terminal 16 as follows: from tap 24, conductor 64, contact M, brush 68, slip ring 73, brush 75, conductor 77, brush 59, conductor 52, left half of resistance 44, tap 45, and, by conductor 46, to the terminal 16. Through brush 67, slip ring 72, brush 74, and conductor 76, tap 30 of winding W^2 is connected to tap 24; the connection of tap 30 to tap 24 is also maintained through the conductor 56 extending to the contact G, with which brush 41 is still in contact. The same above-mentioned voltage is thus applied to output terminals 16 and 11, but now through the left half of resistance 44.

Brush 50 now moves further so that it contacts only contact G, while brush 42 is brought into engagement with contact J; this increment of rotary movement of vernier switch 36 shifts the coarse switch so that brushes 67 and 68 move further along on contact M. The voltage applied to the output terminals is now the voltage of section S^1 plus half the voltage of section A of winding W^2, resistance R splitting the voltage of section A as it did when brushes 41 and 42 occupied similar positions as earlier above described. Bearing in mind that the zero-voltage tap 23 is permanently connected by conductor 21 to the output terminal 11, the potential applied to the companion output terminal 16 will be seen to be the potential of section S^1, to which has been added the split voltage of section A of winding W^2. Thus from tap 24 the circuit extends by conductor 64, contact M, brush 67, slip ring 72, brush 74, conductor 76, to tap 30 of winding W^2, that being the series connection effected between the two windings. By conductors 56 and 57, section A of winding W^2 is connected to contacts G and J, across which, by brushes 41 and 42, resistance 44 is bridged, and, by the variable tap 45, any fraction of the voltage of serially-connected section A of winding W^2 is added to the voltage of section S^1 and applied to the companion output terminal 16.

From this point on, the successive steps above described are repeated, vernier switch 36 adding successive voltage increments as above described, while brushes 67 and 68 of coarse switch 35 coact with contacts M and O in successive steps as they did before coacting with contacts L and M. When the full voltage of winding W^2 has been added to the voltage of section S^1—which means that these two parts are connected in series across the output terminals 16 and 11 through one portion of the resistance 44—the process or steps are repeated, but now by adding successive increments of voltage from the winding W^2 to the voltage of sections S^1 and S^2, which latter thus, for this succeeding cycle, function as a single section.

When vernier switch 36 has again completed a single turn, bringing the voltage across it to the output terminals 16 and 11 equal to the sum of the voltages of sections S^1 and S^2 and winding W^2—that voltage being equal to the voltage of the three sections S^1, S^2, and S^3—the switches now begin to add, in the next stage or cycle, successive increments of voltage from the winding W^2 to the entire winding W^1. To effect that transition, contact P of coarse switch 35 is longer, so that brushes 67 and 68—traveling at increased rate, due to the elliptical gearing—remain in contact with contact P, which, through conductors 66 and 22, is connected to the end terminal 26 of the primary winding W^1 as the series connection with the primary winding W^1 is made to the secondary winding W^2. From that point on, successive increments of rotary motion of the parts of vernier switch 36 add to the voltage of the winding W^1 successive increments of voltage of the secondary winding W^2, in the manner earlier above described, for impression upon the output terminals 16 and 11, so that the maximum voltage—namely, the sum of the voltages of windings W^1 and W^2—may be ultimately impressed upon the output terminals and, hence, upon the load 19. From that point on the switching arrangement moves into the initial starting positions of the parts initially described above, whence the entire cycle may be repeated.

These successive increments of rotary motion may be manually effected by the hand wheel 39, while the dial 87, appropriately graduated, serves, in coaction with the indicator or pointer 86, to indicate the voltage applied across the output terminals 16 and 11—the coarse switch 35 and the pointer 86 making one complete revolution for the complete cycle of voltage change from zero voltage to the sum of the voltages of windings W^1 and W^2. The elliptical gears 80 and 81 have a ratio of drive of 1 to 1, while the ratio of drive between gears 83 and 84 is 1 to the sum of the number of sections in the primary winding W^1 plus 1; where the winding W^1 has three sections, the ratio of drive is thus 1 to 4.

As above pointed out, the relationship of the parts and their coactions make it possible to achieve many practical advantages, and the switch parts, in particular, may be made small, permitting the use of materials like silver throughout, and diminutiveness and compactness of construction of the switch mechanism are readily achievable, making it possible to provide the switch and switch mechanism, together with the transformer itself, as a small compact, and light-weight unit, ideally suited in such case for laboratory and test purposes. The system and apparatus have high electrical efficiency, excellent regulation, and high efficiency of commutation. In this latter connection I am enabled to achieve definite limitation or control of short-circuit current during commutation, the relation of the resistance 44 being, by the switching construction, always maintained, for any commutating transition, such that it functions to limit or control short-circuit current, and thus, also, the transformer windings are effectively protected against overload and need not be designed or wound to cope with such relatively uncontrollable and widely variable factors as are inherent in the use of carbon brushes employed in heretofore known apparatus and which, as is known, frequently cause so-called "hot spots" in the transformer winding. These factors all contribute toward achieving substantial reduction in size and weight over known types of voltage-varying apparatus of equal rating or load capacity.

In Fig. 2 I have shown, in exploded or schematic perspective, how I am enabled to achieve still further compactness of construction and arrangement—in that, instead of arranging the vernier switch and coarse switch substantially side by side, as in Fig. 1—and, hence, with their shafts 38 and 71 in parallel alignment—I may arrange one switch mechanism in back of the other and align them coaxially so that, by making one shaft hollow or tubular, the other shaft may

extend through it and, hence, be coaxial with it. Thus, in Fig. 2, I may arrange the coarse switch 35 in front of the vernier switch 36, and, by making the shaft of coarse switch 35 hollow or tubular—as indicated at 71a—the shaft 38 of the vernier switch 36 passes forwardly through it and thereby, also, as shown in Fig. 2, the hand wheel 39 and the dial and pointer 87—86 may be brought to the front of the apparatus coaxially and closely adjacent to each other. The geared driving connections between the two switches comprise the gears, as in Fig. 1, together with an intermediate idler shaft 82—being simply and appropriately rearranged, as indicated in Fig. 2, to function in the space between the rear of the plate 62 of the coarse switch and the front face 37 of the vernier switch. Any suitable bearings may be provided for the tubular shaft 71a, while the latter can conveniently form a bearing for the vernier switch shaft 38.

It will be understood that the transformer T of Fig. 1 is illustrative of a possible relative arrangement of its parts and windings, and that various other relative arrangements of windings may be employed. For example, should it be desired that the transformer T also function as an isolating transformer, it may be constructed and arranged in the manner indicated in Fig. 2, where I provide the transformer core R with a primary winding 91 which is connected by conductors 92 and 93 to the source 15. In this arrangement the transformer retains the windings W^1 and W^2, as shown in Fig. 2 and as they were described in connection with Fig. 1, and they may have the same relative number of turns and sections, and, in relation to the primary winding 91, the ratio of the number of turns or of voltage transformation, as between the winding 91 and the winding W^2, may be of any desired value—illustratively 1 to 1. In such case the windings W^1 and W^2 serve as secondary windings with respect to winding 91 functioning as a primary transformer winding, and the windings W^1 and W^2, and the circuits connected thereto —all as shown in Fig. 2—are thus isolated and insulated from the electrical circuit of primary winding 91, the transformer in such case embodying any suitable insulating construction or material, in known manner, as may be desired or as is suitable for the particular application. In such case, also, the apparatus may be provided with terminals 94 and 95 to function as input terminals corresponding to the input terminals 11 and 12 of Fig. 1, and it has the same circuit arrangement, in so far as the windings W^1 and W^2 and the two switches are concerned, as in Fig. 1, excepting that the tap or terminal 26 of the winding W^1 is not connected to an input terminal and, hence, terminal 26 is connected by conductors 22 and 66 directly to the contact P.

In the form of both Figs. 1 and 2, the spaces between the contact plates and the switches 35 and 36 are preferably filled in so that the brushes 41—42 and 67—68, as the case may be, have a substantially continuous or uninterrupted plane succession of surfaces to engage and transverse during their rotary movements; such an arrangement may be achieved in any suitable way —as, for example, by recessing the arcuate contact plates into the respective supporting plates 37 and 62, which are made of insulating material, and such an illustrative arrangement is intended to be shown or indicated in the drawings, but in Fig. 1 a dead contact Y is illustrated between contacts E and K, by which the wiping contact

may be prevented from falling down between contacts E and K if the latter are elevated above the plate 37. Fatigue of the flat spring-like wiping contacts or brushes 51—42 and 67—68 and loss of their spring tension, by which they maintain good electrical contact, are thus prevented.

It will thus be seen that there has been provided in this invention a system and switching arrangement in which the various objects hereinbefore noted, together with many thoroughly practical advantages, are successfully achieved. I am enabled to achieve exceeding compactness of construction and high efficiency, with low iron losses and low contact resistance losses, the latter being greatly lessened or minimized where silver or like highly conductive metals are employed for the brushes and contact elements, and, moreover, I am enabled to achieve fine or small increments of voltage change. Physically the transformer and switching mechanism, for a given range or capacity, can be embodied in small and compact form and thus, in contrast to known types of systems and mechanisms, I am enabled to achieve high efficiency of space.

As many possible embodiments may be made of the above invention and as many changes might be made in the embodiment above set forth, it is to be understood that all matter hereinbefore set forth, or shown in the accompanying drawing, is to be interpreted as illustrative and not in a limiting sense.

I claim:

1. Means for providing variable voltage in controllable increments comprising a group of inductive windings each of relatively large voltage, a group of inductive windings each of relatively small voltage, a resistance having an intermediate tap, output terminals respectively connected to a terminal of one of said groups of windings and to said resistance tap, two make and break rotary switching means, each of which has rotatable brush means and arcuate contact means coacting therewith, one of said rotary switching means having connections between its brush means and contact means and the windings of said second group and said resistance to effect, upon rotary movement of said brush means, successive addition in serial relation of the windings of said second group and to impress the resultant voltage upon said output terminals by way of said resistance tap and alternately through only a portion of said resistance and through said resistance in parallel relation to the added windings of said second group, the other of said rotary switch means having connections between its brush means and arcuate contact means and the windings of said first group to effect, upon rotary movement of said brush means, addition in serial relation of successive windings of said first group with respect to the windings of said second group, and driving connections between the two rotary brush means of said two rotary switching means to effect such ratio of drive and varying ratio of angular velocities between said two brush means to cause addition of a winding of said first group in serial relation to the windings of said second group only after the voltage of all of the windings of the second group has been impressed upon said output terminal in successive increments and to thereafter add the voltage of the windings of said second group in successive increments to the added windings of said first group and means for driving the said

first brush means at an accelerated rate in passing between adjacent contacts.

2. A variable voltage means as claimed in claim 1, in which the rotary switch means that affects the connections of the windings of said second group comprises also two stationary spaced brushes connected to the ends of said resistance, the rotary brush means comprising two brush elements coacting with the arcuate contacts of said rotary switching means and having arcuate contact elements respectively coacting with said first-mentioned two brushes.

3. A voltage regulating system comprising, in combination, a first inductive winding divided into a plurality of sections, means for energizing said winding from an A. C. source, the output voltages of said sections being substantially equal, a second inductive winding and means for energizing said second winding from said source to produce therein an output voltage substantially equal to the voltage of one of said sections, contact taps dividing said second winding into a plurality of substantially equal subdivisions, an impedance element having a tap at an intermediate point thereon, a pair of power output terminals, the first of said terminals being connected to said impedance tap, and a switching means having a plurality of cooperating movable and stationary contacts, said switching means being operable in a first series of positions to connect said second output terminal to one end of said second winding, and in successive series of positions to connect said second output terminal to said end of said second winding through successively added sections of said first winding, said switching means being operable in each of said aforementioned series of positions to connect the ends of said impedance element across successive individual subdivisions of said second winding, said switching means effecting transfer of said impedance element connections from one subdivision to the next succeeding subdivision by disconnecting one end of said impedance element from a tap of said second winding and subsequently connecting said end to the second succeeding tap while maintaining the connection of the other end of said impedance to the first succeeding tap.

4. A voltage regulating system comprising, in combination, a first inductive winding divided into a plurality of sections, means for energizing said winding from an A. C. source, the output voltages of said sections being substantially equal, a second inductive winding and means for energizing said second winding from said source to produce therein an output voltage substantially equal to the voltage of one of said sections, taps dividing said second winding into a plurality of substantially equal subdivisions, a resistance element having a tap at an intermediate point thereon, a pair of power output terminals, the first of said terminals being connected to said resistance tap, and switching means having a coarse switch section and a vernier switch section, each of said sections having a plurality of cooperating movable and stationary contacts, said coarse switch section being operable in a first switch position to connect said second output terminal directly to one end of said second winding and in successive switch positions to connect said second output terminal to said end of said second winding through successively added sections of said first winding, said vernier switch section being operable in successive positions to connect the ends of said resistance element across successive individual subdivisions of said second winding, said vernier switch section effecting transfer of said resistance element connections from one subdivision to the next succeeding subdivision by disconnecting one end of said resistance element from a tap of said second winding and subsequently connecting said end to the second succeeding tap while maintaining the connection of the other end of said resistance to the first succeeding tap, rotatable drive shafts supporting the movable contacts of said switch sections, a manual control handle on the vernier drive shaft, and a cyclically variable ratio drive coupling between said vernier drive shaft and the coarse switch drive shaft whereby the contacts of the said coarse switch are driven at an accelerated speed in passing between some of the fixed contacts.

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