Eng. &Tech. Journal, Vol. ٣١, Part (A), No.12, 201٣

Modeling of DC Elevator Motor Drive for Mid-rise Building

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Received on: 2/12/2012 & Accepted on: 4/4/2013

ABSTRACT

An elevator is a platform, either open or enclosed, used for lifting people or freight to upper floors within a building. Elevators are a standard part of any tall commercial or residential building. Mid speed elevators are commonly used in various mid-rise buildings today.

In this paper, a new type of gear traction machine drive system with a permanent-magnet (PM) DC motor for mid-rise and mid-speed elevators is presented. This application of PM motor to the elevator traction machine enables several improvements including higher efficiency, greater ride comfort, and miniaturization and so on.

The ideal elevator drive at larger horsepower levels should have efficient power conversion, regeneration, low harmonic distortion, and near unity power factor at the utility power lines. Therefore, voltage-fed 3-phase PWM rectifier is adopted so that DC bus voltage regulation, bi-directional power flow and controllable power factor with reduced input current harmonics are possible.

Keywords: Elevator, PMDC Motor, Chopper

محاكاة مسوق محرك المصعد ذو التيار المستمر للبنايات ذات الارتفاعات المتوسطة

الخلاصة

المصعد عبارة عن منصة اما ان تكون مفتوحة او مغلفة وتستخدم لرفع الاشخاص او الاثقال الى الطوابق العليا عبر البناية. المصاعد هي جزء قياسي في اي بناية تجارية طويلة أو سكنية. في العصر الحاضر مصاعد السرعة المتوسطة عادةً ما تُستخدم في البنايات ذات الارتفاع المتوسط.

في البحث الحالي تم تقديم نوع جديد من منظومات سوق ماكنات السحب ذات التروس باستخدام محرك التيار المستمر ذو الاقطاب الدائمة في مصاعد السرع المتوسطة والارتفاعات

https://doi.org/10.30684/etj.31.12A10
2412-0758/University of Technology-Iraq, Baghdad, Iraq

المتوسـطة. اسـتخدام محـرك ذو الاقطـاب الدائمـة فـي ماكنـة جـر فـي مصـعد يُمكّـن عـدة تحسـينات تتضمن أعلى كفاءة وأوفر راحة ركوب وأصغر تصميم الخ.

مسـوق المصـعد المثـالي عنـد مسـتويات عاليـة مـن القـدرة يجـب أن يمتلـك أعلـى كفـاءة فـي تحويـل الطاقـة وتجديـدها واقـل تشـويه تـوافقي وعامـل قـدرة عنـد خطـوط الطاقـة المرفقـة يقتـرب مـن الواحـد. لـذلك سـيتم تبنـي مقـوّم فولتيـة ثلاثـي الطـور يعمـل بتضـمين عـرض النبضـة وذلـك لجعـل تنظـيم الفولتيـة المسـتمرة للقضـيب الموصـل وانسـياب القـدرة بالاتجـاهين وقابليـة السـيطرة علـى عامل القدرة وبأقل تشويه توافقي للتيار الداخل ممكناً.

INTRODUCTION

Simply stated, an elevator is a hoisting or lowering mechanism, designed to carry passengers or freight, and is equipped with a car and platform that typically moves in fixed guides and serves two or more landings [2,3].

Elevators are designed for a specific building, taking into account such factors as the height of the building, the number of people traveling to each floor, and the expected periods of high usage [4].

There are two main types of elevators; hydraulic and traction. Traction elevator shown in Figure (1) is the most popular form of elevator designs used widely across the world. They are most often used in mid- and high-rise buildings with five or more floors. These consist of the elevator car and a counterweight held together by steel ropes looped around the sheave. The sheave grips the hoist ropes so that when it rotates, the ropes move, too. This gripping is due to traction.

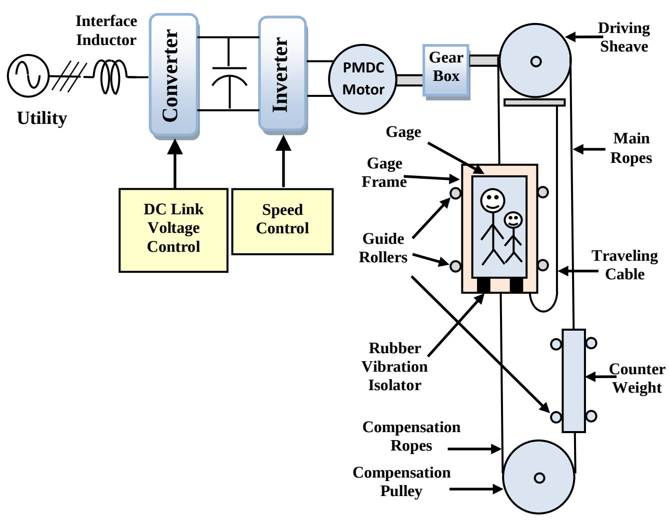


Figure (1) Configuration of mid-speed traction elevator system.

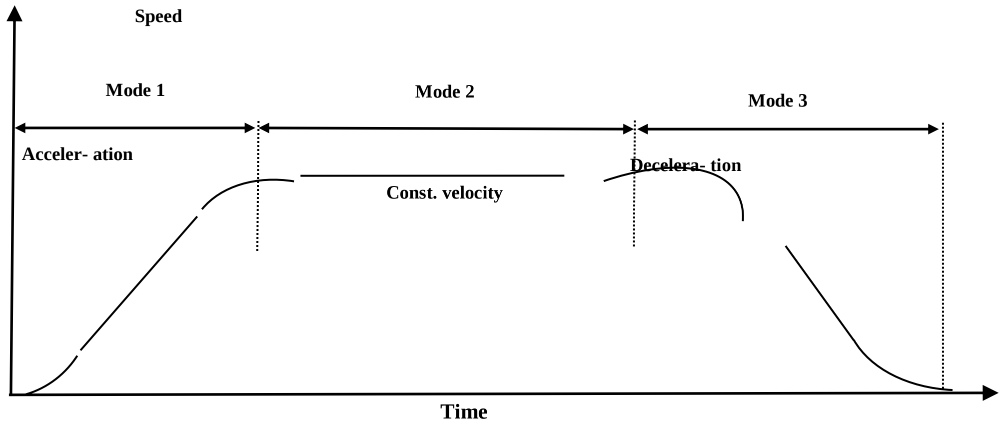


Figure (2) Ideal (typical) elevator typical speed characteristic.

There are two types of traction elevators: Geared and Gearless types. In a geared machine, the motor turns a gear train that rotates the sheave. Geared traction machines are used for medium-speed applications and have effective speeds from 0.5 to 2.0 m/s.

The gear reduction ratios typically vary between 12:1 and 30:1. Geared Traction machines can be driven by AC or DC motors.

In gearless elevators, the motor turns the sheave directly. Gearless traction elevators are specified for high-speed applications having effective speeds varying from 2.5 m/s to 10 m/s. These are generally used on taller structures with more than 10 stories [3].

Some papers have been written in the elevator drive field. Jae et al [5] proposed a fuzzy logic based vector control for the gearless traction machine drive systems using a PM synchronous motor. X. Zhang et al [6] designed parallel energy feedback system to improve the performance of traditional VVVF elevators. The regenerated electric power could be sent back to the grid through the shunt-converter and reduce the waste of energy. S. Wei and R. Wang [7] focused on five-story elevators, designed and implemented a speed-regulation elevator control system using combination of OMRON CJ1M PLC and Yasukawa Inverter. A new standardized type of gearless traction machine drive system with a PM motor for high-speed elevators had been presented by D. W. Chung et al [8]. Some control functions which are indispensable for improving the performance of elevator system had been addressed. J. Fortgang et al [9] suggested that high-rise elevators could be made significantly faster and more comfortable by implementing aggressive acceleration commands that are properly input shaped using a scheduling algorithm based on elevator position. S. ganguli [10] addressed a microcontroller based unipolar stepper motor drive used for an elevator system. All the above studies talk about the gearless high-speed elevators.

The current paper talks about the gear mid-speed (mid-rise) traction elevator and focuses on the electrical drive system. As the type of mid-speed elevator systems varies, standardization of the electrical drive systems is necessary. General requirements are as follows: more comfortable ride, miniaturization, precise and effective speed control, energy saving, and reliability. To meet these requirements, a new type of gear traction machine drive system with a PM motor for mid-speed and mid-rise elevators is proposed. This application of a PM motor to the elevator traction machine enables several improvements including higher efficiency, greater comfort, miniaturization, and so on. A voltage-fed three-phase pulse width modulation (PWM) rectifier is also adopted so that DC bus voltage regulation, bidirectional power flow, and controllable power factor with reduced input current harmonics are possible.

SPEEDS OF ELEVATORS

Elevator speed is determined by travel distance and standard of service. The speed should be selected such that it will provide short round time and 25 to 30 second interval, along with least number of elevators to handle the peak loads. Car speed is chosen so that the driving motor can be run at full speed for much of the running time to maximize the efficiency of power consumption.

The general rules of thumb for the recommended elevator speeds for various travel distances are: car speed of (0.75, 2, 3, and 5-7 m/s) for (4, 9, 15, and over 15 floors), respectively [3].

Fundamentals of Speed Reference Pattern Generation

In most AC or DC drive based elevator systems, the positioning of the elevator is accomplished by the use of a speed reference "pattern" that provides the speed profile required to move the elevator car from the departure floor to the arrival floor in the minimum possible time with minimal discomfort to the passengers.

The theoretically optimum elevator drive performance results when the speed feedback matches the pattern exactly. The smaller the error between the reference and the feedback, the easier it is for the start-up engineer to set the pattern acceleration and deceleration rates along with the acceleration and deceleration jerk rates [11].

S-profile Curve

The principal requirements of an elevator system, viz. shortest travel time and passenger comfort, are directly related to the shape of the elevator speed versus time curve “S-profile” or speed curve as shown in Figure (2). In addition, the elevator should increase speed slowly after it starts and reduce speed gradually before it stops in order to smooth the operation of the elevator and avoid vibration or swing.

The speed-time characteristics indicated in Figure (2) can be divided into three regions corresponding to the three modes.

First, the motor is rapidly accelerated with high torque to a constant speed, at which only small torque is required. In elevators, however, the maximum acceleration-deceleration rate is often limited. After the constant speed phase, high braking torque is required to rapidly decelerate the motor into the desired position. Typically the speed of the motor must be altered smoothly by limiting the initial acceleration to avoid jerking, which could cause some mechanical damage to the application.By limiting the acceleration rates, jerking can be avoided.

The feedback control system automatically adjusts the DC current so that the elevator speed closely follows the reference pattern till it reaches near zero. The speed pattern is generated accurately as a function of the position of the elevator car [12, 13].

POWER LINE POLLUTION

An analysis of typical building installations shows that most elevator equipment rooms are supplied by separate electrical feeder wiring directly from the main source of power to the building. Those feeders also suffer from the effects of additional harmonics caused by conventional SCR-DC or Rectifier/Inverter-drives. These can cause unwanted wire and circuit breaker heating, and, in some cases, acoustical noise.

The ideal elevator drive at larger horsepower levels should have efficient power conversion, regeneration, low harmonic distortion, and near unity power factor at the utility power lines.

Reducing harmonics in the elevator equipment room with these types of motor controls requires specially designed reactors and trap filters.

Rectifier-fed inverter drives are often thought of as having unity power factor. This is only partially true in that current flow from each utility line only when the sinusoidal voltage on that phase is near the peak value. However, the real mathematical definition of power factor is P_f = real power/apparent power, or Watts/VA, where the volt-ampere value must include the effects of all harmonics as well. Therefore, although the 'displacement' power factor may be near unity, the presence of 25% harmonic current can reduce the actual power factor down to 0.8 or worse [4].

Voltage-fed 3-phase PWM rectifier is adopted so that DC bus voltage regulation, bidirectional power flow and controllable power factor with reduced input current harmonics are possible. Moreover, other advanced features such as audible noise reduction and torque ripple minimization, which translates into a more comfortable ride for passengers.

ENERGY SAVING

The type of drive, capacity and the total full load mass of the elevator, number of floors served, elevator system efficiency and the traffic pattern in the building are some of the variables affecting the energy consumption of elevator systems [14].

DC motors have the capability of regenerating energy when operating in the overhauling (negative-load) condition (i.e., driven by the load- Figure (3)).

Examples of overhauling conditions in traction elevators are "full load down" and "empty car up". Regenerative braking involves sending the regenerated energy from the elevator hoist motor back to the electrical power source from the building.

The lift motor is said to operate in "4-quadrants", as represented graphically in Figure (3). In general terms, reducing the performance of the lift when it is "motoring" will save energy. Likewise, increasing the performance of a lift when it is "generating" will regenerate additional energy [15, 16]. High-efficiency traction elevators often use regeneration to offer the greatest efficiency possible [17].

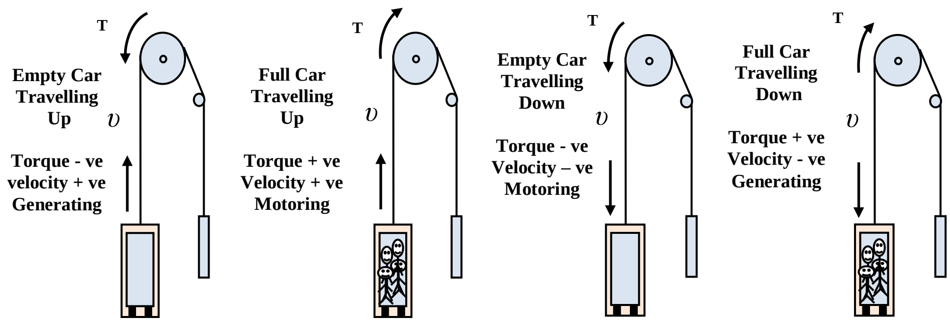


Figure (3) four quadrant operation of lift drive.

GENERAL STRUCTURE OF THE ELEVATOR SYSTEM

In an elevator system, the type of motor used and the speed-control system employed determine, to a large extent, the performance of the driven elevator car.

The general structure of elevator system is shown in Figure (2). The dynamic arrangement of the complete system can be divided into three dynamically coupled sections. First, there is the electrical drive system which includes closed loop control of the velocity of the main sheave; the second part comprises the ropes and the various masses which they interconnect, the characteristics of which are dependent upon the position of the lift in the shaft. Finally, there is the set of isolation pads which joins the car to the sling [8].

Motor Drive System

Outdated, inefficient drives that may be part of existing elevator systems but are no longer on the market include AC two-speed, AC variable-voltage, and DC motor-generator sets. Modern, efficient drives include AC variable-voltage/variable-frequency, DC silicon-controlled rectifier, and DC Pulse Width Modulation PWM drives [17].

PWM inverters make the ride much smoother by precisely adjusting speed control.

The inverters also include the latest low-noise power modules to make the ride even quieter [8].

Recently, with the concern of input power quality, AC-to-DC PWM rectifier is widely adopted in the mid and high speed elevator systems. The PWM converter has inherently both rectifying and regenerating capability and improves the dynamic performance of the whole system. The input line displacement power factor can be maintained at unity over the entire operating condition with reduced line current distortion.

It is very important to continue to run elevator smoothly and safely without any car vibrations, even if the utility voltage applied to the elevator drive system is reduced below the rated voltage. So, the proposed system adopts the PWM rectifier to regulate DC bus voltage constant in all operation conditions.

Table (1) illustrates the motor and elevator parameters of the proposed drive system.

Table (1) Parameters of the Elevator Drive System for (frights or passengers).

Motor parameters		Elevator parameters		
			Freights	Passengers
motor resistance, R_a	0.5 Ω	Nominal motor speed (up/down), ω_m	175 rad/s	175 rad/s
motor inductance, L_a	10 mH	Acceleration (max), a	0.467m.s^{-2}	0.335m.s^{-2}
motor i/p voltage, V_m	100V	Travel height, x	20m@1.4m/s	3m/floor@ 0.6715m/s
torque constant, K_t	0.5 N.m/A	Pulley radius, r	0.1 m	=
voltage constant, K_e	0.5 V/(rad/s)	Pulley inertia, J_p	0.1 Kg.m^2	=
Rotor & gear inertia, J	0.05 Kg.m^2	Car Mass, M_v	100 Kg	=
Viscous friction gain, B_m	0.01 N.m.s	Max. Load weight, M_u	400 Kg	800 Kg
Coulomb friction torque, T_f	0.1 N.m	Counterweight Mass, M_c	300 Kg	500 Kg
		Gravitational acceleration, g	9.81 m/s^2	=
		Reduces gear, K	12.5	26
		Air density, ρ	1.21 kg/m^3	=

PMDC MOTORS

DC motors are used in some industrial applications when adjustable speed operation is required and in building elevator systems where traction drives are specified. A DC motor requires a DC power source for its operation. DC motors provide quick and efficient through dynamic or regenerative braking. The speed of a DC motor can be smoothly controlled down to zero rpm and then accelerated in the opposite direction immediately [18].

The DC motors have staged a comeback with the advent of the silicon-controlled rectifier used for power conversion, facilitating a wide range speed control of these motors [4].

The PMDC motor is usually fed from an adjustable voltage supply, either linear or pulse-width modulated.

In this paper, a PMDC motor was fed by a chopper to control the steady-state speed of this motor. The equations which represent a PMDC steady-state motor are [19]:

$$I_a = \frac{B_m\omega_m + T_L}{K_t} \qquad \dots (1)$$

$$T_e = K_t I_a \qquad \dots (2)$$

$$\omega_m = \frac{K_t}{R_a B_m + K_e K_t} V_m - \frac{R_a}{R_a B_m + K_e K_t} T_L \qquad \dots (3)$$

, where all variables are defined previously in Table (1).

The PMDC motor can be used to drive a variable torque load such as elevator type load. The PMDC motor drive part of the scheme shown in Figure (1) is mainly studied in this paper.

DYNAMIC PMDC MOTOR ELEVATOR DRIVE MODEL

The equivalent circuit of a PMDC motor is illustrated in Figure (4). The parameters and symbols which were used in simulating the system are given in the Table (1).

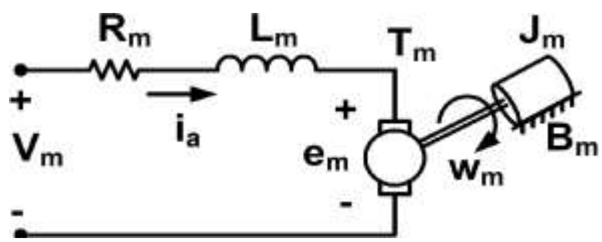


Figure (4) Equivalent circuit of a PMDC motor.

A differential equation for the equivalent circuit can be derived by using Kirchhoff's voltage law around the electrical loop.

$$V_m = R_m I_a + L_m \frac{dI_a}{dt} + e_m \qquad \dots (4)$$

where: $e_m = K_e\ \omega_m$. The sum of torques of the motor must be equal zero, therefore,

$$T_e - J\frac{d\omega_m}{dt} - B_m\omega_m - T_L = 0 \qquad \dots (5)$$

The electromagnetic torque is proportional to the current through the armature winding as illustrated in Eq. 2.

By carrying out a forces assessment of the system charges counterweight given in Figure (1), it is possible to calculate the resistive torque on the shaft of the machine [4]:

$$T_r = (M_u + M_v - M_c)g\frac{r}{k} + J_m\dot{\omega}_m \qquad \dots (6)$$

Expressions (5) and (6) give:

$$J_m \dot{\omega}_m = T_e - B_m \omega_m - (M_u + M_v - M_c) g \frac{r}{k} \qquad \dots (7)$$

$$J_m = J + (J_p + (M_u + M_v + M_c) r^2)/k^2 \qquad \dots (8)$$

$$\omega_m = Kv/r \qquad \dots (9)$$

, where:

$\dot{\omega}_m$: derivative of rotational speed
υ: linear car velocity
T_e: electromechanical torque
T_r: resistive torque
M_v: car mass
M_c: counter weight mass
M_u: load mass
J: rotor and gear inertia
J_P: pulley inertia
g: gravity acceleration
r: pulley radius
K: gear ratio.

The environment factors modeled in the current model are two wind resistances imposed on the car and the counterweight, respectively. There are other environment factors such as the velocity pattern input and load weight which are taken as an input.

During the traveling period, wind in the elevator shaft provides resistance, which is a function of car velocity υ. The wind resistance W_r function has been defined as:

$$W_r = - k \rho \upsilon^2 \, sign(\upsilon) \qquad \dots (10)$$

, where k is set to be 0.05 as the default condition, and ρ is the air density.

The load torque is given by:

$$T_L = (M_u + M_{v-} M_c) \times g \times \frac{r}{k} + W_r \qquad \dots (11)$$

SIMULATION RESULTS AND DISCUSSION

The operational block diagram of the elevator drive system scheme is shown in Figure (5). The drive system has the following parts:

1- Control strategies:

The elevator drive requires different control strategies and different controller parameters. Therefore the controllers used in such a system must handle all the cases with an adaptive property in nature. The addition of dynamic error driven loops to the controller structures increases the ability of the controllers to handle the changes occurring in the overall system. Therefore, three types of control strategies have been applied:

a- DC bus voltage control (DC Regulator Block) loop: DC bus voltage of the inverter will be under control.

b- Motor speed control (Conventional PID Block) loop: PID controller is tuned to eliminate the need for continuous operator attention and used automatically adjust some variables to hold the process variable at the reference value ω_{ref}. When the controller is optimized based on a set of parameters of a typical elevator design, the time and energy consumption will both be smaller, and the system has a better performance. The PID controller is tuned with the following parameters: K_p=50, K_d=0.6 and K_i=4.

c- Motor current control (limiter or Saturation Block): In the simulation model introduced, there is a current limitation loop between the PID controller and the PWM Generator Block. The current reference is obtained by amplification of the angular rotational speed error. This reference is limited to the maximum value tolerable by the motor (50A in the proposed design).

The thresholds relay (Saturation Block) assures a current in the motor equal to the current reference. Depending on the polarity of the current, IGBTs or diodes are the conducting elements.

The current limiter has auxiliary properties as an additional control since the motor speed is the one actually controlled in the system. The reason of using a current limiter is the prevention of high current ripples and spikes, which may cause damages in the motor. The global error goes into PID controller block. After the signal is processed in the block, the PID controller output is limited by the limiter. The limited signal goes into PWM Generator Block.

2- PWM Generator Block: generates four pulses by comparing a triangular carrier waveform with (1 kHz) to a reference modulating signal. 4-pulses are fed to the 4-quadrant chopper (IGBT Inverter Bock).

3- Chopper Fed-DC Motor Drive (IGBT Inverter Bock): The PMDC motor is fed by a DC source through a chopper. The chopper is used to control the motor armature voltage to match the load by adjusting the switching functions for the chopper switches. Therefore, the proposed switch mode model for the PMDC motor can result in more reliable dynamic response and accurate speed tracking performance.

In this paper, a four quadrant chopper with IGBT switches (universal bridge block) at 1 kHz is used to control a PMDC motor. Each IGBT has a freewheeling diode across it and a snubber circuit (not shown in the figure) to limit the rate of rise of the voltage. By varying the on and off times, the mean value of the terminal voltage of the motor is varied and thus the motor speed is varied in both directions.

4- PMDC motor Block: The given simulation model of the PMDC motor is built using resources from the SimPowerSystems and Simulink libraries (there is no PMDC motor function block available in SimPowerSystem Library). The function block is derived from the "DC machine" function block.

5- AC/DC converter (3-Level Bridge Block): A voltage-fed three-phase PWM rectifier is adopted so that DC bus voltage regulation, bidirectional power flow, and controllable power factor with reduced input current harmonics are possible. The converter is controlled to obtain a (120-160) V DC bus which can be used to supply power to PMDC motor (across the IGBT chopper), which is considered to be operated to drive an elevator. The DC bus is terminated by a two capacitors (700μF each) connected across it to maintain constant voltage. The converter is controlled in such a way that the IGBTs in the same arm do not conduct simultaneously.

6- Filter inductor at inverter side is designed for the reduction of audible noise. To guarantee reliability of the whole system, a *RC* terminator at motor side is designed for decreasing *dv*/*dt* at the motor terminal and then preventing insulation failure of the motor. Since the type and length of line cable are almost fixed in case of elevator system, it is easy to standardize the filter design procedure. From the characteristic impedance of the cable, *RC* motor terminator is designed with; *R*=50Ω and *C*=47μF.

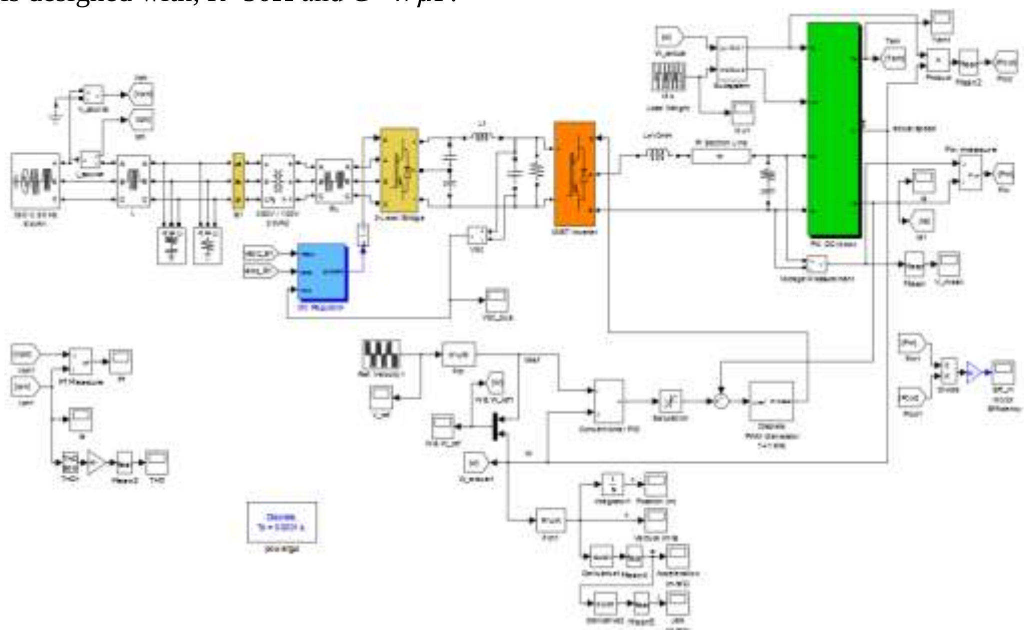


Figure (5) Simulation diagram for mid-rise building elevator system.

Freight Elevator

Freight elevator is an elevator used to carry material rather than people and specially constructed to withstand the rigors of heavy loads.

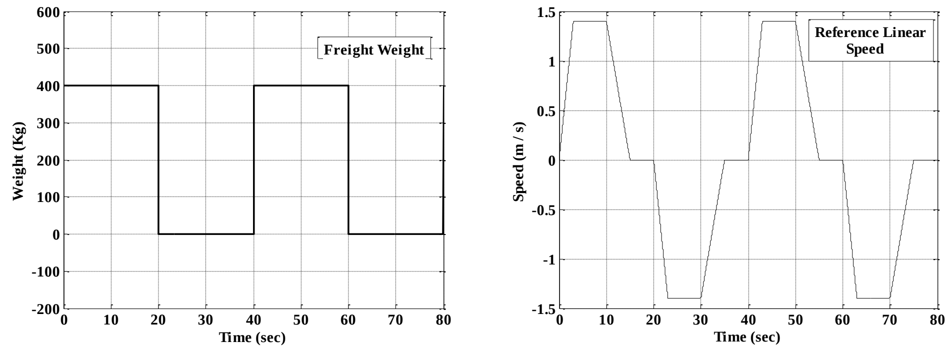
Results of simulation model made in Matlab Simulink are based on a proposed speed profile and load weight (freight) as an input as shown in Figure (6). The simulation is done for a freight elevator with a car weight of 100 kg, balanced with a counterweight of 300 kg.The proposed lifted load weight pattern is (0-400kg) as shown in Figure (6-a).

When a (reference) speed curve of the freight elevator drive shown in Figure (6-b) is applied to the model in Figure (5), the curves of linear (actual) speed υ [m/sec]= [m/min]/60, position *x* [m], acceleration *a* [m/sec^2] and jerk $\dot{a}$ [m/sec^3] of the elevator car shown in Figure 7 (g, h, i, j), can be calculated with the following formulae:

$$x = \int_0^t \upsilon \, dt \qquad \dots (12)$$

$$a = dv/dt \qquad \dots (13)$$

$$\dot{a} = da/dt \qquad \dots (14)$$



(a) (b)

Figure (6) :(a) the load weight (freight elevator) & (b) input reference linear speed profile.

From 0s to 3s, the elevator drive is accelerating from zero speed. From 3s to 10s (rated operation period), it is running at maximum (rated) speed ~175 r/s (~1.4 m/s) steadily. From 10s to 15s, the elevator drive is decelerating from maximum speed and finally stopped.

As shown in Figure (6-b), the profile (reference) speed ω_{ref} is compared with the actual speed ω of the elevator drive. The difference is fed into the PID controller with the following parameters $K_{P=}$50, K_d=0.6, and K_i=4. The product of the controller is fed into the chopper.

It can be seen from Figures (7- i and m) that, from 10 s to 12 s, the efficiency and power factor values of the drive shown in are higher than the rated values. The increase in efficiency means that the energy used by the load for deceleration is approximately totally generated back to the power source.

By using the PID controller, it is expected to have a smoother, overshoot free, fast and less sensitive speed controller when compared to those of classical ones.

The overall performance of the motor drive for freight elevator with diode rectifier and without trap filter can be represented by the curves shown in Figure 7 (a - m) below.

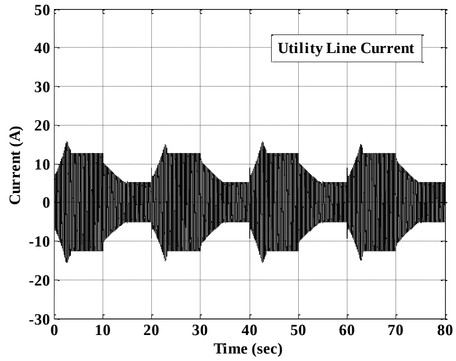


Figure (7-a) Utility line current; I_s

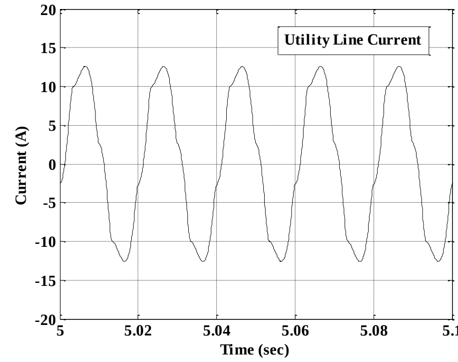


Figure (7-b) Sample of utility line current at rated speed

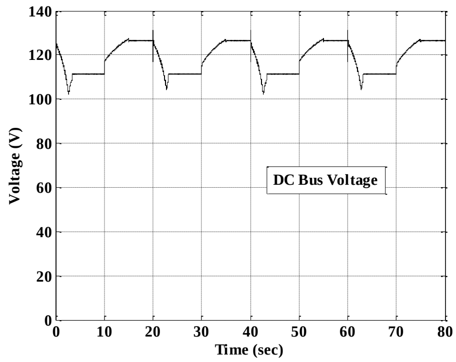


Figure (7-c) DC bus voltage; $V_{dc\text{-}bus}$

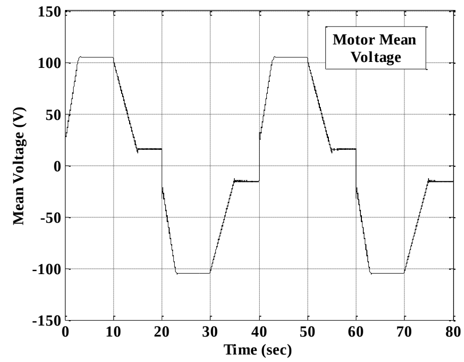


Figure (7-d) Input motor mean voltage; V_{mean}

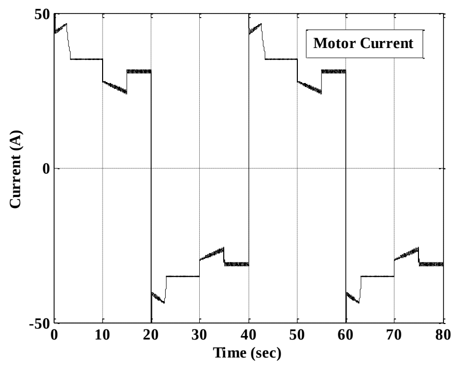


Figure (7-e): Motor current; I_a

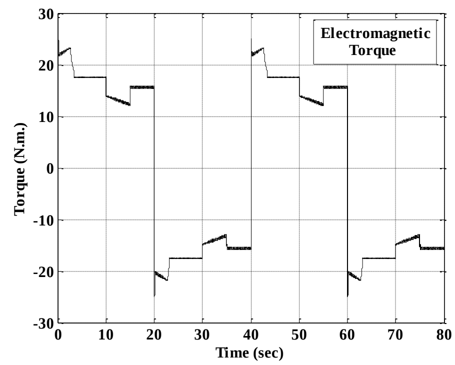
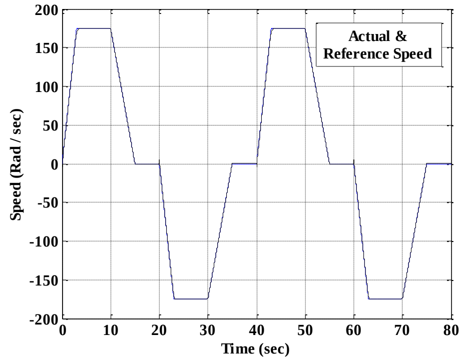
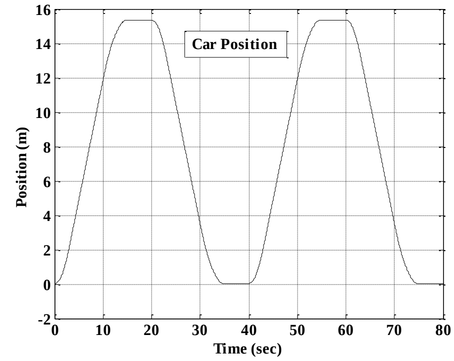


Figure (7-f) Motor electromagnetic Torque; T_{em}



Figure(7-g)Motoractualω&reference Speed; ω_{ref}



Figure(7-h)Elevatorcarposition; *x*

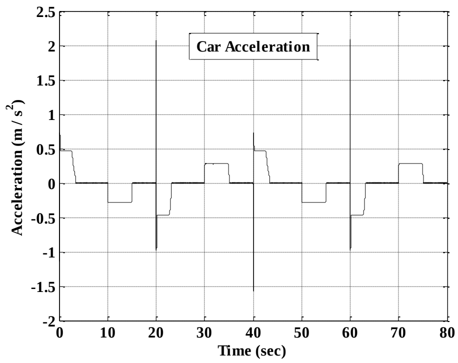


Figure (7-i): Elevator car acceleration; *a*

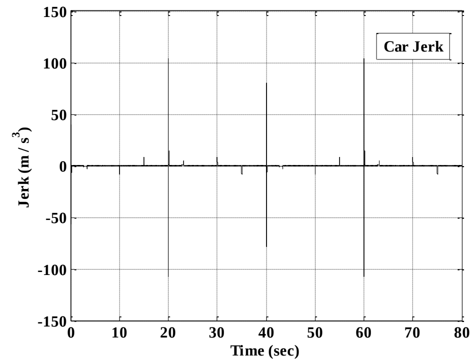
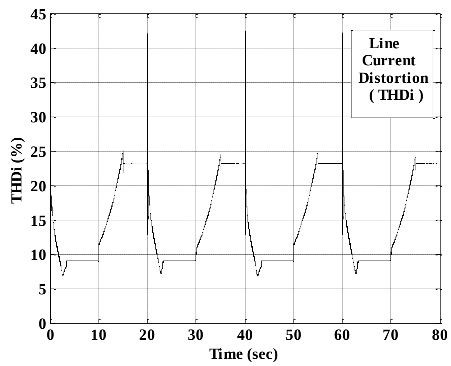


Figure (7-j): Elevator car jerk; $\dot{a}$



Figure(7-k)Line current distortion; THD_i

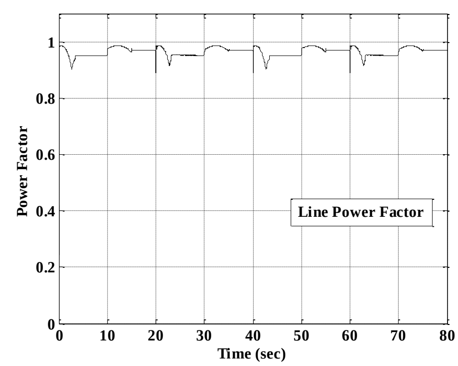


Figure (7-l) Line power factor; P_f.

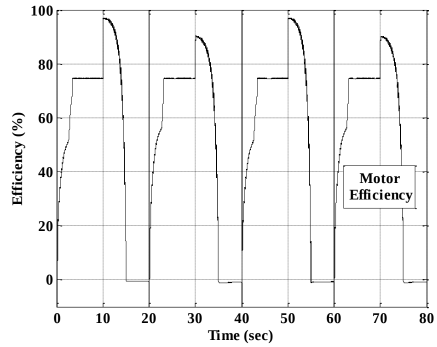


Figure (7-m) Motor efficiency; η.

Figure (7) Drive performance with diode rectifier without trap filter (freight elevator).

To improving the drive performance, especially, the motor efficiency, line power factor, DC bus voltage regulation, and minimization the line current distortion, trap filter or PWM rectifier is added to the system and the comparative corresponding curves can be shown as in Figures 8 (a,b,c,d) and 9 (a,b,c,d), respectively. From these Figures, Table (2) can be deducted, representing the performance comparison between the various techniques proposed.

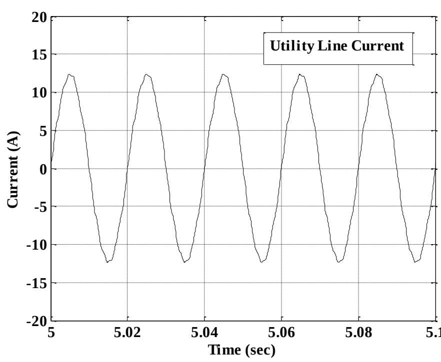


Figure (8-a) Utility line current; I_s

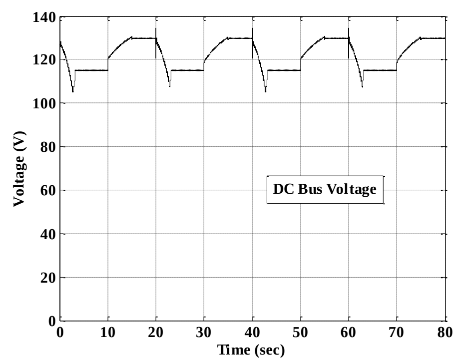
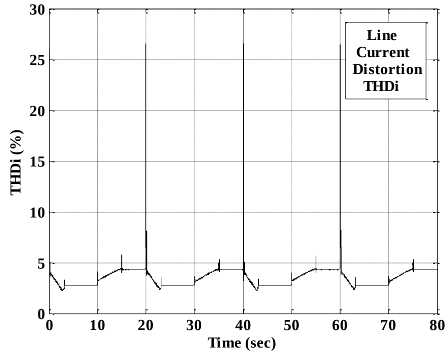


Figure (8-b) DC bus voltage; V_{dc-bus}



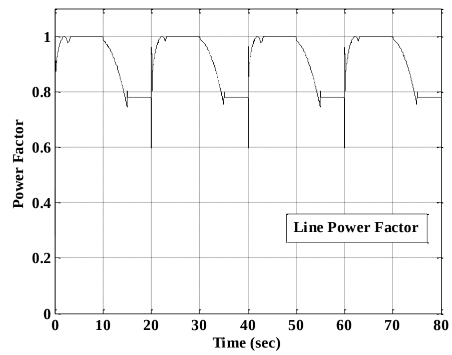
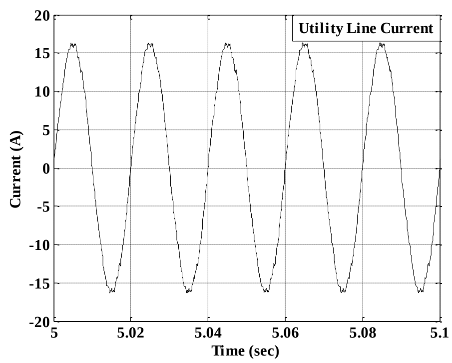


Figure (8-c) Line current distortion; *THD$_i$* **Figure (8-d) Line power factor; *P$_f$*.**

Figure (8) Drive performance with diode rectifier and trap filter (freight elevator).



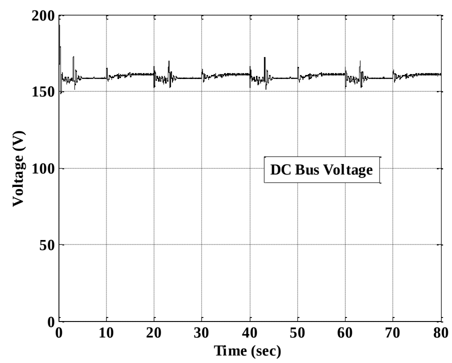
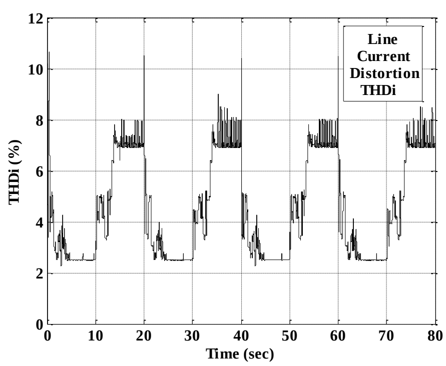


Figure (9-a) Utility line current; *I$_s$* **Figure (9-b) DC bus voltage; *V$_{dc-bus}$***



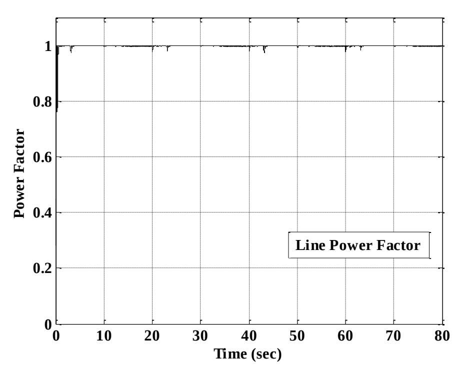


Figure (9-c) Line current distortion; *THD$_i$* **Figure (9-d) Line power factor; *P$_f$***

Figure (9) Drive performance with PWM rectifier (freight elevator).

Table (2) Drive performance comparison for different techniques (freight elevator).

	Diode Rectifier			With Trap Filter			With PWM Rectifier		
Performance Range	Min.	Max.	Rated	Min.	Max.	Rated	Min.	Max.	Rated
motor efficiency η_m (%)		96.8	74.494		96.8	74.5		96.828	74.5
line power factor P_f (p.u.)	0.903	0.9862	0.9518	0.781	0.9996	0.9996	0.9971	0.9996	0.9996
line current distortion, THD_i (%)	6.781	23.148	8.984	2.214	4.33	2.768	2.266	7.0	2.493
motor speed, ω_m (rad/sec)			174.8			174.8			174.8
motor current, I_a (A)			35.09			35.09			35.12
motor torque, T_{em} (N.m)			17.542			17.54			17.53
line current, I_s (A)			8.985			8.655			11.459
car position, x (m)		15.354			15.358			15.359	
car velocity, v (m/s)		1.3992	1.3992		1.3987	1.3987		1.3987	1.3987
car acceleration, a (m/s^2)		0.467	0		0.467	0		0.467	0
car jerk, $\dot{a}$ (m/s^3)			0			0			0
DC bus voltage, $V_{dc\text{-}bus}$ (V)	102.23	126.60	111.36	105.1	129.76	114.93	157.43	160.9	158.51
motor i/p mean voltage, V_{mean} (V)	16.32	106.79	105.83	16.83	107.65	105.85	15.53	110.0	104.96

It can be concluded from the performance curves shown in the Figures (7-9) and Table (2), that the drive performance supplied with PWM rectifier is the better one with minimum line current distortion, maximum line power factor, higher motor efficiency and better DC bus voltage regulation.

Passengers Elevator (Four-floor runs)

The slower speeds are for freight operation, while the higher speeds are typically used for passenger service in mid-rise buildings of ten stories or less. The speed profile and load weight (freight) pattern are proposed for a geared passenger's elevator with 800 kg (~10 passengers) capacity and rated car speed of 0.6715 m/s with full load for a 4-floor run as shown in the Figure (10).

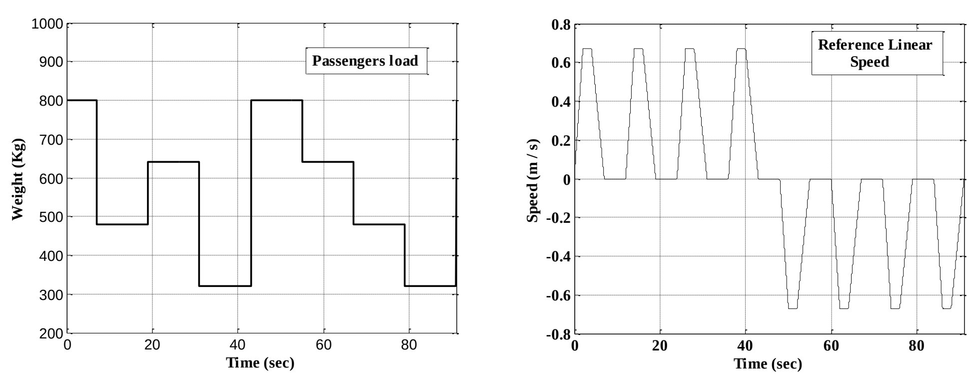


Figure (10) (a) the load weight (passenger's elevator) & (b) input Reference linear speed profile

The curves shown in the Figures (11-13) represent the elevator drive performance from the first floor to the 4th floor with (0-800) kg additional load. The mass of counter weight M_c is usually designed as the sum of car mass M_v and half of max load M_u, which is: 100+800/2=500kg.

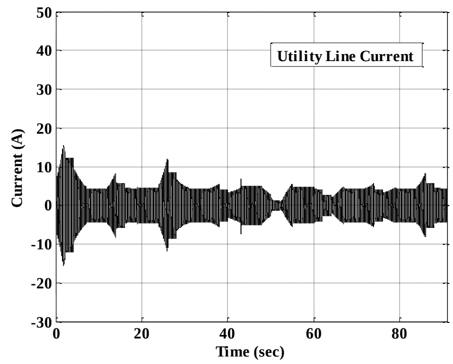


Figure (11-a) Utility line current; I_s

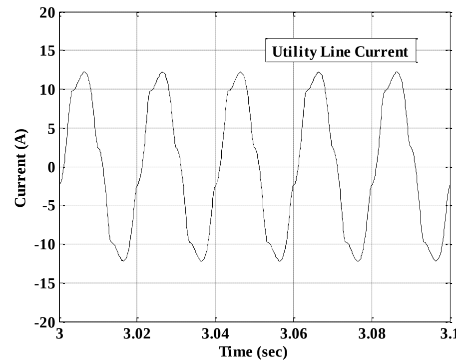


Figure (11-b) Sample of utility line current at rated speed

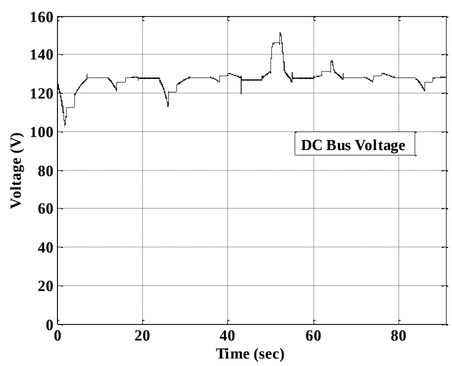


Figure (11-c) DC bus voltage; V_{dc-bus}

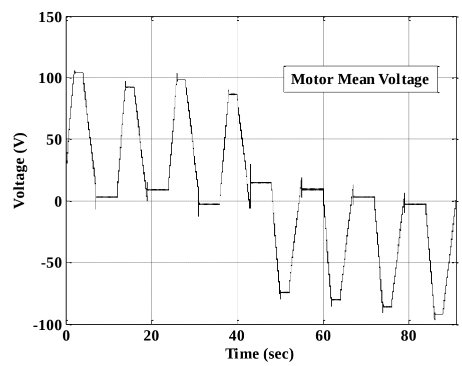


Figure (11-d) Input motor mean Voltage; V_{mean}

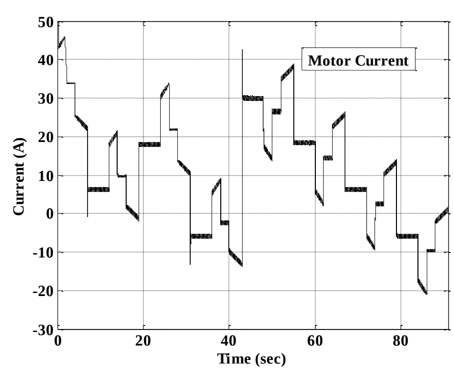


Figure (11-e) Motor current; I_a

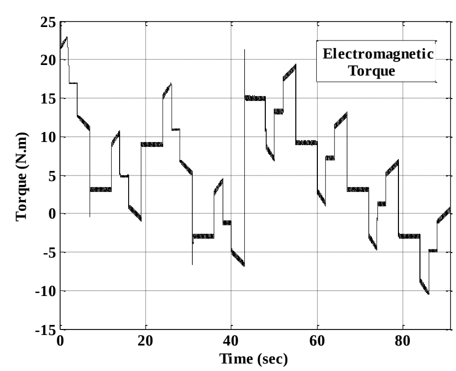


Figure (11-f) Motor electromagnetic

Torque; T_{em}

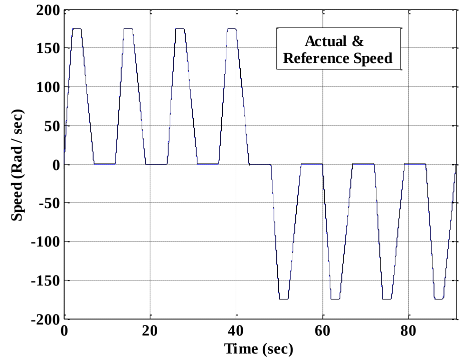


Figure (11-g) Motor actual ω & reference speed; ω_{ref}

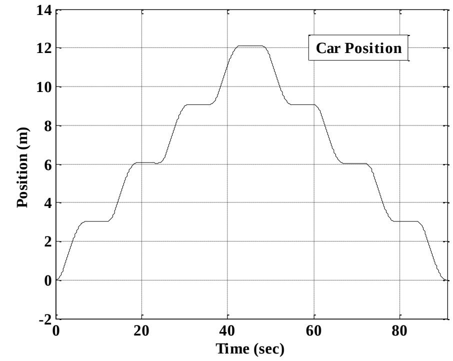


Figure (11-h) Elevator car position; x

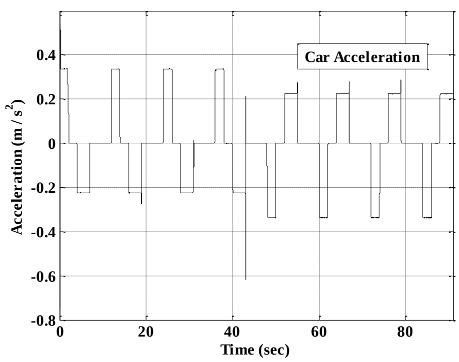


Figure (11-i) Elevator car acceleration; a

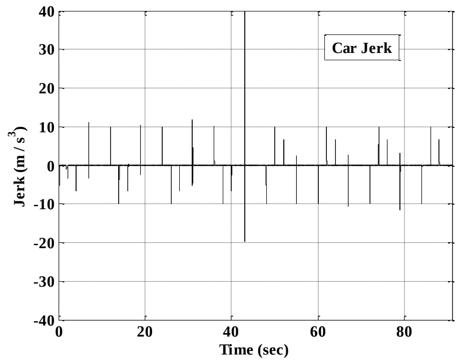


Figure (11-j) Elevator car jerk; J

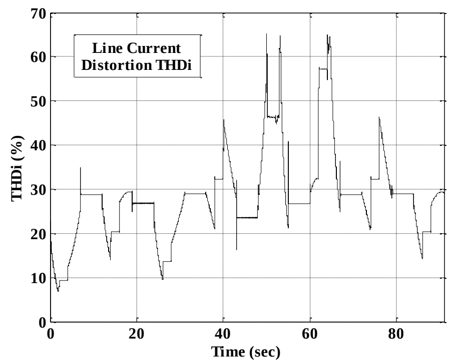


Figure (11-k) Line current distortion; THD_i

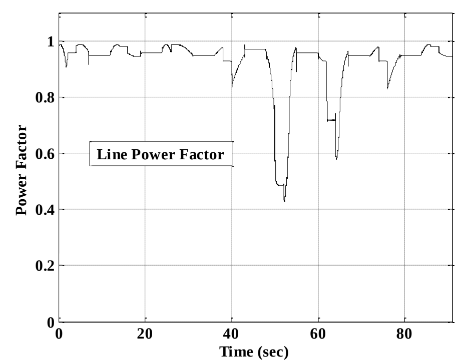


Figure (11-l): Line power factor; P_f

Figure (11) drive performance with diode rectifier no trap filter (Passenger's elevator)

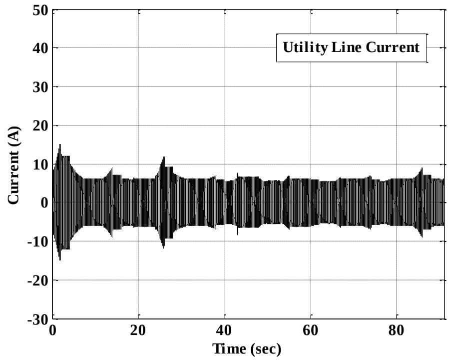


Figure (12-a) Utility line current; I_s

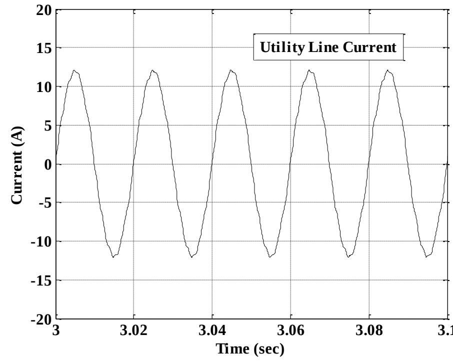


Figure (12-b) Sample of utility line Current at rated speed

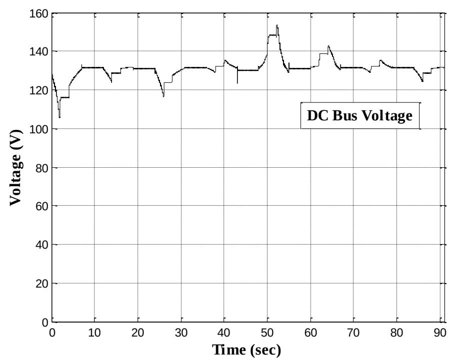


Figure (12-c) DC bus voltage; $V_{dc\text{-}bus}$

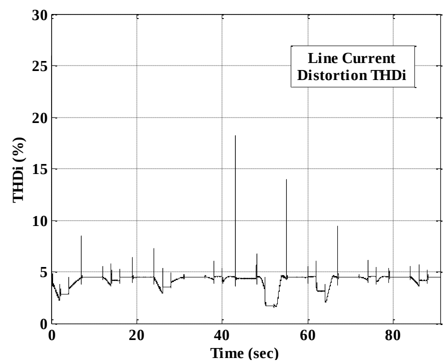


Figure (12-d)Line current distortion; THD_i

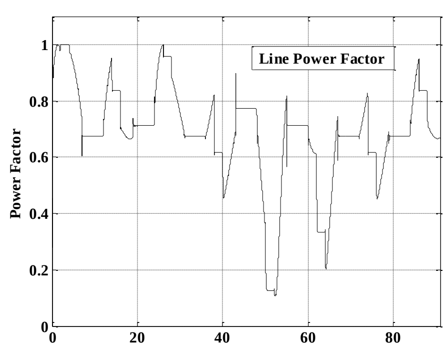


Figure (12-e) Line power factor; P_f.

Figure (12) Drive performance with Diode Rectifier &Trap filter (Passenger's elevator).

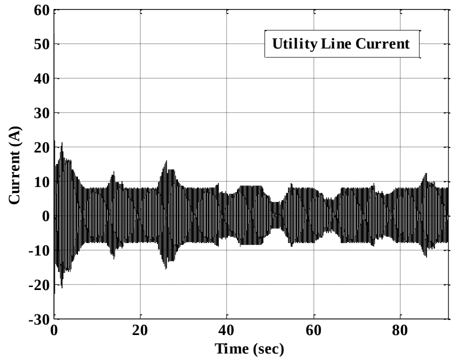


Figure (13-a) Utility line current; I_s

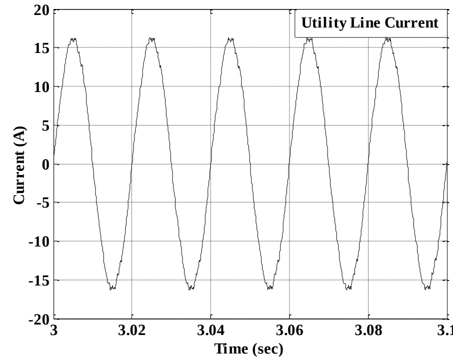


Figure (13-b) Sample of utility line current at rated speed

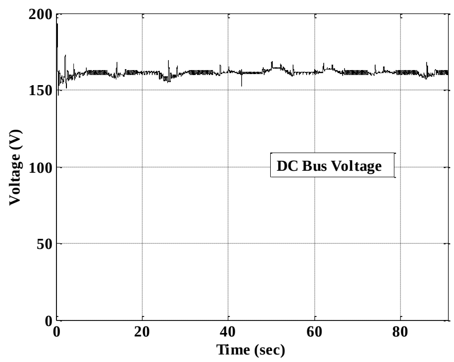


Figure (13-c) DC bus voltage; $V_{dc\text{-}bus}$.

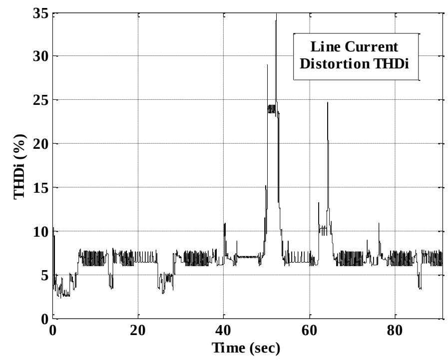


Figure (13-d) Line current distortion; THD_i.

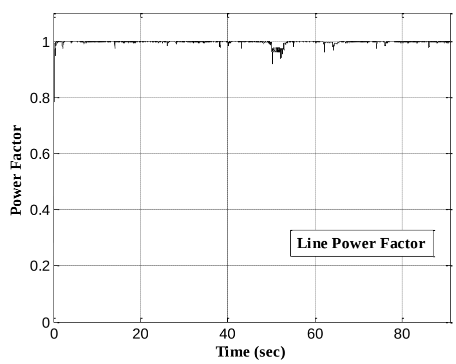


Figure (13-e) Line power factor; P_f.

Figure (13) Drive performance with PWM Rectifier (Passenger's elevator).

CONCLUSIONS

In this paper, a new standardized type of gear elevator traction machine drive system with a PMDC motor for mid-rise buildings and mid-speed elevators is presented, which enables several improvements such higher efficiency, greater comfort, and miniaturization and so on.

Some techniques are proposed to improve the elevator drive such as adding Trap filter to improve the drive performance in spite of some disadvantages like the higher filter design cost, as well as, the filter parameters design changes with the elevator type load and the proposed speed and load weight profile, and etc. Therefore, voltage-fed three-phase PWM rectifier is adopted, so that DC bus voltage regulation, bidirectional power flow, and controllable power factor with reduced input current harmonics and higher efficiency are possible. With a PWM rectifier, the power factor at the utility side is maintained to nearly one. Therefore, PWM rectifier can be considered as an attractive candidate for mid-speed elevator applications even in the cost view point.

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