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Optimization of Electric Passenger Elevator

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Abstract Electric passenger elevator is a constant load torque machinery which runs under light loads most time of loading diagram cycle. This will affect the performance of drive system to become inefficient. In this paper to improve the energy efficiency of electric elevator drive system, the optimal closed- loop drive system with load torque (passengers' number) feed-back signal is proposed. The Genetic Algorithm and Direct Torque Control are implemented as combined searching tool for optimal variables; flux, stator voltage and stator current under different values of load torque. Stator current is used as optimization criterion. The open-loop and optimal closed- loop drive systems of Pulse-Width Modulated inverter- fed three-phase squirrel cage induction motor are modeled and simulated using Simulink /MATLAB software. The proposed optimal model uses information on torque of the squirrel cage motor to generate the appropriate voltage amplitude that minimizes the induction motor stator current. The simulation results of optimal closed-loop and open-loop drive systems show the improvement of drive system parameters leading to energy saving under light loads operation. The energy saving is about 43%.

Keywords Energy efficiency, stator current, genetic algorithm, modeling, simulation

1. Introduction

The electric elevator is a most common solution for vertical transport of passengers and goods in residential and commercial buildings.

Taking into account demographic trends as well as a growing need for convenience, it is expected that the number of elevators will be rising worldwide. Elevators in high-rise buildings consume significant amounts of energy, estimated at (3 - 8) % of the overall consumption of a building, so even marginal improvements of elevator performance can translate into significant energy savings. In recent years, energy efficiency of elevators has attracted more and more attention in the world as many countries are developing policies and programs to control energy use of vertical transportation to enhance energy conservation in buildings [1-5].

Elevator technology is a highly specialized field, with many factors affecting comfort, safety, energy efficiency, and maintenance requirements.

Recently, there has been a steady trend towards the use of frequency-controlled induction motors electric drives in elevators. The use of frequency-controlled electric elevator drive system increases the comfort when moving the cabin, provides quiet and high accuracy of stopping, increases the durability of mechanical equipment, and also reduces power consumption by (40-60) %.

Induction motor is a high efficient electric machine when working closed to its rated torque and speed. However, at light loads, no balance in between copper and iron losses, results considerable reduction in the efficiency. To improve induction motor performance, the optimization criteria should be implemented leading to optimal motor parameters.

The induction motor optimization criteria are: stator current minimization, total losses minimization, input power minimization, power factor maximization and efficiency maximization [6-11].

The evolution of the power digital microcontrollers and development of power electronics enables applying induction motor optimal control methods using scalar control, vector control and direct torque control. To achieve induction motor optimal parameter operation under light loads a searching technique to be used such as artificial neural network, fuzzy logic, expert systems and genetic algorithm [12-16].

This research studies electric elevator parameters optimization using stator current minimization criterion by varying stator voltage and stator frequency for different values of elevator load torque.

The searching tool of optimal flux and optimal stator current is a combined Genetic Algorithm and Direct Torque Control technique to obtain the benefits of both methods and to avoid their individual disadvantages.

Electric elevator drive open-loop and closed-loop (optimized) drive systems have been modeled and simulated using Simulink/MATLAB software.

2. Materials and Methods

2.1. Basic components of electric drive system

Figure 1 shows open-loop electric elevator drive system block-diagram.

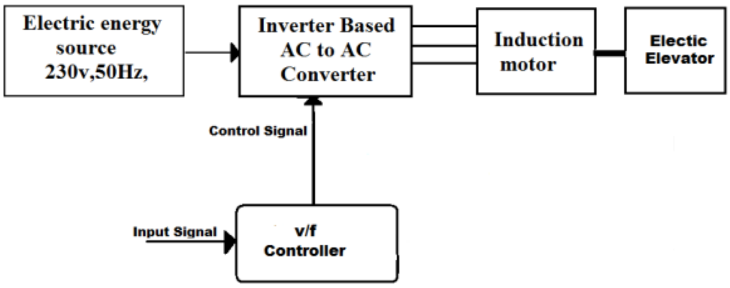

Figure 1: Open-loop electric elevator drive system block-diagram

Electric elevator drive system block-diagram consists of [17]:

I. Electric elevator

Figure 2 shows electric elevator mechanical parts.

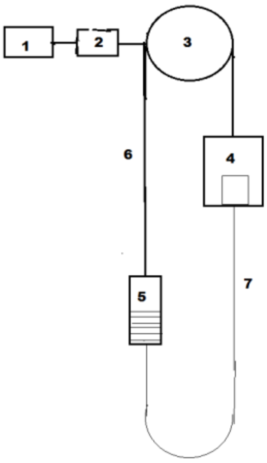

Figure 2: Elevator Mechanical parts

Where:

1- Three-phase squirrel cage ac motor.
2- Gear box.
3- Sheave.
4- Passengers car (Cabin).
5- Counter weight.
6- Hoisting ropes.
7- Compensating ropes.

Traction elevators use hoisting ropes which pass over the traction sheave. The hoisting ropes have the elevator hanging at one end and the counterweight on the other end. The traction sheave is driven by a motor, either directly (gearless) or through a reduction gear. In a traction elevator, the hoisting machine raises the elevator by means of hoisting ropes. The weight of the car is balanced by a counterweight at the other end of the hoisting rope.

The traction to raise and lower the car comes from the friction of the wire ropes against the grooved sheaves. The main sheave is driven by an electric motor through gear box.

The counterweight adds accelerating force when the elevator car is ascending and provides a retarding effort when the car is descending so that less motor horsepower is required. The counterweight is a collection of metal weights that is equal to the weight of the car containing about 50% of its rated load. A set of chains are looped from the bottom of the counterweight to the underside of the car to help maintain balance by offsetting the weight of the hoisting ropes.

Table 1 shows the elevator parameters.

Table 1: Elevator parameters

Parameter	**Symbol**	**Unit**
Car velocity	v	1 m/s
Capacity	N	8 Passengers
Radius of sheave	R	0.35 m
Balancing coefficient	α	0.5
Gear ratio	i	52
Efficiency	η	0.95

The equivalent load torque referred to motor shaft relationship in terms of passengers number is:

$$\mathbf{T_L = 5.213\,(N-4)} \qquad (1)$$

The nominal load torque for nominal elevator capacity (8 passengers) is:

$$T_{LN} = 5.213\ (8-4) = 20.85\ N.m$$

II. Three-phase squirrel cage induction motor

The parameters and ratings of three-phase squirrel cage induction motor are given in table 2.

Table 2: Ratings of three-phase squirrel cage induction motor

Rated Parameter	**Symbol**	**Unit**
Phase voltage	$\mathbf{V_{1N}}$	**230V**
Frequency	$\mathbf{f_{1N}}$	**50Hz**
Power	$\mathbf{P_{2N}}$	**4kW**
Pole pairs	P	**2**
Slip	$\mathbf{S_N}$	**0.0541**
Stator resistance	$\mathbf{R_1}$	**1.405Ω**
Stator inductance	$\mathbf{L_1}$	**0.005839H**
Rotor resistance referred to stator	$\mathbf{R_2^{/}}$	**1.395Ω**
Rotor inductance referred to stator	$\mathbf{L_2^{/}}$	**0.005839H**
Mutual inductance	$\mathbf{L_m}$	**0.1722H**
Total moment of Inertia	$\mathbf{J_\Sigma}$	**0.0131kg.m^2**

III. Inverter-based AC to AC converter

The power converter consists of three-phase uncontrolled rectifier and voltage source pulse- width modulated inverter.

The voltage source inverter is used to convert the dc voltage into an ac signal with a variable frequency and a proportionally variable voltage, using the principle of constant V/f ratio, because the elevator load torque is considered as constant load torque.

Figure 3 shows open-loop electric elevator drive system MATLAB model.

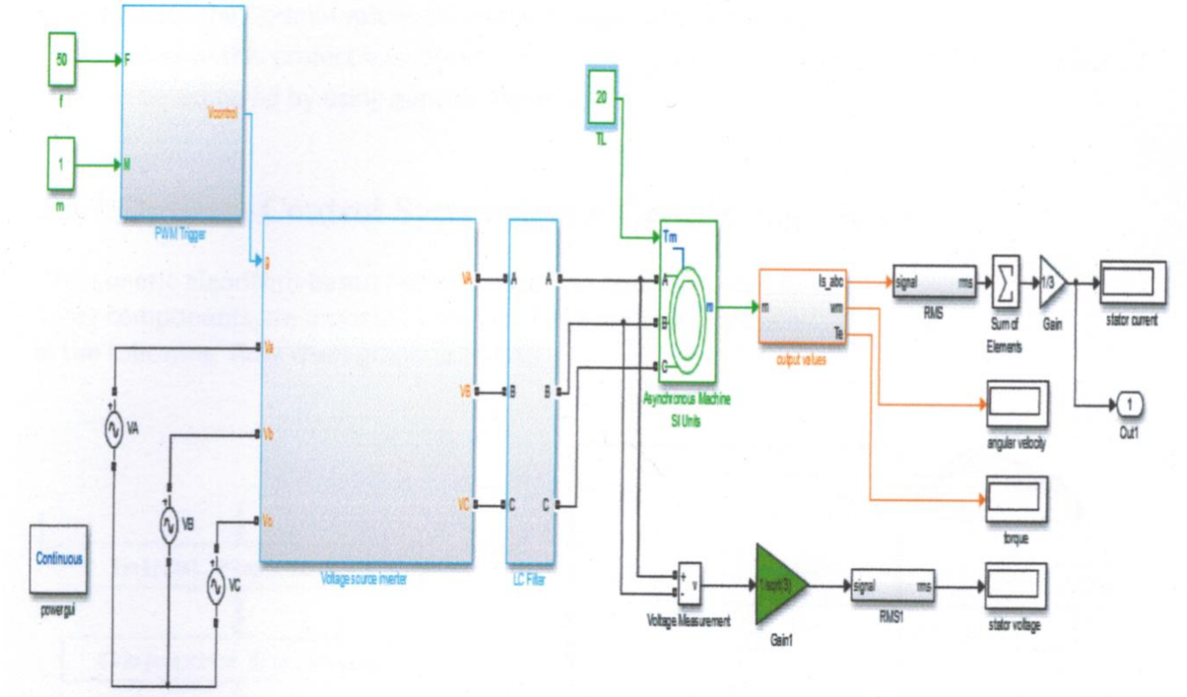

Figure 3: Open-loop electric elevator drive system MATLAB model

The elevator load torque using equation (1) is calculated as function of passengers' number and figure 4 shows elevator load torque model.

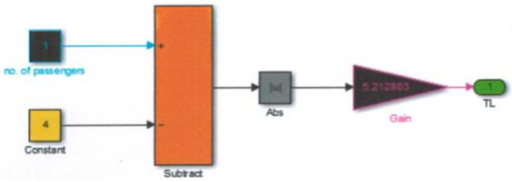

Figure 4: Elevator load torque model

IV. Optimal controller

The optimal control system is a programmed closed –loop drive system, used to generate a control signals according to constant V/f ratio depending on:

- Input reference frequency signal
- Load torque (number of passengers) feed-back signal
- Optimal algorithm using optimization technique and optimal variable searching method.

Figure 5 shows closed-loop electric elevator drive system.

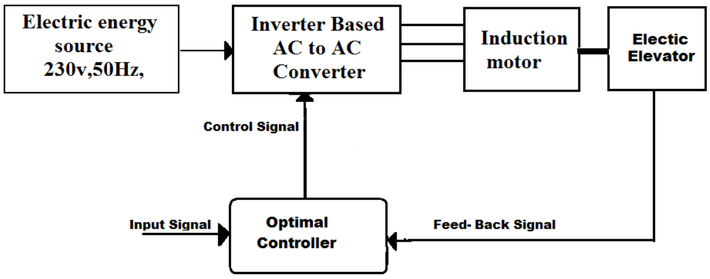

Figure 5: Closed-loop electric elevator drive system

2.2. Electric elevator drive system optimization using Genetic Algorithm and Direct Torque Control techniques

Genetic algorithm is used as a method to optimize the variable to give the motor an optimal voltage at any load torque. The genetic algorithm repeatedly modifies a population of individual solutions. At each step, the genetic algorithm selects individuals randomly from variable population to be parents and use them for producing the children for the next generation. Over successive generations, the population evolves toward an optimal value of the variable [6, 18, and 19].

Direct torque control is a method of optimizing and maintaining normal operation of induction motor.

Direct Torque Control (DTC) became the most popular controller for induction motor control in the last two decades. The popularity is due to its simple structure, and high response for torque requirements compared with the other types of controllers. However, some unavoidable drawbacks exist such as torque and flux ripples, especially at low speeds, at starting, and when transition from state to another. Therefore, an accurate estimation for flux and torque is achieved using Genetic Algorithm (GA) for stator current optimization which can improve the DTC performance. The combined technique, genetic algorithms with DTC used for producing the estimated and optimized output signals of torque, stator flux and flux angle with fast and high degree of response and computations of such control drive [20-23].

2.3. Modeling and simulation of direct torque control using Simulink/ MATLAB software

1- Design of flux and torque estimator model

Stator flux estimation using transformed voltages and currents are given in equations (2 and 3):

$$\vec{\psi}^{e}_{ds} = \int (\vec{V}^{e}_{ds} - R_s\, \vec{i}^{e}_{ds})\, dt \qquad (2)$$

$$\vec{\psi}^{e}_{qs} = \int (\vec{V}^{e}_{qs} - R_s\, \vec{i}^{e}_{qs})\, dt \qquad (3)$$

The stator flux vector and electromagnetic torque are obtained by the following equations:

$$\vec{\psi}^{e}_{s} = \vec{\psi}^{e}_{ds} + j\, \vec{\psi}^{e}_{qs} \qquad (4)$$

$$T_{em} = \frac{3}{2} P (i^{e}_{qs}\, \psi^{e}_{ds} - i^{e}_{ds}\, \psi^{e}_{qs}) \qquad (5)$$

In figure 6 shown Simulink model of flux and torque estimator, based on above mentioned equations.

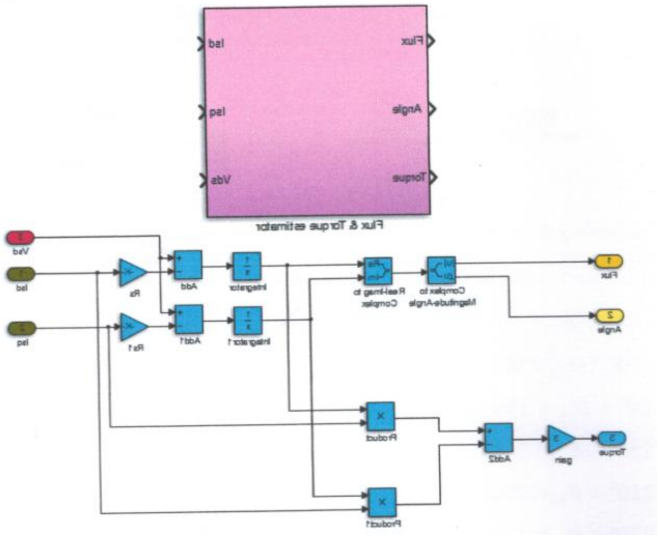

Figure 6: Model of flux and torque estimator

3. Design of flux controller

The estimated stator flux is decreased and increased in order to match the manner of the desired reference flux. A hysteresis band should be allowed and hence a two-level comparator is used for accurate design. The flux controller is shown in figure 7. The flux error which is due to the difference between the estimated and desired stator flux is fed to hysteresis comparator which in turn produces the flux error status.

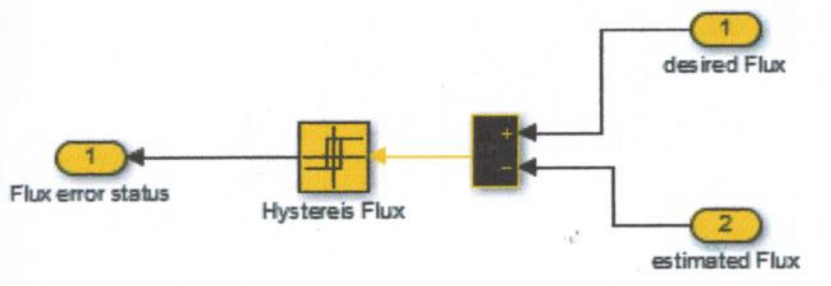

Figure 7: Flux controller

4. Design of torque controller

Evaluate the difference between estimated and desired electro-magnetic torque values similar to the flux control but torque is controlled within its three-level hysteresis band as shown in figure 8.

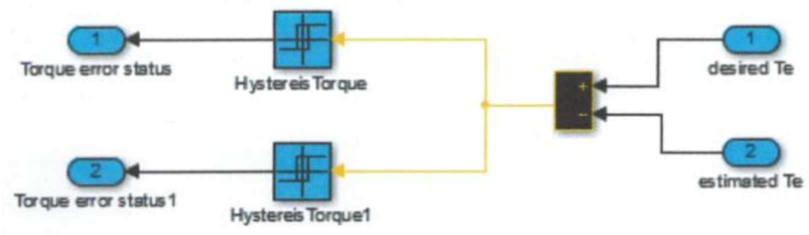

Figure 8: Torque controller

5. Design of switching process model

The stator flux switching sectors can be distributed as follows:

$$-30^{o} < \theta_{s1} < 30^{o}$$

$$30^{o} < \theta_{s2} < 90^{o}$$

$$90^{o} < \theta_{s3} < 150^{o}$$

$$150^{o} < \theta_{s4} < 210^{o}$$

$$210^{o} < \theta_{s5} < 270^{o}$$

$$270^{o} < \theta_{s6} < 330^{o}$$

The stator flux angle in addition to the torque and flux hysteresis status are used to determine the suitable stator flux sector in order to apply the correct voltage vector to the induction motor operating under direct torque control.

Table 3 shows the switching vectors in the different stator flux sectors.

Table 3: Switching vectors in the different stator flux sectors

Error status of		**Sector number**					
ψ_s	T_{em}	**1**	**2**	**3**	**4**	**5**	**6**
		θ_{s1}	θ_{s2}	θ_{s3}	θ_{s4}	θ_{s5}	θ_{s6}
0	1	110	010	011	001	101	100
	0	111	000	111	000	111	000
	-1	011	001	101	100	110	010
1	1	100	110	010	011	001	101
	0	000	111	000	111	000	111
	-1	001	101	100	110	010	011

Figure 9 shows the switching process model.

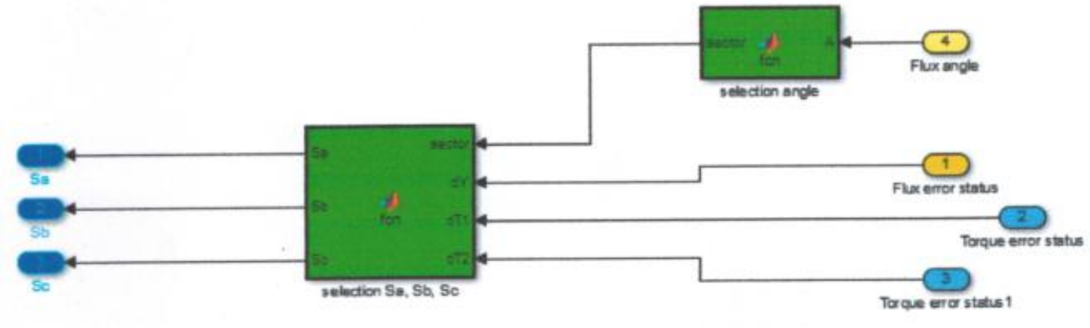

Figure 9: Switching process model

Figure 10 shows MATLAB model of optimal electric elevator drive system based on genetic algorithm and direct torque control technique.

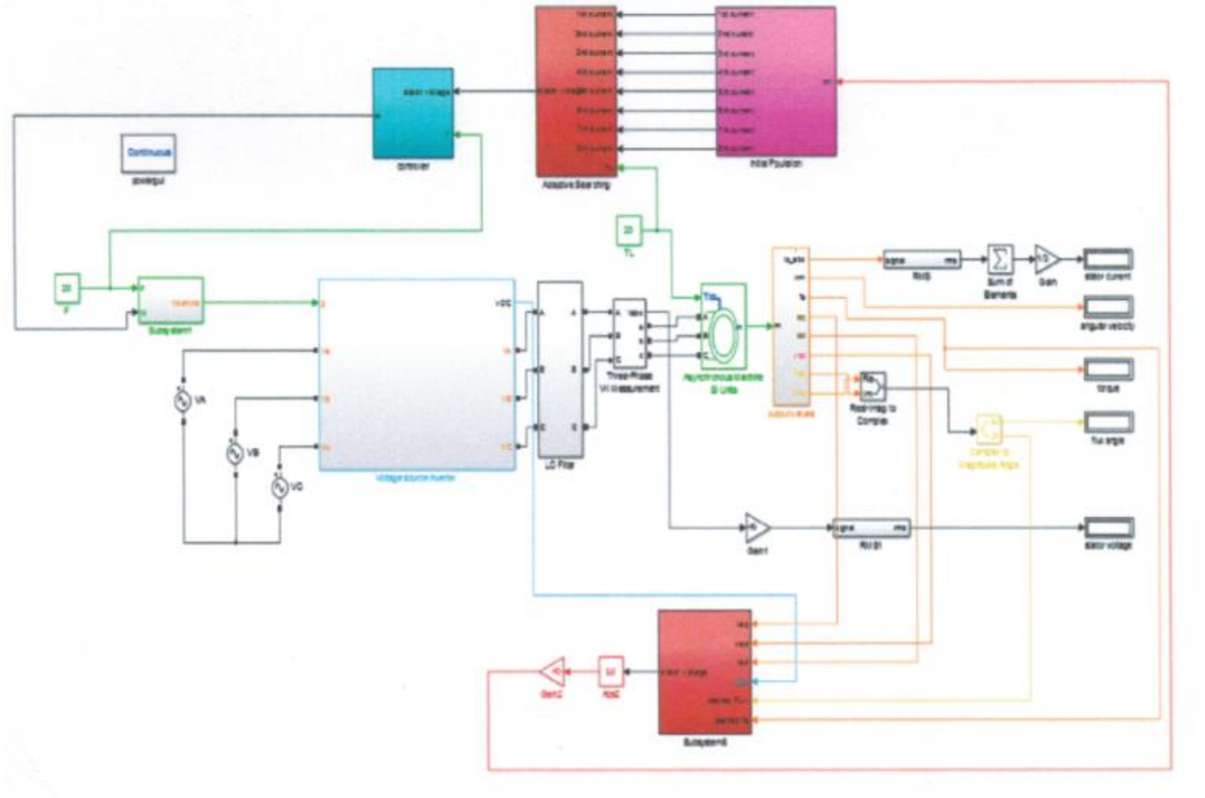

Figure 10: Model of optimal electric elevator drive system based on genetic algorithm and direct torque control technique

6. Results & Discussion

The open-loop elevator drive system Figure 3 and optimal (closed-loop) elevator drive system Figure 10 models are verified through the computer simulations using the software package Simulink /MATLAB. The simulation results are supported by figures that compare the above-mentioned two models for different values of stator frequency.

The figure 11- figure 19 show a stator voltage optimization and stator current minimization operating under different load torques and at different stator frequencies when implementing optimal elevator drive system using genetic algorithm and direct torque control as searching tool .Figure 11 shows the stator voltage versus load torque relationship at 50 Hz stator frequency.

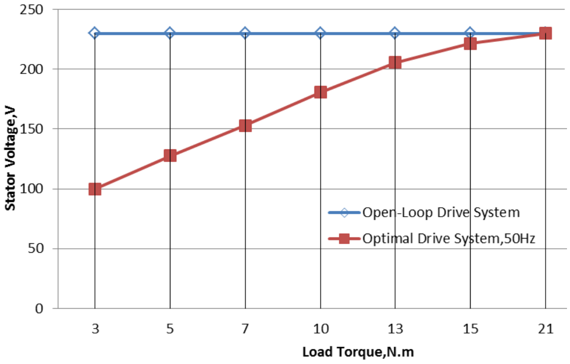

Figure 11: Stator voltage variation at different load torques and at 50 Hz

Figure 12, Figure 13 and Figure 14 represent stator current versus load torque relationship at different stator frequencies.

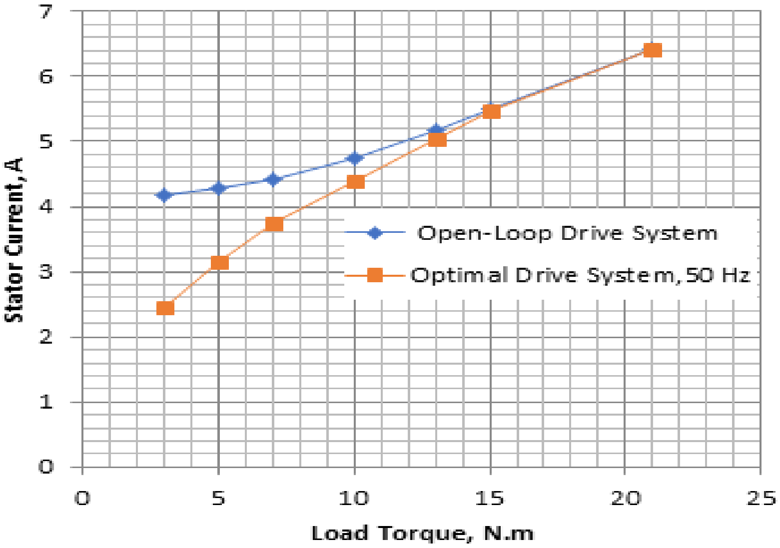

Figure 12: Stator current variation at different load torques and at 50 Hz

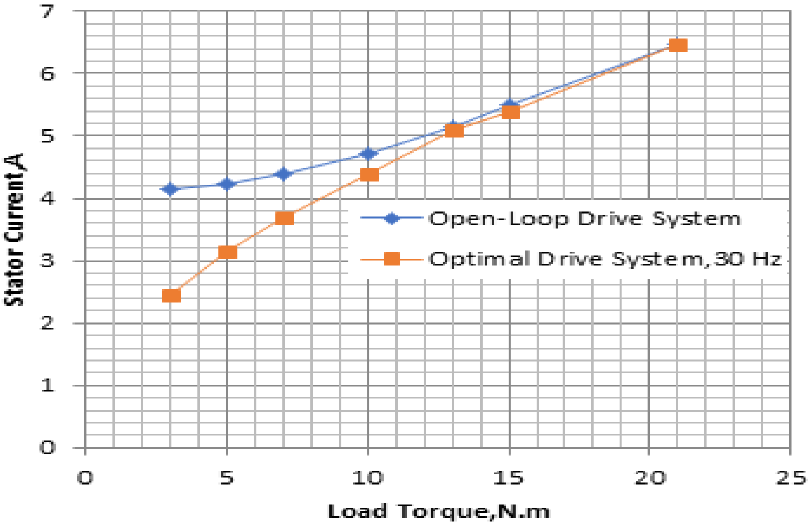

Figure 13: Stator current variation at different load torques and at 30 Hz

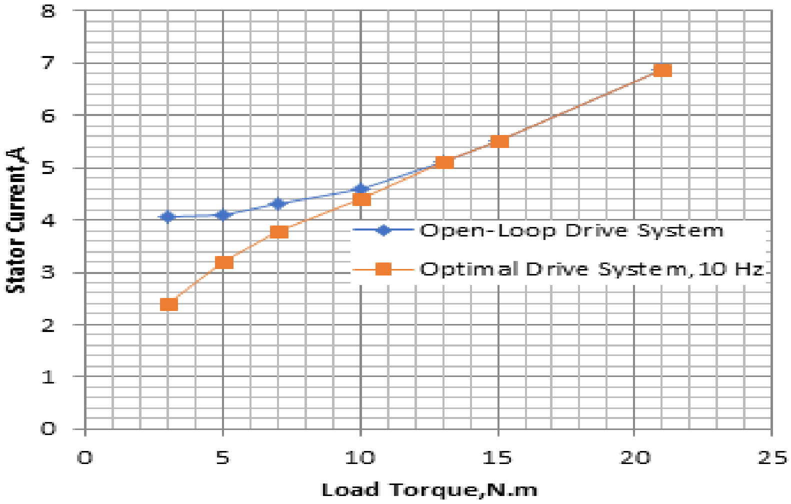

Figure 14: Stator current variation at different load torques and at 10 Hz

Figure 15, Figure 16 and Figure 17 show a real-time stator current comparison at different load torques and different stator frequencies.

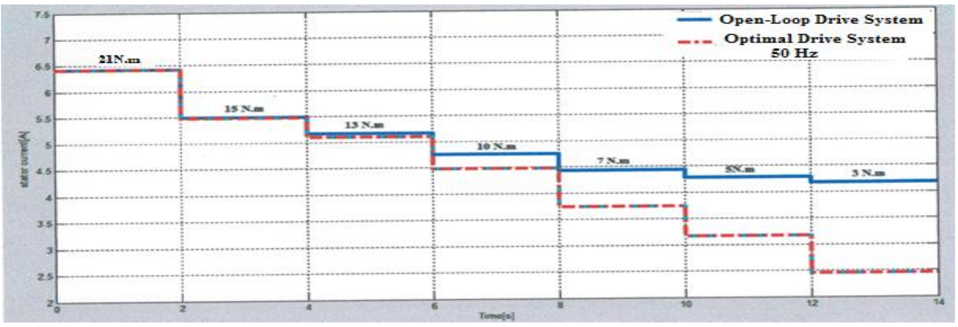

Figure 15: Real-time stator current comparison at different load torques and at 50 Hz

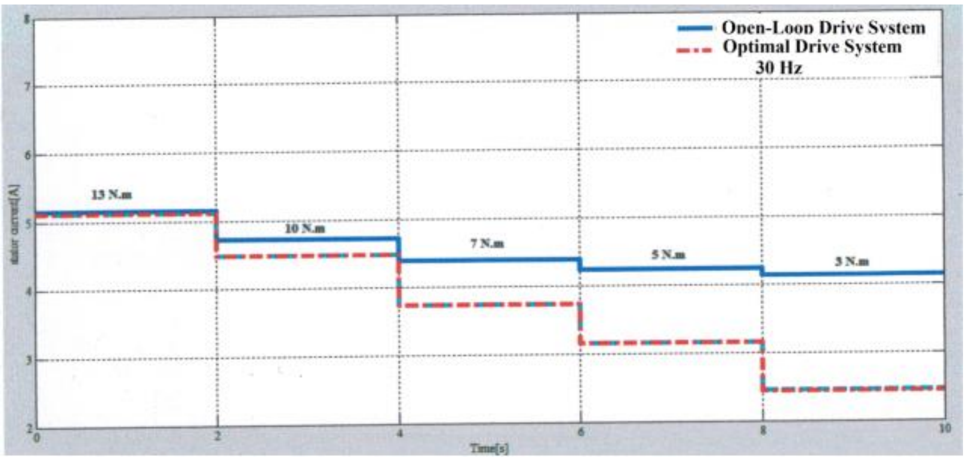

Figure 16: Real-time stator current comparison at different load torques and at 30 Hz

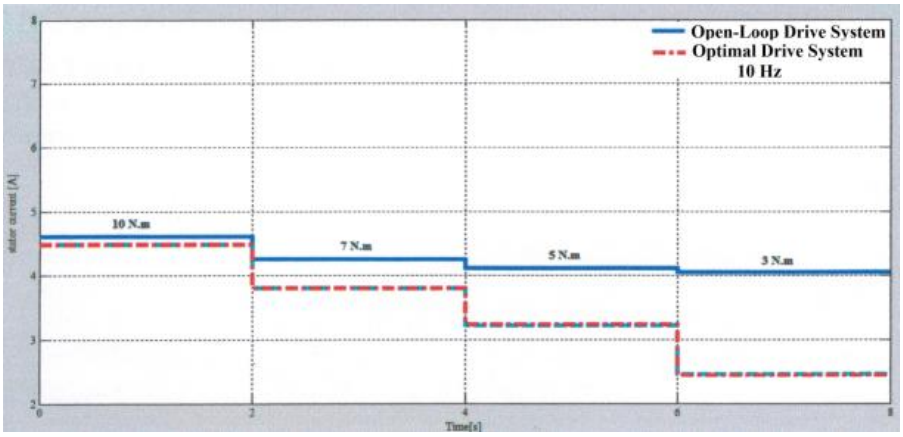

Figure 17:Real-time stator current comparison at different load torques and at 10 Hz

Figure 18 show a real-time stator current comparison at different passengers' number and at 50 Hz stator frequency.

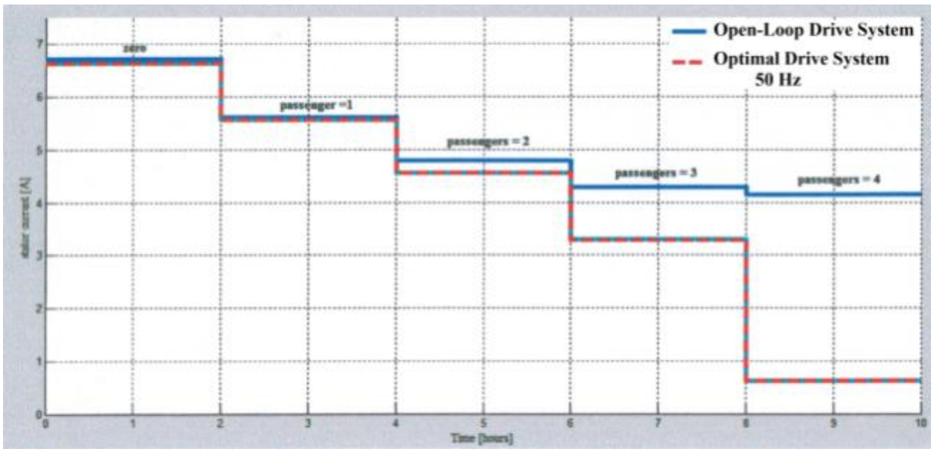

Figure 18:Real-time Stator current comparison at different passengers' number and at 50 Hz

Figure 19 shows a 3-D stator current variation versus load torque and stator frequency.

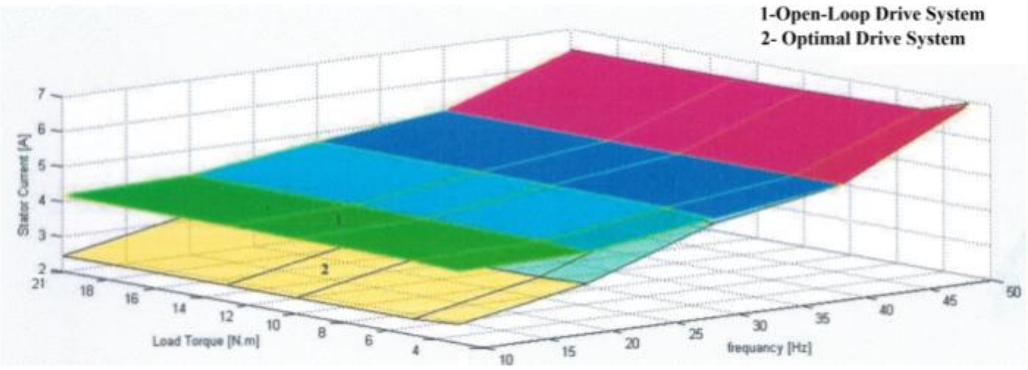

Figure 19: shows a 3-D stator current variation versus load torque and stator frequency

Figure 20 represents elevator loading diagram per day, it shows the time of each elevator average load torque during one day cycle.

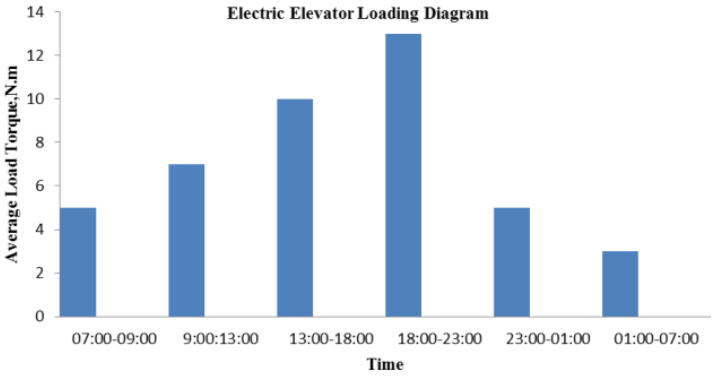

Figure 20: Elevator loading diagram

Consumed power and consumed energy during one day cycle calculated depending on stator voltage variation at different load torques and at 50 Hz figure 11 and stator current variation at different load torques and at 50 Hz figure 12 and elevator loading diagram figure 20.

Figure 21 shows consumed power versus elevator load torque. Open loop drive system total consumed power is 19 kVA and optimal drive system total consumed power is10.45 kVA. So the power saving (economy) is 45%.

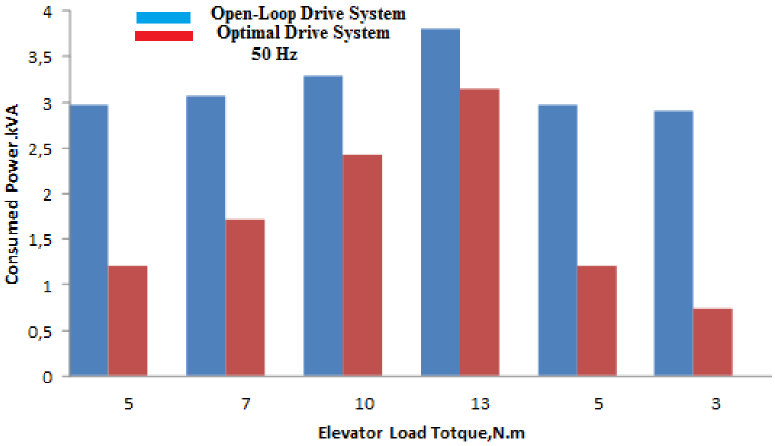

Figure 21: Consumed power versus elevator load torque

Figure 22 shows consumed energy versus elevator load torque. Open loop drive system total consumed energy is 77.07 KVAh and optimal drive system total consumed energy is 43.98 KVAh. So the energy saving (economy) is about 43%.

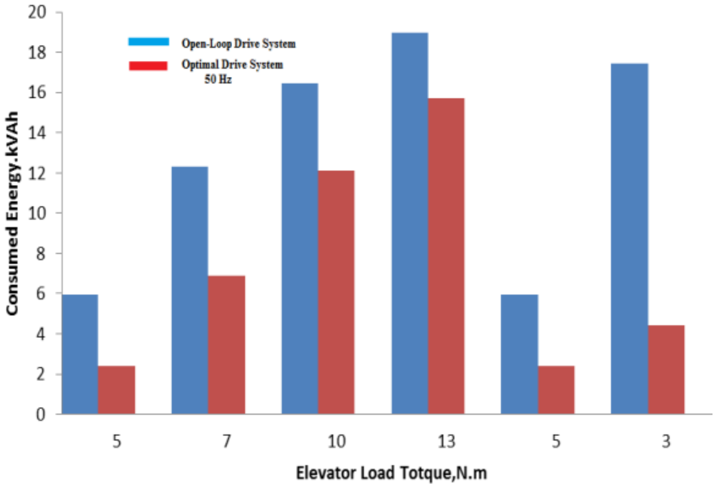

Figure 22: Consumed energy versus elevator load torque

7. Conclusion

The studying and analysis of electric elevator optimal (closed-loop) drive system with load torque feed-back signal and optimal stator current controller depending on genetic algorithm and direct torque control searching tool show that the optimal drive system leads to stator current minimization, power and energy saving especially under light loads. So the electric elevator optimal drive system is efficient electric elevator drive system.

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