

April 19, 1949.

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2,467,901

CONTROL SYSTEM

Filed Jan. 1, 1944

2 Sheets-Sheet 1

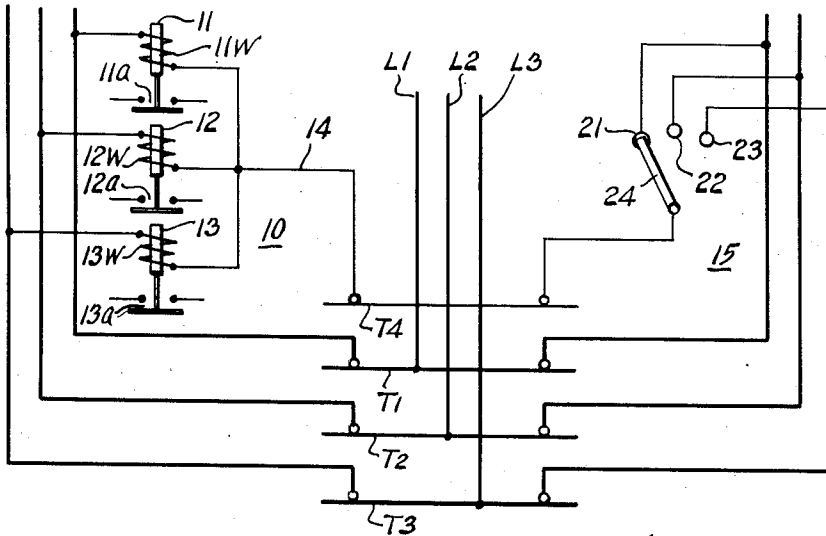


Fig. -1

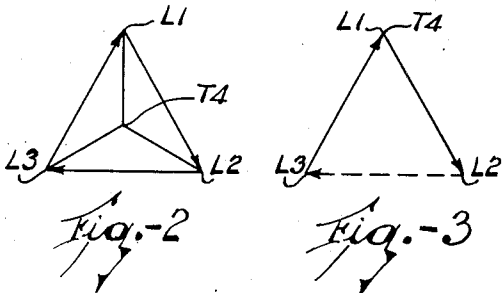


Fig. -2

Fig. -3

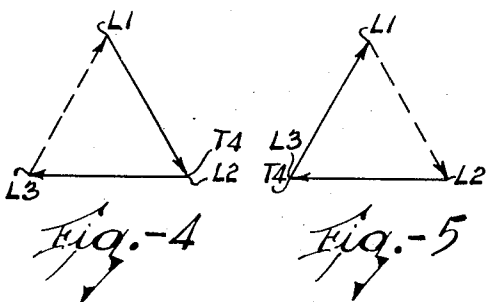


Fig. -4

Fig. -5

		POSITIONS							
		REVERSE				FORWARD			
		4	3	2	1	0	1	2	3
RELAYS	61								
	62								
	63								
	64								
	65								
	66								

DOTS INDICATE PICK-UP

Fig. -8

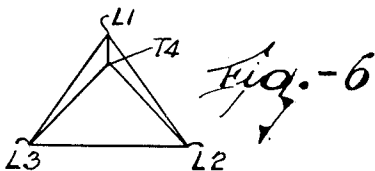


Fig. -6

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2 Sheets-Sheet 2

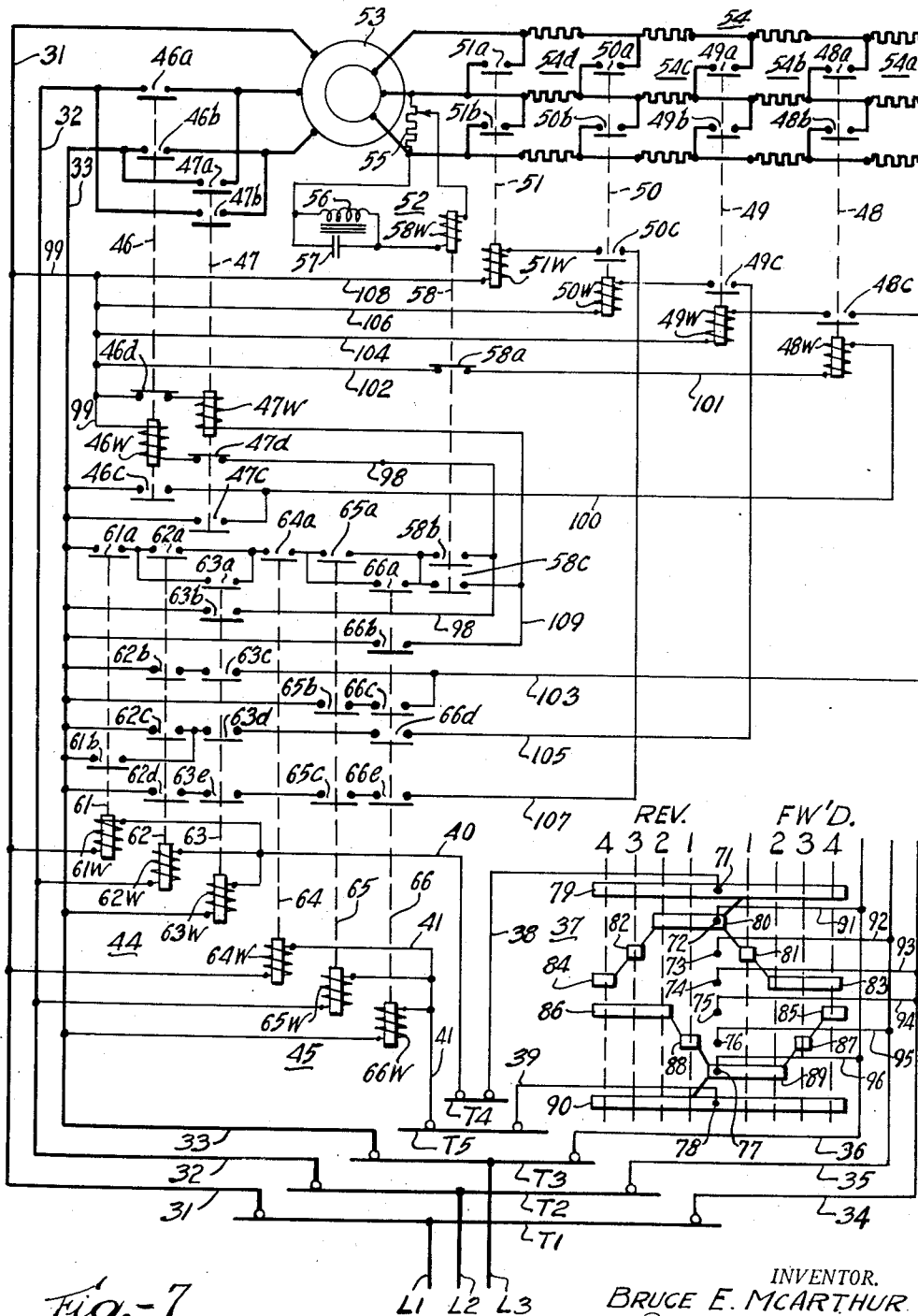


Fig. 7

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UNITED STATES PATENT OFFICE

2,467,901

CONTROL SYSTEM

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Application January 1, 1944, Serial No. 516,725

10 Claims. (Cl. 175—320)

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This invention relates to control systems for actuating electromagnetic devices at one or more controlled stations from a remote or relatively moving controlling station, and more particularly to an alternating current control system using a minimum number of control conductors between the controlling and the controlled stations.

Remote control systems for use with direct current are known in which two electromagnetic switches or relays at a controlled station have their operating windings connected in series across positive and negative power conductors and in which a single control conductor extends from a point between the two windings to a remote controlling station at which means are provided to connect the control conductor selectively to the positive and negative power conductors and to disconnect the control conductor from both of the power conductors. When the remote end of the control conductor is not connected to the power conductors, each of the windings is subjected to one-half of the voltage between the power conductors.

In one form of this type of direct current control system the switches are designed so as to be in their dropped-out positions when the control conductor is disconnected from the power conductors. Connection of the remote end of the control conductor to one of the power conductors causes the full voltage between the power conductors to be applied to one of the windings and causes the voltage across the other one of the windings to be reduced to zero. Under these conditions, the deenergized switch remains in its dropped-out position and the other switch picks up. If the control conductor is connected to the other power conductor, the electrical condition of the two windings is reversed and consequently the switch that was picked-up drops out and the other switch picks up. When the control conductor is again disconnected from both of the power conductors, both of the switches are in their initial dropped-out positions.

In another form of the foregoing type of direct current control system, the switches are designed so as to be in their picked-up positions when the remote terminal of the control conductor is disconnected from the power conductors. With both switches picked-up, connection of the remote end of the control conductor to one of the power conductors causes the full voltage between the power conductors to be applied to one of the windings so that the switch operated by that winding remains picked-up, and causes the voltage across the other one of the

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windings to be reduced to zero so that the switch operated by that winding drops out. When the control conductor is connected to the other power conductor, the electrical condition of the two windings is reversed and consequently the switch that was picked-up drops out and the other switch picks up. When the control conductor is again disconnected from both of the power conductors, both of the switches are in their initial picked-up positions.

Both forms of the direct current control system described have been used, but both have the disadvantage of more or less sluggish operation due to the fact that the closed loops within which the windings are connected to cause the switches to drop out retard the rate of flux decay. The second form of control system has a further disadvantage in that special switches or special windings or both are required since the windings must be capable of holding the switches closed when energized by one-half of line voltage and also must have adequate thermal capacity to withstand the application of full line voltage.

It has long been desired to have available for use in alternating current control applications a control system as simple as the foregoing direct current control system, neither form of which is operable reliably when the power conductors are energized with alternating current instead of direct current.

The unreliable operation that results when alternating current is used is due to the fact that the impedance of the operating winding of an alternating current switch is much less when the switch is dropped-out than when the switch is picked-up. For example, if the power conductors in the first of the foregoing forms of the direct current control system are energized with alternating current, a switch that has picked up due to the connection of the remote terminal of the control conductor to one of the power conductors does not drop out upon disconnection of the control conductor from the power conductor and the switch that was in its dropped-out position tends to flutter or actually picks up. Since the terminal of the control conductor must travel over an insulating space when moving from one power conductor to the other in order to avoid any possibility of a direct electrical connection between the two power conductors, unpredictable operation results even if the disconnected position of the control conductor is not used as an actual control position. As to the second form of the direct current control system when used with alternating current, the undesirable effects

of the voltage changes on the operating windings are not only augmented, but there is no assurance that both switches will pick-up when the power conductors are first energized since one of the switches might start to close ahead of the other and in so doing increase the impedance of the circuit to prevent closure of the other switch.

An object of this invention is to provide a control system utilizing a minimum number of control conductors which has none of the foregoing disadvantages.

A general object is to provide an improved control system operable through a minimum number of control conductors.

Other objects are: to provide a simplified system for controlling the operation of a plurality of alternating current electroresponsive devices from a distant or a relatively movable controlling station through a single control conductor, to provide an alternating current remote control system which is simple in construction and reliable in operation, to provide a control system which utilizes a minimum number of control conductors and which is energized by polyphase power, to provide a control system in which a plurality of alternating current operated electroresponsive devices are selectively controlled by changing the energization of a single control conductor, and to provide an alternating current control system operable through a minimum number of control conductors which is insensible to voltage variations of the usual magnitude experienced in systems wherein power is transmitted through relatively movable conductors.

A more specific object is to provide a simplified alternating current control system for controlling an alternating current motor from a controlling station through a minimum number of control conductors and the usual power conductors.

In accordance with this invention, a plurality of electroresponsive devices such as electromagnetic switches or relays have their respective operating windings connected in a Y network across a plurality of power conductors which are energized by a suitable source of polyphase power of the same number of phases as the number of windings. One of the windings is connected in each leg of the Y network, respectively, and a control conductor connected to the common terminal of the network extends to a remote or relatively moving controlling station at which means are provided to connect the control conductor selectively to the power conductors. A different one of the windings is completely de-energized and the remaining windings are energized by full line voltage in each of the connected positions of the control conductor. While the control conductor is being moved from one connected position to another, the Y network is unbalanced due to the difference between the dropped-out and the picked-up impedances of the windings, and insufficient voltage is impressed across the winding of a dropped-out switch to cause that switch to pick up or to flutter whereas sufficient voltage is impressed across the other windings to hold the other switches in their picked-up positions. The operated positions of the switches therefore remain the same until the switching operations of the control conductor are completed. Thus a phenomenon which has heretofore prevented the use of simple alternating current remote control systems is utilized in accordance with the present invention to insure reliable operation of the switches. In the case of the common three-phase supply source,

three relays are controllable in the foregoing manner giving three different switching combinations, and, if two relay networks and two control conductors are combined in the manner of this invention, nine different switching combinations become available.

Other objects and advantages of this invention will become apparent from the following description wherein reference is made to the drawings, in which

Fig. 1 is a wiring diagram of a preferred embodiment of the invention;

Figs. 2, 3, 4, 5 and 6 are vector diagrams illustrating various voltage conditions of Fig. 1;

Fig. 7 is a wiring diagram of a motor control system using two of the relay systems of Fig. 1 in cooperating relationship, and

Fig. 8 is a relay operating sequence chart for the wiring diagram of Fig. 7.

Referring to Fig. 1, a group 10 of electroresponsive devices such as relays 11, 12 and 13 is arranged so that operating windings 11w, 12w and 13w of the relays 11, 12 and 13, respectively, are connected in a star or Y network energized through trolley wheels from trolley bars T₁, T₂ and T₃. As shown, one terminal of the winding 11w is connected to the trolley bar T₁, one terminal of the winding 12w is connected to the trolley bar T₂, and one terminal of the winding 13w is connected to the trolley bar T₃. The other terminals of each of the windings 11w, 12w, and 13w are connected to a trolley bar T₄ through a control conductor 14 and a trolley wheel. The trolley bars T₁, T₂ and T₃ are fixedly connected to conductors L₁, L₂ and L₃ which are energized from a suitable source of polyphase power (not shown). A master switch 15 for controlling the relays 11, 12 and 13 comprises spaced contact segments 21, 22 and 23 which are connected through trolley wheels to the trolley bars T₁, T₂ and T₃, respectively, and a movable contact arm 24 connected through a trolley wheel to the trolley bar T₄ and arranged to engage selectively the segments 21, 22 and 23.

The relays 11, 12 and 13 may have normally open contacts 11a, 12a and 13a, respectively, and are movable with respect to the trolley bars T₁, T₂, T₃ and T₄ and with respect to the master switch 15 which is also movable with respect to the trolley bars. The relay group 10, for example, may thus be mounted on one of the driving trucks of a cargo bridge and the master switch 15 may be mounted in a control cab movable across the bridge between the driving trucks.

With the arm 24 in engagement with none of the segments 21, 22 and 23, each of the relay operating windings 11w, 12w and 13w is subjected to a voltage substantially equal to fifty-eight per cent of the voltage between the conductors L₁, L₂ and L₃ provided that all of the relays are picked-up or all are dropped-out. This condition is graphically illustrated in Fig. 2 wherein the vectors L₁—L₂, L₂—L₃ and L₃—L₁ represent the voltages between the respective conductors L₁, L₂ and L₃, and the vectors L₁—T₄, L₂—T₄ and L₃—T₄ represent the voltages impressed on the windings 11w, 12w and 13w, respectively. Each of the relays 11, 12 and 13 is preferably so designed that it does not pick up when subjected to a voltage of the indicated magnitude, but as will be explained hereinafter, the voltage relations of Fig. 2 do not represent a normal operating condition of the relay group 10.

If the arm 24 is in engagement with the segment 21, the conductor 14 is connected through

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the trolley bar T_4 , the arm 24, and the segment 21 to the trolley bar T_1 , and the voltage impressed on the winding 11w is equal to zero whereas the voltages impressed on the windings 12w and 13w are equal to the voltages L_1-L_2 and L_1-L_3 , respectively, as indicated by the solid lines in Fig. 3, the neutral point of the network indicated by T_4 having moved to the point indicated by L_1 . Consequently, the relay 11 is completely deenergized, but with line voltage impressed on each of the windings 12w and 13w, the relays 12 and 13 are picked-up and the contacts 12a and 13a are closed.

If the arm 24 is in engagement with the segment 22, the conductor 14 is connected through the trolley bar T_4 , the arm 24, and the segment 22 to the trolley bar T_2 , and the voltage impressed on the winding 12w is equal to zero whereas the voltages impressed on the windings 11w and 13w are equal to the voltages L_1-L_2 and L_2-L_3 , respectively, as indicated in Fig. 4. The winding 12w is completely deenergized, but with line voltage impressed on each of the windings 11w and 13w, the relays 11 and 13 are picked-up and the contacts 12a and 13a are closed.

If the arm 24 is in engagement with the segment 23, the conductor 14 is connected through the trolley bar T_4 , the arm 24, and the segment 23 to the trolley bar T_3 , and the voltage impressed on the winding 13w is equal to zero whereas the voltages impressed on the windings 11w and 12w are equal to the voltages L_1-L_3 and L_2-L_3 , respectively, as indicated in Fig. 5. Under these conditions the winding 13w is completely deenergized, but with line voltage impressed on each of the windings 11w and 12w, the relays 11 and 12 are picked up and the contacts 11a and 12a are closed.

From the foregoing description of the operation of the control system of Fig. 1, it is obvious that positive operation of the relays 11, 12 and 13 for each of three positions of the arm 24 is obtained. While the arm 24 is moving from one of the segments to another, the relays which are closed remain closed since the impedance of the branches of the Y network which include windings of relays that are picked up is very much higher than that of the other branch, so that the voltage across the winding of the relay which has not picked up normally does not approach the pick-up value. This condition is illustrated graphically in Fig. 6 wherein it is assumed that the arm 24 is moving from the segment 21 to the segment 22 and is between those two segments. The neutral point, represented by T_4 , is moved but slightly from its position in Fig. 3 toward its position in Fig. 1. Even under conditions of increased line voltage such as normally experienced on industrial alternating power systems the voltage L_1-T_4 across the winding 11w does not reach the pick-up value of the relay under these unbalanced conditions. Furthermore, since the relays are preferably designed to pick-up at a voltage value well under normal line voltage, the usual decreases of voltage will not cause drop-out of the relays.

The relay group 10 may be used for various purposes such as for controlling an electric motor from a remote station and a plurality of relay groups 10 may be arranged to cooperate and perform extremely complicated control functions. There is shown in Fig. 7 a wiring diagram of a reversing, plugging controller for a wound rotor induction motor which includes an added plug-to-stop feature and which is operated from a

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master switch through only two control conductors and the usual three power conductors. This diagram illustrates the manner in which motor control functions can be accomplished from a remote or relatively movable master switch station by use of the relay control system of Fig. 1.

Referring to Fig. 7, the power conductors L_1 , L_2 and L_3 energized from a suitable source of polyphase power (not shown) are fixedly connected to the trolley bars T_1 , T_2 and T_3 to which, by means of suitable trolley wheels, power conductors 31, 32 and 33 are connected, respectively, and control conductors 34, 35 and 36 are connected, respectively. A master switch or controller 37 energized from and fixedly connected to the conductors 34, 35 and 36 has output control conductors 38 and 39 which are connected to control conductors 40 and 41, respectively, through trolley bars T_4 and T_5 , respectively. The conductors 40 and 41 are control conductors for relay groups 44 and 45, respectively, of a motor controller including reversing contactors 46 and 47, a plugging contactor 48, acceleration and speed control contactors 49, 50 and 51, and a plugging relay circuit 52. The controller controls a polyphase wound rotor motor 53 which is arranged to be reversibly energized from the conductors 31, 32 and 33 depending upon the operation of the contactors 46 and 47 and which has its secondary winding (not shown) connected in the conventional manner to a Y connected resistance bank 54 having resistor sections 54a, 54b, 54c and 54d.

The contactors 46, 47, 48, 49 and 50 each have an operating winding designated by the numeral of the respective contactor and the adscript w and a plurality of normally open contacts designated by the numeral of the respective contactor and the adscript a, b, and c, respectively. In addition, the contactors 46 and 47 have normally closed contacts 46d and 47d, respectively. The contactor 51 has an operating winding 51w and normally open contacts 51a and 51b.

The plugging relay circuit 52 may be of any suitable type, but preferably is of the type disclosed in Patent No. 2,232,257, issued to Asa H. Myles on February 18, 1941, and comprises a voltage divider 55 connected between two secondary terminals of the motor 53, a non-saturable reactor 56 and a condenser 57 connected in parallel with each other, and an operating winding 58w of a relay 58 having normally closed contacts 58a and normally open contacts 58b and 58c. The parallel connected reactor 56 and the condenser 57 are connected in series with the winding 58w across an adjustable portion of the voltage divider 55. The electrical constants of the relay circuit 52 are such that, due to the phenomena of series and of parallel resonance, the relay 58 is picked-up when the frequency of the secondary voltage of the motor 53 is more than a few cycles above the frequency of the primary excitation of the motor and is dropped-out when the frequency of the secondary voltage is equal to or less than the frequency of the primary excitation.

Each of the relay groups 44 and 45 is similar to the relay group 10 of Fig. 1. As shown, the relay group 44 comprises a plurality of relays 61, 62 and 63 having operating windings 61w, 62w and 63w, respectively, which are connected in a Y network across the conductors 31, 32 and 33 with the common terminal of the network connected to the conductor 40, and the relay group 45 comprises a plurality of relays 64, 65 and 66

having operating windings 64w, 65w and 66w, respectively, which are connected in a Y network across the conductors 31, 32 and 33 with the common terminal of the network connected to the conductor 41. The non-common terminals of the windings 61w, 62w and 63w are connected to the conductors 31, 32 and 33, respectively, and likewise the non-common terminals of the windings 64w, 65w and 66w are connected to the conductors 31, 32 and 33, respectively. The relay 61 has normally open contacts 61a and 61b, the relay 62 has normally open contacts 62a to 62d inclusive, the relay 63 has normally open contacts 63a to 63e, inclusive, the relay 64 has normally open contacts 64a, the relay 65 has normally open contacts 65a to 65c, inclusive, and the relay 66 has normally open contacts 66a to 66e, inclusive.

The master switch 37 comprises a plurality of circuit terminals 71 to 78, inclusive, which are relatively movable with respect to a plurality of contact segments 79 to 90, inclusive, to four separate positions on each side of a neutral or off position. The contact segments 79 to 84, inclusive, are electrically interconnected, and the contact segments 85 to 90, inclusive, are electrically interconnected.

As indicated in the relay sequence chart of Fig. 8, while the master switch 37 is in the off position or either of the first and second reverse positions, the relays 61 and 62 are picked-up. The energizing circuit for the windings 61w and 62w with the master switch 37 in these positions is from the conductors 31 and 32 through the windings 61w and 62w, respectively, the common control conductor 40, the trolley bar T4, the conductor 33, the circuit terminal 71, the segments 73 and 80, the circuit terminal 72, and a conductor 91 to the conductor 36. Since the winding 63w is connected to the conductor 33 which is connected through the trolley bar T3 to the conductor 36, the relay 63 is in its dropped-out position at this time.

Due to completion of a circuit from the segment 81 in the first forward position and from the segment 82 in the third reverse position through the terminal 73 and a conductor 92 to the conductor 35, the relay windings 61w and 63w are fully energized and the relays 61 and 63 are picked-up while the master switch 37 is in these positions, and the relay 62 is dropped-out since the winding 62w is completely deenergized due to the fact that both of its terminals are connected to the trolley bar T2.

Due to completion of a circuit from the segment 83 in the second, third and fourth forward positions and from the segment 84 in the fourth reverse position through the terminal 74 and a conductor 93 to the conductor 34, the relay windings 62w and 63w are fully energized and the relays 62 and 63 are picked-up while the master switch 37 is in these positions, and the relay 61 is dropped-out since the winding 61w is completely deenergized due to the fact that both of its terminals are connected to the trolley bar T3.

While the master switch 37 is in the off position or in either of the first and second forward positions, the relays 64 and 65 are picked-up and the relay 66 is dropped-out. The energizing circuit for the windings 64w and 65w under these conditions is from the conductors 31 and 32 through the windings 64w and 65w, respectively, the common control conductor 41, the trolley bar T5, the control conductor 39, the terminal 78, the

segments 90 and 89, the terminal 77, and a conductor 96 to the conductor 36. Since the winding 66w is connected to the conductor 33 which is connected through the trolley bar T3 to the conductor 36, the relay 66 is in its dropped-out position at this time.

Due to the completion of a circuit from the segment 87 in the third forward position and from the segment 88 in the first reverse position through the terminal 76 and a conductor 95 to the conductor 35, the relay windings 64w and 66w are fully energized and the relays 64 and 66 are picked-up while the master switch 37 is in these positions, and the relay 65 is dropped-out since the winding 65w is completely deenergized due to the fact that both of its terminals are connected to the trolley bar T2.

Due to the completion of a circuit from the segment 85 in the fourth forward position and from the segment 86 in the second, third and fourth reverse position through the terminal 75 and a conductor 94 to the conductor 34, the relay windings 65w and 66w are fully energized and the relays 65 and 66 are picked-up while the master switch 37 is in these positions, and the relay 64 is dropped-out since the winding 64w is completely deenergized due to the fact that both of its terminals are connected to the trolley bar T1.

In considering the operation of the control system of Fig. 7, first assume that the motor 53 is at rest and is to be accelerated to full speed in the forward direction by moving the master switch 37 from the off position to the fourth forward position. With the master switch in the off position, the relays 61, 62, 64 and 65 are picked-up but no circuit is completed by their contacts since the relay 58 is deenergized and the relays 63 and 66 are dropped-out.

The relay 63 is picked-up while the master switch 37 is in any of the forward positions and its contacts 63b complete an energizing circuit for the winding 46w from the conductor 33, through a conductor 98, the normally closed contacts 47d, the winding 46w, and a conductor 99 to the conductor 31. The contactor 46 in response to the energization of its winding 46w opens its contacts 46d to prevent subsequent energization of the winding 47w while the master switch 37 is in the forward positions, closes its contacts 46a and 46b to connect the motor 53 to the conductors 31, 32 and 33 for operation in the forward direction, and closes its contacts 46c to complete an energizing circuit for the winding 48w from the conductor 33 through a conductor 100, the winding 48w, a conductor 101, the normally closed contacts 58a, and a conductor 102 to the conductor 99. The contactor 48 in response to the energization of its winding 48w closes its contacts 48a and 48b to short circuit the resistance section 54a, and closes its contacts 48c in the energizing circuit for the winding 49w. The motor 53w if loaded now operates at slow speed with the resistance sections 54b, 54c, and 54d effective in the secondary circuit.

The relay 62 is picked up while the master switch 37 is in the second, third, or fourth forward positions and its contacts 62b are closed to complete the energizing circuit for the winding 49w from the conductor 33 through the now closed contact 63c, a conductor 103, the now closed contacts 48c, the winding 49w, and a conductor 104 to the conductor 99. The contactor 49 in response to the energization of its winding 49w closes its contacts 49a and 49b to short circuit the additional resistance section 54b, and closes

its contacts 49c in an energizing circuit for the winding 50w. The motor 53w now operates at a higher speed with the resistance section 54c and 54d remaining effective in the secondary circuit.

The relay 66 is picked up in the third and fourth forward positions and its contacts 66d are closed to complete the energizing circuit for the winding 50w from the conductor 33 through the now closed contacts 62c and 63d, a conductor 105, the now closed contacts 49c, the winding 50w, and a conductor 106 to the conductor 99. The contactor 50 in response to the energization of its winding 50w closes its contacts 50a and 50b to short circuit the additional resistance section 54c, and closes its contacts 50c in an energizing circuit for the winding 51w. The motor 53 now operates at a still higher speed with only the resistance section 54d effective in the secondary circuit.

The relay 65 is picked up in the fourth forward position of the master switch 37 and its contacts 65c close to complete the energizing circuit for the winding 51w from the conductor 33 through the now closed contacts 62d, 63e and 66e, a conductor 107, the contacts 50c, the winding 51w, and a conductor 108 to the conductor 99. The contactor 51 in response to the energization of its winding 51w closes its contacts 51a and 51b to short circuit all of the sections of the resistance bank 54. The motor 53 now operates at its maximum speed for the load being driven.

The motor 53 may be caused to operate in the reverse direction by moving the master switch 37 from the off position into the reverse positions. As soon as the master switch 37 is moved from the off position to the first reverse position, the relay 66 picks up as hereinbefore described and causes the contactor 47 to pick up and open its contacts 47d to prevent pick-up of the contactor 46 in subsequent reverse positions. In all of the reverse positions the contactor 47 is picked-up and the contacts 48a and 47b are closed to energize the motor 53 for reverse operation due to the completion of an energizing circuit for the winding 47w from the conductor 33, the contacts 66b, a conductor 109, the winding 47w, and the contacts 46d to the conductor 99. Closure of the contacts 47c upon pick-up of the contactor 47 completes the circuit from the conductor 33 to the conductor 100 to effect pick-up of the contactor 48 so long as the contacts 58a remain closed. The contactor 49 is picked-up in the second, third and fourth reverse positions due to completion of a circuit from the conductor 33 to the conductor 103 through the contacts 65b and 66c, the contactor 50 is picked-up in the third and fourth reverse positions due to completion of a circuit from the conductor 33 to the conductor 105 through the contacts 61b, 63d and 66d, and the contactor 51 is picked-up in the fourth reverse position due to completion of a circuit from the conductor 33 to the conductor 107 through the contacts 62d, 63c, 65c and 66c.

If the master switch is returned from any of the forward or reverse positions to the off position, all of the contactors and relays drop out except the relays 61, 62, 64 and 65, the closed contacts of which complete no circuits at this time since the relays 63 and 66 are dropped-out and the contacts 58b and 58c are open. Upon opening of the contactors 46 or 47, the motor 53 coasts to rest or may be stopped by a friction brake (not shown).

If it is desired to plug the motor 53, i. e. to reverse the phase sequence of the primary ex-

citation while the motor is rotating, the master switch 37 may be moved from any one of the forward positions to any one of the reverse positions or from any one of the reverse positions to any one of the forward positions. As soon as the motor is plugged, the frequency of the secondary voltage increases above the frequency of the primary excitation and the relay 58 picks up to open its contacts 58a and close its contacts 58b and 58c. Closure of the contacts 58b and 58c completes no circuit so long as the master switch is in any of the forward or reverse positions other than the first forward or first reverse positions. Opening of the contacts 58a interrupts the circuit for the winding 48w through the conductor 101. The contactor 48 thus cannot be picked-up during the plugging period and its open contacts 48c prevent closure of the contactors 49, 50 and 51. All of the resistance bank 54 is thus effective in the secondary circuit during plugging.

The relay circuit 52 is adjusted to cause the relay 58 to drop out when the frequency of the secondary voltage substantially equals the frequency of the primary excitation and therefore the relay 58 drops out when the motor 53 reaches standstill and closes its contacts 58a to permit acceleration of the motor 53 in the opposite direction, as previously described in starting from rest, to an extent depending upon the position of the master switch 37.

If, however, the master switch 37 is returned to the off position while plugging is in progress, closure of the contacts 61a, 62a, 64a and 65a completes a circuit through the now closed contacts 58b or 58c depending upon which of the contactors 46 and 47 is picked-up during plugging. If the contactor 46 is picked-up during plugging, it remains picked-up after the master switch is returned to the off position due to an energizing circuit for its winding 46w which extends from the conductor 33 through the contacts 61a, 62a, 64a, 65a and 58b, the conductor 98, the contacts 47d, and the winding 46w to the conductor 99. If the master switch 37 remains in the off position, the contactor 46 remains closed to apply plugging power to the motor 53 until the speed of the motor approaches zero, at which time the relay 58 drops out and opens its contacts 58b to effect deenergization of the winding 46w. The contactor 46 thereupon drops out and opens its contacts 46a and 46b to effect deenergization of the motor 53. Preferably the relay circuit 52 is so adjusted that it responds at a motor speed just slightly above zero so that the motor is at standstill when the contactor 46 drops out.

A similar plug-to-stop sequence occurs in plugging from the forward direction of motor rotation except that the contacts 58c of the relay 58 control the operation of the contactor 47 instead of the contacts 58b controlling the contactor 46.

It is to be noted that the contacts 63a are in parallel with the contacts 62a and also complete a circuit to the winding 47w through the contacts 58c in the first master switch position during plugging from the forward direction. This is to insure that the contactor 47, which is picked-up for plugging operations while the master switch is in all of the reverse positions, does not drop out in moving to the off position due to the possibility of the contacts 63b opening before the contacts 62a close. Likewise the contacts 66a in parallel with the contacts 65a insure proper operation of the contactor 46 in plugging-to-stop from the reverse direction of motor rotation. If

desired, the contacts 62a, 63a, 65a and 66a may be omitted and the contactors 46 and 47 controlled during plugging-to-stop operations by using only the series connected contacts 61a and 64a to complete the circuit from the conductor 33 to the contacts 58b and 58c. As indicated in Fig. 8, the contacts 61a and 64a are both closed only while the master switch is in the off position or the first forward and reverse positions.

It will be obvious to those skilled in the art that suitable speed responsive or definite time relays may be added to the controller of Fig. 7 to control the time of pick-up or drop-out or both of the contactors 49, 50 and 51.

Because of permutations and combinations of relay contacts possible when two or more relay groups of the type of the relay groups 10, 44 and 45 are used in a single controller, it is possible to perform extremely complicated control functions through a minimum number of control wires. From a study of Fig. 7 it will become apparent that numerous control functions of various degrees of complexity can be effected through only one or two control conductors. In the case of the more complicated switching sequences such as illustrated by way of example in Fig. 7, exactly the same sequences can be performed as are performed by the usual master switch with numerous control conductors, except that operating movement of the master switch 37 in some instances must be done more slowly in order to permit drop-out and pick-up of the necessary relays at each position before proceeding to the next position. It will be obvious from a study of Fig. 7 that substantially all of the conventional master switch contact combinations are obtainable by the contacts of the relays in the relay groups 44 and 45.

I claim:

1. In a control system, a group of three electroresponsive devices each having a pair of operating terminals, means electrically connecting one operating terminal of each of said devices to a common conductor means, means for connecting the other operating terminal of each of said devices to non-neutral terminals, respectively, of a source of three-phase power, said devices being operative when subjected to the line-to-line voltage of said source, being inoperative when unenergized, and continuing to be inoperative when, in said inoperative condition, they are subjected to the line-to-neutral voltage of said source and means for selectively connecting said conductor means to said terminals.

2. In a control system arranged to be energized from a source of three-phase power through three non-neutral power conductors, a group of three electroresponsive devices each having an operated and a non-operated condition and each having an operating winding the impedance of which increases when the associated device changes from said non-operated condition to said operated condition, each of said devices being operative to change from its non-operated to its operated condition only when the voltage impressed on its associated winding is substantially above the line-to-neutral voltage of said source, means connecting said windings in legs, respectively, of a Y network having a terminal common to said windings and having three legs terminating at three non-common terminals, respectively, means for connecting the non-common terminals of said network to said power conductors, respectively, and means for selec-

tively connecting the common terminal of said network to said power conductors.

3. In a control system energized from a source of three-phase power through three non-neutral power conductors, a group of three electroresponsive devices each having an operated and a non-operated condition and each having an operating winding, the impedance of which increases when the associated device changes from said non-operated condition to said operated condition, each of said devices being operative to change from its non-operated to its operated condition only when the voltage impressed on its associated winding is substantially above the line-to-neutral voltage of said source, means connecting said windings in legs, respectively, of a Y network having a terminal common to said windings and having three legs terminating at three non-common terminals, respectively, means connecting the non-common terminals of said network to said power conductors, respectively, and means connected to said common terminal and to said power conductors for selectively connecting said common terminal to said power conductors.

4. In a control system for a plurality of electroresponsive devices arranged to be energized from a source of three-phase power and having operating windings, respectively, for effecting operation of said devices respectively from a de-energized to an energized position, said windings having substantially the same impedance when the respective devices are all in the same position and increasing in impedance upon operation of the respective devices from their deenergized positions to their energized positions, each of said devices being operable magnetically to its energized position if the voltage across its respective winding is substantially equal to the line-to-line voltage of said source but not so operable if the voltage across its respective winding is less than or substantially equal to the line-to-neutral voltage of said source, means for connecting said windings in a Y network to said source so that when said devices are all in the same position each of said windings is subjected to said line-to-neutral voltage, and means including a common connection to each of said windings made at the neutral of said Y network for connecting said windings to said source so that some of said windings are subjected to the line-to-line voltage of said source, whereby the devices associated with said some of said windings move to their energized positions.

5. In a control system for three electroresponsive devices having operating windings, respectively, which normally have substantially the same impedance but which increase in impedance upon operation of the respective devices to their operated positions, a source of three-phase power, each of said devices being operable magnetically to its operated position only if the voltage across its respective winding is above the line-to-neutral voltage of said source, means for connecting said windings to said source in legs, respectively, of a Y network having a neutral terminal so that normally each of said windings is subjected to said line-to-neutral voltage, and means comprising a single control conductor for connecting the neutral terminal of said network selectively to terminals of said source so that said windings are selectively subjected to the line-to-line voltage of said source, whereby the devices associated with said some of said windings move to their operated positions.

6. In a control system, a plurality of electromagnetic switches having operating windings, respectively, connected in legs, respectively, of a star network having three or more legs and having its non-common terminals connected, respectively, to non-neutral terminals of a source of polyphase power having a line-to-line voltage materially greater than its line-to-neutral voltage, the characteristics of said switches being such that they remain in their normal dropped-out position when, in said dropped-out position, they are subjected to a voltage substantially equal to the line-to-neutral voltage of said source and move to their picked-up positions when subjected to a voltage substantially equal to the line-to-line voltage of said source, means for connecting the common terminal of said network to one terminal of said source, whereby the voltage across one of said windings is zero and the voltage across the remainder of said windings is equal to the line-to-line voltage of said source.

7. The combination with a master controller having contacts arranged to be electrically connected to non-neutral terminals of a source of three-phase power, respectively, and a group of three electrically operated switches having their operating windings connected in legs, respectively, of a normally balanced Y network having a terminal common to said windings, said switches being operative when subjected to the line-to-line voltage of said source, being inoperative when unenergized, and continuing to be inoperative when, in said inoperative condition, they are subjected to line-to-neutral voltage of said source, of means for electrically connecting the non-common terminals of said network to the terminals of the source, respectively, a control conductor electrically connecting the common terminal of said network to a terminal on said controller, and means associated with said controller for selectively connecting said terminal of said controller to said contacts.

8. In a control system, a controlling station, a controlled station, three non-neutral power conductors extending between said stations and arranged to be energized from a source of three-phase power, a group of three electroresponsive devices at said controlled station having their operating windings connected in legs, respectively, of a Y network, said devices being operative when subjected to the line-to-line voltage of said source, being inoperative when unenergized, and continuing to be inoperative when, in said inoperative condition, they are subjected to the line-to-neutral voltage of said source, means connecting the non-common terminals of said network to said power conductors, respectively,

a control conductor extending from the common terminal of said network to said controlling station, and a switching mechanism at said controlling station for selectively connecting said control conductor to said power conductors.

9. The combination with a master controller having a plurality of groups of three contacts each, the three contacts of each group being connected, respectively, to three non-neutral conductors energized from a source of three-phase power, of a plurality of groups of electromagnetic switches of three switches each, the switches of each group having their operating windings connected in legs, respectively, of Y networks, respectively, said networks each having a common terminal and three non-common terminals which are connected to said source conductors, respectively, a control circuit including contacts of a switch in each of said groups, electrical connections between the common terminals of said networks, respectively, and said master controller, and said master controller being arranged to connect said electrical connections to said power conductors selectively.

10. In a control system arranged to be energized from a source of polyphase power provided with a plurality of non-neutral source terminals and having a line-to-line voltage materially greater than its line-to-neutral voltage, a group of electro-responsive devices comprising as many devices as there are non-neutral source terminals, said devices being operative when subjected to the line-to-line voltage of said source, being inoperative when unenergized, and continuing to be inoperative when, in said inoperative condition, they are subjected to the line-to-neutral voltage of said source, means electrically connecting one operating terminal of each of said devices to a common conductor means, means for connecting the other operating terminal of each of said devices to said non-neutral source terminals, respectively, and means for selectively connecting said conductor means to said source terminals.

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