

PATENT SPECIFICATION

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(54) AN ALTERNATING CURRENT CONTROLLING SYSTEM

(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:—

The present invention relates to an alternating current controlling system which controls an AC power source to supply electrical power to a load.

In various fields, an appropriate use has conventionally been made to a system in which a switching device is interposed between an AC power source and a load, and by controlling the switching device, an electrical power supplied to the load is controlled. This switching device corresponds to a thyristor arrangement, for example, and the thyristor arrangement is rendered conductive by the application of a trigger pulse thereto when it is supplied with a forward voltage. In order to control the thyristor arrangement, therefore, it is necessary to produce a signal in synchronism with a voltage of the AC power source and effect controlling of the thyristor in synchronism with the AC power source voltage.

In the United States patent No. 3,497,796 titled "Synchronous Gating of Bilateral Switches in a Three-Phase System", for example, in order to control inverse-parallel connection thyristor arrangements inserted in two phase lines of a three-phase AC power source, a signal in synchronism with a voltage of this power source is derived through a three-phase transformer and this synchronized signal and a control signal are delivered to a trigger circuit by which respective inverse-parallel connection thyristor arrangements are driven. Thus, the inverse-parallel connection thyristor arrangements are controlled in synchronism with the three-phase AC power source and an electrical power in response to the control signal can be supplied to the load.

This synchronizing control of the switching devices or inverse-parallel connection thyristor arrangements will not encounter any difficulty if the output of the AC power source has a normal sine waveform.

However, on-off operation of the switching device or intermittent operation and stoppage of a load (for example, an induction motor or a similar switching device) connected to the same AC power source as connected with former switching device usually causes the AC power source to be disturbed such that the AC power source voltage is distorted so as to contain harmonic components. In such an event, an electrical power supplied to the load becomes very unstable. Accordingly, with an induction motor serving as load, for example, a distorted waveform results in a pulsating current which leads to noise and in extremity of a maximized power source distortion, the normal operation of induction motor will be obstructed.

An object of the present invention is to provide an alternating current controlling system capable of stably supplying an electrical power to a load even when the wave form of an AC power source is distorted.

According to the present invention there is provided an alternating current control system comprising: a three-phase AC power source; a load; a switching device connected to at least one phase line between said three-phase AC power source and said load; a smoothing circuit connected to said three-phase AC power source for smoothing distorted output voltages produced from said three-phase AC power source; a three-phase transformer having a primary winding connected to said three-phase AC power source through said smoothing circuit and a secondary winding for generating a synchronizing signal whose phase lag due to said smoothing circuit is compensated; and a trigger circuit arranged to receive said synchronizing signal and a control signal for

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supplying a trigger signal to said switching device thereby to control electrical power supplied to said load.

Embodiments of the present invention will now be described by way of example with reference to the accompanying drawings, in which:

Figure 1 is a block diagram of an alternating current controlling system embodying the invention which is especially applied to a three-phase alternating current control;

Figure 2 is a circuit diagram of a specified trigger circuit for triggering an inverse-parallel connection thyristor arrangement;

Figures 3A to 3D show signal waveform diagrams which are useful to explain operation of the trigger circuit of Figure 2;

Figures 4A and 4B show waveform diagrams which are useful to explain operations of a square wave generator circuit with a normal waveform of power source and distorted waveform thereof, respectively;

Figure 5 is a circuit diagram of the embodiment shown in the block diagram of Figure 1;

Figures 6A to 6C show vector diagrams of voltages at essential parts of the circuit of Figure 5; and

Figure 7 is a circuit diagram of another embodiment of the alternating current control system according to the invention.

In an alternating current control system embodying the invention as shown in Figure 1, electrical power is supplied to an AC load through inverse-parallel connection thyristor arrangements connected in two phase lines of a three-phase AC power source.

In Figure 1, a three-phase AC power source as represented by phase lines U, V and W makes the phase rotation in the order of U, V and W. Inverse-parallel connection thyristor arrangements S1 and S2 are interposed between a three-phase load LD and the AC power source. The inverse-parallel connection thyristor arrangement S1 inserted in phase line U comprises thyristors S11 and S12. The anode of thyristor S11 coupled with the cathode of thyristor S12 is connected to the phase line U of a power source whereas the cathode of thyristor S11 coupled with the anode of thyristor S12 is connected to a terminal u of the load LD. The inverse-parallel connection thyristor arrangement S2 inserted in phase line W comprises thyristors S21 and S22, and the anode of thyristor S21 and the cathode of thyristor S22 are connected in common to phase line W whereas the cathode of thyristor S21 and the anode of thyristor S22 are connected in common to a terminal w of the load LD. A smoothing circuit FL has input terminals 1, 2 and 3

respectively connected to phase lines U, V and W and produces at its output terminals 4, 5 and 6 voltages obtained by smoothing distorted waveforms of the three-phase AC power source phase lines U, V and W.

A synchronizing circuit AS for generating a synchronizing signal has input terminals 01, 02 and 03 respectively receiving outputs of the smoothing circuit FL corresponding to phase lines U, V and W, and generates at its output terminals 11, 12 and 21, 22 signals in synchronism with the power source voltages.

Trigger circuits A1 and A2 are connected to the output terminals 11, 12 and 21, 21 of the synchronizing circuit AS to receive the synchronizing signals generated by the synchronizing circuit AS. These trigger circuits also receive a control signal CS from an external circuit not shown and controlled thereby to produce a trigger pulse. A trigger pulse produced by the trigger circuit A1 is supplied to the inverse-parallel connection thyristor arrangement S1 through a connection line 111. Another trigger pulse produced by the trigger circuit A2 is supplied to the inverse-parallel connection thyristor arrangement S2 through a connection line 112.

The present invention is based on the fact that unstable load currents are mainly caused by the synchronizing and trigger circuits provided for the inverse-parallel connection thyristor arrangements S1 and S2 and those circuits are sensitive to the waveform distortion of a power source and it is contemplated to derive a voltage of each phase line of the power source through the smoothing circuit FL. Consequently, the inverse-parallel connection thyristor arrangements S1 and S2 are freed from the power source distortion and can always be controlled in proper response to the control signal CS. It is also possible to minimize the size of the smoothing circuit FL and to manufacture the same of low cost as compared with a case where the power source distortion is smoothed in the power source itself.

Referring now to Figures 2 and 3A to 3C, construction and operation of the trigger circuits A1 and A2 will be described in more detail together with an explanation of the relationship between the power source waveform and the trigger circuit. As shown in Figure 2, the trigger circuit comprises a square wave generator circuit RC, a magnetic phase shifter MPS and amplifiers AMP1 and AMP2. The square wave generator circuit RC converts a sine wave as shown in Figure 3A corresponding to the output voltage waveform of the synchronizing circuit AS into a square waveform as shown in Figure 3B. Namely, this generator circuit RC is an inverter

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circuit in which transistors T1 and T2 are operated by the AC input voltage of a sine waveform to chop the voltage at a DC power source B, so that an AC voltage of square waveform is induced across secondary windings of a square wave transformer TR. The square wave generator circuit has on its output side two circuits each connected to a separate AC winding of the magnetic phase shifter MPS. The two circuits include diodes D3 and D4, respectively, to obtain half-wave rectifications in reverse phase relationship to each other. The magnetic phase shifter MPS delivers an output in the form of a pulse waveform as shown in Figure 3C the width of which is varied by the magnitude of control signal CS flowing through a control winding of the magnetic phase shifter MPS. The output pulse of the magnetic phase shifter MPS is amplified by the amplifiers AMP1 and AMP2 to produce a gate pulse as shown in Figure 3D which in turn is supplied to the thyristors S11 and S12.

The square wave generator circuit RC of Figure 2 receives the input voltage of a waveform shown in Figure 4A and delivers the output voltage of a waveform shown in Figure 4B. In the figures, a solid line waveform corresponds to a distorted output voltage of synchronizing circuit AS and a broken line waveform corresponds to that devoid of distortion.

In the case of the input voltage without distortion, as has been explained with reference to Figures 2 and 3, a positive square wave voltage develops at the output of the square wave generator circuit in response to a positive half cycle of the input sine wave and in a similar manner, a negative square wave voltage does in response to a negative half cycle of the input sine wave. In other words, balanced positive and negative voltage waveforms are supplied to the magnetic phase shifter so that it is possible to supply balanced gate pulses to the thyristors S11 and S12, thereby causing them to effect balanced positive and negative phase controls.

In contrast, consider the input voltage with waveform deformation as shown at solid line in Figure 4A. When the input voltage wave travels from negative to positive, it assumes a zero level at time *a* if accompanied by no distortion but at time *a'* earlier than time *a* if accompanied by the distortion with the result that the square wave generator circuit RC produces a positive-going output voltage at time *a'* as shown in Figure 4B. In a similar manner, when travelling from positive to negative, the input voltage wave without distortion assumes the zero level at time *b* but the input voltage wave with distortion assumes

the zero level at time *b'* later than time *b*, causing the square wave generator circuit RC to produce a negative-going output voltage at time *b'* as shown in Figure 4B. It will be seen also that time *c* corresponds to time *a* after one cycle and time *c'* to time *a'* after one cycle. Accordingly, time intervals hold

$$a'b' > ab = bc > b'c'$$

It follows that for the square wave generator circuit output voltage without distortion, positive and negative square waveforms are balanced but, for the output voltage with distortion these waveforms are unbalanced.

If unbalanced positive and negative square waveforms are supplied to the magnetic phase shifter MPS, under the application of a fixed control signal a product of voltage by time at the AC input of the magnetic phase shifter differs dependent on the positive half cycle or the negative half cycle resulting in the generation of unbalanced output gate pulses for positive and negative halves at different times.

As a result, unbalanced currents flow through the inverse-parallel connection thyristor arrangement, obstructing the supply of a normal electrical power to the load. Further, with the trigger circuit in the form of the magnetic phase shifter MPS as shown in Figure 2, the magnetic phase shifter undergoes a gradual DC bias magnetization due to the unbalanced positive and negative synchronizing signals and accordingly, this positive and negative unbalances are accelerated, finally obstructing the control operation.

However, according to the present invention wherein, as explained with reference to a block diagram of Figure 1, respective phase line voltages of the AC power source phase lines U, V and W are delivered to the synchronizing circuit AS through the smoothing circuit FL, the synchronizing circuit AS can always receive the input in the form of a sine wave even with the AC power source of distorted waveform. Accordingly, it is possible to constantly effect an optimum alternating current control without influenced by the AC power source distortion.

The embodiment illustrated in a block form of Figure 1 is specifically shown in a circuit diagram of Figure 5.

A controlling system for the inverse-parallel connection thyristor arrangements S1 and S2 described herein is one proposed recently by the same applicant in the United States Patent No. 4,101,819. According to this proposed system, the inverse-parallel connection thyristor arrangement S1

inserted in the phase line U is advantageously controlled by a synchronizing signal having a phase angle of 30° lead relative to a phase line voltage of the phase line U whereas the inverse-parallel connection thyristor arrangement S2 inserted in the phase line W is advantageously controlled by a signal in synchronism with a phase line voltage of the phase line W. With this construction, it is possible to suppress, even with a small control angle, an unbalanced single-phase circulating current which would flow into the load and even with a large control angle, prevent the failure of ignition, thereby ensuring a control operation with control angles ranging from 0° to 180°.

In Figure 5, the smoothing circuit FL comprises resistors R_U , R_V and R_W and capacitors C_U , C_V and C_W . These resistors and capacitors are selected such that the power source distortion can be smoothed with a phase angle of 30° lag.

The synchronizing circuit AS comprises a three-phase transformer whose primary windings $P_U P_N$, $P_V P_N$ and $P_W P_N$ are connected in star connection, points P_U , P_V and P_W being connected to a three-phase output line of the three-phase smoothing circuit. Secondary windings $S_U X_U$ and $S_W X_W$ have, on the one hand, ends X_U and X_W connected to each other and, on the other hand, ends S_U and S_W separately connected to the trigger circuit A2. The remainder of secondary winding $S_V X_V$ has one end S_V and the other X_V separately connected to the trigger circuit A1.

Figures 6A to 6C show vector diagrams showing input-output phase relations of the smoothing circuit FL and synchronizing circuit AS of Figure 5. In relation to input voltage vectors $\vec{E}_U$, $\vec{E}_V$ and $\vec{E}_W$ of the smoothing circuit FL as shown in Figure 6A, primary voltage vectors $\vec{E}'_U$, $\vec{E}'_V$ and $\vec{E}'_W$ of the three-phase transformer (corresponding to output voltage vectors of the smoothing circuit FL) as shown in Figure 6B have a phase of 30° lag due to phase-lagging elements of the smoothing circuit FL, respectively. Among secondary voltage vectors of the three-phase transformer as shown in Figure 6C, a voltage vector $-\vec{e}'_V$ supplied to the trigger circuit A1 is in 180° lagging or leading phase relative to the primary voltage vector $\vec{E}'_V$ of the three-phase transformer and in 30° leading phase relative to the power source voltage vector $\vec{E}_U$. A voltage vector $\vec{e}'_{wu}$ i.e., one of secondary voltage vectors of the three-phase transformer, supplied to the trigger circuit A2 is in 30° leading phase relative to the primary voltage vector $\vec{E}'_W$ of three-phase transformer and in phase with the power source voltage vector $\vec{E}_W$. Here, by making the number of winding turns of

the secondary winding $S_V X_V$ of the three-phase transformer $\sqrt{3}$ times the number of winding turns of the secondary windings $S_U X_U$ and $S_W X_W$, an equation in absolute value stands as $|\vec{e}'_V| = |\vec{e}'_{wu}|$, as will be seen from Figure 6C.

That is to say, the phase lag due to the smoothing circuit FL is compensated so that the inverse-parallel connection thyristor arrangement S1 in the phase line U may be controlled by a synchronizing signal of 30° leading phase relative to the phase line voltage of phase line U and the inverse-parallel connection thyristor arrangement S2 may be controlled by a synchronizing signal in phase with the phase line voltage of phase line W.

It will be appreciated from the foregoing embodiment that respective phase line voltages of the three-phase power source may be freed from its distortion waveform at the smoothing circuit FL to take a sine wave-form and then delivered to the synchronizing circuit AS. Consequently, the control operation can always be synchronized with the AC power source. Since the waveform distortion is not amplified any further, a stable AC power can be supplied to the load LD. Taking an induction motor as load LD, for example, it is possible to obtain a stable rotation free from abnormal noise. Additionally, radio wave interaction which would result from the power source distortion can be prevented.

Moreover, by using the three-phase transformer as synchronizing circuit AS as in the foregoing embodiment when the three-phase AC power source is controlled, it is possible to readily compensate for the phase lag due to the smoothing circuit FL by changing the winding connection of the transformer without requiring any additional compensating means (for example, a Toulon circuit). Briefly, this embodiment proves to be a highly simple and reliable three-phase alternating current control system capable of ensuring the control operation with control angles ranging from 0° to 180° under any waveform distortion of the power source.

Turning now to Figure 7, another embodiment of this invention will be described which is applicable to supply of electrical power to a reversible three-phase induction motor.

A reversible induction motor 3 IM is rotated forwardly when main contacts 11 are thrown in whereas it is rotated reversely when the phase rotation of the power source is reversed by throwing in main contacts 12. Switching devices, such as inverse-parallel connection thyristor arrangements S1 and S2 which are inserted between the main contacts 11 or 12 and the three-phase

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induction motor 3IM, control the current flowing through the three-phase induction motor 3IM irrespective of its forward or reverse rotation. The inverse-parallel connection thyristor arrangements S1 and S2 are connected such that when the main contacts 11 are thrown in, the inverse-parallel connection thyristor arrangement S1 is inserted in the phase line U and the inverse-parallel connection thyristor arrangement S2 is inserted in the phase line W. Conversely, when the main contacts 12 are thrown in, the inverse-parallel connection thyristor arrangement S1 is inserted in the phase line W and the other arrangements S2 is inserted in the phase line U.

Synchronizing circuit AS produces synchronizing signals to be supplied to trigger circuits A1 and A2 irrespective of the connection of thyristor arrangements S1 and S2 to the phase lines for either forward or reverse rotation.

A three-phase smoothing circuit FL including resistors R_u , R_v and R_w and capacitors C_u , C_v and C_w is connected to smooth the power source distortion. The phase of power source voltage is subjected to 30° lagging at the three-phase smoothing circuit owing to its phase-lagging elements. On the other hand, a three-phase transformer included in the synchronizing circuit AS has three primary windings P_u , P_v and P_w , the beginnings of these primary windings being respectively connected to the phase lines U, V and W of three-phase power source and the terminations of them being connected in common, thus completing a star connection of the primary windings. Secondary windings have two windings for each one of three-phases. Windings S_{u1} and S_{u2} , S_{v1} and S_{v2} , and S_{w1} and S_{w2} are opposite to the primary windings P_u , P_v and P_w , respectively.

The synchronizing circuit AS further includes relay contacts 11X and 12X. The relay contacts 11X and 12X are auxiliary relays capable of operating in co-operation with the main contacts 11 and 12 inserted in the main line. The auxiliary relay 11X is turned on in synchronism with the main contact 11 and the auxiliary relay 12X is turned on in synchronism with the main contact 12. When the auxiliary contact 11X is turned on, on the one hand, a reversed phase voltage of the secondary winding S_{v1} whose phase is in a 30° lead relative to the phase line U is supplied to the trigger circuit A1 and on the other hand, a voltage defined by a vector sum of voltages of the secondary windings S_{w2} and S_{u2} whose phase is in phase with the phase line W is supplied to the trigger circuit A2. By making the number of turns of the secondary winding S_{v1} $\sqrt{3}$ times the number of

turns of the secondary windings S_{w1} and S_{u2} , absolute values of voltages supplied to the trigger circuits A1 and A2 are made equal. Next, when the auxiliary relay 12X is turned on, a voltage defined by a vector sum of voltages of the secondary windings S_{w1} and S_{u1} whose phase is in phase with the phase line W is supplied to the trigger circuit A1 and a reversed phase voltage of the secondary winding S_{v2} whose phase is in a 30° lead relative to the phase line U is supplied to the trigger circuit A2. By making the number of turns of the secondary winding S_{v2} $\sqrt{3}$ times the number of turns of the secondary windings S_{w1} and S_{u1} , absolute values of the voltages supplied to the trigger circuits A1 and A2 are made equal.

Summing up the above, when the main contact 11 and auxiliary relay 11X are enabled, one inverse-parallel connection thyristor arrangement S1 is inserted in the phase line U and the phase of power source voltage of the trigger circuit A1 for controlling the arrangement S1 is in a 30° lead relative to the phase line U. At this time, the other inverse-parallel connection thyristor arrangement S2 is inserted in the phase line W and the phase of the power source voltage of the trigger circuit A2 for controlling the arrangement S2 is in phase with the phase line W. Next, when the main contact 12 and auxiliary relay 12X are enabled, one inverse-parallel connection thyristor arrangement S1 is inserted in the phase line W and the phase of the power source voltage of the trigger circuit A1 for controlling the arrangement S1 is in phase with the phase line W. Concurrently, the other arrangement S2 is inserted in the phase line U and the phase of power source voltage of the trigger circuit A2 for controlling the arrangement S2 is in a 30° lead relative to the phase line U.

Namely, one inverse-parallel connection thyristor arrangement to be inserted in the phase line U is always controlled by one trigger circuit whose power source voltage phase is in a 30° lead relative to the phase line U. In contrast thereto, the other inverse-parallel connection thyristor arrangement to be inserted in the phase line W is always controlled by the other trigger circuit whose power source voltage phase is in phase with the phase line W. In this manner, the effect of this invention is applicable to the load of a three-phase induction motor irrespective of its forward rotation or reverse rotation.

The invention has been described by way of preferred embodiments but it should not be limited to the foregoing embodiments. Alternating current control systems may include, as the switching device, a thyristor

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half wave rectifier circuit, a thyristor-diode full wave rectifier circuit, an inverse-parallel connection thyristor-diode circuit or the like. The invention may be applied to all alternating current control systems of the type wherein the switching device inserted in the AC power source line is required to be controlled in synchronism with the AC power source voltage.

The smoothing circuit may be connected such that the input waveform to the trigger circuit can be a sine wave. For convenience of explanation, the foregoing embodiments have been explained by referring to the 30° phase lag at the smoothing circuit, but actually any phase lagging angle (not less than 20°) corresponding to the time constant capable of substantially attaining the adequate smoothing effect is applicable to the smoothing circuit and besides it is easy to compensate the phase lagging angle by adjusting the number of turns of the secondary windings of three-phase transformer.

In any modifications mentioned above, the intended object of this invention may easily be attained.

WHAT WE CLAIM IS:

1. An alternating current control system comprising: a three-phase AC power source; a load; a switching device connected to at least one phase line between said three-phase AC power source and said load; a smoothing circuit connected to said three-phase AC power source for smoothing distorted output voltages produced from said three-phase AC power source; a three-phase transformer having a primary winding connected to said three-phase AC power source through said smoothing circuit and a secondary winding for generating a

synchronizing signal whose phase lag due to said smoothing circuit is compensated; and a trigger circuit arranged to receive said synchronizing signal and a control signal for supplying a trigger signal to said switching device thereby to control electrical power supplied to said load.

2. An alternating current control system according to claim 1, wherein said switching device comprises a first bidirectional switching device connected to a first phase line and a second bidirectional switching device connected to a second phase line, said three-phase transformer being arranged to produce a first synchronizing signal which is in phase with a voltage of said first phase line and second synchronizing signal which is in leading phase of a predetermined angle relative to a zero-potential point of a voltage of said second phase line.

3. An alternating current control system according to claim 1 or 2, wherein said trigger circuit comprises: means connected to an output of said transformer and arranged to generate a square wave in accordance with positive and negative periods of said output of the transformer; and a magnetic phase shifter arranged to receive the square wave and the external control signal and generate the trigger signal.

4. An alternating current control system substantially as hereinbefore described with reference to the accompanying drawings.

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synchronizing signal whose phase lag due to said smoothing circuit is compensated; and a trigger circuit arranged to receive said synchronizing signal and a control signal for supplying a trigger signal to said switching device thereby to control electrical power supplied to said load.

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