Escalator Driven by the High Performance Inverter System

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Abstract

Line starting using contactors is a conventional method for escalator system. Recently, consumer's requirements for energy saving and variable functions are increasing. To satisfy these demands, LG · OTIS Elevator has developed an escalator that is driven by inverter system. In this paper, technical schemes of the developed escalator are introduced and the performance of the proposed system is experimentally verified.

1. INTRODUCTION

Escalator is an up-down transportation system to continuously convey many passengers and the transportation capacity of escalator is several tens more than that of elevator. So this system is appropriate for the subway, department store, express terminals, office building and so forth. In the department store, escalator is located at the proper position to convey 80 % of customers. Especially the arrangement of the escalators near the stores, restaurants and others. induced the increasing of coefficient of utilization of building and shopping mall.

The elevator should frequently start and stop with various loads, so it needs the inverter system for the operation like that. However escalator has been run continuously without loads and sometimes with full loads. So its utilization is less than 50%.

International activity for energy saving arises and customers require an escalator with various

and excellent performances -- which are like the high quality ride, no noise, assured safety, durability and so on – and various functions like the service for handicapped persons, the adjustable speed. These requirements should be treated with mechanic techniques as well as with electrical techniques. In electrical measures, the line-starting escalator has the limit to reduce the mechanical vibrations for the high quality ride. And at the line starting, it occurs the large inrush current that causes shocks to decrease the lifetime of escalator.

To satisfy the requirements, it is essential for escalator to be driven by inverter and it has many merits and functions. Inverter is able to control the speed of escalator so it can provide the good service for the handicapped, the old and the weak, the operation for energy saving and others. Besides, it has no inrush current causing shocks at starting and gives the method to decrease mechanic vibration by motor control. In addition, Inverter-driven escalator can give useful information to the owner by the controller and sensors. So owners can utilize these information at their business and analysis.

In this paper, the structure of inverter-driven escalator, merits and its excellency are introduced and verified by the experiment.

2. THE ELECTRICAL DRIVING SYSTEM OF ESCALATOR

Fig. 1 shows the overall configuration of inverter system for escalator. The system is composed of several parts; the inverter for driving motor, the converter that converts AC voltage to DC voltage and controls AC voltage to be unity power factor, the controller for inverter and converter.

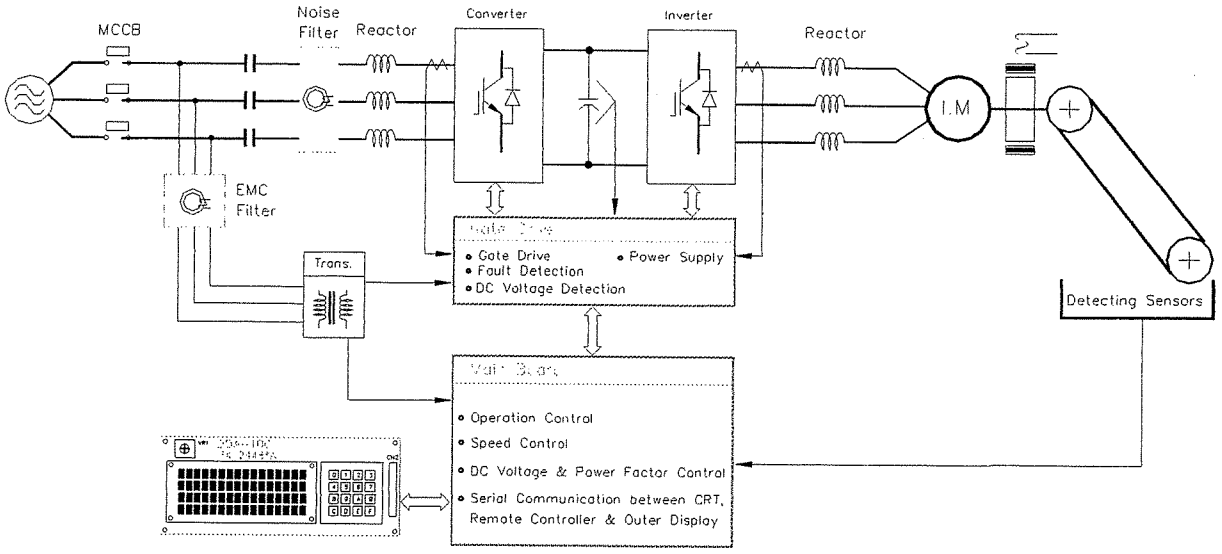
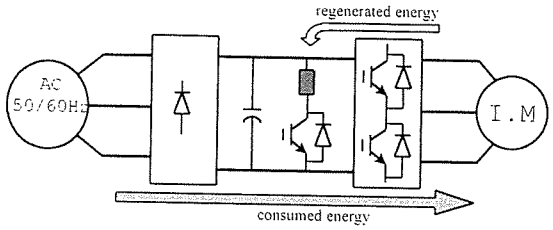
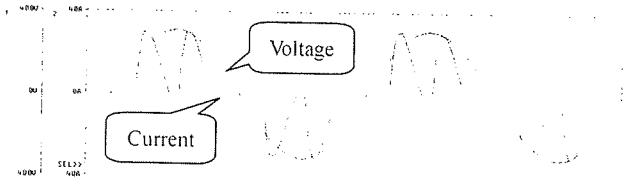


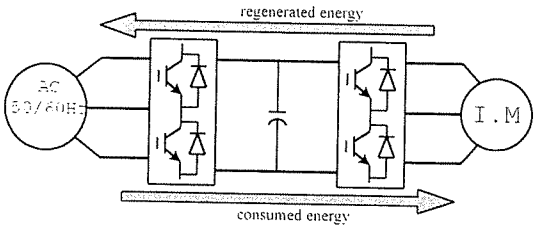
Fig. 1 The configuration of inverter-driven escalator



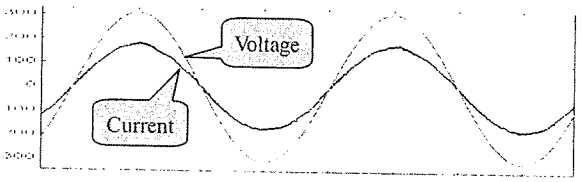
(a) inverter with rectifier



(b) input current and voltage of rectifier



(c) inverter with PWM converter



(d) input current and voltage of PWM converter

Fig. 2 The characteristics of inverter with rectifier and with PWM converter

2.1 AC To DC Converter

Diode rectifier or PWM converter is used to converter AC voltage to DC voltage. In the Fig. 2, the characteristics of diode rectifier and PWM converter are shown. Diode rectifier is simple but can not recycle the regenerated energy into the AC source. PWM converter can return it but is complex. Voltage-type PWM converter, which converts AC voltage to DC, controls the line's power factor to be unity and supplies effective power to the inverter. And the regenerated energy, which is produced when downward escalator runs with loads or when the escalator decreases speed with loads, is returned to the input line. So PWM converter can reduce the consumption energy very much, up to 63% less than that of rectifier [1]. The total current harmonic distortion(THD) of PWM converter is below 5% but diode rectifier's about 40% to 90%, which depends on the load. As THD affects the quality of AC source for other equipments, so diode rectifier can deteriorate the quality of AC source.

2.2 Inverter

To control motor speed and torque for loads, inverter supplies AC power to motor with variable frequency and variable voltage [1]. Inverter reduces the shocks which cause the damage or abrasion of gear and chains. So inverter improves the durability of the escalator and cuts down the maintenance cost. And removing of inrush current minimizes the capacity of power feeder. Also inrush current can cause serious problems at other equipment using the input line.

Although there is a little difference of it according to the installed site, the average load per day of most escalator is nearly less than 50% of full load. In light load, as the core loss of motor is larger than the copper loss, so the magnetizing current affects the total loss larger than the torque current. Therefore the magnetizing current can be controlled to maximize the total efficiency of motor. In 7.5kW escalator, when the magnetizing current is controlled to maximize the efficiency at the state of continuous operation, the resumption energy is reduced to about 32% less than the uncontrolled escalator.

2.3 Operating Control Part

Operating control part composed of the annunciator for monitoring an escalator, the supervisor system at control center in building for monitoring escalators and controlling, the remote monitoring system in maintenance center, the exterior display unit at the entrance of escalator and the communication unit. These system transfers the state of escalator to maintenance engineer for quick service and efficient maintenance and it provides the variable operations like the both-direction operation.

2.4 The Protection of Motor

Recent advancements in power electronic switching devices have enabled high frequency switching operation and have improved the performance of ASD. While the high switching speed improved the performance of the inverter-fed motors, the high rate of voltage-rise in inverter output rises the excessive over-voltage in the motor terminal, which has serious adverse effect on the motor insulation [4]-[6]. The over-voltage at the motor terminal is clearly analyzed with the voltage reflection theory for the cable, which explains that the overshoot depends on rise-time of inverter output-voltage, cable length, and reflection coefficient of the cable at the cable end [7][8].

So these repeated over-voltages damage the insulator of motor by producing the arc discharge to cause the aging of insulator and to destroy it. To comply with the standard, Part 30 NEMA MG1-1993, for the restraint of surge voltage at motor, the filter is used for the suppression of the over-voltage and the synchronized switching frequency is used between converter and inverter [2][3].

In this paper, the motor reactor is accepted for the suppression of over-voltage at motor. It extended the rise-time of over-voltage and reduced the overshoot as shown in Fig. 6. The effect of motor reactor is discussed at clause 3.

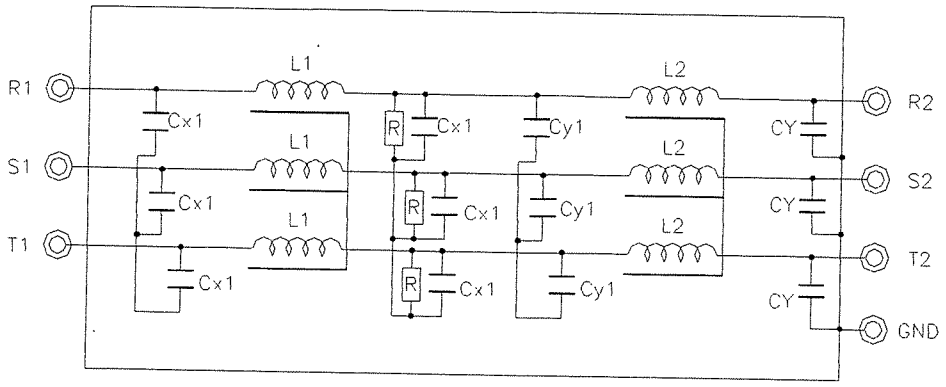


Fig. 3 The equivalent circuit of EMI filter

2.5 The Measures against The Conductive EMI

Electromagnetic Noise is a significant problem of inverter-controlled system. Electromagnetic interference (EMI) occurs when the power semiconductors are switched and its magnitude depends on the conditions; the switching characteristics, the magnitude of DC-link voltage. the structure of power circuit and others [3]. To comply with CISPR Pub. 22 Class A for EMI, the noise filter is installed for conductive EMI at input line and measures against radiant EMI is considered in the design of control panel. Fig. 3 shows the circuit of EMI filter.

2.6 Reduction Method Of Mechanical Vibration

At the escalator system, the step's vibration, back and forth, is inevitable, which is produced by sprocket and rollers of step. The step's vibration is related to the ripple of step's velocity, shown in Fig. 4(a). So we tried to reduce the ripple with motor speed control. So the motor speed control reduced it very much..

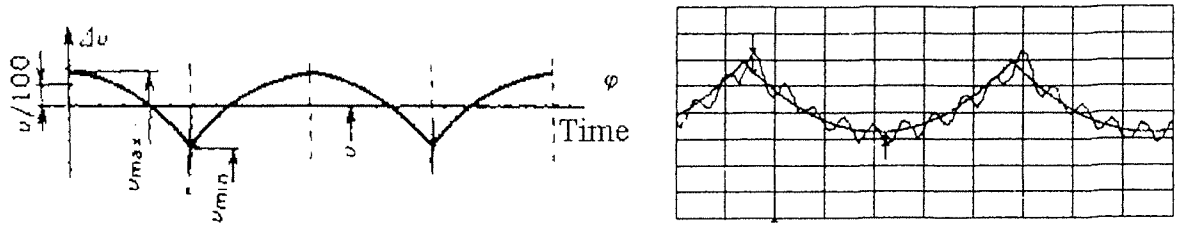
Shown ini Fig. 4, motor's speed is controlled like Fig. 4(b). This speed-wave form is opposite to the ripple of step's speed, Fig. 4(a), caused by the mechanic structure. This method almost removed the step's vibration at the frequency of the ripple. So the ride quality was very improved. Fig. 9 is the experimental result. Yet this algorithm tunes manually parameters for the control of vibration suppression, not automatically but the research is on process of automatic tune of the parameters.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Next experimental results show the performance and functions of inverter-controlled escalator and these systems have been produced. Used motor and power semiconductor is the Intelligent Power Module(IPM), 1200V 75A, of Mitsubishi and induction motor, 7.5kW, LG · OTIS Elevator. The experiments were made at the escalator.

Fig. 5 shows the speed, step vibration and line current of the conventional line-starting escalator. When it started, the maximum value of vibration is about 190 gal and is occurred by shock that is induced by large inrush current, which is 90A. This shock between motor and machine weakens the mechanic strength of coupling and inrush current affects other equipments that are connected the same power supply unit.

Fig. 6 shows the speed, vibration and line current of inverter-controlled escalator. Relatively to conventional escalator, line current is slowly increased, so the large vibration is disappeared when it starts.



(a) ripple of step's velocity *(b) ripples of commanded velocity and real velocity of motor*

Fig. 4 The ripple of step's velocity and motor's

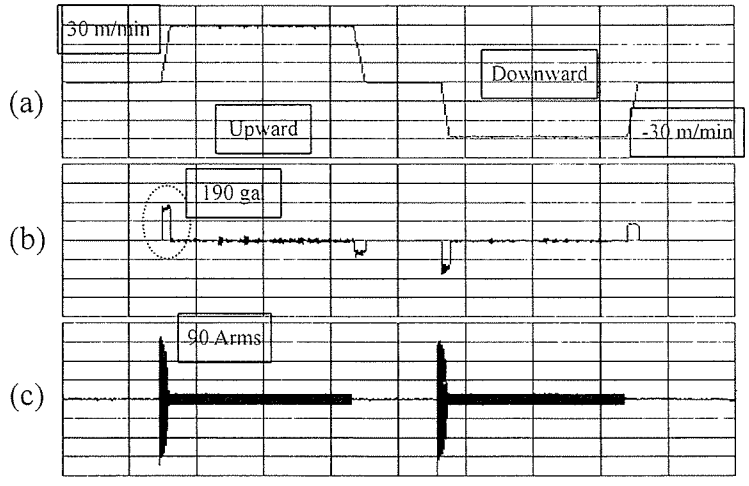


Fig. 5 Speed, vibration and input current at the line starting escalator (a) speed : 10m/min/div, (b) vibration : 200gal/div, (c) current : 40A/div

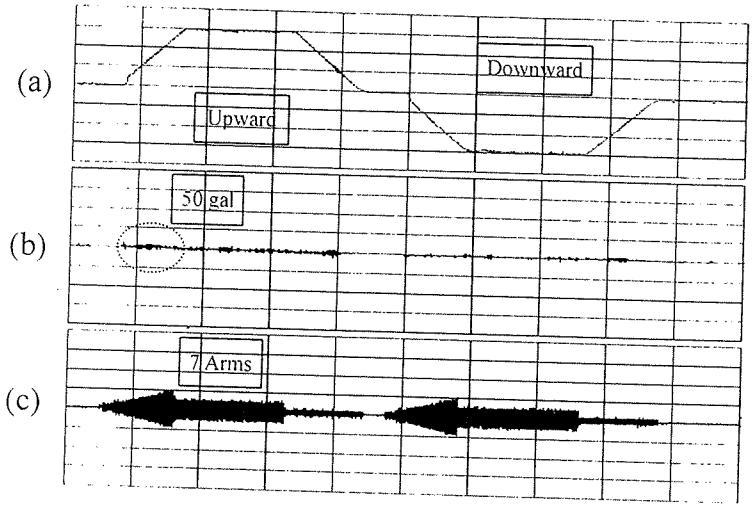


Fig. 6 Speed, vibration and input current at the inverter-controlled escalator
(a) speed : 10m/min/div, (b) vibration : 200gal/div, (c) current : 10A/div

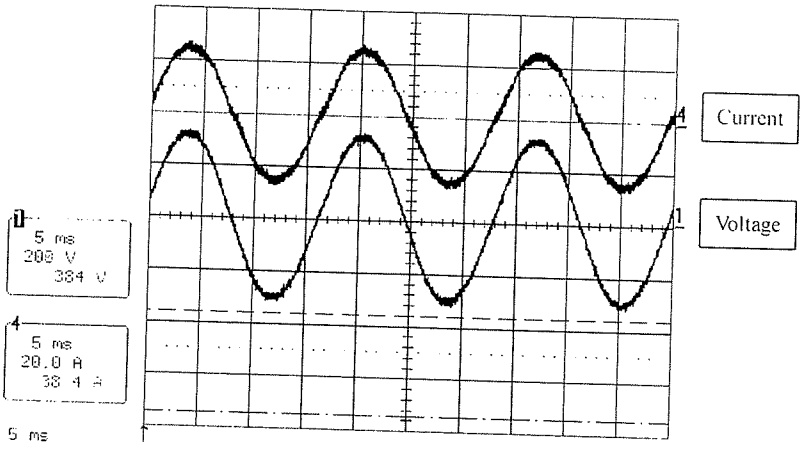
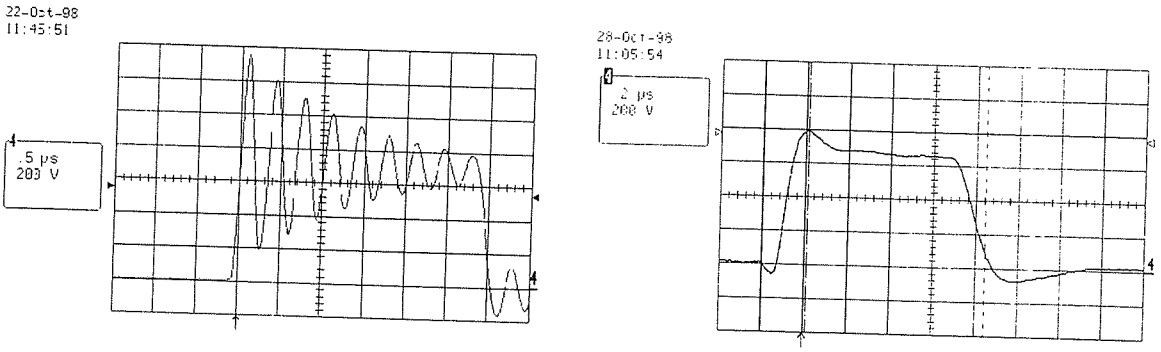


Fig. 7 Input current and Input voltage of inverter
(voltage : 200V/div, current : 20A/div, Time : 2 ㎲/div)



(a) without motor reactor *(b) with motor reactor*

Fig. 8 Surge voltage at terminal of motor
(voltage : 200V/div, Time : 2 ㎲/div)

Fig. 7 shows line voltage and current with inverter system. The power factor is about 0.97 and THD of current is 4%. So the inverter system does not deteriorate the quality of the power source, that is, not affect other equipments.

In Fig. 8, the rise rate of over-voltage at the input terminal of motor is presented. Without motor reactor, the rise rate is over 6000V/μs. This value is very high and rapidly reduces the lifetime of motor. But in the case with motor reactor, the rise rate is about 615V/μs, less than the recommended rate in NEMA Part 31, 1000V/μs.

In Fig. 9, the graph is the measured EMI and the limit by the Regulation, CISPR Pub. 22. The result complied with CISPR Pub. 22 with margin.

In Fig. 10, the results shows the amount of the saved energy in comparison with the consumed energy of line-starting escalator when inverter-controlled escalator are used with energy saving mode.

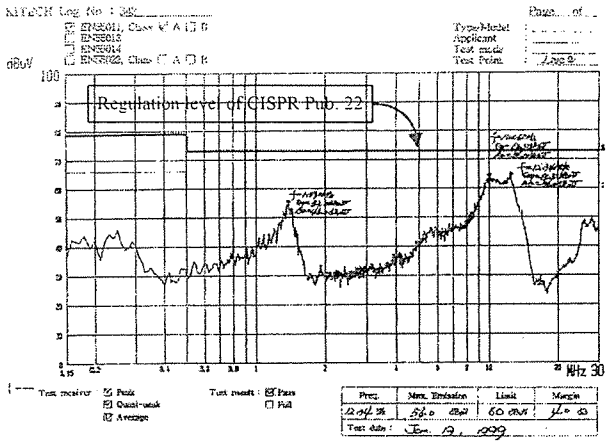


Fig. 9 EMI measured at input line

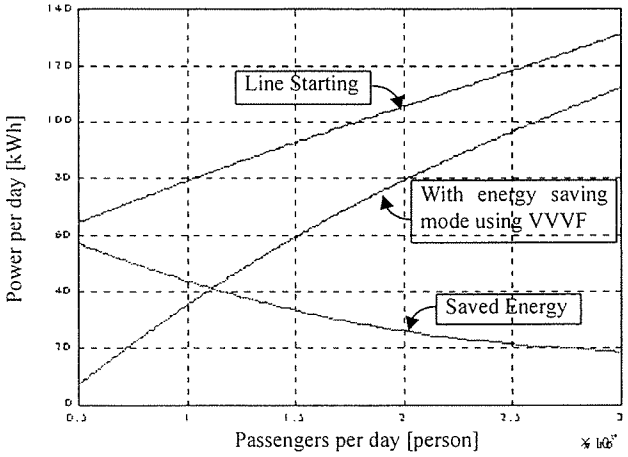


Fig. 10 The characteristics of energy saving (operating time : 20 hours a day)

4. CONCLUSION

In this paper the inverter-controlled escalator with three-phase PWM converter is introduced. The various measurement is made to prove the high performance of the inverter-controlled escalator: speed patterns, starting vibration and shock, power factor at input line, the characteristics of surge suppression and EMI test.

Especially at subway station and department store, the energy saving is very high, which is individually about 46% and 26% less than that of the conventional escalator.

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