

AC ELEVATOR CONTROL SYSTEM

(12)

BACKGROUND OF THE INVENTION

This invention relates to improvements in an AC elevator control system for controlling an elevator car driven by an AC motor.

There have been already known AC elevator control systems for controlling the speed of the induction motor used as an electric motor for driving an elevator car, by supplying to the induction motor an AC power with a variable voltage and a variable frequency inverted from a DC power with a constant DC voltage by a pulse width modulation type inverter. In those AC elevator control systems, mechanical energy is transformed to electrical energy during the descent of the elevator car under heavy loading, the ascent thereof under light loading or the deceleration thereof. That electrical energy is then returned back to the DC side through the inverter. When a DC source involved is formed of a battery, the latter is excessively charged to evolve a harmful gas or gases. This has resulted in a decrease in lifetime of the battery. Alternatively, when the DC source is formed of a rectifier and a capacitor connected thereacross, the capacitor has increased in voltage thereacross resulting in a fear that the component forming the inverter may be dielectrically broken down. Further if a ratio of a voltage applied across the induction motor to a frequency thereof exceeds a predetermined magnitude then the induction motor has been saturated in magnetic flux flowing

therethrough resulting in an excessive current flowing through the induction motor.

Thus the AC elevator control systems as described above have necessarily included the equipment for treating the regenerative power returned back to the DC side. For example, with the DC source formed of a rectifier and a capacitor connected thereacross, a separate inverter has been connected across the rectifier and controlled by a return-of-power control device connected across the DC side of the firstmentioned inverter. When a DC voltage across the capacitor exceed a predetermined magnitude upon the occurrence of the regenerative power as described above, the return-of-power control device has been operated to actuate the separate inverter with the result that the DC voltage is returned back to the AC side of the rectifier.

However, the separate inverter and the return-of-power device have been too expensive for an induction motor having an efficiency of operation which does not quite offer a problem because of its relatively small capacity. Also with a three-phase AC source involved formed of an emergency three-phase generator, adverse influences might occurs. For example, the generator has increased in three-phase voltage thereacross.

Accordingly, it is an object of the present invention to provide a new and improved AC elevator control system capable of consuming, by the interior of an induction motor involved, a regenerative power developed thereon during the descent of an associated elevator car under heavy loading, the ascent thereof under light loading or the

deceleration thereof resulting in the elimination of the necessity of using an equipment for treating the regenerative power.

The present invention provides an AC elevator control system comprising a DC source, an inverter connected to said DC source to invert a DC power from said DC source to an AC power having a variable voltage and a variable frequency under the control of both a command voltage signal and a command frequency signal, an AC motor driven with said inverted AC power, an elevator car operated with said AC motor, and a circuit for changing said command frequency signal in the regenerative braking mode of operation of said AC motor to decrease a frequency imparted to said AC motor to a magnitude smaller than that upon the initiation of said regenerative braking mode of operation and such that substantially the whole of the regenerative braking energy is absorbed within the motor.

In a preferred embodiment of the present invention, the AC elevator control system may comprise, in addition to the DC source, the inverter, the AC motor and the elevator car as described in the preceding paragraph, a speed sensor connected to the AC motor to generate an actual speed signal indicating an actual speed of the elevator car, a command speed generator for generating a command speed signal, an adder applied with the command speed signal and the actual speed signal to produce a difference signal therebetween, a command frequency generator for generating a command frequency signal dependent upon the command speed signal, a command voltage generator for generating a command

15 voltage signal substantially proportional to the command frequency signal, an inverter control means responsive to both the command frequency signal and the command voltage signal to control a frequency and a pulse width with which
5 the AC motor is driven, a first gain regulator connected between the command frequency generator and the command speed generator to produce a predetermined output signal in accordance with the command speed signal, a second gain regulator connected between the adder and the command
10 voltage generator to produce an output signal in response to the difference signal from the adder, and a switching means connected to the adder to be responsive to the polarity of the difference signal therefrom to switch connections so that the output signals from the first and second gain
15 regulators are supplied to the command frequency generator and the command voltage regulator respectively, the arrangement being so that, in the regenerative braking mode of operation of the AC motor in which the descent of the elevator car under heavy loading, the ascent thereof under
20 light loading and the deceleration thereof are selectively effected, the command frequency signal is changed to decrease a frequency imparted to the AC motor to a magnitude smaller than that upon the initiation of the braking mode of operation of the AC motor.

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BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will become more readily apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

Figure 1 is a combined circuit and block diagram of a conventional AC elevator control system;

Figure 2 is a diagram of an L type equivalent circuit to a three-phase induction motor useful in
5 explaining the principles of the present invention;

Figure 3 is a block diagram of one embodiment according to the AC elevator control system of the present invention;

Figure 4 is a graph illustrating waveforms of
10 signals developed at various points in the arrangement shown in Figure 3; and

Figure 5 is a diagram similar to Figure 3 but illustrating a modification of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

15 Referring now to Figure 1 of the drawings, there is illustrated a conventional AC elevator control system. The arrangement illustrated comprises a rectifier 10 connected to a three-phase electric source labelled, R, S and T to rectify a three-phase voltage from the electric
20 source into a predetermined constant direct current, a smoothing capacitor 12 connected across the DC output of the rectifier 10 and an inverter generally designated by the reference numeral 14 and connected across the capacitor 12.

The inverter 14 is of a pulse-width modulation
25 type well known in the art and includes three pairs of serially connected NPN transistors Q_1 and Q_4 , Q_2 and Q_5 and Q_3 and Q_6 connected in parallel circuit relationship to one another and also across the capacitor

12. More specifically the transistor Q_1 , Q_2 and Q_3 include respective collector electrodes connected to one side of the capacitor 12 and respective emitter electrodes connected to the collector electrodes of the mating
5 transistors Q_4 , Q_5 and Q_6 respectively and also semiconductor diodes D_1 , D_2 and D_3 connected across the collector and emitter electrodes thereof respectively and so poled that a current flows from the emitter to the collector electrode of the mating transistor. Each of the
10 transistors Q_4 , Q_5 and Q_6 includes an emitter electrode connected to the other side of the capacitor 12 and a semiconductor diode D_4 , D_5 or D_6 connected across the collector and emitter electrodes hereof in the same manner as the diode D_1 , D_2 or D_3 .

15 All the transistors include base electrode connected to an inverter control device as will be described later.

The inverter 14 is operative to invert a constant direct voltage across the capacitor 12 to an alternating
20 current having a variable voltage and a variable frequency.

Then a three-phase induction motors 16 is connected to the junction of the emitter electrode of one of the pairs of serially connected transistors and the collector electrode of the other thereof for each phase to
25 be driven by the inverter 14. The three-phase inductor motor 16 is mechanically connected to a sheave 18 of a hoist to drive the latter. Subsequently a length of a traction rope 20 is trained over the sheave 18 and connected at both ends to an elevator car 22 and a balance weight 24.

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The arrangement comprises further a command speed generator 26 for generating a command speed signal V_p , connected to a command frequency generator 28 and a command voltage generator 30. The generators 28 and 30 are

5 operative to generate a command frequency signal V_f dependent upon the command speed signal V_p and a command voltage signal V_z substantially proportional to the command frequency signal V_p respectively. The generators 28 and 30 are connected to an inverter control device 32

10 which is, in turn, connected to the base electrodes of all the transistors as described above. The inverter control device 32 is responsive to the command frequency and voltage signals V_f and V_v respectively from the generators 28 and 30 to control a frequency and a pulse width of the

15 inverter 14 thereby to control an output voltage therefrom.

Further, a separate inverter 34 is connected across the rectifier 10 and also on the DC side to return-of-power control device 36 and also across the smoothing capacitor 12.

20 In operation the inverter 14 is controlled by the control device 34 to supply an AC current at both a variable voltage and a variable frequency to the induction motor 16 which, in turn, drives the elevator car 28 through the sheave 18 and the length of traction rope 20. This results

25 in the control of a traveling speed of the elevator car 22.

It is now assumed that the elevator car 22 is descending while it is carried with passengers corresponding to its loadage which is equal to a maximum load capable of being carried by the elevator car upon the actual use.

Under the assumed conditions, the induction motor 16 acts as an induction generator to permit an electric power to flow into the DC side of the inverter 14 through the diodes D_1 through D_6 resulting in the charge of the capacitor 12 and therefore, in an increase in voltage thereacross. When the voltage across the capacitor reaches a predetermined magnitude, the return-of-power control circuit 36 is operated to actuate the inverter 34 to return the DC power back to the AC side of the rectifier 10.

10 However where the induction motor 16 has a relatively small capacity so that the same is of an operation efficiency which does not quite offer a problem, the inverter 34 and the return-of-power control device 36 have been excessively expensive. Also the AC source R, S, T
15 formed of an emergency three-phase generator might cause adverse influences such as an increase in voltage thereacross and others.

 The present invention contemplates to eliminate the objections to the prior art practice as described above
20 by the provision of means for decreasing a frequency imparted to a three-phase traction motor involved during the descent of an elevator car under heavy loading, the ascent thereof under light loading or the deceleration of the elevator car thereby to eliminate the necessity of using an
25 equipment for treating a regenerative electric power.

 First the principles of the present invention will be described in conjunction with Figure 2 wherein there is illustrated an L type equivalent circuit to an induction motor. The arrangement illustrated comprises a parallel

combination of an excitation susceptance b_0 and an excitation conductance g_0 of an induction motor is connected across a series combination of a primary resistance r_1 a primary reactance x_1 , a secondary resistance x_2 , and secondary reactance x_2 of the induction motor and a resistance $(1-s)r_2/s$ due to a slip s of the induction motor. Noticing only the effective power developed in the regenerative braking mode of operation of the induction motor, mechanical energy is entirely consumed by the interior of the induction motor and the effective electric power is not supplied from the DC side provided that the slip s is controlled so that an electric power P_l consumed by the interior of motor may be expressed by

$$P_l = V^2 g_0 + r_1 (V/Z)^2 + r_2 (V/Z)^2 \quad (1)$$

where V designates a voltage across the induction motor as shown in Figure 2 and

$$Z = \sqrt{(x_1 + x_2)^2 + (r_1 + r_2/s)^2} \quad (2)$$

holds and that an electric power P_g generated as a regenerative power may be expressed by

$$P_g = (V/Z)^2 \left(\frac{1-s}{s} \right) r_2 \quad (3)$$

$$\text{where} \quad P_l + P_g = 0 \quad (4)$$

holds. By substituting the expressions (1) and (3) into the expression (4) and rearranging it,

$$s = - \frac{r_2}{r_1 + g_0 Z^2} \quad (5)$$

results where $Z = Z(s)$ holds.

From the expression (5) it is seen that the slip s holding the expression (5) permits all the regenerative

power to be consumed by the interior of the induction motor resulting in the generation of a braking force regardless of the voltage across the induction motor and without the effective power externally supplied to the motor.

- 5 Accordingly it is not required to supply to the induction motor an electric power required for the DC excitation thereof as in the DC braking. Also a quantity of heat generated on the induction motor is not large as compared with the DC braking. Further a braking torque T_b may be
10 expressed by

$$T_b = (V/Z)^2 \left(\frac{1-s}{s} \right) r_2 \cdot \frac{1}{n} \quad (6)$$

- wherein n designates the number of rotation in unit time of the induction motor as will readily be understood from the expression (3). Thus it is seen that the braking torque can
15 be controlled by controlling the voltage across the induction motor.

- Referring now to Figure 3, there is illustrated one embodiment according to the AC elevator control system of the present invention which utilizes the principles
20 thereof described above in conjunction with Figure 2. In the arrangement illustrated, a speed sensor 38 such as a tachometer generator is mechanically connected to the induction motor 16 to generate a signal for the actual speed
14 of the elevator car 22 and electrically connected to an
25 adder 40 to which the command speed generator 26 is also connected. The adder 40 is connected at one input to a

switching device 42 including two sets of normally closed contacts 42a and 42b and two sets of normally open contacts 42c and 42d. As shown in Figure 3, the adder 40 is applied with both the actual speed signal V_t with a negative polarity from the speed sensor 38 and the command speed signal V_p with a positive polarity from the command speed generator 26 to generate a difference signal therebetween. The switching device 42 is responsive to the polarity of the difference signal from the adder 42 to switch the sets of contacts from one to the other of the closed and open positions.

The command speed generator 26 is further connected via the set of normally open contacts 42_c_ to a first gain regulator 44 subsequently connected to the command frequency generator 28 and also connected to the command frequency generator 28 and the command voltage generator 30 through the sets of normally closed contacts 42a and 42b respectively. The first gain regulator 44 is operative to generate an output signal in response to an input signal applied thereto from the command speed generator 26.

The adder 40 includes the other output connected to a second gain regulator 46 which is, in turn, connected to the command voltage generator 30 through the set of normally open contacts 42d. The second gain regulator 46 is operative to generate an output signal in response to an input signal applied thereto from the adder 40.

In other respects the arrangement of Figure 3 is identical to that shown in Figure 1 and therefore like

reference numerals have been employed to identify the components identical to those shown in Figure 1.

The operation of the arrangement shown in Figure 3 will be now be described in conjunction with Figure 4 wherein there are illustrated waveforms of the signals developed at various points therein.

In a region in which the command speed signal V_p for the elevator car 22 is higher than the actual signal V_t thereof, the adder 40 produces the difference signal with the positive polarity between the positive command speed signal $+V_p$ from the command speed generator 26 and the negative actual signal $-V_t$ from the speed sensor 38. The switching circuit 42 responds to the positive polarity of the difference signal from the adder 40 to maintain the sets of normally closed contacts 42a and 42b in their closed position and the sets of normally open contacts 42c and 42d in their open position.

Thus the arrangement of Figure 3 is the same as that shown in Figure 1. Under these circumstances the induction motor 16 is operated in such a manner that the voltage and frequency thereof are changed to be substantially proportional to each other following the command speed signal V_p . That is, the induction motor 16 is operated according to the so-called constant voltage-to-frequency ratio control. At that time it is assumed that the elevator car 22 is descending under heavy loading. Under the assumed conditions, the actual speed signal V_t becomes higher than the command speed signal V_p upon the completion of the particular acceleration of

the elevator car and the operation is entered into the regenerative mode.

When the switching circuit 42 senses that the actual speed signal is equal to or higher than the command speed signal V_p , the sets of the now closed contacts 42a and 42b are open while the sets of now open contacts 42c and 42d are closed. This closure of the contacts 42c causes the gain regulator 46 to be operated to regulate the input to the command frequency generator 28 so as to decrease the command frequency signal V_f to a magnitude thereof at which the slip of the induction motor 16 fulfills the expression (5).

On the other hand, the closure of the contacts 42d causes the output from the gain regulator 44 to be applied to the command voltage generator 30. Thus the command voltage signal V_v has a magnitude proportional to the difference signal between the command speed signal V_p and the actual speed signal V_t . The command voltage signal V_v with such a magnitude is supplied to the inverter 14 to control an output voltage therefrom. Also the braking torque T_p expressed by the expression (6) is controlled so that the elevator car 22 is operated in accordance with the command speed signal V_p .

Even if the absolute value of the slip tends to be higher than a value as defined by the expression (5) then the supply power is only increased correspondingly which attains the object of the present invention that no power is regenerated on the DC side in the regenerative braking mode of operation.

In Figure 5 wherein like reference numerals designate the components identical to those shown in Figure 3 there is illustrated a modification of the present invention. The arrangement illustrated is different from that shown in Figure 3 only in that in Figure 5, the gain regulator 46 is directly connected at the input to the command speed generator 26 and connected at the output to the command frequency generator 28 through a series combination of an adder 48 and the set of normally closed contacts 42c. The positive output of the rectifier 10 is connected to a gain regulator 50 subsequently connected to the adder 48.

As shown in Figure 5, the adder 48 has applied thereto an output with both a negative polarity from the gain regulator 56 and an output with a positive polarity from the gain regulator 46 to produce a difference signal therebetween which is, in turn, applied to the command frequency generator 28 through the set of contacts 42c put in its closed position.

The arrangement of Figure 5 is intended to return, as a signal, a flow of an electric power through the DC side of the rectifier 10 back to the command frequency generator 28 in the braking mode of operation thereby to control the frequency of the generator 28. More specifically, during a flow of an electric power from the rectifier 10 through the inverter 14, the induction motor 16 supplies to the inverter 14 a regenerative power increased so as to render the frequency of the inverter 14 higher while upon an increase in voltage across the induction motor, the latter supplies

to the inverter a regenerative power decreased so as to render the frequency of the inverter lower. This measure permits regenerative energy to compensate for a loss of the inverter 14 resulting in the operation of the induction motor 16 with a high efficiency as compared with the arrangement shown in Figure 3.

In other words, when the induction motor 16 is operated at such a frequency that the slip thereof fulfills the expression (5), regenerative energy can only compensate for a loss due to both winding resistances and an excitation. However, by feeding the electric power back to the DC side to maintain the flow of the electric power through the DC side always null, the resulting regenerative power can compensate for not only the loss due to both the winding resistances and the excitation but also for a loss of the inverter 14.

Such an operation is not desirable for the induction motor 16 high in capacity because the resulting efficiency of operation becomes low as compared with the arrangement shown in Figure 1. However, if that operation is performed only when an emergency generator is employed during a power failure of the electric source R, S, T. Then the emergency generator can be smaller sized. Alternatively with a battery used as a DC source, it is possible to prevent the battery from reducing in lifetime due to the rapid charge thereof.

From the foregoing it is seen that the present invention provides an AC elevator control system comprising an inverter for inverting a DC power to an AC power having a

variable voltage and a variable frequency, an induction motor energized with the AC power, and an elevator car driven by the induction motor wherein a command frequency signal is changed in the regenerative braking mode of

- 5 operation for example, during the descent of the elevator car under heaving loading, during the ascent thereof under light loading or during the deceleration thereof to decrease a frequency imparted to the induction motor to a magnitude lower than that upon the initiation of the braking thereof.
- 10 Therefore upon the regenerative braking of the induction motor, a slip thereof can be controlled so as to render a regenerative power applied the the DC side null. This permits the elimination of the necessity of using an equipment for treating the regenerative power.

- 15 Also with an electric power for driving the electric car supplied by an emergency electric source such as an emergency AC generator or a battery, the present invention can render the emergency electric source small-sized, alternatively the battery can increase in
- 20 lifetime because the same is prevented from rapidly charging.

- While the present invention has been illustrated and described in conjunction with a few preferred embodiments thereof it is to be understood that numerous
- 25 changes and modifications may be resorted to without departing from the scope of the present invention. For example, while the present invention has been described in conjunction with the determination of the frequency of the induction motor so as to cause the slip

thereof to fulfill the expression (5) on the basis of the command speed signal for purposes of simplification it is to be understood that the same is equally applicable to such determination of the frequency of the induction motor on the basis of the actual speed signal. Also it will readily be understood that the induction motor in the power running mode of operation may be subjected to any one of the well known controls such as the slip frequency control, the vector control etc. other than the constant voltage-to-frequency ratio control as described above.

CLAIMS:

1. An AC elevator control system comprising a DC source, an inverter connected to said DC source to invert a DC power from said DC source to an AC power having a variable voltage and a variable frequency under
5 the control of both a command voltage signal and a command frequency signal, an AC motor driven with said inverted AC power, an elevator car operated with said AC motor, and a circuit for changing said command frequency signal in the regenerative braking mode of operation of
10 said AC motor to decrease a frequency imparted to said AC motor to a magnitude smaller than that upon the initiation of said regenerative braking mode of operation and such that substantially the whole of the regenerative braking energy is absorbed within the motor.
- 15 2. An AC elevator control system as claimed in claim 1 wherein a selected one of the descent of said elevator car under heavy loading and the ascent thereof under light loading is effected in said regenerative braking mode of operation of said AC motor.



3. An AC elevator control system comprising an AC source, a rectifier for rectifying an AC power from said AC source into a DC power, an inverter connected to said rectifier to invert said DC power from said rectifier to
5 an AC power having a variable voltage and a variable frequency under the control of both a command voltage signal and a command frequency signal, an AC motor driven with said inverted AC power, an elevator car operated by said AC motor, an emergency electric source
10 enabled to supply DC power to said inverter during a power failure of said AC source, and a circuit for changing said command frequency signal in the regenerative braking mode of operation of said AC mode during the power failure of said AC source thereby to
15 decrease a frequency imparted to said AC power to a magnitude smaller than that upon the initiation of said regenerative braking mode of operation of said AC motor and such that substantially the whole of the regenerative braking energy is absorbed within the motor.
- 20 4. An AC elevator control system as claimed in claim 3 wherein said emergency electric source comprises an emergency AC generator for supplying AC power to the rectifier.
5. An AC elevator control system as claimed in claim 3
25 wherein said emergency electric source comprises a battery for supply DC power to said inverter.



6. An AC elevator control system comprising a DC source, an inverter connected to said DC source to invert a DC power from said DC source to an AC power having a variable voltage and a variable frequency under the control of both a command voltage signal and a command frequency signal, an AC motor driven with said inverted AC power, an elevator car operated by said AC motor, a speed sensor connected to said AC motor to generate an actual speed signal indicating an actual speed of said elevator car, a command speed generator for generating a command speed signal, an adder applied with said command speed signal and said actual speed signal to produce a difference signal therebetween, a command frequency generator for generating a command frequency signal dependent upon said command speed signal, a command voltage generator for generating a command voltage signal substantially proportional to said command frequency signal, an inverter control means responsive to both said command frequency and said command voltage signal to control a frequency and a pulse width with which said AC motor is driven, a first gain regulator connected between said command frequency generator and said command speed generator to produce a predetermined output signal in accordance with said command speed signal, a second gain regulator connected between said adder and said command voltage generator to produce an output signal in response to said difference signal from said adder, and a switching means connected



to said adder to be responsive to the polarity of said difference signal therefrom to switch connections so that said output signals from said first and second gain regulators are supplied to said command frequency

5 generator and said command voltage regulator respectively, the arrangement being so that in said regenerative braking mode of operation of said AC motor in which the descent of said elevator car under heavy loading, the ascent thereof under light loading and the
10 deceleration thereof are selectively effected, said command frequency signal is changed to decrease a frequency imparted to said AC motor to a magnitude smaller than that upon the initiation of said regenerative braking mode of operation of said AC motor
15 and such that substantially the whole of the regenerative braking energy is absorbed within the motor.

7. An elevator control system substantially as herein described with reference to Figs. 3 and 4 or Fig. 5 of the accompanying drawings.

