

PATENT SPECIFICATION

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(54) PHASE CONTROL APPARATUS

(71) We, HITACHI LTD., a Corporation organised under the laws of Japan, of 5-1, 1-chome, Marunouchi, Chiyoda-ku, Tokyo, Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 The present invention relates to an improvement in a phase control apparatus using a magnetic phase shifter.

As is well known, a magnetic phase shifter utilizes a principle of a magnetic amplifier and includes at least a saturable core and an A.C. winding (sometimes referred to as an output winding) and a control winding wound on the core. When the A.C. winding is connected between an A.C. power supply and a load and a D.C. voltage is applied to the control winding, saturation of the core can be controlled in accordance with the change of the D.C. voltage. As the core saturates, the impedance of the A.C. winding suddenly decreases so that for example a phase controlled voltage may be applied suddenly to the load. Accordingly, this principle has been widely used to effect phase control of an A.C. circuit by connecting a gate circuit of a main thyristor connected to the A.C. circuit, as the load.

The A.C. power supply connected to the A.C. winding of the magnetic phase shifter must be in synchronism with the A.C. power supply connected to the main thyristor. To this end, it has been a common practice to use a sinusoidal wave A.C. signal as a synchronizing signal source, which signal is produced by stepping down the A.C. voltage applied to the main thyristor.

However, the following disadvantages are included when a sinusoidal wave A.C. signal is used as the synchronizing signal source of the magnetic phase shifter.

45 (1) The phase angle of the phase shifter

is not proportional to the input control signal.

(2) The range of phase control is narrow.

(3) The characteristic of the phase shifter is unstable.

In order to overcome these disadvantages, it is desirable to use a square wave A.C. signal as the synchronizing signal source of the magnetic phase shifter. It has been proposed in copending British patent specification No. 1504429 to use a transistor inverter for that purpose. Such a transistor inverter usually includes at least a D.C. power supply, an inverter transistor, and a pair of transistors which are switched at the end of every half-cycle of an A.C. signal which is synchronized with a main circuit. A voltage across a secondary winding of the inverter transformer is used as the synchronizing signal source of the phase shifter.

As is well known, the inverter encounters a problem of saturation of the inverter transformer. Namely, if that one of the pair of transistors which is rendered conductive first at the restart of an inverter operation is the same as that which has been rendered conductive at the stop of the previous inverter operation, the inverter transformer is magnetized in one direction and hence it is saturated. As a result, the one transistor shortcircuits the D.C. power supply to cause a rush current to flow. Accordingly, complex means to prevent biased magnetization of the inverter transformer has evolved, as is well known in the art of the inverter or alternatively use is made of a transistor of a sufficiently large current capacity to withstand the rush current. In any case, those approaches necessarily result in an un economical phase control apparatus.

It is a primary object of the present invention to provide an economic phase control apparatus of a magnetic phase shifter

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According to the present invention there is provided a phase control apparatus comprises a synchronizing signal source, first and second switching devices which are alternately switched by the synchronizing signal source, a D.C. power supply, first and second magnetic phase shifters each having a saturable core and an A.C. and a control winding which are wound on said core, a first load connected in a first closed circuit including said D.C. power supply, said first switching device and the A.C. winding of said first magnetic phase shifter, and a second load connected in a second closed circuit including said D.C. power supply, said second switching device and the A.C. winding of said second magnetic phase shifter.

According to a preferred embodiment of the present invention, the respective gate circuits of first and second thyristors are connected as the first and second loads mentioned above.

According to another preferred embodiment of the present invention, first and second pulse transformers are connected in series with the above-mentioned first and second thyristors, respectively, so that first and second main thyristors are fired through the respective pulse transformers.

The above and other features and advantages of the present invention will become more apparent from the following detailed description of the preferred embodiments of the invention when taken in conjunction with the accompanying drawings, in which:

Fig. 1 is an electrical circuit diagram of one embodiment of a phase control apparatus of the present invention;

Fig. 2 shows an electrical circuit diagram of another embodiment of the present invention; and

Fig. 3 shows an electrical circuit diagram of still another embodiment of the present invention.

Referring now to Fig. 1, thick lines show a main circuit in which main thyristors 1 and 2 are connected in reverse-parallel relation between terminals 3 and 4 of an A.C. active circuit. A phase shifter, for example, is used to phase control the parallel-opposing thyristors.

A construction of the phase shifter is explained below.

A synchronizing signal source 5 generates an A.C. voltage which is in synchronism with an A.C. signal applied between the terminals 3 and 4. In usual practice, the A.C. voltage applied between the terminals 3 and 4 is stepped down by a transformer to provide the synchronizing signal source 5. The synchronizing signal source 5 is connected to a pair of transistors 81 and 82 through a switch 6 and a resistor 7 to alternately switch the transistors. Namely, during a

positive half-cycle period of the voltage from the synchronizing signal source 5, the first transistor 81 is turned on by a closed circuit which emanates from the signal source 5 through the resistor 7, a base-emitter junction of the first transistor 81, a first diode 91 and the switch 6 and goes back to the signal source 5. On the other hand, during a negative half-cycle period of the voltage from the signal source 5, the second transistor 82 is turned on by a closed circuit which emanates from the signal source 5 through the switch 6, a base-emitter junction of the second transistor 82, a second diode 92 and the resistor 7 and goes back to the signal source 5.

A D.C. power supply 10 feeds a first load through an A.C. winding 112 of a first magnetic phase shifter 11 and the first transistor 81. The D.C. power supply 10 also feeds a second load through an A.C. winding 122 of a second magnetic phase shifter 12 and the second transistor 82. In the illustrated embodiment, a gate circuit of a thyristor 21 is connected as the first load and a gate circuit of a second thyristor 22 is connected as the second load. That is, a first closed circuit is constituted by the D.C. power supply 10, a diode 13, the A.C. winding 112 of the magnetic phase shifter 11, a resistor 31, the gate circuit of the thyristor 21 (load), the transistor 81 and back to the D.C. power supply 10. On the other hand, a second closed circuit is constituted by the D.C. power supply 10, the diode 13, the A.C. winding 122 of the magnetic phase shifter 12, a resistor 32, gate circuit of the thyristor 22 (load), the transistor 82 and back to the D.C. power supply 10.

The magnetic phase shifters 11 and 12 include saturable cores 111 and 121, and control windings 113 and 123, respectively. D.C. control inputs are applied from terminals 14 and 15 to control windings 113 and 123 of the magnetic phase shifters 11 and 12, respectively.

The thyristors 21 and 2 are connected between the D.C. power supply 10 and the respective first and second transistors 81 and 82 through pulse transformers 41 and 42 as their loads. In this case, a third closed circuit is constituted by the D.C. power supply 10, the primary winding 411 of the pulse transformer 41, the thyristor 21, the transistor 81 and back to the D.C. power supply 10 while a fourth closed circuit is constituted by the D.C. power supply 10, the primary winding 421 of the pulse transformer 42, the thyristor 22, the transistor 82 and back to the D.C. power supply 10. Alternatively, the thyristors 21 and 22 are connected in an A.C. circuit (not shown) to be additionally loaded.

Voltages across the secondary windings 412 and 422 of the pulse transformer 41 and

42 are applied to the gate circuits of the main thyristors 1 and 2 through diodes 51 and 52, respectively.

The operation of the circuit will be now 5 described.

When the synchronizing signal source 5 is connected by turning on the switch 6, the first and second transistors 81 and 82 are alternately turned on as described above. 10 When the transistor 81 is turned on, the voltage of the D.C. power supply 10 is applied between the anode and cathode of the thyristor 21 through the above-mentioned third closed circuit. At the same time, the 15 voltage of the D.C. power supply 10 is also applied to the A.C. winding 112 of the first magnetic phase shifter 11 through the above-mentioned first closed circuit. As a result, the saturable 20 core 111 of the first magnetic phase shifter 11 saturates at a phase angle which is determined in accordance with a control input applied to the control winding 113 so that the impedance of the A.C. winding 112 suddenly decreases. Thus, a current flows from 25 the D.C. power supply 10 to the gate circuit of the thyristor 21 through the above-mentioned first closed circuit and the thyristor 21 is rendered conductive. As a result a 30 voltage is applied across the primary winding 411 of the pulse transformer in the third closed circuit so that a voltage is induced across the secondary winding 412 to fire the main thyristor 1. 35 When the polarity of the voltage of the synchronizing signal source 5 changes, the first transistor 81 is turned off so that the first and third closed circuits are opened. At the same time, the second transistor 82 is 40 turned on so that the main thyristor 2 is fired at a desired phase angle in a similar manner to that described above.

As is well known, it is very easy to avoid the biased magnetization problem in a pulse 45 transformer. This may be attained by applying a D.C. current to a reset winding provided therein or by enlarging the gap formed in the core thereof.

With the above construction, the A.C. 50 voltage waveforms applied to the respective A.C. windings 112 and 122 of the magnetic phase shifters 11 and 12 are square waves, which result in a number of advantages of the magnetic phase shifter as described above. Furthermore, no inverter 55 transformer is required and the first and second transistors 81 and 82 may be of smaller current capacity. No complex and expensive means to prevent the saturation 60 of the inverter transformer is required. As a result, economization of the phase control apparatus is attained.

Furthermore, since the circuit is arranged such that the A.C. winding circuits of the 65 magnetic phase shifters are turned on and

off by the switching devices such as the transistors 81 and 82, jumping of the magnetic phase shifter in a reset region can be prevented to ensure a stable operation of the phase shifter. 70

Assuming that the control inputs applied to the terminals 14 and 15 include large ripples to cause large fluctuations in the voltages across the control windings 113 and 123, the magnetic phase shifter which is in 75 the gated period is not at all affected by such fluctuations because it is clamped by the A.C. voltage applied to its A.C. winding, as is well known. On the other hand, in a magnetic phase shifter which is in the 80 reset region, there would generally be a risk of voltage application to the load (e.g. gate-cathode of the thyristor 21 or 22.), but in the apparatus of the present invention there is no such risk since the circuit is 85 blocked by the first or second switching device 81 or 82. Accordingly, jumping of the phase shifter can be effectively prevented.

In a preferred embodiment of the present 90 invention, a capacitor 16 is connected in parallel with the D.C. power supply 10. Since the capacitor 16 is continuously charged by the voltage of the D.C. power supply 10 the voltage across the D.C. power 95 supply 10 does not substantially deviate even if there occurs a substantial deviation in the voltage of the D.C. power supply 10. Thus, a sharp rise characteristic can be given to the output of the magnetic phase shifter. 100

Furthermore, as shown in the drawing, when the same D.C. power supply 10 feeds the third closed circuit including the primary winding 411 of the pulse transformer 41, the thyristor 21 and the transistor 81, the 105 rise of the voltage across the pulse transformer 41 is also sharpened by the provision of the capacitor 16. Accordingly, operation speed of the overall circuit can be increased with only one capacitor. However, there is a little power loss because of 110 a small charge/discharge current of the capacitor.

In the above embodiment of the present invention, the control windings 113 and 123 115 are connected in series with each other. For example, if the transistor 81 is turned off when a current flows in the winding 112, spike voltages are produced in the windings 112 and 113. The spike voltage thus produced 120 in the winding 113 is applied to the winding 123 through a low impedance of the control circuit connected between the terminals 14 and 15.

As soon as the transistor 81 is turned off 125 the transfer 82 is turned on so as to begin the gate period of the core 121. Since the spike voltage is applied at the beginning of this gate period, the core 121 is supplied with a high level gate voltage at the begin- 130

ning of the gate period thereof so as to be early saturated. For this, the range of phase control is expanded to the extent of nearly $\alpha = 0$.

- 5 Similarly to this, the range of phase shift of the phase shifter 11 is expanded by the spike voltage which is applied to the winding 113 when the transistor 82 is caused to be turned off.
- 10 By slightly modifying the apparatus of Fig. 1, a DC-DC converter can be constructed. Fig. 2 shows an example of the DC-DC converter. The pulse transformers 41 and 42 of Fig. 1 have been eliminated and a load 171 is connected in a common path to the third and fourth closed circuits. An additional second D.C. power supply 101 may be provided to establish a sufficiently high voltage source to the load 171. The other component elements serve to operate in the same manner as Fig. 1 and therefore a detailed description is not necessary. With this arrangement, a D.C. voltage which changes in proportion with a D.C. control input applied to the terminals 14 and 15 may be applied to the load 171.

Fig. 3 shows another modification of the embodiment of Fig. 1 according to the present invention, in which the transistors 81 and 82 are of PNP type. The circuit of Fig. 3 differs from that of Fig. 1 in that the positions of the loads (pulse transformers in the illustrated embodiment) 41 and 42 and the thyristors 21 and 22 have been exchanged. If these loads were connected to the cathodes of the thyristors 21 and 22, the loads, e.g. the primary winding 411 of the pulse transformer 41 would be connected in the first closed circuit including the D.C. power supply 10, the transistor 81, the diode 131, the A.C. winding 112, the resistor 31, the gate circuit of the thyristor 21 and back to the D.C. power supply 10. When the load is connected to the gate circuit of the thyristor, the impedance of the load, particularly the reactance thereof makes the firing of the thyristor difficult. For this reason, the load is connected to each of the anodes of the thyristors 21 and 22. Numerals 131 and 132 denote diodes.

WHAT WE CLAIM IS:

1. A phase control apparatus comprising:
 - a synchronizing signal source;
 - 55 first and second switching devices adapted to be alternately switched by said synchronizing signal source;
 - a D.C. power supply;
 - first and second magnetic phase shifters
 - 60 each having a saturable core, an A.C. winding, and a control winding, said A.C. and control windings being wound on said core;
 - a first load connected in a first closed
 - 65 circuit including said D.C. power supply,

said first switching device, and said A.C. winding of said first magnetic phase shifter; and

a second load connected in a second closed circuit including said D.C. power supply, said second switching device, and said A.C. winding of said second magnetic phase shifter.

2. A phase control apparatus according to Claim 1, wherein said first and second loads are the respective gate circuits of first and second thyristors connected to a voltage source which is in synchronism with said synchronizing signal source.

3. A phase control apparatus according to Claim 2, wherein said first thyristor is connected in a third closed circuit including said D.C. power supply and said first switching device, and wherein said second thyristor is connected in a fourth closed circuit including said D.C. power supply and said second switching device.

4. A phase control apparatus according to Claim 3, wherein third and fourth loads respectively are connected to anodes of said first and second thyristors in said third and fourth closed circuits.

5. A phase control apparatus according to Claim 4, wherein the third and fourth loads comprise respectively primary windings of first and second pulse transformers connected in said third and fourth closed circuits, and said apparatus further comprises third and fourth thyristors adapted to be fired by voltages across the respective secondary windings of said first and second pulse transformers.

6. A phase control apparatus according to Claim 2, comprising a second D.C. power supply, said first thyristor being connected in a third closed circuit including said first and second D.C. power supplies and said first switching device, said second thyristor being connected in a fourth closed circuit including said first and second D.C. power supplies and said second switching device.

7. A phase control apparatus according to Claim 6, wherein a third load is connected in a common path to said third and fourth closed circuits.

8. A phase control apparatus according to any one of the preceding claims, wherein a capacitor is connected in parallel with said D.C. power supply.

9. A phase control apparatus according to any one of the preceding Claims, wherein the respective control windings of said first and second magnetic phase shifters are connected in series with each other.

10. A phase control apparatus according to any one of the preceding Claims, wherein said first and second switching devices comprise first and second transistors, respectively, said synchronizing signal



ning of the gate period thereof so as to be early saturated. For this, the range of phase control is expanded to the extent of nearly $\alpha = 0$.

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- 10 By slightly modifying the apparatus of Fig. 1, a DC-DC converter can be constructed. Fig. 2 shows an example of the DC-DC converter. The pulse transformers 41 and 42 of Fig. 1 have been eliminated and a load 171 is connected in a common path to the third and fourth closed circuits. An additional second D.C. power supply 101 may be provided to establish a sufficiently high voltage source to the load 171. The other component elements serve to operate in the same manner as Fig. 1 and therefore a detailed description is not necessary. With this arrangement, a D.C. voltage which changes in proportion with a D.C. control input applied to the terminals 14 and 15 may be applied to the load 171.

Fig. 3 shows another modification of the embodiment of Fig. 1 according to the present invention, in which the transistors 81 and 82 are of PNP type. The circuit of Fig. 3 differs from that of Fig. 1 in that the positions of the loads (pulse transformers in the illustrated embodiment) 41 and 42 and the thyristors 21 and 22 have been exchanged.

35 If these loads were connected to the cathodes of the thyristors 21 and 22, the loads, e.g. the primary winding 411 of the pulse transformer 41 would be connected in the first closed circuit including the D.C. power supply 10, the transistor 81, the diode 131, the A.C. winding 112, the resistor 31, the gate circuit of the thyristor 21 and back to the D.C. power supply 10. When the load is connected to the gate circuit of the thyristor, the impedance of the load, particularly the reactance thereof makes the firing of the thyristor difficult. For this reason, the load is connected to each of the anodes of the thyristors 21 and 22. Numerals 131 and 132 denote diodes.

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1. A phase control apparatus comprising:
 - a synchronizing signal source;
 - 55 first and second switching devices adapted to be alternately switched by said synchronizing signal source;
 - a D.C. power supply;
 - first and second magnetic phase shifters
 - 60 each having a saturable core, an A.C. winding, and a control winding, said A.C. and control windings being wound on said core;
 - a first load connected in a first closed
 - 65 circuit including said D.C. power supply,

said first switching device, and said A.C. winding of said first magnetic phase shifter; and

a second load connected in a second closed circuit including said D.C. power supply, said second switching device, and said A.C. winding of said second magnetic phase shifter.

2. A phase control apparatus according to Claim 1, wherein said first and second loads are the respective gate circuits of first and second thyristors connected to a voltage source which is in synchronism with said synchronizing signal source.

3. A phase control apparatus according to Claim 2, wherein said first thyristor is connected in a third closed circuit including said D.C. power supply and said first switching device, and wherein said second thyristor is connected in a fourth closed circuit including said D.C. power supply and said second switching device.

4. A phase control apparatus according to Claim 3, wherein third and fourth loads respectively are connected to anodes of said first and second thyristors in said third and fourth closed circuits.

5. A phase control apparatus according to Claim 4, wherein the third and fourth loads comprise respectively primary windings of first and second pulse transformers connected in said third and fourth closed circuits, and said apparatus further comprises third and fourth thyristors adapted to be fired by voltages across the respective secondary windings of said first and second pulse transformers.

6. A phase control apparatus according to Claim 2, comprising a second D.C. power supply, said first thyristor being connected in a third closed circuit including said first and second D.C. power supplies and said first switching device, said second thyristor being connected in a fourth closed circuit including said first and second D.C. power supplies and said second switching device.

7. A phase control apparatus according to Claim 6, wherein a third load is connected in a common path to said third and fourth closed circuits.

8. A phase control apparatus according to any one of the preceding claims, wherein a capacitor is connected in parallel with said D.C. power supply.

9. A phase control apparatus according to any one of the preceding Claims, wherein the respective control windings of said first and second magnetic phase shifters are connected in series with each other.

10. A phase control apparatus according to any one of the preceding Claims, wherein said first and second switching devices comprise first and second transistors, respectively, said synchronizing signal



(12)

source being connected between the respective bases of said first and second transistors, the respective emitters of said first and second transistors being connected
5 in common, and first and second diodes bypassing the respective base-emitter junctions of said first and second transistors.

11. A phase control apparatus substantially as hereinbefore described with re-

ference to Fig 1 or Fig 2 or Fig 3 of 10 the accompanying drawings.

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