Dec. 29, 1931. A. E. GREENE 1,839,148

ELECTRIC FURNACE AND VOLTAGE CONTROL

Filed Aug. 14, 1929 6 Sheets-Sheet 1

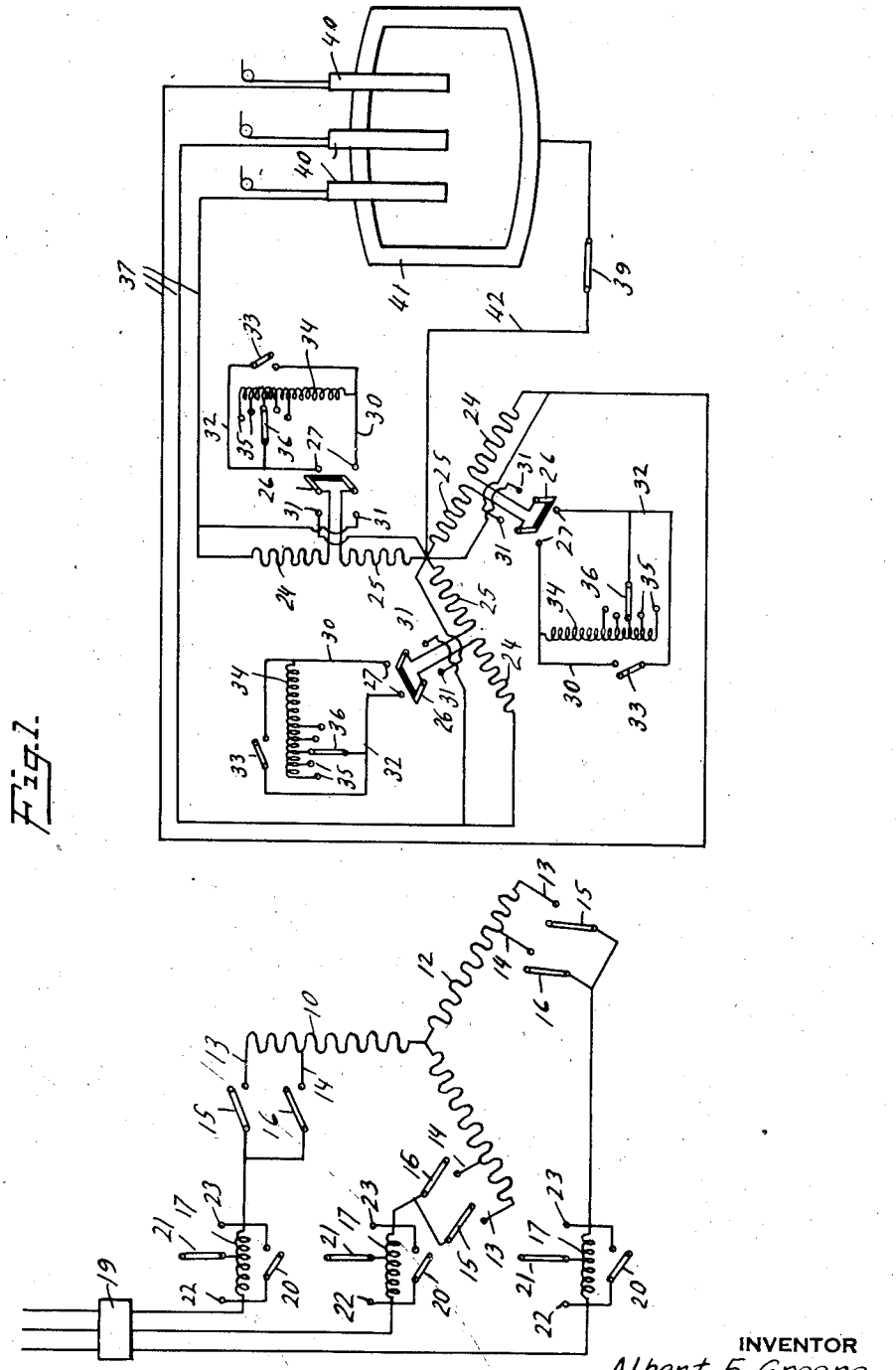


Fig. 1.

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ELECTRIC FURNACE AND VOLTAGE CONTROL

Filed Aug. 14, 1929 6 Sheets-Sheet 2

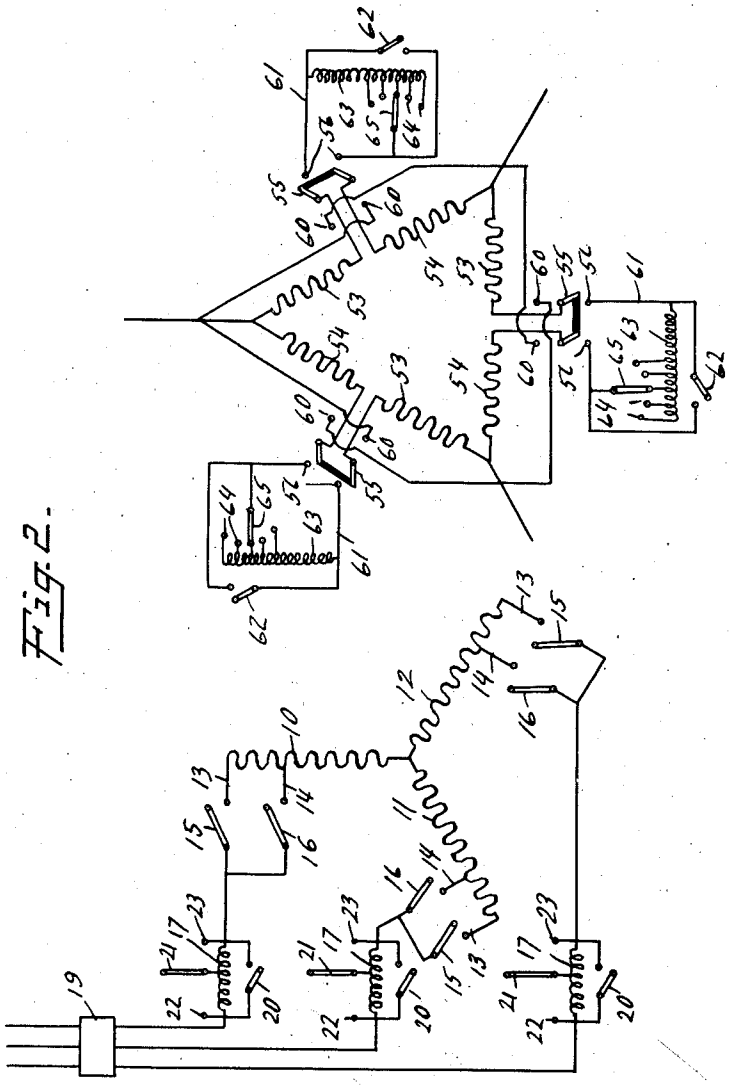


Fig 2.

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ELECTRIC FURNACE AND VOLTAGE CONTROL

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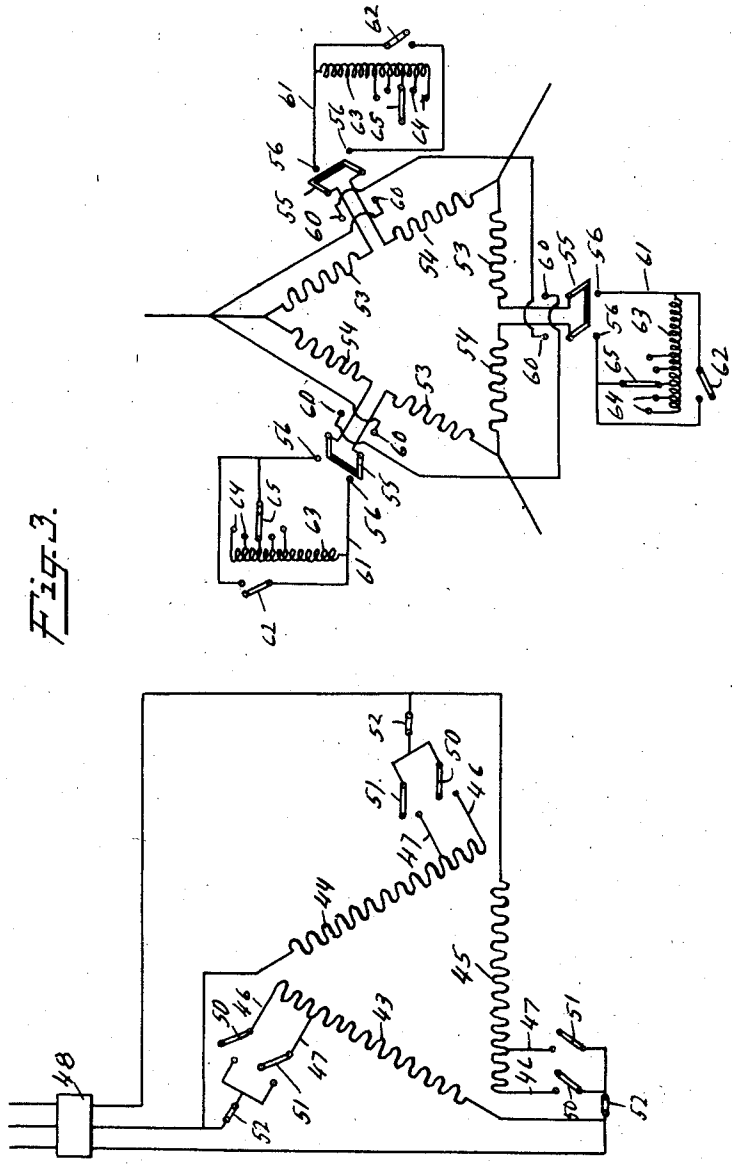


Fig. 3.

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ELECTRIC FUPNACE AND VOLTAGE CONTROL

Filed Aug. 14, 1929 6 Sheets-Sheet 4

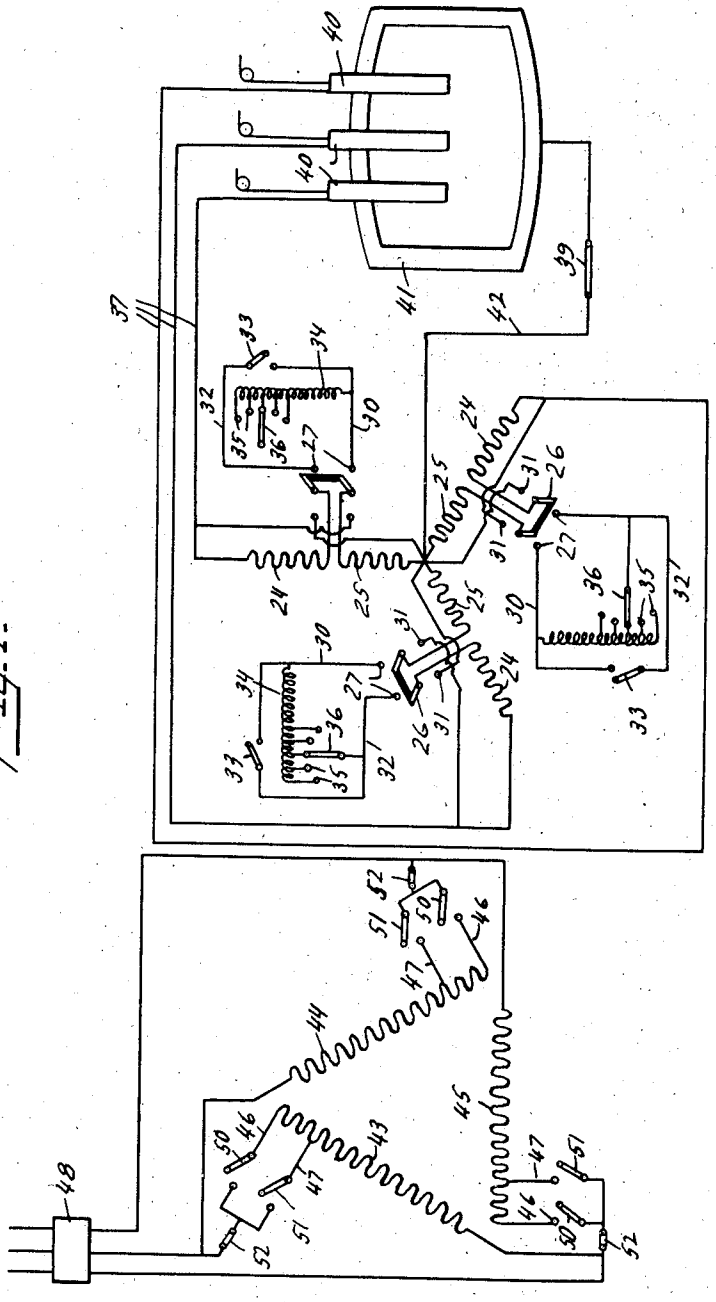


Fig. 4.

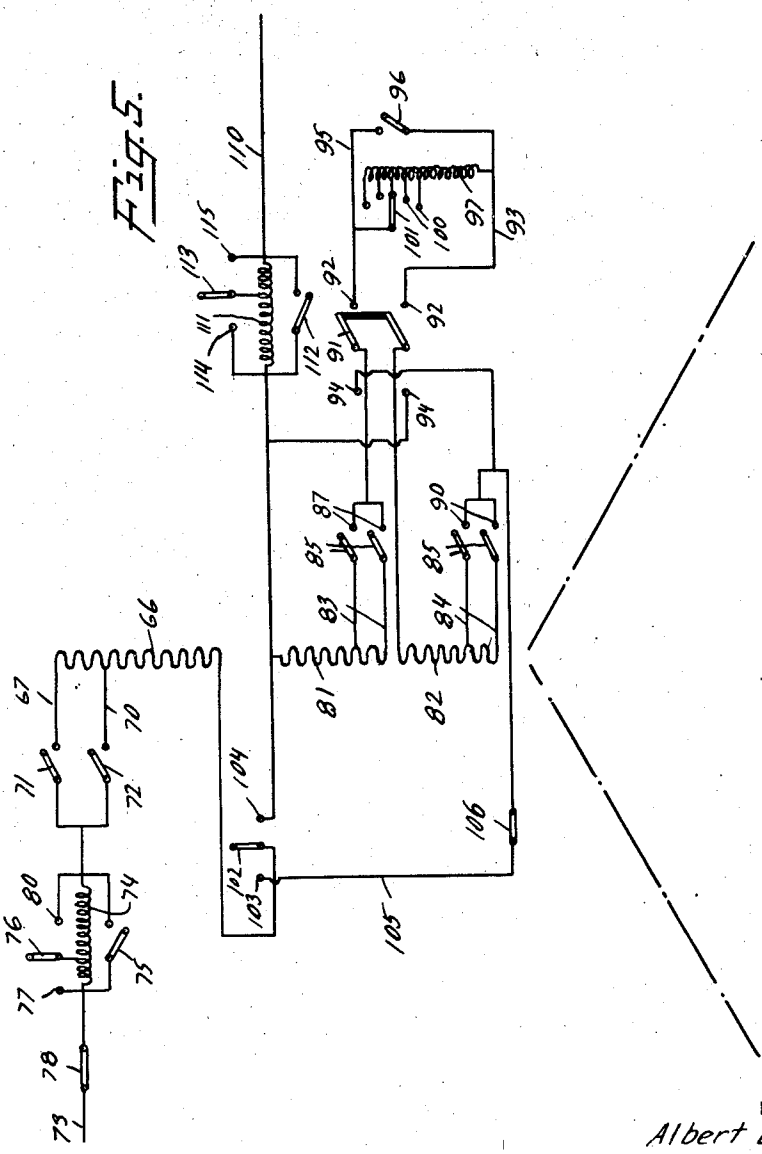
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ELECTRIC FURNACE AND VOLTAGE CONTROL

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Fig. 5.



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ELECTRIC FURNACE AND VOLTAGE CONTROL

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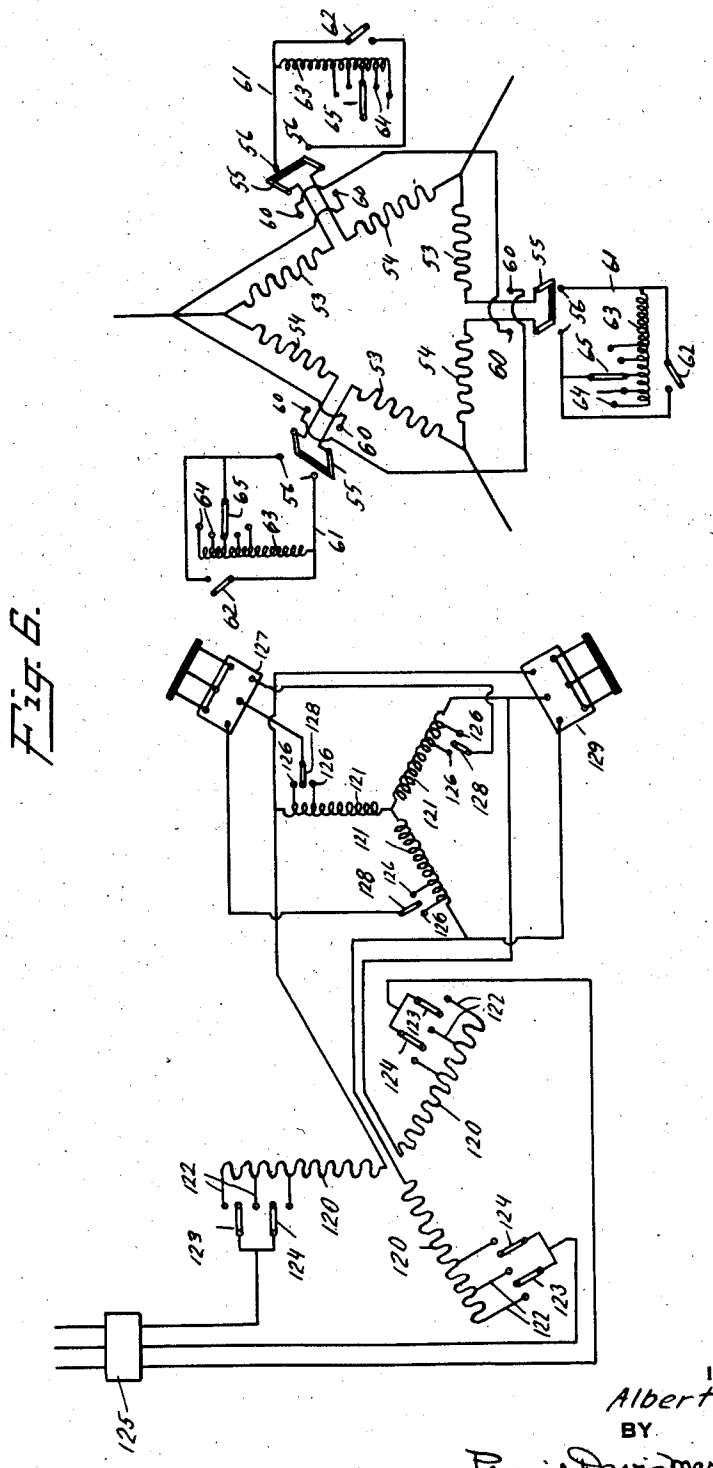


Fig. 6.

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UNITED STATES PATENT OFFICE

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ELECTRIC FURNACE AND VOLTAGE CONTROL

Application filed August 14, 1929. Serial No. 385,706.

The present invention relates to electric arc furnaces and has for an object the provision of improved apparatus and methods for voltage control. The invention further contemplates the provision of improved methods of electric furnace operation and the provision of improved apparatus for carrying out such methods.

This application is a continuation in part of application Serial No. 157,931, filed March 28, 1917, and application Serial No. 322,298, filed September 8, 1919.

In the heretofore customary operation of electric arc furnaces employing transformers provided with primary and secondary windings, the voltages applied to the electrodes have been changed to some extent in accordance with changes of conditions within the furnace, and various methods and apparatus for voltage control have been employed. Thus, it is customary to use a high voltage for melting down and a low voltage for refining in the treatment of iron and steel. In some cases three or more voltages are used in carrying out electric furnace operations. In electric furnace operations involving the use of several voltages, control of reactance and control of the arc length are also practiced.

Various arrangements of apparatus for controlling the voltage applied to the electric arc furnaces are employed. Thus, in my pending applications, hereinbefore referred to, I have described electric furnaces in combination with transformers having secondary windings which may be selectively connected in series or in parallel, and electric furnaces in combination with transformers having primary windings provided with taps for connecting different numbers of turns in circuit. Transformers provided with means for connecting the windings alternately in star and delta are also employed.

The use of known arrangements of apparatus for voltage control is sometimes objectionable because of the large amounts of copper required in the transformer windings and the large amounts of iron required in the cores. Thus, when different voltages are obtained at different times on the secondary terminals of a transformer system through the use of different numbers of turns on the primaries, the transformer construction must be such that sufficient copper is provided in the primary and secondary windings to carry the current required at each voltage in order to give full KVA capacity.

Furthermore, when three or more voltages are desired and the voltage changes are all made by changing the taps on the primary windings, or by delta-star change on the primary, the switching apparatus required on the primary is relatively expensive especially in systems supplying voltages above 15,000 volts. Thus, for example, when it is desired to change voltages by using at least two tap changing switches to connect different portions of the primary windings to the supply circuit, and other switches to change from star to delta on the primary side, it will require at least four switches, and, in addition, a main oil circuit breaker is usually provided. If knife switches are used to change the primary from star to delta and vice versa, then an excess of wiring on the primary side of the transformer system is required, and two different types of switches which are expensive to interlock to avoid opening under load must be provided.

The present invention provides an improved method and simplified means for providing a number of secondary voltages. The method of the present invention involves the combined use of primary and secondary switches for changing voltage between electrodes. The apparatus of the invention comprises a transformer having primary windings provided with taps by means of which a relatively small range of voltage may be obtained, and secondary windings comprising a plurality of coils and provided with means for selectively connecting the coils in series or in parallel.

Heretofore, it has been considered impractical to switch large currents on the secondary, and that has been one of the chief reasons for utilizing primary tap changing switches for voltage control of electric arc furnaces.

According to the present invention, the windings for each phase of the secondaries

may comprise two coils and it is necessary to provide a switch on the secondary side for only one half of the secondary full load current. One of the coils of the secondary of a given phase may be connected at one end to the circuit to the electrode and the other end may be switched either one of two ways, to provide for operation of the coil in series or in parallel with the other coil of the same phase.

The important advantage of this improved arrangement for obtaining a plurality of voltages over a wide range, is that the reactance of the transformer is little affected by the operation of two secondary coils either in series or in parallel, and it is therefore possible to have a comparatively low reactance inherent in the transformer and to operate at the lowest electrode voltage with this minimum reactance.

Comparison of the results of the method and apparatus of the present invention with the results of the methods and apparatus heretofore used emphasizes the advantages of the present invention. Thus, when a transformer is constructed to provide a certain range of secondary voltage with definite inherent reactance at the maximum secondary voltage, the reactance will be considerably greater and may easily be doubled when the minimum secondary voltage is used. This is in part due to the fact that in order to supply the same load in KVA at the maximum and minimum voltages a greater secondary current is required at the lower voltage. This objection does not apply to the series-parallel arrangement of the secondary windings because approximately the same current flows through each coil, and these currents are added when the coils are in parallel and the voltages are added when they are in series, the current remaining approximately the same through each coil for the same KVA load.

The invention further contemplates the provision of an improved apparatus and method for reactance control, which are particularly suitable for use in conjunction with the apparatus and method for voltage control. In accordance with the present invention, a variable reactance element is provided and means are provided for connecting all or any portion of the reactance element between the two secondary coils when they are in series and for cutting out the reactance element when the secondary coils are in parallel. The reactance element takes the place of the short-circuit connection of the switch. In addition to providing reactance elements for use in conjunction with the secondary coils, external reactance elements may be connected either on the primary or secondary side. Control of reactance may also be effected through the use of different taps on the primary windings. Thus, when providing primary taps for low and high voltages on the secondary terminals, the windings may be so connected as to provide a relatively higher reactance when the high voltage is obtained on the secondary and a relatively lower reactance when the lower voltage is obtained on the secondary.

The invention further contemplates the provision of an improved method and apparatus for simultaneously varying voltage and reactance. Apparatus embodying this feature of the invention may conveniently comprise a transformer provided with windings which may be selectively connected as separate primary and secondary windings or to provide an auto transformer. Such apparatus is particularly advantageous for use in situations in which the available primary voltages are relatively low.

High voltages may be obtained by connecting the windings as separate primary and secondary windings. In constructing the transformer, ample inherent reactance to prevent excessive surges may be readily secured by properly spacing and connecting the coils. Low voltages may be obtained by connecting the primary and secondary portions of the windings to provide an auto transformer to increase the number of turns between the supply lines and decrease the voltage per turn correspondingly. Such a change in connections results in a decrease in reactance. Additional means may be provided for further reactance and voltage control.

The invention will be better understood from a consideration of the following description in conjunction with the accompanying drawings, in which;

Fig. 1 is a diagrammatic outline of a three-phase transformer in combination with an electric arc furnace and showing star connected primary and secondary windings;

Fig. 2 shows star connected primary windings, and delta connected secondary windings;

Fig. 3 shows delta connected primary and secondary windings;

Fig. 4 shows delta connected primary windings and star connected secondary windings;

Fig. 5 shows a three-phase transformer provided with windings which may be selectively connected as separate primary and secondary windings or to provide an auto transformer, only one phase being shown in detail; and

Fig. 6 shows star connected primary windings and delta connected secondary windings with reactance elements between the separate coils and the neutral point of the primary.

The drawings show several arrangements of primary and secondary transformer windings, voltage control means, and reactance control means for use in combination with electric arc furnaces. The star connected

primary windings shown in Figs. 1 and 2 comprise coils 10, 11, and 12 for three phases. The coil for each phase is provided with two taps 13 and 14, and two switches 15 and 16 are provided for connecting the taps with a supply line. The switches 15 and 16 may be operated in any suitable manner. The taps 13 are preferably located at the ends of the coils so that the full windings are in circuit when the switches 15 are closed. The taps 14 are preferably so located as to provide a secondary voltage of about 30 to 40% above the secondary voltage obtained when the taps 13 are used.

Additional taps and switches may be provided to connect any desired portions of the coils with the supply lines. For the purpose of obtaining additional voltages, suitable connections may be provided for selectively connecting the complete coils or portions of the coils in delta or star.

A reactance element 17 is located in each supply line ahead of the switches 15 and 16. A switch 20 is provided for short-circuiting the reactance coil when desired. A switch 21 is connected to the reactance coil between the center and end, and it may be connected to the taps 22 and 23 at the ends of the coil to short-circuit any desired portion of the coil. A main breaker 19 may be provided in the supply lines before the primary.

Each phase of the star connected secondary windings shown in Figs. 1 and 4 comprises two coils 24 and 25. Two opposite ends of the coils 24 and 25 are connected to a double throw switch 26 mounted for contact with the contact elements 27 in a circuit 30. The other opposite ends of the coils 24 and 25 are connected to contact elements 31 adjacent the switch 26 and so arranged that when contact between the elements 31 and switch 26 is established the coils 24 and 25 are connected in parallel. The circuit 30 comprises a conductor 32 connected to the contact elements 27 and provided with a switch 33. A reactance coil 34 provided with taps 35 is connected to the conductor 32 on one side of the switch 33, and a switch 36 adapted for contact with the taps 35 is connected to the conductor 32 on the other side of the switch 33. When the switch 26 is in contact with the elements 27 and one of the switches 33 and 36 is closed, the coils 24 and 25 are connected in series.

The secondaries are suitably connected by means of the conductors 37 to the three adjustable electrodes 40 of the electric arc furnace 41. The neutral point of the secondary windings is operatively connected to the bottom of the furnace 41 by means of the conductor 42. A switch 39 may be inserted in the line 42.

The delta connected primary windings shown in Figs. 3 and 4 comprise coils 43, 44 and 45 for three phases. The coil for each phase is provided with two taps 46 and 47, and two switches 50 and 51 are provided for connecting the taps with a supply line. The switches 50 and 51 may be operated either manually or mechanically and by direct or remote control means. Each of the primary coils may be provided with any desired number of taps. Adjustable external reactance means similar to those shown in connection with the star connected primaries may be provided. Switches 52 are provided for connecting the coils to one another and to the supply lines. A main breaker 48 is provided in the supply lines before the switches 52.

Each phase of the delta connected secondary windings shown in Figs. 2, 3 and 6 comprises two coils 53 and 54 which may be suitably connected to the electrodes of an electric furnace (not shown). Two opposite ends of the coils 53 and 54 are connected to a double throw switch 55 mounted for contact with the contact elements 56 in a circuit 57. The other opposite ends of the coils 53 and 54 are connected to the posts 60 adjacent the switch 55 and so arranged that when contact between the contact elements 60 and switch 55 is established the coils 53 and 54 are connected in parallel. The circuit 57 comprises a conductor 61 connected to the contact elements 56 and provided with a switch 62. A reactance coil 63 provided with taps 64 is connected to the conductor 61 on one side of the switch 62, and a switch 65 adapted for contact with the taps 64 is connected to the conductor 61 on the other side of the switch 62. When the switch 55 is in contact with the contact elements 56 and one of the switches 62 and 65 is closed, the coils 53 and 54 are connected in series.

Fig. 5 shows a transformer having windings and connections which permit it to be operated as either an auto transformer or a transformer with separate primary and secondary windings. For purposes of illustration, only one phase is shown in detail as the three phases are similar. The primary winding 66 is provided with two taps 67 and 70 which may be connected by means of switches 71 and 72 to the supply line 73. A reactance coil 74 is included in the supply line before the switches 71 and 72. A switch 75 is provided for short-circuiting the reactance coil, and a switch 76 connected to the reactance coil between the center and an end may be utilized for short-circuiting different portions of the coil through contact with the contact elements 77 and 80 connected to the opposite ends of the coil. A switch 78 is positioned before the reactance coil 74.

Each of the two secondary coils 81 and 82 is provided with two taps 83 and 84 which may be connected by means of switches 85 and 86 to the contact elements 87 and 90. The contact elements 87 and an end of the coil 82 are connected to a double throw

switch 91 mounted for contact with the contact elements 92 in a circuit 93. The contact elements 90 and an end of the coil 81 are connected to the contact elements 94 adjacent the switch 91 and so arranged that when contact between the contact elements 94 and switch 91 is established the coils 81 and 82 are connected in parallel. The circuit 93 comprises a conductor 95 connected to the contact elements 92 and provided with a switch 96. A reactance coil 97 provided with taps 100 is connected to the conductor 95 on one side of the switch 96, and a switch 101 adapted for contact with the taps 100 is connected to the conductor 95 on the other side of the switch 96. When the switch 91 is in contact with the contact elements 92 and one of the switches 96 and 101 is closed, the coils 81 and 82 are connected in series. A double throw switch 102 is connected to the neutral end of the primary 66 and is adapted for contact with the contact elements 103 and 104. The contact element 103 is connected by means of a conductor 105 and switch 106 to the neutral point of the system. The contact element 104 is connected to an end of the secondary coil 81. A conductor 110 having a reactance coil 111 included therein is connected to an arcing electrode (not shown). A switch 112 is provided for short-circuiting the coil 111, and a switch 113 connected to the reactance coil between the center and an end provides means for short-circuiting different portions of the coil through contact with the posts 114 and 115 connected to the opposite ends of the coil.

The primary of the transformer shown in Fig. 6 comprises three coils 120, one for each phase, connected in star through star connected reactance elements 121. Each of the coils 120 is provided with a plurality of taps 122 by means of which the coils may be connected to the supply lines through the switches 123 and 124. A main breaker 125 is connected in the supply lines before the switches 123 and 124.

Each of the reactance elements is provided with a plurality of taps 126. Any desired taps on the reactance elements may be connected to an oil switch 127 by means of switches 128. An oil switch 129 is connected to the neutral ends of the primary coils for short-circuiting the reactance elements.

The primary hook-up shown in Fig. 6 may be used advantageously for operation under load without stopping the arcs.

The apparatus illustrated in Figs. 1 to 4, inclusive, is particularly well adapted to supply different voltages to the electrodes while controlling the reactance of the circuit. The reactance effect may be secured by means of the reactance elements connected to the primary coils or by means of the reactance elements connected between the separate coils of the secondary windings, and in suitable instances all of the reactance elements may be utilized. In the control of voltage and reactance by means of the secondary connections, for instance in the apparatus shown in Fig. 1, the double throw switches 26 may be manipulated to connect the coils 24 and 25 in series or in parallel. When a relatively high voltage is desired the switch 26 is moved into contact with contact elements 27. If the use of reactance is unnecessary the switch 36 may be opened and the switch 33 closed. If it is desired to increase the reactance of the circuit the switch 36 may be closed and the switch 33 opened. The desired amount of reactance may be obtained by connecting the switch 36 to a suitable tap 35. When a relatively low voltage is desired the switch 26 may be moved into contact with the contact elements 31 to connect two coils 24 and 25 in parallel, and the reactance element 34 is automatically cut out.

The apparatus of the invention thus provides means for applying a high voltage between the electrodes with the inclusion of a controllable reactance, and means for applying a low voltage between the electrodes with all reactance, except the inherent reactance, eliminated. Further control of the reactance of the circuit may be obtained by means of the reactance coil 17 and the switches 20 and 21 associated therewith. It may be noted that control of the voltage by means of the secondary connections may be accomplished by means of a switch whose carrying capacity need not be greater than the carrying capacity of the copper in either one of the secondary coils which are operated either in series or in parallel. One of the secondary coils, such as 24, may be permanently connected with the conductors leading to the electrode and when the two coils are operated in parallel the voltage changing switch merely serves to switch the other coil 25 in parallel with the coil 24. Thus, the switch need only be large enough to carry the current of one coil. The conductors 37 and the electrodes 40 should be large enough to carry the current of two coils, which is approximately double the current through one coil.

The switches 15 and 16 may be manipulated for the purpose of connecting the desired number of primary turns in circuit. In the circuit of the apparatus shown in Fig. 1, four different voltages may be applied to the electrodes. Thus, for example, if the induced voltage of the secondary coils 24 and 25 is approximately 57 volts between the ends of these windings, when the primary is connected to the switch 15 through the tap 13 to include the full winding, and the secondary coils 24 and 25 are connected in parallel, the voltage between any two electrodes will be approximately 100 volts. If the coils 24 and

25 are then connected in series the voltage between electrodes will be 200 and the voltage in the two coils in series will be approximately 114. Thus a range of 100 to 200 volts is available without changing the primary connections. The voltage applied to the secondary coils may be increased by manipulating the switches 15 and 16 to cut out a portion of the primary coils and include only a portion in the circuit through a tap 14. Thus, with the secondary coils in parallel, manipulation of the switches 15 and 16 will result in a slight change of the lower voltage. The taps may be so arranged that a range of about 100 to 120 volts is provided at the lower voltage. This is advantageous because near the finish of an operation when it is necessary to add cold material, to form a second slag, for example, a higher voltage is necessary to maintain the bath at the proper temperature. A much higher voltage, such as is available in the heretofore customary types of apparatus results in too high a temperature with resultant damage to the furnace. A low voltage range of about 100 to 120 volts permits ready control of the temperature.

The apparatus of the invention permits the use of simplified winding for the transformer and the use of relatively less expensive voltage changing switches.

The three phase transformer illustrated in Fig. 5 may be operated either as an auto transformer or a transformer with secondary windings. In the latter case it is only necessary that the three primary coils for the different phases have their neutral ends connected together and it is not necessary that this neutral phase be connected with the neutral point of the secondary system. If desired, the secondary windings may be operated in delta instead of in star as shown.

This system serves to supply a wider range of voltage to the electrodes. When the transformer is operated as an auto transformer, and the secondary coils are in series, voltage between electrodes will be approximately double the voltage of each coil. When the secondary coils are connected in parallel the voltage between electrodes is equal to the voltage of each coil. The voltages may also be varied by means of the secondary taps, and the reactance may be adjusted in accordance with the voltage.

The apparatus of the invention is well suited for carrying out an improved method of operating electric arc furnaces. The various connections provided permit ready control of the operating voltage through reactance changes, changes in transformer connections, or combined changes in reactance and transformer connections. Thus, the apparatus of the invention is particularly suitable for carrying out a process involving the use of three or more voltages during different operating stages. For example, an electric furnace melting operation may be started with the transformer connected to give a relatively high secondary voltage and with full reactance cut in the circuit. The arcs may be operated under such conditions until a small amount of the charge is melted and the arcs are steadied, or until the electrodes arc to a puddle of molten material. The operating voltage may then be increased by reducing the reactance or changing the transformer connections, or by reducing the reactance and changing the transformer connections. Subsequently, the operating voltage may be reduced by a change in transformer connections with or without a change in reactance.

I claim:

1. The combination with an electric furnace of a transformer having a plurality of secondary windings, a reactance element associated with said secondary windings, and means for selectively connecting said secondary windings and said reactance element in series or said secondary windings in parallel.

2. The combination with an electric furnace of a transformer having a plurality of secondary windings, an adjustable reactance element associated with said secondary windings, and means for selectively connecting said secondary windings and said reactance element in series or said secondary windings in parallel.

3. The combination with an electric furnace of a transformer having a plurality of secondary windings, a reactance element associated with said secondary windings, means for selectively connecting said secondary windings and said reactance element in series or said secondary windings in parallel, and means for varying the effect of said reactance element.

4. The combination with an electric furnace of a transformer having a plurality of secondary windings, a reactance element associated with said secondary windings, means for selectively connecting said secondary windings and said reactance element in series or said secondary windings in parallel, and means for short-circuiting said reactance element when said secondary windings are connected in series.

5. The combination with an electric furnace of a transformer comprising a primary winding, and a secondary winding having a plurality of coils, means for selectively connecting different portions of said primary winding with a source of supply of power, a reactance element associated with said secondary coils, and means for selectively connecting said secondary coils and said reactance element in series or said secondary coils in parallel.

6. The combination with an electric furnace of a transformer comprising a primary winding, and a secondary winding having a plurality of coils, means for selectively con-

necting different portions of said primary winding with a source of supply of power, an adjustable reactance element associated with said secondary coils, and means for selectively connecting said secondary coils and said reactance element in series or said secondary coils in parallel.

7. The combination with an electric furnace of a transformer comprising a primary winding, and a secondary winding having a plurality of coils, an adjustable reactance element associated with said primary winding, means for selectively connecting different portions of said primary winding with a source of supply of power, an adjustable reactance element associated with said secondary coils, and means for selectively connecting said secondary coils and said reactance element in series or said secondary coils in parallel.

8. The combination with an electric furnace of a transformer comprising a primary winding, and a secondary winding having a plurality of coils, a reactance element associated with said primary winding, means for selectively connecting different portions of said primary winding with a source of supply of power, a reactance element associated with said secondary coils, and means for selectively connecting said secondary coils and said reactance element in series or said secondary coils in parallel.

9. The method of operating an electric furnace which comprises using a relatively high voltage during one stage with reactance in the secondary circuit, and using a relatively low voltage during another stage with the reactance cut out of the secondary circuit and with portions of the transformer secondary windings connected in parallel.

10. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give a relatively high operating voltage and with relatively high reactance in the circuit, and subsequently changing the operating voltage by varying the reactance.

11. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give a high secondary voltage and with relatively high reactance in the circuit, operating the arcs under such conditions until a small amount of the charge is melted, then reducing the reactance to increase the operating voltage, and subsequently operating at a lower voltage.

12. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give a relatively high voltage and with relatively high reactance, reducing the reactance to increase the operating voltage, and subsequently reducing the operating voltage by varying the transformer connections.

13. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give a relatively high voltage and with relatively high reactance, reducing the reactance to increase the operating voltage, and subsequently reducing the operating voltage by varying the transformer connections and the reactance.

14. In combination, an electric furnace having adjustable arcing electrodes, a transformer having primary and secondary windings, the secondary windings comprising two sets of coils which may be operated in series or parallel, connection between one end of one of these coils and an electrode, and a double throw switch for connecting the other coil in series with a reactance coil and also the first mentioned coil, and for alternately connecting the second coil in parallel with the first mentioned coil without the reactance in circuit.

15. The method of operating an electric arc furnace which method consists in operating the furnace with a high voltage applied to the electrodes by operating with two secondary coils connected in series through a separate reactance coil, and at a different stage changing the connections and operating with the coils in parallel without the reactance coil in circuit.

16. In combination, an electric arc furnace having adjustable arcing electrodes, and a transformer system comprising separate primary and secondary windings, and means for connecting the primary windings to a supply circuit and inducing a relatively high voltage in the secondary windings for applying to the electrodes, and means for connecting the primary and secondary windings together as an auto transformer for a lower secondary voltage.

17. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give high secondary voltage and with relatively high reactance in the circuit, operating the arcs under such conditions until a small amount of the charge is melted, then reducing the reactance and changing the transformer connections to increase the operating voltage, and subsequently operating at a lower voltage.

18. The method of operating an electric arc furnace which comprises starting the melting operation with a transformer connected to give high secondary voltage and with relatively high reactance in the circuit, operating the arcs under such conditions until a small amount of the charge is melted, then reducing the reactance and changing the transformer connections to increase the operating voltage, and subsequently changing

the reactance and transformer connections to reduce the operating voltage.

19. In combination, an electric furnace having adjustable arcing electrodes, a transformer having primary and secondary windings, the secondary winding comprising two sets of coils which may be operated in series or parallel, a separate secondary reactance coil, and means for including said reactance coil in series with the two secondary coils when they are connected in series and for cutting the reactance coil out of circuit when they are connected in parallel.

In testimony whereof I affix my signature.

ALBERT E. GREENE.