

April 30, 1968

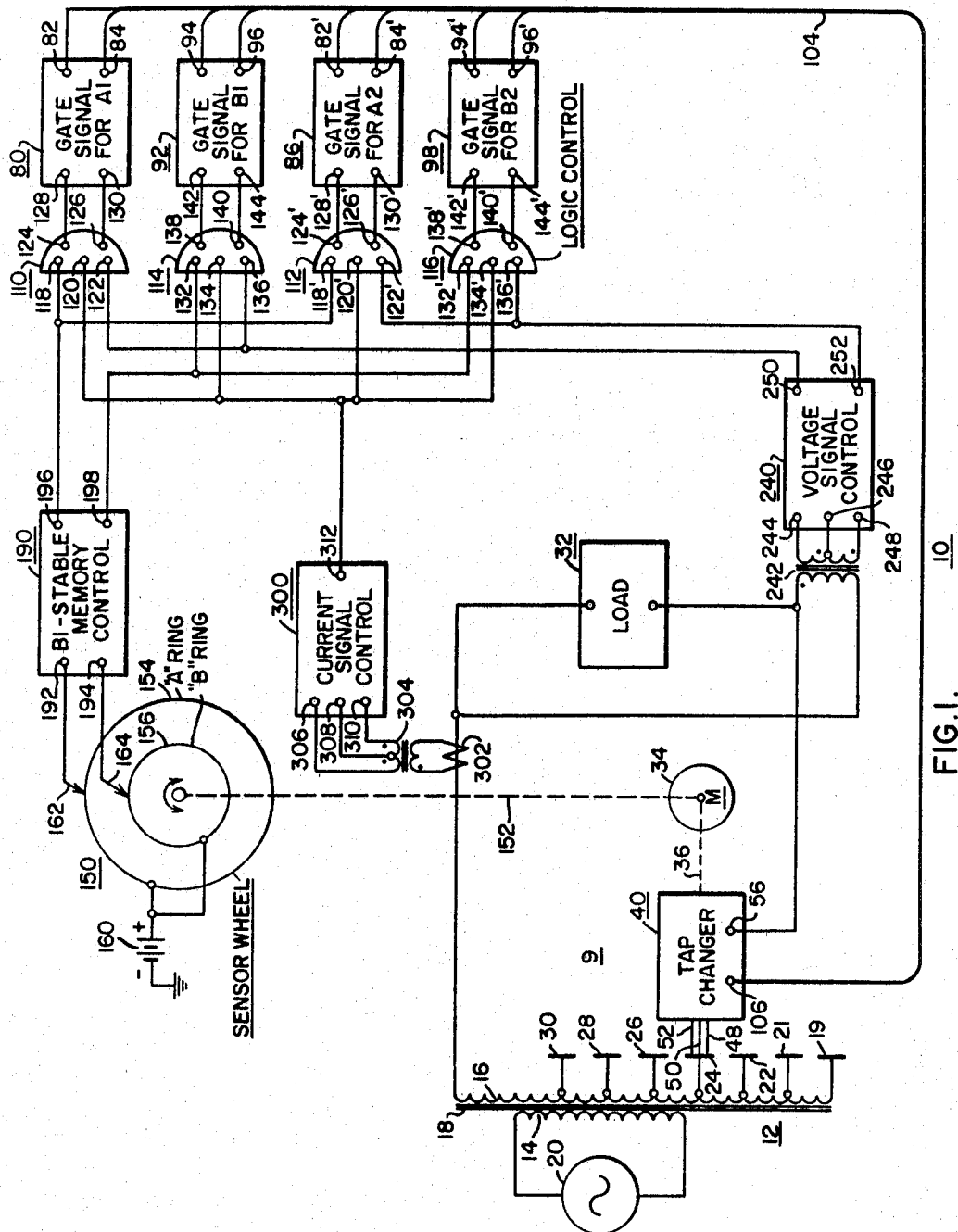
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3,381,213

TAP CHANGER APPARATUS

Filed March 29, 1966

4 Sheets-Sheet 1



WITNESSES:

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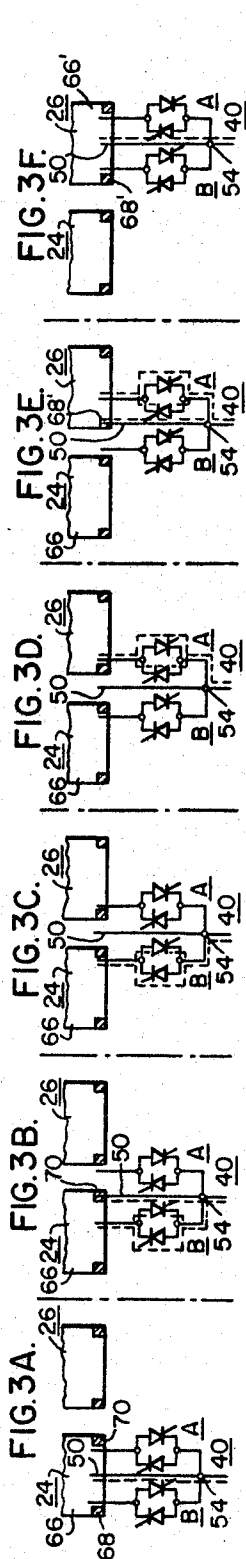
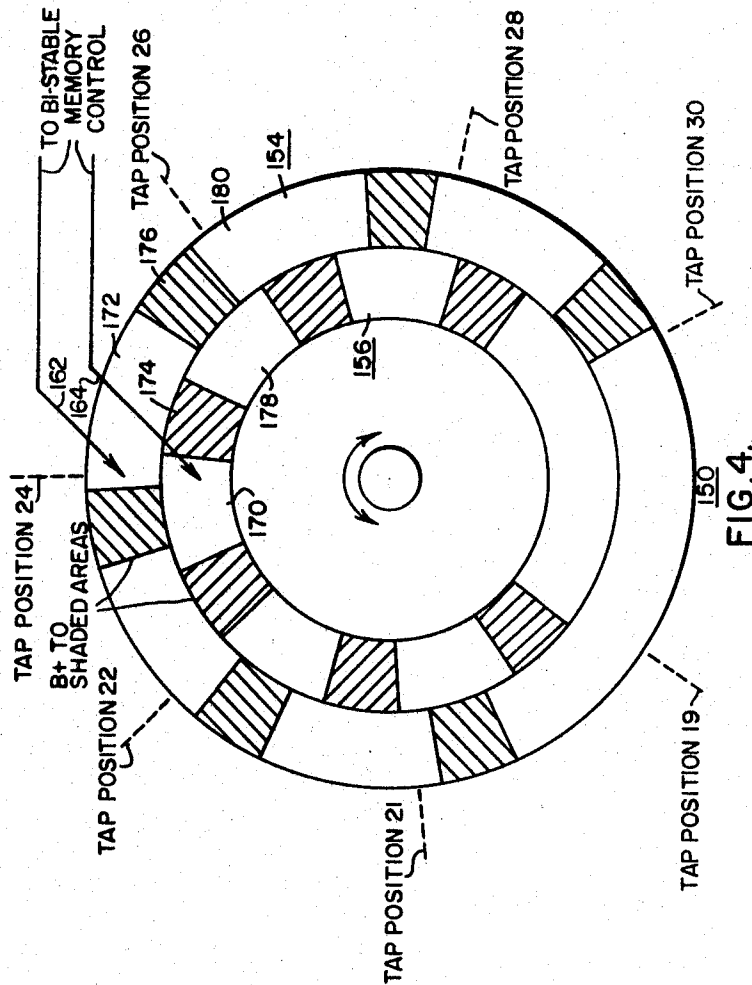
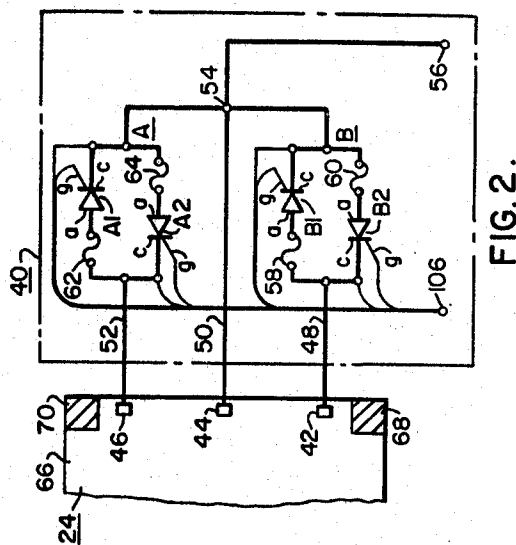
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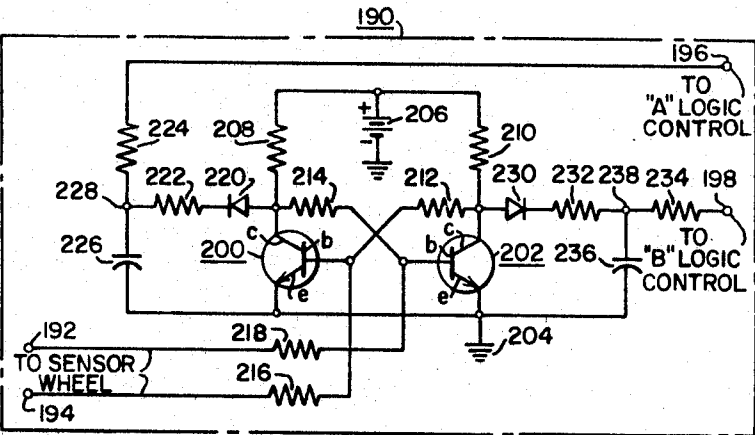


FIG. 5.

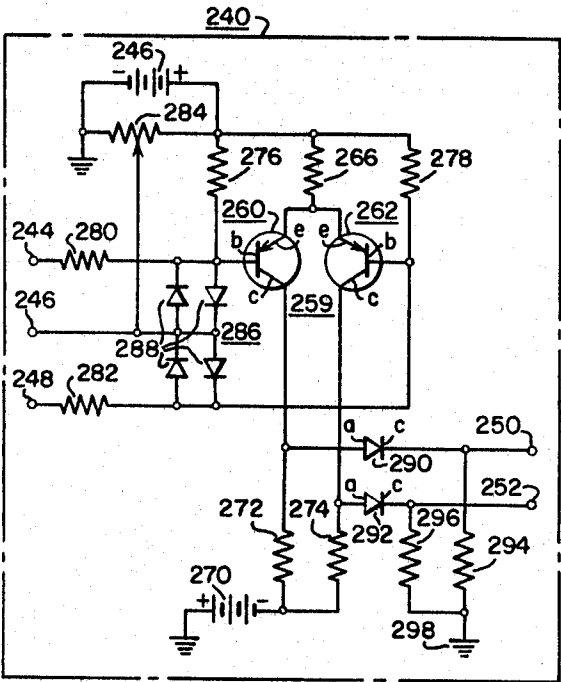


FIG. 6.

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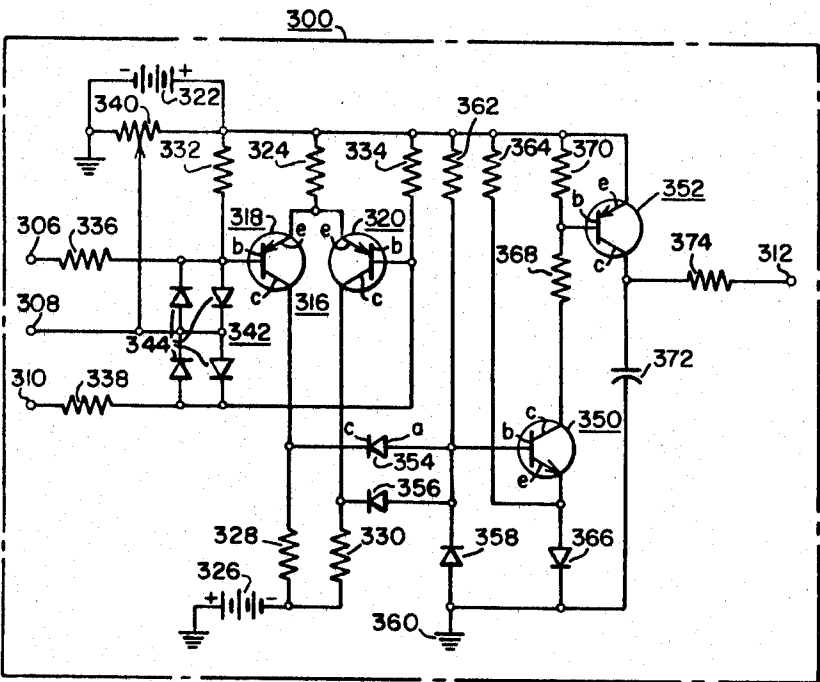


FIG. 7.

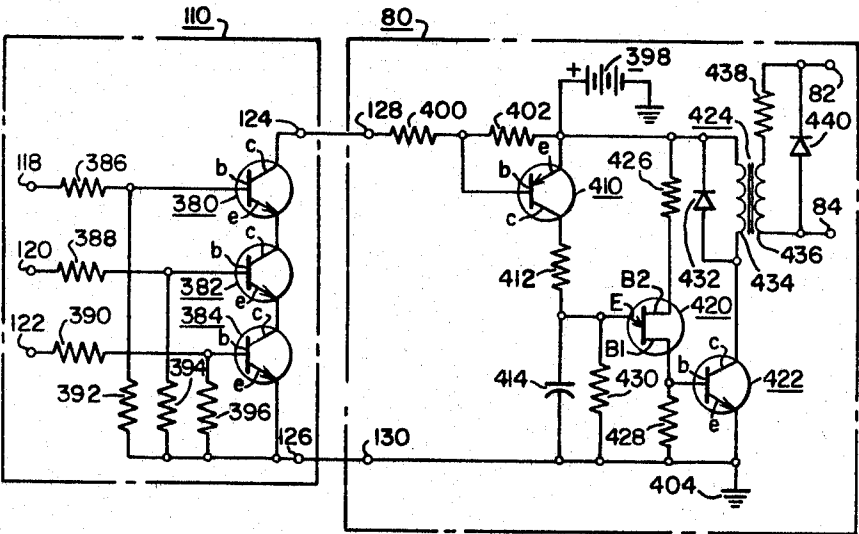


FIG. 8.

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TAP CHANGER APPARATUS

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7 Claims. (Cl. 323—43.5)

This invention relates in general to tap changer apparatus for electrical inductive apparatus, such as transformers, and more particularly to tap changer apparatus for changing taps on electrical inductive apparatus in a substantially arcless manner.

In tap changer apparatus for electrical transformers, the speed and frequency of switching taps, and the total number of switching cycles, is limited by the life of the contacts. The arcing produced between the stationary and movable contacts of the tap changer, during each switching cycle, causes melting and pitting, which destroys their usefulness after a limited number of switching cycles, resulting in periodic maintenance and replacement of the contacts. The maintenance of the contacts is not only costly, but it requires that the apparatus be taken out of service during these periods. As the voltage rating of the electrical apparatus whose taps are to be switched increases, the arcing problem becomes more acute, necessitating more frequent contact replacement. It would be desirable to eliminate, or substantially eliminate, the arcing between the contacts of the tap changer apparatus for electrical transformers, and thus greatly extend the useful operating life of the contacts, which would reduce the maintenance required on the tap changer apparatus, and reduce the time the associated transformer is out of service.

Accordingly, it is an object of the invention to provide new and improved tap changer apparatus for electrical transformers.

A further object of the invention is to provide new and improved tap changer apparatus for electrical inductive apparatus connected in an electrical power system which substantially increases the useful operating life of the tap changer contacts.

Another object of the invention is to provide new and improved tap changer apparatus for electrical transformers which changes taps under load in a substantially arcless manner.

Still another object of the invention is to provide new and improved tap changer apparatus for electrical transformers which allows taps to be quickly changed at a rate and frequency limited only by the mechanical speed of the tap changer, without appreciable arcing at the tap changer contacts, regardless of the magnitude of the voltage being switched.

Briefly, the present invention accomplishes the above cited objects by providing tap changer apparatus in which the electrical current is continuous throughout each tap changing cycle, with the current always being switched between taps at a current zero point.

More specifically, the invention discloses tap changer apparatus which utilizes switching means having a movable contact member which includes a main current carrying member flanked on each side by auxiliary controllable current carrying means. The auxiliary controllable current carrying means includes static switching devices which switch to conduct current at a predetermined time during a tap switching cycle, responsive to the mechanical position of the movable contact member, the instantaneous polarity of the voltage to be switched, and to the current zero point of the current being switched. Two parallel connected, oppositely poled, static switching devices are used in each auxiliary controllable current carrying

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means, one for each polarity of the electrical current being switched. A static switching device switches to its conductive state at a current zero when the movable contact member of the switching means is in the proper mechanical position relative to the taps, and the polarity of the potential on the device is proper. Before the main current carrying member leaves a tap, a certain auxiliary controllable current carrying means is rendered conductive, allowing the main current carrying member to leave the tap without interruption of the electrical current. Before the conducting auxiliary controllable current carrying means leaves the tap, the other auxiliary controllable current carrying means contacts the new tap, and current is transferred to this auxiliary controllable current carrying means from the conducting auxiliary current carrying means at a current zero. After the main current carrying member contacts the new tap, the now conducting auxiliary current carrying means ceases to conduct, thus accomplishing a tap change without any substantial arcing, and without requiring the use of bridging reactors, resistors, or preventive autotransformers commonly used in the prior art.

FIGURE 1 is a diagram, partially schematic and partially in block form, illustrating tap changer apparatus constructed according to the teachings of the invention;

FIG. 2 is a schematic diagram illustrating tap changer switching means constructed according to the teachings of the invention;

FIGS. 3A through 3F schematically illustrate a complete tap changing sequence;

FIG. 4 is a diagram of a sensor wheel which may be used to provide signals for correlating the switching of the tap changer switching means with the mechanical position of the movable contact portion of the switching means;

FIG. 5 is a schematic diagram of rotational memory control which may be used to provide electrical signals responsive to the rotation of the sensor wheel shown in FIG. 4;

FIG. 6 is a schematic diagram of control means which may be used to provide signals responsive to the polarity of the voltage to be switched;

FIG. 7 is a schematic diagram of control means which may be used to provide signals responsive to the current zero points of the current to be switched; and

FIG. 8 is a schematic diagram of the logic and control signal means which may be used to provide control signals for the controllable static switching devices in the tap changer means in response to the signals of the rotational memory control, the voltage polarity control means, and the current zero control means of FIGS. 5, 6 and 7, respectively.

Referring now to the drawings, and FIGURE 1 in particular, there is shown tap changer apparatus 10, partially schematic and partially in block form, constructed according to the teachings of the invention. FIG. 1 illustrates an electrical power system 9 which includes electrical inductive apparatus, such as transformer 12, which has windings 14 and 16 disposed in inductive relation with magnetic core 18. Winding 14 is connected to a source 20 of alternating potential, and winding 16, which has a plurality of tap connections, such as taps 19, 21, 22, 24, 26, 28 and 30, is connected to a load circuit 32 through tap changer switching means 40. Tap changer switching means 40 is driven by suitable driving means, such as motor 34, through a suitable linkage 36. Driving means 34 may be responsive to a suitable voltage regulator (not shown), which regulates the load voltage to a predetermined magnitude.

Transformer 12 is shown for illustrative purposes only; any electrical inductive apparatus arrangement which has

windings having taps thereon which are to be changed under load would be equally suitable. For example, the transformer 12 instead of having isolated windings, may be of the autotransformer type.

The tap changer switching means 40 is shown schematically in FIG. 2, and includes three contacts 42, 44 and 46, supported by conductor arms 48, 50 and 52, respectively. Conductor arms 48, 50 and 52 extend outwardly in spaced relation from a common electrical connection 54, which is in turn connected to terminal 56, adapted for connection to the load circuit 32. Conductor arms 48, 50 and 52 are mechanically related such that they may be moved in unison from tap position to tap position by driving means 34, with their contacts 42, 44 and 46 being in engagement with the stationary tap positions.

Conductor arm 50 of tap changer switching means 40 is the main current carrying element, which may be constructed of copper, or other suitable low resistance material, and is disposed between arms 48 and 52.

Arms 48 and 52 are auxiliary current carrying members and they have a controllable ability to conduct electrical current. Conductor arm 48, which will also be referred to as the B arm, has two parallel connected controllable static switching devices B1 and B2, connected "back to back." For example, the switching devices B1 and B2 may be controlled rectifiers, such as semiconductor silicon controller rectifiers, each having an anode electrode *a*, a cathode electrode *c*, and a gate or control electrode *g*. Switching device B1 is poled to conduct electrical current from tap 24 to terminal 54, and switching device B2 is poled to conduct electrical current from terminal 54 to tap 24. In other words, the anode electrode *a* of device B1 is connected to the cathode electrode *c* of device B2, and this common connection is connected to contact 42, and the cathode electrode *c* of device B1 is connected to the anode electrode *a* of device B2, and this common connection is connected to terminal 54. Fuses 58 and 60 may be connected in series with devices B1 and B2, respectively, if desired.

Conductor arm 52, which will also be referred to as the A arm, is constructed in a manner similar to conductor arm 48, having two parallel, back-to-back connected switching devices A1 and A2, which may be silicon controlled rectifiers, each having anode, cathode and gate electrodes, and protected by serially connected fuses 62 and 64, respectively.

As shown in FIG. 2, each stationary tap, such as tap 24, includes a main current carrying conductor 66, formed of copper or other good electrical conductor, and having two areas 68 and 70 disposed to be the first or last areas of the tap which are contacted by the switching means 40, depending upon whether it is the tap to which the switching means is proceeding, or the tap from which the switching means is leaving. Areas 68 and 70 serve a dual purpose. They should have a slightly higher electrical resistance than the main conductor portion 66, in order to cause the voltage drop across the main conductor arm 50 to more nearly match the voltage drop across the auxiliary conductor arms A and B, which substantially eliminates any arcing when the main conductor leaves or first contacts a tap. Further, the higher resistance material removes the effective "short" across the switching devices in the auxiliary conductor arms which is effectively provided by the main conductor arm 50 when it is contacting portion 66 of the tap. Thus, sufficient voltage across the switching devices is provided which allows the devices to switch to their conductive states when gated, when the main conductor arm 50 moves from the portion 66 of the tap of low resistivity to the portion of the tap of higher resistivity. This higher resistivity area may be provided by material such as tungsten.

Tap changer switching means 40 is moved from tap to tap, to either increase or decrease the voltage, in the sequence shown in FIGS. 3A through 3F. In FIG. 3A, the tap changer switching means 40 is on tap 24, and the

current is flowing through the main conductor arm 50, as shown by the broken line. For purposes of illustration, assume that the regulating means calls for the tap changer switching means 40 to move to tap 26. When the tap changer switching means starts to move in the direction of tap 26, gating signals are applied to the devices in the B arm, with one of the devices having a signal applied thereto on one polarity of the alternating current to be switched, and the other device having a signal applied thereto on the opposite polarity. As long as the main conductor arm 50 is on the main conductor portion 66 of the stationary tap 24, the voltage across the devices in the B leg will be insufficient to cause them to conduct, as the voltage drop across the main conductor arm 50 is very small. When the main conductor arm contacts the higher resistance material 70, however, as shown in FIG. 3B, the voltage drop from tap 24 to terminal 54 will be sufficient to cause the devices in the B arm to conduct. Current will then flow through the main conductor arm 50, and the B arm, as shown in FIG. 3B. Since current is flowing in the B arm, the main conductor arm 50 may now leave tap 24 without interrupting the load current, as shown in FIG. 3C. It will be noted in FIG. 3C, that conductor arm A has now made contact with tap position 26, and that the total load current is still being carried by conductor arm B on tap 24. Once the tap changer switching means 40 is in the position shown in FIG. 3C, the current is switched from conductor arm B on tap 24 to conductor arm A on tap 26, as shown in FIG. 3D. This is accomplished, as will be hereinafter explained, by switching the current between the arms at a current zero, which precludes shorting out the winding through the tap changer switching means 40. The current zero point is used rather than a voltage zero point, as the phase angle between the voltage and current may not be zero degrees. Once the current has been switched to the A arm on tap 26, the main conductor arm 50 may now make contact with tap 26 with substantially no arc. The main conductor arm 50 first contacts the higher resistance material or area 68' on tap 26, which allows conductor arm A to continue to conduct, as shown by the broken lines in FIG. 3E, and reduces arcing to a substantially negligible amount. Once the main conductor arm 50 moves off of the higher resistance material 68' to the main conductor portion 66' of tap 26, the voltage drop across the devices of conductor arm A will be insufficiently to cause them to continue to conduct, and only the main conductor arm 50 will carry current as shown in FIG. 3F.

Tap changer switching means 40 may also move in the opposite direction, by reversing the described operation and following the sequence shown in FIG. 3F to FIG. 3A.

Thus, a complete tap change has been made with negligible arcing, as the load current is never interrupted. The only arcing is due to any slight differences in the voltage drop across the main conductor arm 50 compared with the voltage drop across the auxiliary conductor arm A or B.

The duty cycle on the devices in the conductor arms A and B is very low, allowing surge current ratings to be utilized to carry the high currents encountered. The voltage rating of the devices need only be that of the tap voltage i.e., the voltage between adjacent taps, as the devices are never subjected to the total transformer voltage.

It should also be noted that the tap changer switching means 40 does not require resistors, bridging reactors, or autotransformers, to make a tap change. However, if it is desirable to increase the number of voltage steps without increasing the number of taps on the transformer winding, another tap changer switching means 40 could be utilized, with each being electrically connected to an end of a preventive autotransformer.

To accomplish the switching of the tap changer switch-

ing means 40 from one tap to another in a substantially arcless manner, requires the coordination of several factors. The gating or control signals must be applied to the proper auxiliary conductor arm, and to the proper device, at the proper time, and this requires coordination between the mechanical position of the tap changer switching means, the polarity of the alternating potential, the current zero points, and the gating or control means which provides signals for initiating the conduction of the switching devices in the auxiliary conductor arms A and B.

Each of the devices A1, A2, B1 and B2 in the auxiliary conductor arms A and B as shown in FIG. 2, have their own gating means, as shown in FIG. 1. Device A1 has gate signal control means 80, which has output terminals 82 and 84, device A2 has gate signal control means 86 which has output terminals 82' and 84', device B1 has gate signal control means 92 which has output terminals 94 and 96, and device B2 has gate signal control means 98 which has output terminals 94' and 96'. The various output terminals of gate control means 80, 86, 92 and 98 are connected to the tap changer switching means 40, as shown generally by conduit 104 and terminal 106 on tap changer switching means 40. The conductors from the gate signal control means 80, 86, 92 and 98 are connected to the gate and cathode electrodes of its associated device A1, A2, B1 and B2, respectively, as shown in FIG. 2.

A particular static switching device should receive gate signals when: (1) the tap changer switching means is in a predetermined position, (2) the polarity of the alternating potential is proper for the device, and (3) the alternating load current is at a zero point in its waveform. This may be accomplished by logic control means 110, 112, 114 and 116 connected to the gate control means 80, 86, 92 and 98, respectively, with the logic control means providing a signal to its associated gate control means when the three factors mentioned above all occur or are present simultaneously.

Logic control means 110, 112, 114 and 116 may each comprise an "AND" circuit, providing an output signal when it has an input signal present at all of its input circuits. For example, logic control means 110 and 112 may have input terminals 118, 120 and 122, and 118', 120' and 122', respectively, responsive to the position of the tap changer switching means 40, the current zero points of the load current, and the polarity of the alternating potential, respectively. When the tap changer switching means reaches a position where conductor arm A should be conductive, a signal is applied to terminals 118 and 118'. When the load current reaches a zero point in its waveform, a signal is applied to terminals 120 and 120'. When the polarity of the alternating potential is positive, a signal is applied to terminal 122 of logic control means 110, and when the polarity of the alternating potential is negative, a signal is applied to terminal 122' of logic control means 112. Each time input terminals 118, 120 and 122 of logic control means 110 all have a signal present, logic control means 110 will apply a signal from its output terminals 124 and 126 to input terminals 128 and 130, respectively, of gate signal control means 80, and gate signal control means 80 will apply gate or control signals to the gate electrode g of device A1.

In like manner, each time input terminals 118', 120' and 122' of logic control means 112 receive or have a signal present simultaneously, logic control means 112 will apply a signal from its output terminals 124' and 126' to input terminals 128' and 130' of gate signal control means 86, and gate signal control means 86 will apply gate or control signals to a gate electrode g of device A2.

Logic control means 114 and 116 may have input terminals 132, 134, and 136, and 132', 134' and 136', respectively, which are connected to be responsive to the position of tap changer switching means 40, the current zero points of the load current waveform, and the polarity of the alternating potential, respectively. When the tap

changer switching means reaches a position where the B conductor arm should be conductive, a signal is applied to terminals 132 and 132'. When the load current reaches a zero point, a signal is applied to terminals 134 and 134'.

When the polarity of the alternating potential is positive, a signal is applied to terminal 136 of logic control means 114, and when the polarity is negative, a signal is applied to terminal 136' of logic control means 116. Each time input terminals 132, 134 and 136 of logic control means 114 have a signal present simultaneously, logic control means 114 will apply a signal from its output terminals 138 and 140 to the input terminals 142 and 144, respectively, of gate signal control means 92, and gate signal control means 92 will apply gate signals to the gate electrode g of device B1.

In like manner, each time input terminals 132', 134' and 136' of logic control means 116 have a signal present simultaneously, logic control means 116 will apply a signal from its output terminals 138' and 140' to the input terminals 142' and 144', respectively, of gate signal control means 98, and gate signal control means 98 will apply gate signals to the gate electrode g of device B2.

Signals responsive to the position of tap changer switching means 40 may be obtained, as shown in FIG. 1, by a sensor wheel 150 which is mechanically coupled, via linkage 152, to the driving means 34, which also drives the tap changer switching means 40. Sensor wheel 150 may include two concentrically disposed rings, an A ring 154 for signaling when conductor arm A should be conductive, and a B ring 156 for signaling when conductor arm B should be conductive. Each ring may have a unidirectional potential applied thereto, from a source of unidirectional potential, such as represented by battery 160. The surface of each ring 154 and 156 may have certain areas insulated, such that when it rotates in response to driving means 34, stationary sensor arms 162 and 164, which ride on the surface of the A and B rings 154 and 156, respectively, will contact areas of potential and areas which are insulated from the potential, depending upon whether the tap changer switching means 40 is in position for the A or B arms to be conductive.

For example, sensor wheel 150 may be constructed as shown in FIG. 4, in which the shaded areas of the A and B rings 154 and 156, respectively, indicate areas connected to the supply potential, and the unshaded areas indicate areas insulated from the supply potential. The tap positions on the sensor wheel 150 are marked for the various taps 19, 21, 22, 24, 26, 28 and 30 shown in FIG. 1. It will be noted that one area of potential lies between each tap position on each ring, with the areas of potential on the A and B rings being spaced circumferentially from one another. For example, with the tap changer switching means 40 on tap 24, as shown in FIG. 1, the A and B sensor arms 162 and 164 contact the A and B rings 154 and 156 at tap position 24, with both sensor arms 162 and 164 contacting areas 170 and 172, which are insulated from the supply potential. If the sensor wheel 150 moves counterclockwise, signifying a change from tap position 24 to tap position 26, sensor arm 164 comes into contact with area 174, which is connected to the supply potential, while sensor arm 162 continues to contact insulated area 172. As sensor wheel 150 continues to rotate, sensor arm 164 reaches insulated area 178, while sensor arm 162 is still in contact with the insulated area 172. Then, sensor arm 162 contacts area 176, which is connected to the supply potential, with sensor arm 164 still being in contact with insulated area 178. The sensor wheel 150 continues to rotate until the sensor arms 162 and 164 are in contact with the sensor wheel at tap position 26, at which point sensor arm 162 is in contact with insulated area 180, and sensor arm 164 is in contact with insulated area 178.

Thus, in moving from tap 24 to tap 26, first the B ring 156 provides a signal that conductor arm B of switching means 40 should be energized, and then the A ring 154 provides a signal that conductor arm A of switching

means 40 should be energized. This is the switching sequence desired when moving from tap 24 to tap 26, as illustrated in FIGS. 3A-3F. If the tap changer switching means 40 moves from tap 24 to tap 22, the sensor wheel 150 would move clockwise, first signaling that the A arm should be conductive, and then the B arm, which is the required sequence when moving in this direction, as shown by following the sequence illustrated in FIGS. 3F through 3A.

It will be noted that the insulated areas 172 and 178 overlap, providing a point during the tap changing cycle where neither sensor arm 162 or 164 are in contact with the supply potential, and yet the requirements are for either the A arm or the B arm to be receiving gating signals once a tap change has been initiated. This space between the areas of potential does not provide any discontinuity in the gating signals, however, as the sensor wheel 150 does not directly provide signals for the logic control means. A bi-stable memory control 190 is disposed between the sensor wheel 150 and the various logic control means, which continuously provides output signals for either the A arm or the B arm to switch, with the areas of potential on sensor wheel 150 being used to switch the output signal from one output terminal of the bi-stable memory control to the other. The bi-stable memory control 190 is used to provide signals which indicate which conductor arm of tap changing means 40 should be ready for switching, as difficulties are encountered when attempting to use the signals directly from the sensor wheel 150. For example, the devices, such as silicon controlled rectifiers, which are used in the A and B conductor arms of the tap changer switching means 40, do not have sufficient voltage capacity to let the current go to zero at the same time that the voltage is rising. Therefore, the energized areas on the sensor wheel would have to have some overlap. If the areas of potential overlap, then during the overlap period both positive or both negative connected devices on arms A and B would be gated simultaneously, with the device on the conductor arm in contact with the lower voltage tap being "auctioneered off" by the device in the arm in contact with the higher voltage tap. Thus, the tap changer switching means could only move satisfactorily in one direction, i.e., to move to the higher voltage taps. It would not operate properly in the reverse direction, i.e., to move to the lower voltage taps. To overcome this difficulty, the sensor wheel 150 is used to control the output of bi-state memory control means 190. Bi-stable memory control means has input terminals 192 and 194 connected to the sensor arms 162 and 164, respectively, and output terminals 196 and 198. Output terminal 196 of memory control means 190 is connected to input terminals 118 and 118' of logic control means 110 and 112, respectively, and output terminal 198 is connected to input terminals 132 and 132' of logic control means 114 and 116. Thus, when the A arm of tap changer switching means 40 may be conducting, terminal 196 provides an output signal, and when the B arm may be conducting, terminal 198 provides an output signal.

Bi-stable memory control means 190 may provide an output signal continuously at one or the other of its output terminals, with the terminal providing the output signal being determined by the sensor wheel 150. The memory control 190 may provide an output signal, even when the tap changer switching means 40 is in its steady state position on one of the taps, since when the main conductor arm 50 is shunting the A and B conductor arms and is in contact with the main conductor portion 66 of the stationary tap, the voltage drop across the main conductor arm is insufficient to cause the devices to conduct even though they are receiving gating signals. If, for some reason, however, it is not desirable to provide gating signals when the tap changer switching means 40 is in a steady state position on a tap, many different disabling arrangements may be used. For example, the logic control circuits may have an additional input circuit responsive to

an additional ring on the sensor wheel 150, which is energized except when the tap changer means is squarely on a tap position.

A bi-stable memory control 190 which may be used to provide signals to the logic control means responsive to sensor wheel 150 is shown in FIG. 5. The bi-stable memory control 190 may be a solid state bi-stable "flip-flop" circuit, which includes transistors 200 and 202, which may be of the NPN junction type shown, having base, collector, and emitter electrodes *b*, *c*, and *e*, respectively. The emitter electrodes *e* of transistors 200 and 202 are connected in common to ground 204, their collector electrodes *c* are connected to a source of unidirectional potential, represented by battery 206, through current limiting resistors 208 and 210, respectively, their base electrodes *b* are connected to the collector electrodes *c* of the other transistor through collector coupling resistors 212 and 214, respectively, and their base electrodes *b* are connected to input terminals 194 and 192 through biasing resistors 216 and 218, respectively.

The collector electrode *c* of transistor 200 is connected to output terminal 196 through asymmetrically conductive device 220, such as a diode poled to conduct current from collector electrode *c* to the terminal 196, and through current limiting resistor 222 and resistor 224. A capacitor 226 is connected from the emitter electrode *e* of transistor 200 to the junction 228 between resistors 222 and 224.

In like manner, the collector electrode *c* of transistor 202 is connected to the output terminal 198 through asymmetrically conductive device 230, poled to conduct current from the collector electrode *c* to terminal 198, and through current limiting resistor 232 and resistor 234. A capacitor 236 is connected from the emitter electrode *e* of transistor 202 to the junction 238 between resistors 232 and 234.

In the operation of bi-stable memory control means 190, one of the transistors will be saturated and the other cut off or non-conductive, due to inherent differences in the devices, with base drive being supplied to the saturated transistor from supply potential 206 through resistor 212 or resistor 214. Assume that transistor 202 is conducting and transistor 200 is cut-off. An output signal will thus be applied to terminal 196 from the collector of transistor 200. Now assume that sensor wheel 150 shown in FIG. 4 starts to rotate counterclockwise, with sensor arm 164 contacting the energized area 174. Base drive is thus applied to the base electrode *b* of transistor 200 through resistor 216, causing transistor 200 to saturate which causes transistor 200 to become cut-off, as its base electrode *b* is connected to ground 204 through the saturated transistor 200. A signal is now applied to terminal 198 and the B logic circuits 114 and 116 from the collector electrode *c* of transistor 202. As sensor wheel 150 continues to rotate, the position is reached where both sensor arms 162 and 164 are contacting insulated areas. However, the memory circuit continues in its previous mode of operation, as transistor 200 receives base drive from source 206 through resistor 212. When sensor arm 162 contacts energized area 176, base drive is applied to the base electrode *b* of transistor 202, causing it to saturate and causing transistor 200 to cut-off. The output signal is thus switched to terminal 196 and the A logic circuits 110 and 112. Upon reaching tap position 26, the memory control will continue in its last mode of operation. Assume that the sensor wheel now starts to rotate clockwise to return to tap position 24 from tap position 26. Sensor arm 162 contacts energized area 176, but since transistor 202 is already saturated, the circuit will not "flip," continuing to provide an output signal to terminal 196 and the A logic circuits. When sensor arm 164 contacts energized area 174, the circuit will "flip," to provide an output signal to the B logic circuits from terminal 198, and the circuit will remain in this mode until a new tap changing sequence is desired.

In order to preclude the possibility of gating or con-

trol signals being required while the circuit is switching from one mode of operation to the other, capacitors 226 and 236 are provided, which are charged through diodes 220 and 230. When the circuit flips or changes from one mode of operation to the other, the capacitors are discharged to provide signals to both output terminals. While both the positive or both negative connected devices in the A and B conductor arms may fire or become conductive during this short interval, only the device of the higher potential will continue to conduct.

To insure that a short circuit will not be produced across a tapped portion of the transformer winding when the A and B arms are on different taps, by having a device in one arm poled in one direction receive a gating signal, and by having a device in the other arm poled in the opposite direction receive a gating signal, voltage signal control means 240 is provided which only supplies signals to the logic control circuits of one polarity or the other. For example, devices A1 and B1 of tap changer switching means 40 shown in FIG. 2, are poled in the same direction, and devices A2 and B2 are poled in the same direction. When the polarity of the transformer voltage is proper for either device A1 or B1 to conduct, sensed by a potential transformer 242 connected to be responsive to the transformer voltage and to the input terminals 244, 246 and 248 of voltage signal control means 240, a signal is provided at output terminal 250 of voltage signal control means 240 which is applied to the input terminals 122 and 136 of logic control means 110 and 114, respectively. No signal is provided at output terminal 252.

When the polarity of the transformer voltage is proper for either device A2 or B2 to conduct, a signal is provided at output terminal 252 which is applied to input terminals 122' and 136' of logic control means 112 and 116, respectively. Thus, oppositely poled devices in conductor arm A and conductor arm B may never be gated at the same time.

A voltage signal control circuit 240 which may be utilized is shown in FIG. 6. The voltage signal control circuit includes a balanced differential amplifier 259 which includes transistors 260 and 262, which may be of the PNP junction type, each having a base, emitter, and collector electrodes, *b*, *e*, and *c*, respectively. The emitter electrodes *e* of transistors 260 and 262 are connected in common, and the common connection is connected to the positive terminal of a source of unidirectional potential, represented by battery 246, through a resistor 266 which acts as a constant current source. The collector electrodes *c* of transistors 260 and 262 are connected to the negative terminal of a source of unidirectional potential, represented by battery 270, through resistors 272 and 274, respectively. Bias resistors 276 and 278 are connected from the base electrodes *b* of transistors 260 and 262, respectively, to the source potential 246. The base electrodes *b* of transistors 260 and 262 are also connected to be responsive to the voltage applied to input terminals 244, 246 and 248 by potential transformer 242, with terminal 244 being connected to the base electrode *b* of transistor 260, and terminal 248 being connected to the base electrode *b* of transistor 262, through current limiting resistors 280 and 282, respectively.

The mid-tap of a potential transformer which is connected to terminal 246, is connected to the emitter electrodes *e* of transistors 260 and 262 through adjustable bias resistor 284.

Clamping means 286, which may include a plurality of parallel back-to-back diodes 288, may be connected across input terminals 244, 246 and 248 to limit the magnitude of the incoming signal. The collector electrodes *c* of transistors 260 and 262 are connected to output terminals 250 and 252 through asymmetrically conductive devices 290 and 292, such as diodes having an anode electrode *a* and a cathode electrode *c*, poled to conduct current from the collectors to the output terminals, and including resistors

294 and 296 connected from the cathode electrode *c* of diodes 290 and 292, respectively, to ground 298.

In the operation of the voltage signal control means 240, the transistor whose base electrode is more negative will be saturated and the other transistor will be cut-off or non-conducting. Thus, assuming that the dots on the potential transformer 242 of FIG. 1 are positive, transistor 260 will be turned on while transistor 262 and diode 292 will be biased off. This allows the collector voltage of transistor 260 to rise above ground and forward bias diode 290, providing a positive output signal at terminal 250.

Assuming that dots on potential transformer 242 to be negative, transistor 262 will be turned on and transistor 260 and diode 290 will be biased off. This allows the collector voltage of transistor 262 to rise above ground and forward bias diode 292, which provides a positive output signal at terminal 252. Thus, terminal 250 provides a signal on one half cycle of the transformer voltage, and terminal 252 provides a signal on the other half cycle, with the signal from terminal 250 being applied to logic control circuits 110 and 114, which are associated with devices A1 and B1, which are poled in the same direction, and the signal from terminal 252 being applied to logic control circuits 112 and 116, which are associated with devices A2 and B2, and which are also poled in the same direction, but opposite to the devices A1 and B1.

In order to switch the current from one tap to the next and insure that a lagging current does not keep a device in one conducting arm conducting as an oppositely poled device is gated in the other arm, which would cause the tapped winding to be short circuited through the tap changer switching means 40, the switching from one controllable conductor arm to the other should be made at a current zero. Further, since the current zero time is so short, the signal responsive to the current zero points must exist for a time sufficient to insure the current in the device to be switched to its conductive state is above the holding current before its gating signal is removed.

A signal responsive to the current zero point in the current waveform is provided by current signal control means 300 shown in FIG. 1, which is responsive to the load current through current transformers 302 and 304. Current transformer 304 is center-tapped, and has its output terminals connected to input terminals 306, 308 and 310 of current signal control means 300. The output terminal 312 of current signal control means 300 is connected to input terminals 120, 120', 134, and 134' of logic control means 110, 112, 114 and 116, respectively.

Current signal control means 300 which may be used for providing signals responsive to the zero points in the waveform of the load current is shown in FIG. 7. Current signal control means 300 includes a differential amplifier 316, similar to the differential amplifier used in the voltage signal control means 240, shown in FIG. 6. The differential amplifier 316 includes transistors 318 and 320, which may be of the PNP junction type shown, each having base, collector and emitter electrodes, *b*, *c* and *e*, respectively. The emitter electrodes *e* of transistors 318 and 320 are connected in common, and the common connection is connected to the positive terminal of a source of unidirectional potential represented by battery 322, through a resistor 324, which acts as a constant current source. The collector electrodes *c* of transistors 318 and 320 are connected to a negative terminal of a source of unidirectional potential, represented by battery 326, through resistors 328 and 330, respectively. Bias resistors 332 and 334 are connected from the base electrodes *b* of transistors 318 and 320, respectively, to the source potential 322. The base electrodes *b* of transistors 318 and 320 are also connected to be responsive to signals applied to input terminals 306, 308 and 310 by current transformer 304, with terminal 306 being connected to the base electrode *b* of transistor 318 through current limiting resistor 336, and terminal 310 being connected to the base elec-

trode *b* of transistor 320 through current limiting resistor 338. The mid-tap of the current transformer 304, which is connected to terminal 308, is connected to the emitter electrodes *e* of transistors 318 and 320 through adjustable bias resistor 340. Clamping means 342, which may be a plurality of parallel connected, back-to-back diodes 344, may be connected across the input terminals 306, 308 and 310 to limit the magnitude of the incoming signal.

Also included in current signal control means 300 are transistors 350 and 352. Transistor 350 may be of the NPN junction type, having a base electrode, a collector electrode, and emitter electrode, *b*, *c*, and *e*, respectively, and transistor 352 may be of the PNP type, having base, collector and emitter electrodes *b*, *c*, and *e*. The base electrode *b* of transistor 350 is connected to the collector electrodes *c* of transistors 318 and 320 through asymmetrically conductive devices 354 and 356, respectively, such as diodes which are poled to conduct electrical current away from the base electrode *b* of transistor 350. The base electrode *b* of transistor 350 is also connected to the source 322 of unidirectional potential through resistor 362, and to ground 360 through asymmetrically conductive device 358, such as a diode poled to conduct electrical current in the direction from ground 360 to the base electrode *b*. The emitter electrode *e* of transistor 350 is connected to the source 322 of unidirectional potential 322 through resistor 364, and to ground 360 through asymmetrically conductive device 366, such as a diode poled to conduct electrical current away from the emitter electrode *e*. The collector electrode *c* is connected to the source 322 of unidirectional potential through resistors 368 and 370.

Transistor 352 has its emitter electrode *e* connected to the source 322 of unidirectional potential, its base electrode *b* connected to the junction between the collector resistors 368 and 370, and its collector electrode *c* connected to ground 360 through capacitor 372, and to the output terminal 312 through resistor 374.

In the operation of the current signal control means 300, base bias is provided the base electrode *b* of transistors 318 and 320 such that with a zero signal from the current transformer 304, transistors 318 and 320 will have identical collector currents, and the collector voltages will be equal. The diodes 354, 356 and 358 will be reverse biased, and current can flow through resistor 362 to the base electrode *b* of transistor 350, switching it to its conductive state. When transistor 350 is switched to its conductive state, transistor 352 is switched on, which applies a signal to the output terminal 312. Since the condition where a zero signal is applied to the input terminals from current transformer 304 occurs when the current goes through zero, a signal will be applied to output terminal 312 each time the load current goes through its zero point. Since the time when the current transformer 304 is not applying a signal to the input terminals is very short, some means must be added to increase the duration of the output signal to insure that the devices in tap changer switching means 40 will conduct when a gate signal is applied thereto. This "stretching" of the output signal may be accomplished by the RC circuit comprising capacitor 372 and resistor 374. When transistor 352 conducts, capacitor 372 will be charged. When transistor 352 ceases to conduct, capacitor 372 will discharge through resistor 374 to the output terminal 312, thus extending the duration of the output signal.

When current transformer 304 is applying a signal to the input terminals 306, 308 and 310, i.e., when the load current is not at a zero point, one of the transistors 318 or 320 will be saturated and the other will be cut-off on one half cycle, and the reverse will be true for the other current half cycle. Thus, either diode 354 or diode 356 will be forward biased, and current will flow through resistor 362 through the forward biased diode, clamping

transistor 350 in its non-conductive state and preventing signals from being applied to the output terminal 312.

Summarizing to this point, bi-stable memory control means 190 provides signals in response to the position of the tap changer switching means 40, which signals select which arm, the A or the B arm of tap changer switching means 40, which should be ready to conduct, voltage signal control means provides signals responsive to the polarity of the alternating potential of the system, which selects which device in the selected arm should be ready to conduct, and current signal control means 300 provides signals responsive to the current zero points and the load current waveform, which determines when the device selected should be gated to its conductive state.

The function of correlating these signals and providing an output signal when all three signals for a certain device exist simultaneously, is provided by the logic control means 110, 112, 114, and 116 shown in FIG. 1, and gating signals are applied to the device in tap changer switching means 40 in response to signals from the logic control means, which function is provided by gate signal control means 80, 92, 86 and 98, also shown in FIG. 1. Each device A1, A2, B1, and B2 in the tap changer switching means 40 shown in FIG. 2, has its own logic control means and gate signal means. Since the logic control and gate signal means is similar for each device, only the logic control and gating control for one device will be described in detail, such as logic control means 110 and gate signal control means 80, for device A1.

Many different logic and gating arrangements may be used, with FIG. 8 illustrating a typical logic and gating circuit which may be utilized.

Specifically, the logic control means 110 shown in FIG. 8 includes NPN transistors 380, 382 and 384, which may be of the NPN junction type, each having collector, emitter and base electrodes, *c*, *e* and *b*, respectively. The emitter and collector electrodes of transistors 380, 382 and 384 are connected in series, with the emitter electrode *e* of transistor 380 being connected to the collector electrode *c* of transistor 382, and the emitter electrode *e* of transistor 382 being connected to the collector electrode *c* of transistor 384. The collector electrode *c* of transistor 380 is connected to a source 398 of unidirectional potential through resistors 400 and 402. The emitter electrode *e* of transistor 384 is connected to ground 404. The base electrodes *b* of transistors 380, 382 and 384 are connected to input terminals 118, 120 and 122, respectively, through current limiting resistors 386, 388 and 390, respectively. Bias resistors 392, 394 and 396 are connected through the base electrodes *b* of transistors 380, 382, and 384, respectively, to ground 404. Thus, current will not flow through resistors 400 and 402 and through the collector-emitter circuits of transistors 380, 382 and 384, until positive signals are applied to input terminals 118, 120 and 122, which signals must exist simultaneously. When a positive signal is applied to all three input terminals, current will flow through the collector-emitter circuits of transistors 380, 382 and 384, which is a signal for the gate signal control means 80 to provide gating signals for its associated switching device A1.

Gate signal control means 80 includes a transistor 410, which may be of the PNP junction type having base, collector and emitter electrodes *b*, *c* and *e*, respectively, connected to switch to its conductive condition when current flows through the logic control circuit 110. Transistor 410 has its emitter electrode *e* connected to a source 398 of unidirectional potential, and its base electrode *b* to the junction between resistors 400 and 402. Thus, current flow through resistors 402 and 404 will forward bias transistor 410, switching it to its conductive condition. The collector *c* of transistor 410 is connected to ground 404 through resistor 412 and capacitor 414. Thus, capacitor 414 charges exponentially towards the magnitude

of the supply potential 398 when transistor 410 becomes conductive.

A unijunction transistor 420 is used in a relaxation oscillator circuit to provide pulses which are amplified by transistor 422 and applied to a pulse transformer 424. The unijunction transistor 420 has two base electrodes base-one (B1) and base-two (B2), and an emitter electrode E. The emitter electrode E is connected to the junction of resistors 412 and capacitor 414, and is thus responsive to the charge of capacitor 414. Electrode base-two is connected to the source 398 of unidirectional potential through resistor 426, and electrode base-one is connected to ground 404 through resistor 428. A resistor 430 may be connected across capacitor 414 to keep it from charging due to the leakage current of transistor 410 when it is cut-off. Thus, each time transistor 410 conducts in response to a signal from the logic control circuit 110, capacitor 414 charges until reaching the voltage equal to the voltage between electrodes base-one and base-two times the intrinsic stand-off ratio of the unijunction transistor 420. At this voltage, the emitter E becomes forward biased and the dynamic resistance between the emitter E and base-one drops to a low value. Capacitor 428 then discharges through the emitter E. When the emitter E voltage drops to a predetermined magnitude, the emitter E ceases to conduct and the cycle is repeated, at a frequency responsive to the value of the capacitor 414 and the resistor 428.

The current pulse flowing in the base-one circuit when capacitor 430 discharges is applied to the base electrode b of transistor 422. Transistor 422 has its emitter electrode e connected to ground 404, and its collector electrode c connected to source 398 of unidirectional potential through primary winding 434 of pulse transformer 424. Each time the base electrode b is pulsed by unijunction transistor 420, transistor 422 switches to its conductive state, which pulses the primary winding 434 of pulse transformer 424, providing a pulse in the secondary winding 436 which is applied to output terminals 82 and 84 through resistor 438. Asymmetrically conductive devices, such as diodes 432 and 440 may be connected across the primary winding 434 of pulse transformer 424 and across the output terminals 82 and 84, respectively, with diode 440 being poled to prevent a negative potential from being applied to the gate circuit of device A1, and diode 432 being poled to act as a free wheeling diode, to dissipate the energy in the primary winding 434 each time transistor 422 is cut-off.

The duration of the "stretched" signal from current signal control means 300 allows the logic control means 110 and the gate signal means 80 time to provide gating signals at output terminals 82 and 84 for a minimum of 2 milliseconds, which will insure that the load current in the gated device is above the holding current of the device before the gate signal is removed, even in a lagging power factor circuit.

Thus, in summary, sensor wheel 150 and bi-stable memory control means 190 provides a signal at output terminal 196 or output terminal 198, in response to the mechanical position of the tap changer switching means 40. If the output terminal 196 is providing the signal, conductor arm A is selected as the arm which should be prepared for conducting. Voltage signal control means 240 provides a signal at its output terminal 250 or at its output terminal 252, with one terminal having an output voltage during the positive half cycle of the alternating potential, and the other terminal having an output signal during the negative half cycle of the alternating potential. These output signals determine which device should be ready for conducting in the particular arm selected by the sensor wheel 150. The current signal control means 300 puts out a signal each time the circuit load current goes through zero, which thus determines when the selected device in the selected arm should be fired or rendered conducting. This sequencing limits any arcing to the very small

voltage differences between the voltage drop across the A and B auxiliary conductor arms, and the voltage drop across the main conductor arm. Since the main conductor arm always leaves and contacts a higher resistance area on each stationary tap, the voltage drop across the main conductor arm at the time of leaving or first contacting a tap is very close to the voltage drop across the A or B arm, thus causing substantially no arcing. The selecting of a device in each arm poled in the same direction, and the switching of the current between the A and B arms at a current zero, insures that the tapped winding will never be short circuited through the tap changer switching means 40.

Since numerous changes may be made in the above-described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.

We claim as our invention:

1. Tap changer apparatus for changing taps on an electrical winding connected in an alternating current system, comprising:

tap changer switching means including a main conductor arm and first and second controllable conductor arms disposed in predetermined spaced relation on opposite sides of the main conductor arm, driving means for said tap changer switching means, for selectively engaging the taps on the electrical winding, said first and second controllable conductor arms each including first and second parallel connected static switching means poled to carry alternate current half cycles and each including a control electrode which controls its switching characteristic, first means providing signals responsive to the mechanical position of said tap changer means, second means providing signals responsive to the polarity of the alternating potential of the alternating current system, third means providing signals responsive to the current zero points of the current in the alternating current system, separate control signal means connected in circuit relation with each of said static switching means, each of said control signal means being responsive to the signals provided by said first, second and third means, providing control signals for said static switching means in a predetermined sequence as the tap changer switching means moves from one tap position to another, the predetermined switching sequence of the static switching means allowing said tap changer means to change taps while maintaining a continuous current flow in the alternating current system.

2. The tap changer apparatus of claim 1 wherein said third means includes means which increases the duration of the signals responsive to the current zero points, ensuring that said control signal means will provide control signals which persist at least until the current magnitude in the static switching means exceeds its holding value.

3. The tap changer apparatus of claim 1 wherein said control signal means includes logic circuitry and pulse producing means, said logic circuitry initiating control signals from said pulse producing means when signals from said first, second and third means all exist on the input to the logic circuitry simultaneously.

4. The tap changer apparatus of claim 1 wherein said first means includes a sensor wheel mechanically coupled with said driving means and bistable memory control means having a first output terminal connected in circuit relation with the control signal means for the static switching means in one controllable conductor arm, and a second output terminal connected in circuit relation with

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the control signal means for the static switching means in the other controllable conductor arm, said bi-stable memory control being responsive to the mechanical position of said sensor wheel, providing an output signal at one or the other of said output terminals as required to switch the conductor arms in the desired sequence.

5 5. The tap changer apparatus of claim 1 wherein said second means includes a differential amplifier and first and second output terminals, said first output terminal being connected in circuit relation with the control signal means associated with the static switching means in the first and second controllable conductor arms poled to carry the positive current half cycles, and the second output terminal being connected in circuit relation with the control signal means associated with the static switching means in the first and second controllable conductor arms poled to carry the negative current half cycles, said differential amplifier being responsive to the alternating potential in the alternating current system, providing an output signal to its first output terminal when the alternating potential is positive, and an output signal to its second output terminal when the alternating potential is negative.

10 6. The tap changer apparatus of claim 1 wherein said third means includes a balanced differential amplifier which is balanced each time the current in the alternating current system goes through zero, means providing an output signal when said differential amplifier is balanced, and means increasing the duration of the output signal,

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said output signal being applied to each of said control signal means.

7. The tap changer apparatus of claim 1 including stationary taps connected to the electrical winding, said stationary taps having areas of higher electrical resistance where the main and controllable switching arms of said tap changer switching means first make contact with the tap and where contact is last made with the tap, than the electrical resistance of the remaining portion of the taps, said areas of higher electrical resistance reducing arcing due to the difference in voltage drop across the main conductor arm and across the controllable conductor arms, and also increasing the voltage across the switching means in the controllable conductor arms which is on the same tap as the main conductor arm, allowing them to conduct when the main conductor arm is in contact with an area of higher resistance and control signals are applied to the control electrodes of the static switching means.

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