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H. C. GUHL
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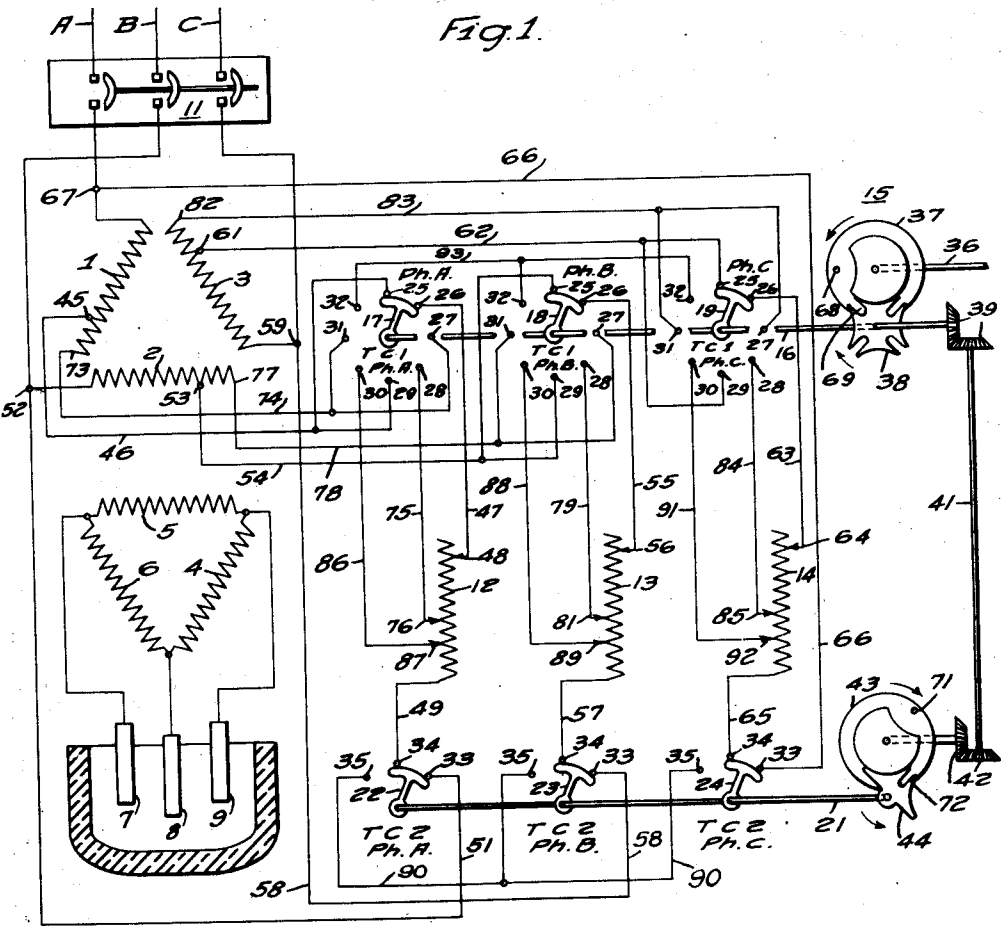


Fig. 2.

Sequence of Operation of No-Load Top Changing Equipment.

Position of Top Changer	Pos. of T.C. Sw. TC 1	Contacts Bridged	Pos. of T.C. Sw. TC 2	Contacts Bridged	Connection	Reactance
1	1	25-26	1	33-34	Delta.	All in.
2	2	27-28	1	33-34	Delta.	Part in.
3	3	29-30	2	34-35	Star.	Part in.
4	4	31-32	2	34-35	Star.	All out.

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2 Sheets-Sheet 2

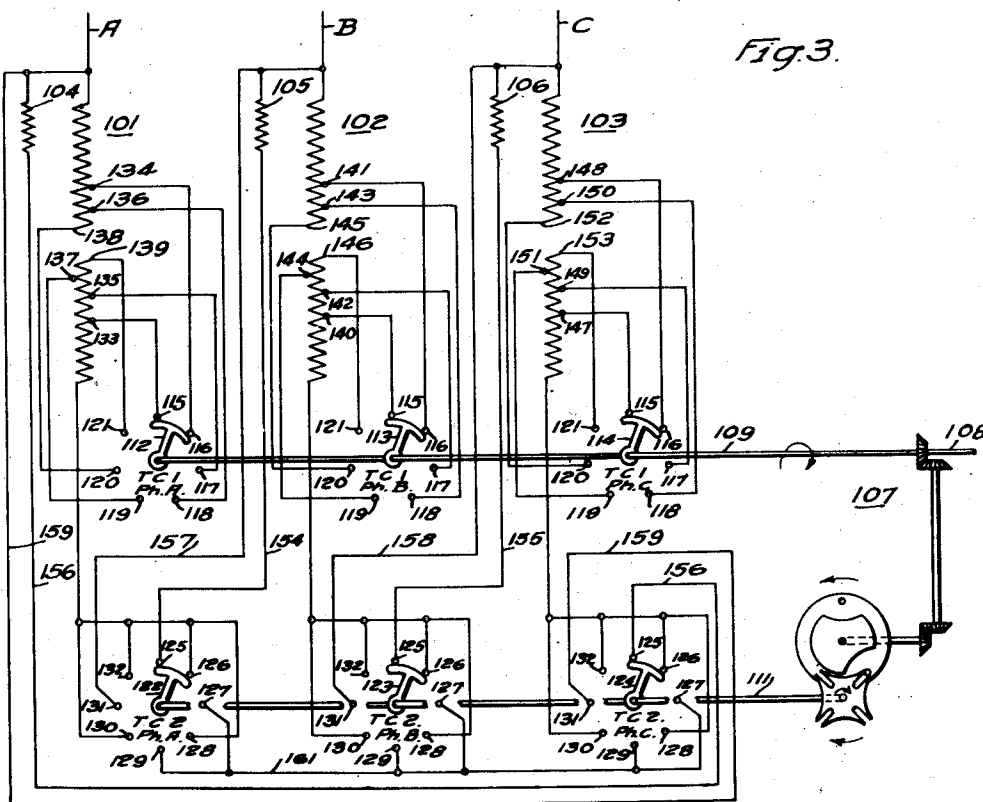


Fig. 4.

Position of Top Changer	Pos. of T.C. Sw. TC 1	Contacts Bridged	Connection	Pos. of T.C. Sw. TC 2	Contacts Bridged	Reactance
1	1	115-116	Delta	1	125-126	All in Δ
2	2	116-117	"	1	125-126	" " "
3	3	117-118	"	1	125-126	" " "
4	4	118-119	"	2	131-132	All out
5	5	119-120	"	2	131-132	" "
6	6	120-121	"	2	131-132	" "
7	1	115-116	Star	3	129-130	" "
8	2	116-117	"	3	129-130	" "
9	3	117-118	"	3	129-130	" "
10	4	118-119	"	4	127-128	" "
11	5	119-120	"	4	127-128	" "
12	6	120-121	"	4	127-128	" "

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5 Claims. (Cl. 171-119)

My invention relates to electrical apparatus such as polyphase transformers in which provision is made to vary the ratio of transformation between the primary and secondary windings and to vary the connections between the primary windings of the transformers for varying the current output from the secondary windings thereof.

My invention is particularly applicable to transformers employed for supplying power to electric arc furnaces, although it is not limited in its application to such service.

In polyphase transformers employed for supplying power to electric arc furnaces, it is possible to control the voltage of the secondary windings and, therefore, the current output therefrom by controlling the ratio of voltage transformation between the primary and secondary inductively related windings, by changing the tap connections to the primary windings to eliminate portions thereof from the winding circuit, by changing the connections between the several primary windings, and by inserting additional outside reactance in circuit with the several primary windings.

It is an object of my invention to provide a transformer of the above indicated character and tap changing switching mechanism therefor so constructed and so operated as to provide a relatively large number of voltage steps with a relatively small number of taps to the transformer windings.

Other objects of my invention and advantages thereof will appear from the following description of apparatus and circuits embodying certain preferred embodiments thereof.

Referring to the drawings, Figure 1 is a diagrammatic view illustrating circuits and apparatus organized in accordance with one preferred embodiment of my invention.

Fig. 2 is a chart showing the sequence of operation of the switches forming part of the tap changing equipment illustrated in Fig. 1.

Fig. 3 is a diagrammatic view illustrating circuits and apparatus employed in the second preferred embodiment of my invention, and

Fig. 4 is a chart showing the sequence of operation of the tap changing equipment illustrated in Fig. 3.

Referring to Fig. 1 of the drawings, transformer primary windings 1, 2 and 3 are illustrated, one end of which is connected, respectively, to the three phase conductors A, B and C by means of the three pole circuit breaker 11, and inductively related, respectively, to three secondary windings 4, 5 and 6 that are illustrated as connected

in delta relation to each other and to the electrodes 7, 8 and 9 of an electric furnace. Three reactor windings 12, 13 and 14 are illustrated as associated respectively with the three primary windings 1, 2 and 3.

A tap changing mechanism illustrated generally at 15, is provided comprising a set of tap changing switches, indicated as TC1, on the drawings and a set of tap changing switches, indicated as TC2 on the drawings. The tap changer TC1 comprises three tap changing switches for the three phases A, B and C, respectively, of the three-phase circuit, and a shaft 16 for actuating the three moving contact members 17, 18 and 19, respectively, of the three tap changing switches. The tap changer TC2 also comprises three tap changing switches and a shaft 21 that operates the three moving elements 22, 23 and 24 thereof, respectively, for the three phases A, B and C of the three-phase circuit.

Associated with the movable contact members 17, 18 and 19 of the three switching mechanisms comprising tap changer TC1 (on drawings) are sets of fixed contact members, similarly numbered 25 to 32, inclusive, for the three tap changing switches associated with the windings 1, 2 and 3 representing phases A, B and C, respectively, of the three-phase circuit. The moving elements of the three switching mechanisms will, therefore, bridge similarly positioned and similarly numbered contact members for a given position of the tap changer mechanism to complete similar circuits respecting the three windings 1, 2 and 3 of the three phase circuit. For the same reason, the three sets of fixed contact members associated with each of the three switching mechanisms of tap changer TC2 and similarly cooperating, respectively, with the movable contact members 22, 23 and 24 thereof, are similarly numbered 33, 34 and 35 for the three switching mechanisms. The position of the complete tap changer mechanism is determined by the position of the operating shaft 36 which may be driven either manually or by an electric motor, and which is connected to a gear 37 which cooperates with a gear 38 of a Maltese cross gear mechanism for intermittently operating the shaft 16 through a given arc during a portion of each revolution of the shaft 36. The shaft 16 is operatively connected to the shaft 21 of the tap changer TC2 by means of the bevel gears 39, a shaft 41, the gears 42 and the gears 43 and 44 of a Maltese cross gear mechanism.

The illustrated position of the several switches comprising the tap changing mechanism corre-

sponds to position 1 in the chart of Fig. 2, in which the movable elements 17, 18 and 19, respectively, of the tap changer TC1 each bridge contact members 25 and 26 of their respective phase circuit switches and the movable contact members 22, 23 and 24 of the tap changer TC2, each bridge contact members 33 and 34 of their respective phase circuit switches thus connecting portions of the three primary windings 1, 2 and 3 in series relation with the reactor windings 12, 13 and 14, respectively, and in delta relation with respect to each other. Tracing the circuit through tap changers TC1 and TC2 for phase A, a point 45 on the winding 1 is connected by the conductor 46 to the fixed contact member 25 and through the movable contact member 17 of the tap changer TC1 for phase A, through contact member 26, conductor 47 to the terminal point 43 of the reactor 12, through the reactor 12 and by conductor 42, contact members 34 and 33 of the tap changer TC2 for phase A that are bridged by the movable contact member 22, and conductor 51 to the terminal 52 of the winding 2 that is connected to the phase conductor B.

Similarly, the tap changing switches TC1 and TC2 for phase B connect the point 53 on the winding 2, by conductor 54, fixed contact members 25 and 26 of the tap changing switch TC1 for phase B that are bridged by the movable contact member 18, conductor 55 to the terminal point 56 of reactor 13, through the reactor 13 and by conductor 57, the contact member 34 of the tap changing switch TC2 for phase B, through the movable contact member 23 thereof, contact member 33, and conductor 58 to the terminal 59 of the winding 3 that is connected to the phase conductor C. Similarly, the tap changing switches for phase C complete a circuit from the point 61 of winding 3, by conductor 62, through fixed contact members 25 and 26 of the tap changing switch TC1 for phase C that are bridged by the movable contact member 19, through conductor 63 to the terminal 64 of the reactor 14, through the reactor 14 and by conductor 65 and the fixed contact members 33 and 34 of the tap changer switch TC2 for phase C that are bridged by the movable contact member 24, and by conductor 66 to the terminal 67 of the winding 1 that is connected to the phase conductor A. In the position 1 of the tap changer mechanism it is seen, therefore, that a delta circuit is completed comprising that portion of the winding 1 between the terminal 67 and the point 45 in series with the reactor 12, that portion of the winding 2 between the terminal 52 and the point 53 in series with the reactor 13 and that portion of the winding 3 between the terminal 59 and the point 61 in series with the reactor 14, thus providing a relatively low excitation for the primary windings 1, 2 and 3 and a corresponding low voltage and current supplied from the secondary windings 4, 5 and 6 to the terminals 7, 8 and 9 of the furnace.

If now it is desired to operate the tap changing equipment from position 1 to position 2 indicated on the chart in Fig. 2, the shaft 36 and the gear wheel 37 are revolved through one revolution in a counter clockwise direction, thus causing the pin 68 of the gear 37 to engage the slot 69 in the gear 38 and actuate this gear one-quarter turn in a clockwise direction, thus moving the shaft 16 and the contact members 17, 18 and 19 carried thereby to a position to bridge the contact members 27 and 28 of the switch mechanisms for their respective phases A, B and

C. The gear 43 of the tap changing mechanism TC2 is operated through a one-quarter turn simultaneously with the gear 38 by means of the interconnecting pinion gears 39 and 42 and the shaft 41. The pin 71 of the gear 43 is accordingly moved from its illustrated position to a position adjacent to the slot 72 of the gear 44, but the movement of the gear 43 is not sufficient to move the gear 44 from its illustrated position and the contact members 22, 23 and 24 carried by the shaft 21 are, accordingly, maintained in their illustrated positions bridging the contact members 33 and 34 of the tap changer TC2 for the phases A, B and C, respectively.

It will be seen that the circuit now closed through the tap changing switches TC1 and TC2 for phase A extends from the terminal 73 of the winding 1 through conductor 74, contact members 27 and 28 bridged by the contact member 17, the conductor 75 to the point 76 on the reactor 12 through the lower portion of the reactor and by conductor 49, contact members 33, 34 and 22 and conductor 51 to the terminal 52 of the winding 2. Continuing the delta circuit through the winding 2 to the terminal 77 thereof, through conductor 78, through contact members 27, 28 and 18 of the tap changer TC1 for phase B and conductor 79 to the point 81 on the reactor winding 13, through the lower portion of the reactor winding, conductor 57, contact members 34, 23 and 33 of the tap changer TC2 for phase B, and conductor 58 to the terminal 59 of the winding 3, thence through the winding 3 to the terminal 82 thereof and by conductor 83, contact members 27, 28 and 19 of the tap changer TC1 for phase C, conductor 84 to the point 85 on the reactor winding 14 through the lower portion of the winding 14 and through conductor 65, contact members 33, 34 and 24 of the tap changer TC2 for phase C, and conductor 66 to the terminal 67 of the winding 1. The circuit just traced, thus completes a delta circuit including all of the winding turns of the windings 1, 2 and 3 and a portion of the reactor windings 12, 13 and 14. The excitation of the primary windings 1, 2 and 3 is, therefore, increased, thus increasing the voltage and the current supplied from the secondary windings 4, 5 and 6 to the arc furnace.

If now it is desired to operate the tap changing equipment to position 3, indicated on the chart in Fig. 2, the shaft 36 is rotated through another revolution in a counter-clockwise direction, thus actuating the gear 38 and the shaft 16 through another quarter turn in a clockwise direction and causing the contact members 17, 18 and 19 to bridge the contact members 29 and 30, respectively, of the tap changer TC1 for the phases A, B and C. The gear 43 is similarly actuated through a second quarter turn in a clockwise direction, thus rotating the pin 71 from a position 90° in advance of its illustrated position to a position of 180° in advance thereof. During this quarter turn the pin 71 engages the slot 72 of the gear 44 thus actuating the gear 44 and the shaft 21 in a counter-clockwise direction causing the contact members 22, 23 and 24 of the tap changer TC2 for the phases A, B and C, respectively to be actuated in a position to bridge the contact members 34 and 35 of their respective switch mechanisms.

In this position of the tap changing switches, the terminal 73 of the winding 1 that is remote from the phase conductor A is connected by conductor 74 to the contact member 31 of the tap

changing switch TC1 for phase A, and through the contact member 17 thereof, contact member 30, conductor 86 to the point 87 on the reactor 12, through the lower portion of the reactor 12, conductor 49 and contact members 34, 35 and 22 of the tap changing switch TC2 for phase A to a conductor 90 that is a common conductor connecting the three contact members 35 of the tap changer TC2 for the phases A, B and C, together, thus forming a neutral point for the star connected windings. Similarly, the terminal 17 of the winding 2 that is remote from the phase conductor B is connected by the conductor 78, contact members 31, 18 and 30 of the tap changing switch TC1 for phase B through conductor 88 to the point 89 on the reactor winding 13, through the lower portion of the reactor 13 and through contact members 34, 35 and 23 of the tap changer TC2 for the phase B to the common neutral point conductor 90. In the same manner, the terminal 82 of the winding 3 that is remote from the phase conductor C is connected by conductor 83, contact members 31, 19 and 30 of the tap changer TC1 for phase C through conductor 91 to the point 92 on the reactor 14, through the lower portion of the reactor 14, conductor 65 and contact members 34, 35 and 24 of the tap changer TC2 for phase C to the common neutral conductor 90. The third position of the tap changing equipment, therefore, connects the three primary windings 1, 2 and 3 in star relation with a portion of the reactors 12, 13 and 14, respectively, in series therewith.

The fourth position of the tap changing equipment shown on the chart in Fig. 2, connects the primary windings of the transformer in star relation with the reactors 12, 13 and 14 entirely out of the circuit. This position of the equipment is effected by rotating the shaft 36 and the gear 37 through a third revolution in a counter clockwise direction, thus rotating the gear 38 and the shaft 16 through a third quarter turn in a clockwise direction, thus causing the contact members 17, 18 and 19 for the phases A, B and C, respectively, of the tap changer TC1 to bridge the contact members 31 and 32. This position of the tap changer TC1 connects the terminal 73 of the winding 1 through conductor 74, contact members 31, 32 and 17 of the tap changing switch TC1 of phase A to a conductor 93 that is a common or neutral conductor connecting the three contact members 32 of the tap changing switches for the phases A, B and C, respectively. In a similar manner, the terminal 17 of the winding 2 is connected by conductor 78 and contact members 31, 32 and 18 of the tap changing switch TC1 for phase B to the neutral conductor 93, and the terminal 82 of the winding 3 is connected by conductor 83 and contact members 31, 32 and 19 of the tap changing switch TC1 for phase C to the neutral conductor 93, thus connecting the windings 1, 2 and 3 in star relation with no outside reactors in circuit therewith.

Obviously, a different number of voltage ratios may be obtained with the system described above employing a different number of taps on the windings 1, 2 and 3 and on the reactor windings 12, 13 and 14, with a corresponding number of positions of the tap changer switches being provided. It will be apparent that a relatively large number of tap positions and secondary voltage values are obtainable with the above described system without employing a large number of tap connections to the primary windings of the transformer.

Referring to Fig. 3 which shows another embodiment of my invention having tap changer positions and sequence of operating steps shown in Fig. 4, the primary conductors 101, 102 and 103, each comprising upper and lower winding sections, are connected, respectively, to the phase conductors A, B and C. For the sake of simplicity in Fig. 3, the secondary windings of the transformers that are connected to the furnace electrodes and the usual three pole circuit breaker switch connecting the primary windings to a three-phase supply circuit are omitted from this figure although it will be understood that these parts would ordinarily be used in practice in the same manner as shown in Fig. 1. Reactor windings 104, 105 and 106 are provided, associated respectively with the primary windings 101, 102 and 103, the high voltage terminal ends of the associated reactor and transformer windings being connected together.

A tap changing mechanism that is, in general, similar to that provided in Fig. 1 is indicated at 107, the gearing mechanism thereof being driven from a shaft 108 and driving, through suitable Maltese cross gears for effecting an intimate motion of the shafts 109 and 111, which actuate, respectively, tap changers TC1 and TC2 each having a tap changing switch for each of the phases of the three-phase system. The tap changer TC1 comprises the movable contact members 112, 113 and 114 associated respectively with phases A, B and C and similarly operated by the shaft 109. Each of the tap changer switches TC1 for the three phases are provided with stationary contact members numbered 115 to 121, inclusive, that are engaged by the movable contact members 112, 113 and 114, respectively, of the three switches. The tap changing switches TC2 for the phases A, B and C of the system are respectively provided with moving contact members 122, 123 and 124, all similarly actuated by the shaft 111, and each of the switches are provided with stationary contact members 125 to 132, inclusive. It will be noted by reference to Fig. 4 that the embodiment of the invention illustrated in Fig. 3 provides twelve positions of the tap changing equipment giving twelve different voltages in the secondary windings of the transformers. The gearing mechanism controlling the shafts 109 and 111 are so designed that there are six operative positions for the shaft 109 and the tap changer TC1, which six positions are repeated from the seventh to twelfth positions of the tap changing equipment as a whole, and the relation of the gears are such that the shaft 111 and the tap changer TC2 driven thereby are operated from one switch closing position to the next succeeding switch closing position of the tap changer during every third operation of the tap changing mechanism, there being a total of four positions for the tap changer TC2.

The primary winding 101 is provided with a series of tap connections numbered 133 to 139, inclusive, and connected, respectively, to the contact members 115 to 121, inclusive, of the tap changing switch TC1 for phase A. In a similar manner, the primary winding 102 is provided with a similar number of taps numbered 140 to 146, inclusive, and connected, respectively, to the contact members 115 to 121, inclusive of the tap changing switch TC1 for phase B, and the primary winding 103 is also provided with a similar arrangement of taps connecting the points 147 to 153, respectively, to the contact

members 115 to 121 of the tap changing switch TC1 for phase C.

In the illustrated position of the tap changing equipment which corresponds to position 1 on the chart in Fig. 4, the contact members 112, 113 and 114 of the switches of tap changer TC1, for the three phases, bridge the contact members 115 and 116 of their respective switches, thus cutting out of circuit, the winding turns between the points 133 and 134 of the winding 101, between points 140 and 141 of the winding 102, and between the points 147 and 148 of winding 103. The lower terminal of the winding 101 is connected through the contact members 126, 122 and 125 of tap changing switch TC2 for phase A and conductor 154 to the lower terminal of the reactor 105, the upper terminal of which is connected to the phase conductor B. The lower terminal of the winding 102 is connected through contact members 125, 126 and 123 of the tap changing switch TC2 for phase B, and by conductor 155 to the lower terminal of the reactor 106, the upper terminal of which is connected to the phase conductor C, and the lower terminal of the winding 103 is connected through the contact members 126, 124 and 125 of the tap changing switch TC2 for phase C and conductor 156 to the lower terminal of the reactor 104, the upper terminal of which is connected to the phase conductor A. In this position of the tap changing mechanism all of the reactance of the reactors 104, 105 and 106 is connected in series with the windings 101, 102 and 103 in delta relation.

In the second and third positions of the tap changing mechanism, as indicated in the chart in Fig. 4, the tap changer TC1 remains in its first position while the movable contact members of the tap changer TC1 bridges consecutively the contact members 116 and 117, and then contact members 117 and 118, thus introducing two additional sections of the primary windings into the circuit. In the second position of the tap changer TC1 the points 134 and 135 on winding 101, 141 and 142 on winding 102, and 148 and 149 on winding 103 are, respectively, connected together through the contact members 116 and 117, and in the third position of the tap changer TC1 the points 135 and 136 on winding 101, 142 and 143 on winding 102, and 149 and 150 on winding 103 are, respectively, connected together through the contact members 117 and 118 of their associated phase switches.

During the next three positions of the tap changing equipment numbered 4, 5 and 6 in the left-hand column of Fig. 4, the tap changer TC1 bridges consecutively the contact members 118—119, 119—120, and 120—121, thus introducing step by step the entire winding turns of the windings 101, 102 and 103 into the primary or energizing circuit of the transformers. When the tap changing mechanism moves from its third to its fourth position, the movable elements 122, 123 and 124 of the tap changer TC2 move in a counter clockwise direction to bridge the contact members 131 and 132, thus eliminating the reactors 104, 105 and 106 from the transformer winding circuits and connecting the lower terminal of the winding 101 through the conductor 157 to the phase conductor B, the lower terminal of the winding 102 through conductor 158 to the phase conductor C, and the lower terminal of winding 103 through conductor 159 to the phase conductor A. The tap changer TC2 re-

mains in this position for positions 4, 5 and 6 of the tap changing mechanism.

When the tap changing mechanism is operated from its sixth to the seventh position, as indicated in the column at the left in the chart in Fig. 4, the tap changer TC1 is moved from its sixth to its first or illustrated position bridging the contact members 115—116 and the tap changer TC2 is moved from a position bridging the contact members 131—132 to a position bridging the contact members 129—130, thus connecting the lower ends of the three windings 101, 102 and 103 to a common or neutral conductor 161. In this position of the tap changing mechanism, all of the tapped sections of the primary windings are excluded from the primary winding circuit. During the remaining steps of the tap changing mechanism, the several tapped sections are introduced by the tap changer TC1 in the same manner as in the first six positions of the tap changing mechanism. During the last six positions of the tap changing mechanism, the lower terminals of the windings 101, 102 and 103 are maintained connected to the neutral conductor 161 through the contact members 129 of the tap changer TC2 and one of the contact members 128 or 130, depending upon the position of the tap changing switch TC2.

It will be apparent to those skilled in the art that a number of modifications of the circuits and apparatus described may be made without departing from the spirit of my invention, and I do not wish to be limited other than by the scope of the appended claims.

I claim as my invention:

1. The combination with a transformer comprising a plurality of primary and secondary windings, of reactors for connection with said primary windings, and means for varying the voltage supplied from said secondary windings comprising circuits and tap-changing switching mechanism operative in a predetermined sequence of circuit establishing positions for connecting consecutively, portions of said primary windings in series circuit relation, respectively, with their associated reactors and in delta circuit relation to each other, then said primary windings in series, respectively, with portions of their associated reactors and in delta circuit relation to each other, then said primary windings in series, respectively, with portions of their associated reactors and in star relation to each other, and then in star relation to each other with said reactors excluded from said circuit.

2. The combination with a polyphase power circuit comprising three conductors, of three transformers, each having a primary winding and a secondary winding, one terminal of said primary windings being connected respectively to each of said conductors, a reactor associated with each primary winding, said primary windings being provided with terminal and intermediate taps and said reactors being provided with terminals and intermediate taps, a tap-changing switching-mechanism for selectively connecting one terminal tap or an intermediate tap to a selected tap on its associated primary winding, and a second tap-changing switching mechanism for selectively connecting the other terminal taps of said reactors together, or to selected conductors of said power circuit.

3. The combination with three transformers for connection to a polyphase system, each having a primary winding and a secondary winding, of a reactor associated with each primary winding, means for varying the voltage supplied from said

secondary windings comprising a plurality of tap connections on said primary windings, a tap-changing switching mechanism for each winding for correspondingly changing the circuit connections between said taps to remove selected portions of said winding from the primary winding circuits, and a second switching mechanism for each winding for connecting said windings in star and delta relations at predetermined circuit connecting positions of said first named tap-changing mechanism, and for connecting said reactors in circuit with their associated windings in certain of the above-mentioned positions in which said windings are connected in delta relation.

4. In a transformer system having primary and secondary windings, in combination, reactors associated with the primary transformer windings, a plurality of tap-changing switching mechanisms disposed to connect the primary transformer windings in delta circuit relation with the reactors in series circuit relation with their corresponding primary windings, means for driving the tap-changing switching mechanisms step-by-step at different speeds to perform switching operations in a predetermined manner, a plurality of circuit connections associated with the tap-changing switching mechanisms, the circuit connections and tap-changing switching mechanisms being so disposed that the latter are operated to shunt the

reactors and change the circuit connections of the primary transformer windings to star circuit connections.

5. In a transformer system having primary and secondary windings, in combination, reactors associated with the primary transformer windings, a plurality of interconnected tap-changing switching mechanisms, means for driving the tap-changing switching mechanisms step-by-step at different speeds to actuate them to different positions to perform predetermined switching operations, a plurality of circuit connections associated with the tap-changing switching mechanisms, one of the tap-changing switching mechanisms disposed to control the circuit connections of the primary windings, another tap-changing switching mechanism disposed to cooperate with said one of the tap-changing switching mechanisms to connect the primary windings in delta circuit relation with the reactors in series circuit relation with their corresponding primary windings when said tap-changing switching mechanisms are moved to predetermined circuit connecting positions, the tap-changing mechanisms further cooperating with each other in a predetermined manner to shunt the reactors from the circuit and connect the primary windings in a predetermined star circuit relation.

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