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(54) CONTROL SYSTEM FOR INDUCTION MOTORS

(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 a control system for induction motors, and more particularly, to an improvement in the system for controlling both motoring and braking of induction motors.

Induction motors are used in various fields of industry due to their general utility. In particular, they have been widely employed where precise speed control is unnecessary. However, with the development of the thyristor, it has become possible to use them for applications requiring quite precise control by the use of thyristor control circuits.

For example, in the case of elevators, popular types of elevator have employed induction motors while high class types of elevator have employed DC motors, whose speed can easily be precisely controlled. However, since a considerable degree of precision can now be achieved by utilizing thyristors for the speed control of induction motors, the use of the induction motor is gradually spreading.

Among the various modes in which the speed of the induction motor is controlled whilst motoring by the use of a thyristor, the system of primary voltage control, in which a thyristor is connected between the AC source and the induction motor is the most common one. In this system there are two main types of circuit: one in which an anti-parallel circuit of a pair of thyristors is employed and one in which an anti-parallel circuit of a thyristor and a rectifying element is employed. Further, there are other modes of one phase control in which the anti-parallel circuit is connected only to one phase, of two phase control in which the anti-parallel circuits is connected to each of two

phases, and of three phase control in which the anti-parallel circuit is connected to each of all three phases.

On the other hand, where speed control of the induction motor whilst braking is required using a thyristor, the method of DC control in which DC power is applied between any two terminals is the most prevailing.

To achieve speed control of an induction motor from motoring to braking by a combination of one phase control by an anti-parallel circuit of a pair of thyristors, and DC braking control by a controllable rectifying circuit including a thyristor, a pair of thyristors are necessary for motoring, two to four sets of thyristors are necessary for braking, and at least two sets of phase shifters are necessary for ignition or firing control of each thyristor. Consequently, there are the disadvantages that the system is complicated and expensive.

One aim of the present invention is to provide a speed control system for controlling the speed of the induction motor from motoring to braking by a combination of one phase control and DC braking control with a simple and inexpensive construction.

A control system, according to the invention, for a three-phase induction motor comprises:

- a three phase AC source;
- a rectifying bridge including at least one pair of thyristors;

means arranged to connect an anti-parallel circuit composed of the pair of thyristors in the bridge between one terminal of the AC source and one terminal of the induction motor when it is motoring; and

means arranged to connect the AC terminals of the bridge with two terminals of the AC source and to connect the DC terminals of the bridge with two terminals of the induction motor when it is braking.

By this construction, only a pair of thyristors are required for the main circuit of the induction motor throughout from motoring to braking.

A preferred feature of the present invention is that the control system comprises a phase shifter for ignition controlling the pair of thyristors, means for supplying the difference between two line voltages of the three phase AC source to the phase shifter at the time of motoring, and means for supplying one line voltage of the three phase AC source to the phase shifter at the time of braking.

By using this construction the induction motor can be controlled by only one phase shifter throughout from motoring to braking.

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

Figure 1 is an embodiment of the control system for the induction motor according to the present invention applied to an elevator;

Figure 2 is a circuit diagram of the relay sequence in the circuit of Figure 1;

Figure 3a is a schematic diagram of the main circuit of the system of Figure 1 at the time of motoring;

Figure 3b is a torque characteristic of the circuit of Figure 3a;

Figure 4a is a schematic diagram of the main circuit of the system of Figure 1 at the time of braking; and

Figure 4b is a torque characteristic of the circuit of Figure 4a.

Though the present invention can be applied to many uses in which the torque of the induction motor is controlled at the time of motoring and braking, the following description will be made about the application to the driving system of the elevator by way of example only.

In Figure 1, start contactors S1 and S2, up running or ascending operation contactors U1 and U2 which are closed at the time of up running of the elevator, and down running or descending operation contactors D1 and D2 which are closed at the time of down running are connected to a three phase AC source U, V and W. The terminals U and V of the three phase AC source are further connected to two terminals of a three phase induction motor IM for elevator driving through contactors M1 and M2. The remaining source terminal W is connected to a first AC terminal a1 of a controllable rectifying bridge RE through the contactor S2. A contactor B1 is provided for connecting the other AC terminal a2 of this bridge RE to the source terminal U or V. A contactor M3 is provided for short-circuiting the DC terminals d1 and d2 of the bridge circuit RE. A contactor B2 is provided for connecting the DC terminal d1 to one terminal v of the induction motor IM. The other DC terminal d2 is directly connected to another

terminal w of the induction motor IM. The bridge RE is comprised of a pair of thyristors TH1 and TH2 and a pair of rectifying elements SR1 and SR2.

The above is the main circuit construction of the three phase induction motor for elevator driving. The contactors M1, M2, and M3 are closed by an exciting coil M (Figure 2) which operates during the time that the induction motor is to be subjected to motoring, while the contactors B1 and B2 are closed by an exciting coil B (Figure 2) which operates during the time that the motor is to be subjected to braking. Consequently, both groups of contactors never close simultaneously. The operation of these contactors will be explained hereinbelow.

The induction motor IM is connected to an elevator sheave SE through an electromagnetic brake MB. An elevator car CA and a counter weight CW are suspended from the sheave SE on each side thereof.

The speed of the three phase induction motor IM is detected by a tachometer generator TG and transmitted to the feedback coil CF of a magnetic phase shifter MPS through a resistor R1 and change-over contactors MX1, MX2, BX1 and BX2. The control coil CC of the magnetic phase shifter MPS is supplied with the output of a pattern generator PG through a resistor R2 and change-over contactors MX3, MX4, BX3 and BX4. The pattern generator PG is connected to a DC source DC1 through a switch ST1 and produces a speed instruction which increases with time. This speed instruction commonly decreases at the time of deceleration or braking in accordance with the position of the elevator.

The magnetic phase shifter MPS can compare the speed instruction supplied from the pattern generator PG and the feedback speed supplied from the tachometer generator TG. In order to bias the region which can utilize the characteristic of the magnetic phase shifter MPS, a bias coil CB is connected in series with a DC source DC2 and a resistor R3 as is commonly made.

The magnetic phase shifter MPS includes a pair of AC windings CA1 and CA2 and appropriately phase shifts the voltage of the secondary windings of a transformer TR to supply the phase shifted secondary voltage between the gate and cathode of the thyristors TH1 and TH2 through resistors R4 and R5 and back or reverse current preventing rectifying elements SR3 and SR4.

A constant voltage circuit CV can make the output of the transformer TR into a rectangular wave of a constant amplitude. Consequently, the characteristics of the magnetic phase shifter MPS can be improved. The constant voltage circuit CV consists of a rectifying bridge composed of rectifying elements SR5, SR6, SR7 and SR8 and a

Zener diode ZD connected on the DC side of the latter bridge.

The primary winding of the transformer TR is connected between the lines U—W or V—W of the three phase AC source through the constant voltage circuit CV and further through resistors R6 and R7. When a switch MX5 which is to be closed at the time of motoring of the induction motor IM is closed, a resistor R8 is connected to the source terminal V, so that the difference between the U—W line voltage and the V—W line voltage is supplied to the transformer TR. For this purpose the resistances of the resistors R7 and R8 are selected to be the same.

A description will next be made of the operation of the system of Figure 1 referring to Figure 2. Here, it is to be noted that the circuit of Figure 2 is very simplified and is considerably different from the actual relay sequence for the elevator.

When the direction in which the elevator is to travel is determined by landing call or car call, contactors U1, U2 and a contact U3 are closed when the elevator is to go up, while contactors D1, D2 and a contact D3 are closed when it is to go down. Here, it is assumed that the elevator is to go up for the sake of description, in which case contacts PDU and PDD which are to be opened when the elevator car comes to the position where braking is to start, and contacts PSU and PSD which are to be opened when the elevator car comes to the position where it is to stop are all closed, so that a deceleration or braking relay PD is excited through the circuit

(+)-U3-PDU-PD-(-)

while a stop relay PS is excited through the circuit

(+)-U3-PSU-PS-(-)

In this state, if the contacts ST1 and ST2 are closed by the start instruction, the pattern generator PG in Figure 1 starts to produce the speed instruction. And, at the same time, an acceleration or motoring preparation relay coil MX is energized, and the motoring contactor coil M is energized through the circuit

(+)-MX7-PD3-B3-M-(-)

Further, a start relay S and an electromagnetic brake coil MB are also excited. As a result, in the main circuit of Figure 1 the contactors S1, S2, U1, U2, M1, M2, and M3 are closed to form the main circuit shown in Figure 3a. In this example, the induction motor IM starts to move in the direction to make the elevator car go up.

On the other hand, since the contactors MX1, MX2, MX3, MX4, and MX5 in Figure

1 are closed, the speed instruction and the feedback speed are compared by the magnetic phase shifter MPS to phase control the thyristors TH1 and TH2 in accordance with the difference therebetween. As a result, the speed of the elevator varies following the output of the pattern generator.

In this case, since the thyristors TH1 and TH2 are connected between the W-phase terminal of the three phase AC source and the terminal w of the induction motor IM, these thyristors are supplied with the difference voltage between the U—W line voltage and the V—W line voltage. Consequently, it is necessary that this difference voltage is also supplied, as the voltage source, to the magnetic phase shifter MPS which controls the thyristors. In fact, the primary winding of the transformer TR which is the power source of the phase shifter MPS is supplied with the U—W line voltage of the three phase AC source through the resistors R6 and R7 and with the V—W line voltage of the three phase AC source through the resistors R6 and R8 due to the closure of the contact MX5. Since the resistors R7 and R8 are of the same resistance as stated above, the primary winding of the transformer TR is provided with the difference voltage between the U—W line voltage and the V—W line voltage of the three phase AC source, which is transmitted to the magnetic phase shifter MPS. As a result, the voltage applied to the thyristors TH1 and TH2 and the voltage applied to the magnetic phase shifter MPS are synchronized with each other, so that a normal phase control, i.e. one phase control of the thyristors is possible. Figure 3b shows slip vs. torque characteristic of the one phase control with the control phase angle α taken as a parameter.

When the elevator car runs and reaches the position at which braking is to start, a brake limit switch PDU opens. Consequently, the brake relay PD is deenergized to open the contacts PD1 and PD3 and to close the contacts PD2 and PD4. As a result, the motoring preparation relay coil MX and the motoring contactor coil M are deenergized, and instead the braking preparation relay coil BX and the braking contactor coil B are energized.

Consequently, since the contactors B1 and B2 alone are closed in the main circuit of the induction motor IM of Figure 1, the circuit construction of Figure 4a, i.e. a DC braking control circuit results.

On the other hand, in the system of Figure 1, since all the contactors MX1, MX2, MX3, and MX4 are opened and all the contactors BX1, BX2, BX3, and BX4 are closed, the speed instruction and the feedback speed are of opposite polarities to each other in the motoring mode, which are compared by

the magnetic phase shifter MPS to phase control the thyristors TH1 and TH2 in accordance with the difference therebetween. At this time, since the speed instruction, the output of the pattern generator PG, decreases as shown in Figure 1, the speed of the elevator car decreases only due to the braking torque against its inertia to follow the speed instruction.

At this time, since the thyristors TH1 and TH2 are connected between the lines V and W of the three phase AC source, it is necessary to supply, as its voltage source, the V-W line voltage to the phase shifter MPS which controls these thyristors.

In fact, since the contact MX5 in Figure 1 is open, the V-W line voltage is supplied to the primary winding of the transformer TR through the resistors R6 and R7 and is further supplied to the magnetic phase shifter MPS. Consequently, in braking mode also, the voltage supplied to the thyristors TH1 and TH2 and that supplied to the phase shifter MPS can be synchronized with each other, so that the control of the DC braking torque due to the phase control is possible.

A slip vs. torque characteristic of the induction motor IM with the braking current I_b taken as a parameter at the time of braking is shown in Figure 4b. At this time, since the rectifying bridge RE consists of the series connection of the thyristors TH1 and TH2 and the series connection of the rectifying elements SR1 and SR2, it has the fly-wheel effect through the circuit $w \rightarrow d2 \rightarrow Sr2 \rightarrow a2 \rightarrow SR1 \rightarrow d1 \rightarrow B2 \rightarrow v$ at the time of zero or a low value of the source voltage which is a sinusoidal alternating current to stabilize the braking torque.

When the elevator car CA reaches a point immediately before the set floor while being speed controlled following the output of the pattern generator PG in the manner described above, the stop limit switch PSU is opened. Consequently, the stop relay PS is deenergized, the contact PS1 is opened, and the start contactor coil S is deenergized. Also, the contact S5 is opened to release the electromagnetic brake coil MB. Consequently, the induction motor IM is released from the power source by the opening of the contactors S1 and S2 and, at the same time, the electromagnetic brake is operated to stop the elevator car. Further, the braking preparatory relay BX and the braking contactor coil B are deenergized by the opening of the contacts S3 and S4 to return the sequence circuit of Figure 2 to its original state.

Though the above description covers the upward movement of the elevator, it will be appreciated that the downward movement of

the elevator involves a similar sequence of operations.

WHAT WE CLAIM IS:—

1. A control system for a three-phase induction motor, comprising:
 - a three phase AC source;
 - a rectifying bridge including at least one pair of thyristors;
 - means arranged to connect an anti-parallel circuit composed of the pair of thyristors in the bridge between one terminal of the AC source and one terminal of the induction motor when it is motoring; and
 - means arranged to connect the AC terminals of the bridge with two terminals of the AC source and to connect the DC terminals of the bridge with two terminals of the induction motor when it is braking.
2. A control system according to Claim 1, in which the rectifying bridge comprises a pair of thyristors connected in series in the same direction and a pair of rectifying elements series connected in the same direction.
3. A control system according to Claim 1, comprising:
 - a phase shifter for ignition controlling the pair of thyristors; and
 - means for supplying the difference between two line voltages of the three phase AC source to the phase shifter when the induction motor is motoring, and for supplying one line voltage of the three phase AC source to the phase shifter when the induction motor is braking.
4. A control system according to Claim 3, in which the means for supplying the voltage to the phase shifter comprises:
 - a transformer including the secondary winding connected to the phase shifter;
 - means for connecting one terminal of the primary winding of the transformer to one terminal of the three phase AC source;
 - means for connecting the other terminal of the primary winding of the transformer to another terminal of the three phase AC source through a first resistor; and
 - means for connecting the other terminal of the primary winding of the transformer to the remaining terminal of the three phase AC source through a make-and-break element which is arranged to make when the induction motor is motoring and a second resistor having substantially the same resistance as that of the first resistor.
5. A control system according to Claim 1, comprising:
 - a pattern generator;
 - means for detecting the speed of the induction motor; and
 - a phase shifter for ignition controlling the

the magnetic phase shifter MPS to phase control the thyristors TH1 and TH2 in accordance with the difference therebetween. At this time, since the speed instruction, the output of the pattern generator PG, decreases as shown in Figure 1, the speed of the elevator car decreases only due to the braking torque against its inertia to follow the speed instruction.

At this time, since the thyristors TH1 and TH2 are connected between the lines V and W of the three phase AC source, it is necessary to supply, as its voltage source, the V-W line voltage to the phase shifter MPS which controls these thyristors.

In fact, since the contact MX5 in Figure 1 is open, the V-W line voltage is supplied to the primary winding of the transformer TR through the resistors R6 and R7 and is further supplied to the magnetic phase shifter MPS. Consequently, in braking mode also, the voltage supplied to the thyristors TH1 and TH2 and that supplied to the phase shifter MPS can be synchronized with each other, so that the control of the DC braking torque due to the phase control is possible.

A slip vs. torque characteristic of the induction motor IM with the braking current I_B taken as a parameter at the time of braking is shown in Figure 4b. At this time, since the rectifying bridge RE consists of the series connection of the thyristors TH1 and TH2 and the series connection of the rectifying elements SR1 and SR2, it has the fly-wheel effect through the circuit $w \rightarrow d2 \rightarrow Sr2 \rightarrow a2 \rightarrow SR1 \rightarrow d1 \rightarrow B2 \rightarrow v$ at the time of zero or a low value of the source voltage which is a sinusoidal alternating current to stabilize the braking torque.

When the elevator car CA reaches a point immediately before the set floor while being speed controlled following the output of the pattern generator PG in the manner described above, the stop limit switch PSU is opened. Consequently, the stop relay PS is deenergized, the contact PS1 is opened, and the start contactor coil S is deenergized. Also, the contact S5 is opened to release the electromagnetic brake coil MB. Consequently, the induction motor IM is released from the power source by the opening of the contactors S1 and S2 and, at the same time, the electromagnetic brake is operated to stop the elevator car. Further, the braking preparatory relay BX and the braking contactor coil B are deenergized by the opening of the contacts S3 and S4 to return the sequence circuit of Figure 2 to its original state.

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 - means arranged to connect an anti-parallel circuit composed of the pair of thyristors in the bridge between one terminal of the AC source and one terminal of the induction motor when it is motoring; and
 - means arranged to connect the AC terminals of the bridge with two terminals of the AC source and to connect the DC terminals of the bridge with two terminals of the induction motor when it is braking.
2. A control system according to Claim 1, in which the rectifying bridge comprises a pair of thyristors connected in series in the same direction and a pair of rectifying elements series connected in the same direction.
3. A control system according to Claim 1, comprising:
 - a phase shifter for ignition controlling the pair of thyristors; and
 - means for supplying the difference between two line voltages of the three phase AC source to the phase shifter when the induction motor is motoring, and for supplying one line voltage of the three phase AC source to the phase shifter when the induction motor is braking.
4. A control system according to Claim 3, in which the means for supplying the voltage to the phase shifter comprises:
 - a transformer including the secondary winding connected to the phase shifter;
 - means for connecting one terminal of the primary winding of the transformer to one terminal of the three phase AC source;
 - means for connecting the other terminal of the primary winding of the transformer to another terminal of the three phase AC source through a first resistor; and
 - means for connecting the other terminal of the primary winding of the transformer to the remaining terminal of the three phase AC source through a make-and-break element which is arranged to make when the induction motor is motoring and a second resistor having substantially the same resistance as that of the first resistor.
5. A control system according to Claim 1, comprising:
 - a pattern generator;
 - means for detecting the speed of the induction motor; and
 - a phase shifter for ignition controlling the



thyristors in accordance with the difference between the output of the pattern generator and the detected value of the speed.

- 5 6. A control system for an induction motor, substantially as described herein, with reference to the accompanying drawings.

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