Dec. 6, 1966 V. C. SHANEMAN 3,290,577

STARTING APPARATUS FOR A MULTI-PHASE INVERTER

Filed April 30, 1963 3 Sheets-Sheet 1

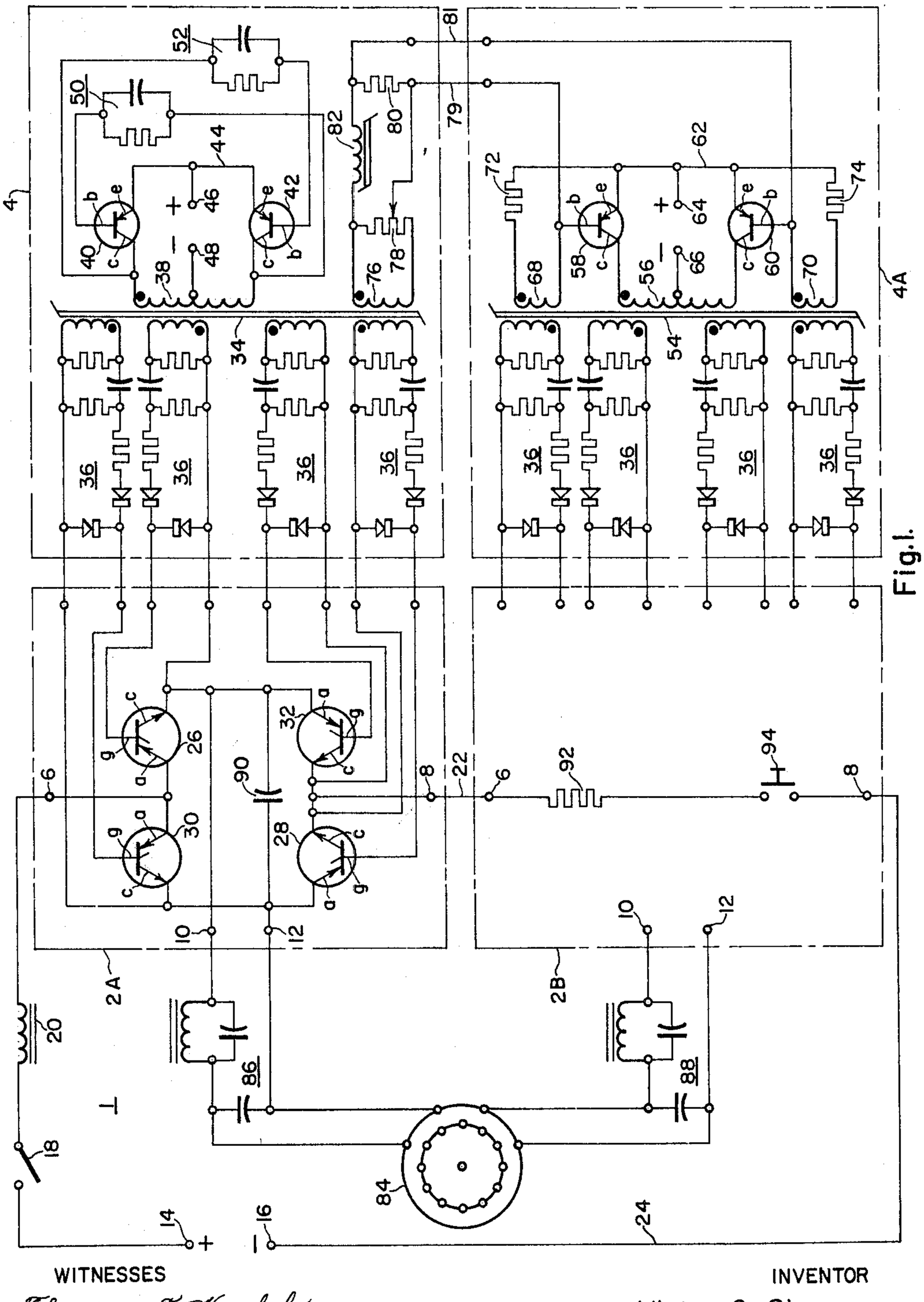


Fig.1.

WITNESSES

Theodore F. Wrobel

James F. Young

INVENTOR

Victor C. Shaneman

BY John L. Stoughton

ATTORNEY

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STARTING APPARATUS FOR A MULTI-PHASE INVERTER

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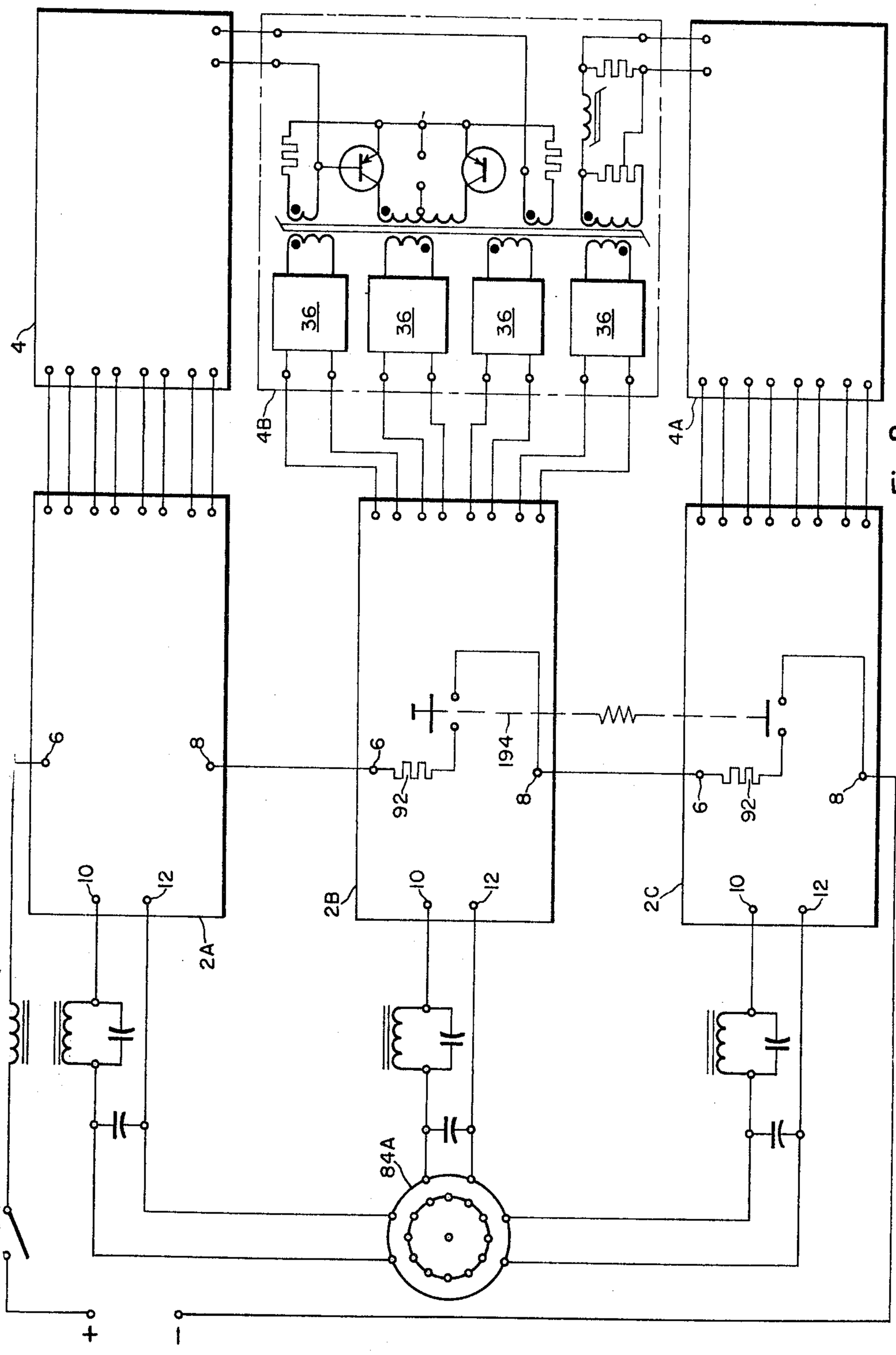


Fig.2.

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STARTING APPARATUS FOR A MULTI-PHASE INVERTER

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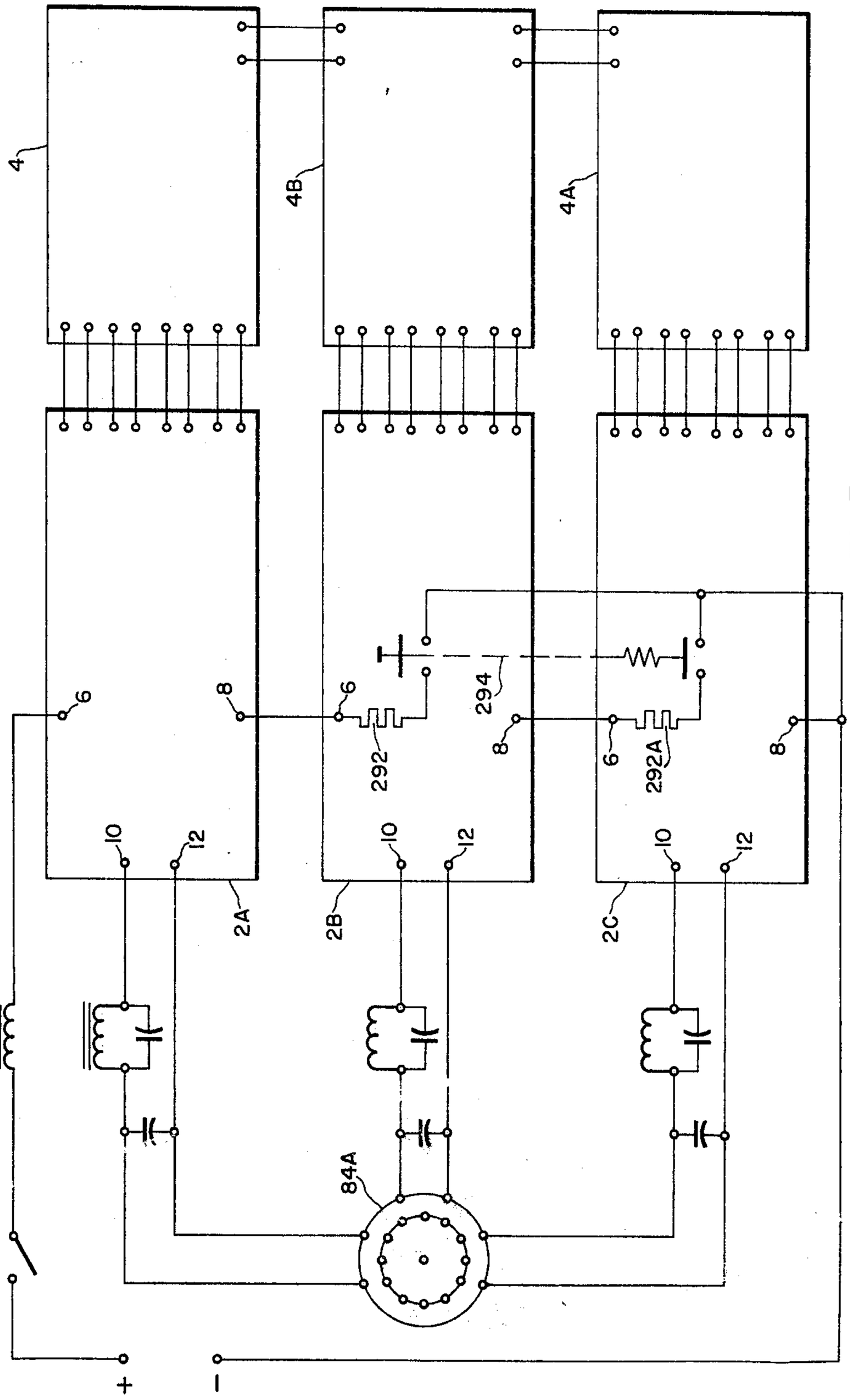


Fig.3.

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STARTING APPARATUS FOR A MULTI-PHASE INVERTER

Victor C. Shaneman, Shawnee Township, Allen County, Ohio, assignor to Westinghouse Electric Corporation, Pittsburgh, Pa., a corporation of Pennsylvania

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This invention relates generally to multiphase inverting apparatus utilizing discontinuous type control valves and more particularly to means for starting such inverting apparatus.

In inverting apparatus utilizing discontinuous type control valves it is desirable from the standpoint of economy and the standpoint of overheating to fire the control valves with pulses of short duration. It will be appreciated that in a multi-phase inverter network the valves in one inverter will be rendered conductive at a time distinctly separate from the valves in any of the other inverters. Therefore, in starting a multi-phase inverter of this type, I propose to temporarily energize a shunt circuit around all except one of the inverters so that when a conducting pulse is applied to a control valve of the non-shunted inverter the control valve to which the pulse is applied will complete a circuit and become conductive. I further propose to provide impedance in such a shunting circuit so that sufficient voltage is maintained across the terminals of the shunted inverters so that as their control valves are pulsed into conductive conditions they will also conduct. Thereafter, the shunting circuits may be opened and the control valves will be pulsed into conducting condition by the pulse source in the normal manner.

It is an object of this invention to provide an improved means for starting polyphase inverting apparatus of the series type.

It is a further object of this invention to provide in such an inverting apparatus shunting means for at least N–1 of the inverters whereby the rendering of a control valve conductive will render it conducting.

Another object is to provide impedance means in such shunting circuit to limit the current flow through the conducting valve to a magnitude sufficient to maintain the discontinuous control valve conductive when the initiating pulse is discontinued.

A further object is to provide sufficient impedance in such shunting circuit to maintain sufficient voltage across the shunted inverters so that when its control valves are pulsed conductive these valves will also conduct.

Another object is to provide an improved method for operating the shunting circuits whereby they may be sequentially opened upon initiation of operation of the polyphase inverting apparatus.

Other objects will be apparent from the specification, the appended claims and the drawings, in which drawings:

FIGURE 1 is a schematic view of a two-phase inverting apparatus embodying the invention;

FIG. 2 is a view of a three-phase inverting apparatus embodying the network; and

FIG. 3 is a modified form of three-phase apparatus as shown in FIG. 2.

Referring to the drawings by characters of reference the numeral 1 designates generally a two-phase inverting apparatus having a pair of single-phase inverters 2A and 2B driven respectively by a master oscillator 4 and a slave oscillator 4A. The inverters 2A and 2B are provided with input terminals 6 and 8 and output terminals 10 and 12. The oscillators derive their energy from a suitable source of unidirectional-potential electrical energy (not shown) which maintains a supply terminal 14 positive with respect to a supply terminal 16. The terminal

14 is connnected through a disconnect switch 18 and an inductance 20 to the input terminal 6 of the inverter 2A. The terminal 8 of the inverter 2A is connected to the terminal 6 of the inverter 2B by a conductor 22 while the terminal 8 of the inverter 2B is connected by a conductor 24 to the negative supply terminal 16.

The inverters 2A and 2B are identical and the details of only the inverter 2A is illustrated. Each inverter comprises a pair of current conducting paths interconnecting its input terminals 6 and 8 with the output terminals 10 and 12. The first path extends from the input terminal 6 through a first silicon controlled rectifier 26 to the output terminal 10 and from the output terminal 12 through a second silicon controlled rectifier 28 to the input terminal 8. Similarly, the second current path extends from the input terminal 6 through a third silicon controlled rectifier 30 to the output terminal 12 and from the output terminal 10 through a fourth silicon controlled rectifier 32 to the input terminal 8. Each of the silicon controlled rectifiers or discontinuous control type electric valves 26, 28, 30 and 32 is provided with an anode *a*, a cathode *c* and a gate *g* and is rendered conducting anode *a* to cathode *c* by applying a pulse between the gate *g* and the cathode *c* in a direction to render the gate *g* positive with respect to the cathode *c*. For this purpose the gates *g* and cathodes *c* of the valves, commonly referred to as the control or pulsing circuit, are connected to individual secondary windings of a saturating core transformer through individual pulse producing networks 36. The pulsing circuits of the inverter 2A are energized from secondary windings of the transformer 34 of the master oscillator while those of the inverter 2B are energized from the secondary windings of the transformer 54 of the slave oscillator 4A. The networks 36 are arranged to provide a voltage wave of steep wave front to ensure the firing of the valves.

Preferably, the core of the transformers 34 and 54 are fabricated of iron having a substantially rectangular hysteresis loop. The transformer 34 of the master oscillator 4 is provided with a center tapped primary winding 38; the end terminals of which are connected to collectors *c* of transistors 40 and 42 and the center tap of which is connected to a negative power input terminal 48. The emitters *e* of these transistors 40 and 42 are connected to a common emitter bus 44 which is connected to the positive power input terminal 46. The base *b* of the transistor 40 is connected through a network 50 to the lower end terminal of the winding 38. Likewise, the base *b* of the transistor 42 is connected through a second network 52 to the upper terminal of the primary winding 38. The oscillator 4 is self-oscillating. Since the transistors 40 and 42 are not absolutely identical in their leakage characteristics, one or the other thereof will commence to conduct more than the other thereof. Assuming that the transistor 40 has the greater leakage current, the leakage conduction will initiate a feedback potential to the base circuits which will cause the most conductive transistor 40 to become fully conducting and the other transistor 42 to be blocking. Transistor 40 continues to conduct until such time that the core of the transformer 34 saturates. When this occurs, the flux will cease to increase and the transistor 42 will no longer be driven nonconductive. When this occurs flux in the core 34 will decrease in magnitude from the saturated value to the remanence value inducing a voltage of opposite polarity in the winding 38. This will cause base drive current to flow in the transistor 42 initiating a regenerative action whereby the transistor 42 rapidly becomes fully conductive whereby current flows into the primary winding 38 in the opposite direction until it drives the core of the transformer 34 to saturation in the opposite direction. The master oscillator will continue to oscillate as above

described thereby inducing an alternating voltage in the secondary windings of its transformer **34**.

The voltages induced in the secondary windings are substantially rectangular in shape. The networks **36** transform these square wave pulses into peaked pulses which are applied in proper polarity to the silicon controlled rectifiers or valves **26** to **32**. During one-half cycle of the output voltage of the oscillator **4** the produced pulses will render the valves **26** and **28** conducting and during the other half-cycle will render the valves **30** and **32** conducting.

The corresponding valves of the inverter **2B** are similarly connected to the secondary windings of the transformer **54** of the slave oscillator **4A** through networks **36** identical to the networks **36** associated with the master oscillator **4**. The transformer **54** is provided with a center tapped primary winding **56**; the end terminals of which are connected to the collectors *c* of a pair of transistors **58** and **60** and the emitters *e* of which are connected through a common emitter bus **62** to a positive power input terminal **64**. The negative input terminal **66** is directly connected to the center tap of the winding **56**. The conduction of the transistors **58** and **60** is primary controlled by a feedback voltage derived from the secondary winding **68** and **70** of the transformer **54**. For this purpose the winding **68** is connected between the base *b* and the emitter *e* of the transistor **58** through a current limiting resistor **72** and the winding **70** is connected between the base *b* and emitter *e* of the transistor **60** through a current limiting resistor **74**.

The master oscillator **4** and slave oscillator **4A** are each designed to operate at the same frequency, but in order to maintain the frequency of the slave oscillator **4A** exactly that of the master oscillator **4** and of a fixed phase relation therewith triggering pulses derived from a secondary winding **76** of the transformer **34** are applied to the control circuit of the slave oscillator **4A**. For this purpose the resistance winding of a potentiometer **78** is connected across the winding **76**. The potentiometer **78** is provided with a movable contact connected to one terminal of a resistor **80**. The other of the resistor **80** is connected through a saturating core reactor **82** to one end of the resistance element of the potentiometer **78**. The voltage appearing across the resistor **80** is applied to the slave oscillator by a pair of conductors **79** and **81** which connect end terminals of the resistor **80** between the bases *b* of the transistors **58** and **60**. Prior to saturation of the reactor **82** insufficient potential appears across the resistor **80** to influence operation of the slave oscillator **4A**. However, when the reactor **82** saturates the potential appearing across the resistor **80** is sufficient to reverse operation of the slave oscillator **4A**.

The potentiometer **78** varies the voltage applied to the saturating reactor **82** and consequently the time interval between reversal of the polarity of the transformer **34** and the transmission of the reversing signal to the slave oscillator **4A** for determining the phase difference of the output voltages of the inverters **2A** and **2B**. In the case of the two-phase system, as shown in FIG. 1, this time interval would be 90° measured with respect to the output voltage of the transformer **34** or in the case of the three phase system as illustrated in FIGS. 2 and 3 the delay would be 120 electrical degrees.

A two-phase induction motor **84** has one of its phases connected through a network **86** to the output terminals **10** and **12** of the inverter **2A** while the other phase of the motor **84** is connected through a similar network **88** to the output terminals **10** and **12** of the inverter **2B**. The networks **86** and **88** are necessary in view of the inductive characteristics of the motor **84**. If the networks **86** and **88** were omitted the resultant voltage waveform across the commutating capacitors **90** would be an exponentially damped sinusoid, the natural frequency of which would be a function of the inductance of the inductor **20** and the capacity of the commutating capacitors **90** and the

inductive characteristics of the load **84**. If the natural frequency of the circuit just described is approximately the same as the operating frequency of the inverter, the capacitor voltage at the instant of commutation will be close to zero and the silicon controlled rectifiers cannot be shut off. If the natural frequency is greater than the operating frequency the capacitor voltage at the instant of commutation will be opposite to that required for shut off. On the other hand, if the natural frequency is approximately half or less of the operating frequency the voltage waveform across the capacitor will become triangular in shape. The system will operate in this case but the power handling capability of the system is seriously reduced and the load voltage waveform is very poor.

Proper selection of the values of the network components eliminates most of these problems and they may be selected so that sinusoidal waveforms of voltage and current will be applied to the motor **84**. Assuming a motor which has at standstill an effective resistive impedance of .32 ohm and an inductive impedance of .78 ohm and at full speed has a resistive impedance of 3.45 ohms and an inductive impedance of 2.26 ohms and a filter capacitor of 75 microfarads, the capacitor in shunt with the motor windings should be 50 microfarads, the inductance .195 millihenry and the capacitor in shunt circuit with the inductance of 15 microfarads.

It is believed that the remainder of the description may best be set forth by a description of operation which is as follows: Upon closure of the disconnect switch **18**, voltage from the power supply terminals **14** and **16** is applied through the inductance or constant current device **20** between the input terminal **6** of the inverter **2A** and the input terminal **8** of the inverter **2B**. If, at the same time, a potential is supplied to the terminals **46** and **48** of the master oscillator and **64** and **66** of the slave oscillator, firing pulses will be applied to the silicon controlled rectifiers of the inverters **2A** and **2B**. These inverters will not immediately commence to conduct because of the sequence at which the pulses are supplied thereto; the pulses supplied to the inverter **2A** occurring at intervals when no pulses are supplied to the inverter **2B**.

In order that the valves **26–28** or **30–32** may become conductive when pulses are applied thereto from the master oscillator **4**, a shunting circuit is provided between the input terminals **6** and **8** of the inverter **2B**. This shunting circuit comprises a resistor **92** and a momentary closure switch **94**. With the switch **94** closed and pulses being applied by the master oscillator **4**, one of the sets of valves **26–28** or **30–32** will receive a conducting pulse. When this occurs, current will flow from the supply terminal **14** through the now closed disconnect switch **18** and inductance **20** to the input terminal **6** of the inverter **2A**. From terminal **6** the current will flow through the one of the sets of valves **26–28** or **30–32** which has received the conductive pulse. For purposes of explanation assume that the conductive pulse is supplied to the rectifier valves **26** and **28** of the inverter **2A**. These valves are consequently rendered conductive and current will flow from the input terminal **6** through the valve **26**, the output terminal **10**, the network **86**, one-phase winding of the motor **84**, the other output terminal **12**, the valve **28**, the input terminal **8** of inverter **2A**, the input terminal **6** of the inverter **2B**, the resistor **92**, now closed switch **94**, the terminal **8** of the inverter **2B**, and conductor **24** to the negative terminal **16**. Since the value of the resistor **92** is chosen so that at least a sustaining value of current will flow through the conducting valves **26** and **28** they will remain conducting when the firing pulse disappears and potential of a first polarity will continue to be supplied to the terminals **10** and **12**.

Subsequently the slave oscillator **4A** will supply conducting pulses to the corresponding valves **26** and **28** of the inverter **2B** which become conducting since the voltage across the resistor **92** provides a sufficient potential across these valves. Current will now flow through the

inverter 2B from its input terminal 6 through its valve 26, the network 88, the other phase winding of the motor 84, its other output terminal 12, its valve 28 back to its input terminal 8 and conductor 24 to the negative terminal 16 whereby potential of the first polarity will continue to appear across its terminals 10 and 12.

One hundred eighty degrees after firing of the valves 26 and 28, the master oscillator 4 will render the valves 30 and 32 of the inverter 2A conducting. Since the charge on the capacitor 90 cannot immediately change, the rendering of these valves conducting will raise the potential of the cathode of the associated valve 26 to a higher potential than that of the anode and this valve 26 will become extinguished. Similarly, the capacitor 90 will lower the potential of the anode of the associated valve 28 below that of its cathode and this valve 28 will become extinguished. The valves 30 and 32 will then continue to conduct and potential of a second polarity will be applied to the output terminals 10 and 12. Ninety degrees later or 270° after initial firing of the valves 26 and 28 of the inverter 2A, the slave oscillator 4A will provide conducting pulses to the valves 30 and 32 of the inverter 2B whereby they conduct and the commutating capacitor 90 of this inverter 2B will render its valves 26 and 28 blocking, as described above in connection with the inverter 2A, whereby potential of the second polarity will exist across its output terminals 10 and 12.

The oscillator and master oscillator will continue to cause staggered pulses to be applied to the inverters 2A and 2B whereby two-phase alternating polarity output voltages appear at the output terminals 10 and 12 of these inverters. The switch 94 may be opened and preferably is opened as soon as possible after the inverter 2B commences to have its valves fired by the slave oscillator 4A.

While the switch 94 is desirable so that during the majority of the operating time of the network 1 the resistor 92 is deenergized, it is appreciated that the switch 94 may be omitted and the resistor 92 maintained permanently connected between the terminals 6 and 8.

In Fig. 2 there is shown a modified form of the invention as applied to a three-phase inverter. It will be apparent that two of the inverters must be supplied with shunting networks so that they may be shunted to permit the unshunted one of the networks to have their electric valves fired. As illustrated the switch 194 sequentially opens the inverter 2B and 2C. While sequential opening is desirable and certain advantages are obtained thereby in its more generic form the switch 194 could open the shunting circuits substantially simultaneously. Again as in the two-phase system the switch 194 could be omitted entirely but in this instance again the efficiency would be reduced due to the continual energization of the shunting resistors 92.

FIG. 3 also shows a three-phase system, however, in this instance it will be noted that two inverters 2B and 2C are shunted by the first shunting circuit which includes the resistor 292 and switch 294. The other of the inverters 2C is shunted by the resistor 292A which is connected through separate contacts on the switch 294. Again the switch 294 is shown as sequentially opening the shunting circuits and again certain advantages such as removal of shock to his system are obtained thereby, however, in its more generic form the switch 294 could simultaneously open the two shunting circuits or could be omitted entirely.

From the foregoing it will be seen that the number of phases and consequently the number of single-phase producing inverter apparatuses is immaterial, however, it is apparent that when the inverter network supplies a source having "N" phases there need to be N-1 shunting circuits. These may take the form as shown in FIG. 2 wherein each shunting circuit shunts a single inverter or may take the form as shown in FIG. 3 in which the first shunting circuits shunts N-1 inverters, the second shunting circuit shunts N-2 inverters and so on down until the last or the N-1st shunting circuit shunts only a single inverter.

While only a limited number of embodiments of the invention have been shown, it will be appreciated that many modifications may be made thereto and still come within the scope of the appended claims.

What is claimed and is desired to be secured by United States Letters Patent is as follows:

1. In an inverting system for energizing a polyphase network of *n* phases, an individual inverting apparatus for individually supplying each of the *n* phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, and a unidirectional current conducting shunting network connected in series with one of said inverting apparatuses and said supply terminals for conduction of current through said one inverting apparatus and between said supply terminals, said shunting network including *n*-1 impedance elements connected in shunt with all of said apparatuses except said one apparatus.

2. In an inverting system for energizing a polyphase network of at least two phases, an individual inverting apparatus for individually supplying each of the *n* phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, and a unidirectional current conducting shunting circuit including an impedance element, said shunting circuit being connected in shunt with at least one of said inverting apparatuses and in series with said supply terminals to conduct unidirectional current between said terminals.

3. In an inverting system for energizing a polyphase network of *n* phases, an individual inverting apparatus for individually supplying each of the *n* phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, a shunting network including *n*–1 switches connected to shunt *n*–1 of said inverting apparatuses, said shunting network being arranged such that progressive operation of said switches removes the shunt around a progressively increasing number of said *n*-1 inverting apparatuses.

4. In an inverting system for energizing a polyphase network of *n* phases, an individual inverting apparatus for individually supplying each of the *n* phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, a shunting network including *n*–1 switches and *n*–1 impedance elements connected to shunt *n*–1 of said inverting apparatuses, said shunting network being arranged such that progressive operation of said switches progressively removes said impedance elements and removes the shunt around a progressively increasing number of said *n*–1 inverting apparatuses.

5. In an inverting system for energizing a polyphase network of *n* phases, an individual inverting apparatus for individually supplying each of the *n* phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, *n*–1 shunting networks, means connecting a first of said shunting networks in shunt with *n*–1 of said inverting apparatuses and a second of said shunting networks in shunt with *n*–2 of said inverting apparatuses until all of said shunting networks are utilized, each said shunting network including an impedance device and a switch, means interconnecting said switch for sequential opening of said shunting circuits in the order named above.

6. In an inverting system for energizing a polyphase network of n phases, an individual inverting apparatus for individually supplying each of the n phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, $n-1$ shunting networks, each said network including an impedance element and a switch, and means individually connecting said shunting networks in shunt circuit with $n-1$ of said inverting apparatuses.

7. In an inverting system for energizing a polyphase network of n phases, an individual inverting apparatus for individually supplying each of the n phases of the system, a pair of supply terminals for energization from a unidirectional-potential electrical energy supply, means connecting said inverting apparatuses in series circuit between said supply terminals, $n-1$ shunting networks, each said network including an impedance element and a switch, means individually connecting said shunting networks in shunt circuit with $n-1$ of said inverting apparatuses, and means interconnecting said switches for sequential operation.

8. In an inverting system; first and second inverting networks; each said network having a pair of input terminals, a pair of output terminals, first and second discontinuous type valve devices, and first and second paths interconnecting said pairs of terminals; said first path including said first valve device and effective when said first valve device is conductive to energize said output terminals at a first polarity relative to said input terminals, said second path including said second valve device and effective when said second valve device is conductive to energize said output terminals at a second polarity relative to said input terminals; firing means rendering said first valve devices conductive in sequence and said second valve devices conductive in sequence; a pair of supply terminals; means connecting said input terminals in series between said supply terminals; an impedance; and circuit means connecting said impedance across said input terminals of one of said inverting networks for flow of unidirectional current therethrough between said pair of supply terminals and through one of said paths of the other of said inverting networks.

9. In an inverting system; first and second inverting networks; each said network having a pair of input terminals, a pair of output terminals, first and second discontinuous type valve devices, and first and second paths interconnecting said pairs of terminals; said first path including said first valve device and effective when said first valve device is conductive to energize said output terminals at a first polarity relative to said input terminals, said second path including said second valve device and effective when said second valve device is conductive to energize said output terminals at a second polarity relative to said input terminals; firing means rendering said first valve device conductive in sequence and said second valve devices conductive in sequence; a pair of supply terminals; means connecting said input terminals in series between said supply terminals; an impedance; a switch and means connecting said impedance in series with said switch across said input terminals of one of said inverting networks.

10. In an inverting system; first and second inverting networks; each said network having a pair of input terminals, a pair of output terminals, a plurality of discontinuous type valve devices, and first and second paths interconnecting said pairs of terminals; said first path including a first and a second of said valve devices, said first paths being effective when said first and second valve devices are conductive to energize said output terminals at a first polarity relative to said input terminals, said second path including a third and a fourth of said valve devices, said second path being effective when said third and said fourth valve devices are conductive to energize said output terminals at a second polarity relative to said input terminals, firing means rendering said first and second valve devices conductive substantially simultaneously and said third and fourth valve devices conductive substantially simultaneously; means for operating said firing means of said first network in staggered relation to said firing means of said second network; a pair of supply terminals; means connecting said input terminals in series between said supply terminals; an impedance; and means connecting said impedance across said input terminals of one of said inverting networks.

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JOHN F. COUCH, *Primary Examiner.*

W. H. BEHA, *Assistant Examiner.*