Variable Speed Drives in Electric Elevator Systems: A Review

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Abstract. Due to the industrial development and the growing modernity, the elevator systems have become indispensable in many multi-story buildings. When electrical elevators are employed to transport people, riding comfort becomes a very important issue, especially when high-speed elevators are used in high-rise buildings. The elevator systems should provide a good stop accuracy and excellent levels of ride comfort. Passengers experience some problems that affect their comfort such as vibration and jerk that occur when travelling between elevator floors especially when starting and stopping the cabin. To minimize the effects of these problems, the cabin must be driven in such a way as to ensure smooth operation and smooth starting and stopping. Therefore, there is a need to control the voltage and frequency of the electric motor that drives the elevator cabin.

This paper introduces a look at the different types of variable speed drives and how they're used in electric elevator systems, discussing current systems as well as recent development in the field. Therefore, a variable-speed design that provides smooth movement is needed to include a smooth ride, accurate leveling, and a large number of start and stop operations. First, some basic principles in driving systems, such as load curves and driving speed/torque, as well as their relationship to stability, are discussed; reference curve generation; speed curve profiling of the elevator system to achieve smooth transmission. The latest study in this topic reached the implementation of an elevator prototype driven by permanent magnet linear synchronous motor (PMSLM) loaded by 24kg. The motor was controlled by voltage frequency drive (VFD) programmed with offline S-curve to get a smooth start and smooth stop for the elevator cabin and constant travel speed with the least jerk possible, estimated by 88% compared the that without using the driver.

Keywords: variable speed drives, VVVF, motors, jerk, acceleration, vibration.

1. Introduction

In residential and commercial buildings, the most common solution for vertical transportation of passengers and goods is an electrical elevator. Elevators in particular are widely used throughout the world [1]. Its structure hasn't changed enough since the first commercial elevators of this type were built. While, Control systems, safety features, driving capacity, longevity, and economy are in constant evolution. High transport speed, low jerk, precise positioning, quick and efficient control, and a limited number of sensors are all requirements for modern passenger elevators. [2,3].

Although elevators can be classified based on different characteristics, the principles of design and component manufacturing depend on the driving method used. There are three types of elevator based on the drive method; Electric elevators [4-6], Hydraulic elevators [7-9], and Pneumatic elevators
[10-12]. The Electric Elevators can be further classified into three types; Traction drive, geared or gearless [13-15], Positive drive (drum drive) [16,17], and Linear Motor drive [18-20].

The comfort and comfort of passengers are of special concern in modern elevators. Today there are elevators which reach the nominal speed of 18 meter per second in order to increase their availability in high office buildings with a high frequency of traffic. In these elevators there is a high vibration when they travelling and When starting and stopping, there is a strong jerk, which can cause discomfort of the riders. as well as they affect the performance of the electrical and mechanical subsystem, as well as the reduce the system life expectance. To solve these problems many researchers have submitted appropriate solutions in literature review. Most of these researchers are focused on regulating the electric motor's rotational speed the elevator through employment variable-speed drives. There are specific requirements that variable-speed drives must meet when driving an elevator, such as:

1- Comfort when riding: The movement of the elevator cabin should be smooth, within the limits of acceleration and jerk values. The jerk value of ride softness and comfort is particularly important and it represents the rate of acceleration change.
2- Start and stop: Elevator systems are known for high number of start and stop operations, with some systems needing as many as 240 starts every hour. Special conditions are introduced as a result of the amount of heat produced by the electric motor.
3- Accuracy of level: High accuracy is needed at each stop operation of the elevator cabin may reach 1-2 mm.
4- Speed feedback: Modern systems usually need to employ position and speed feedback to provide efficient speed control, ride comfort, and accurate leveling.
5- Electric braking: To accurately control the speed of the elevator, electric braking should be integrated into the driving system. There are many ways that can be used for brake systems of elevators.

2. Comprehensive Research in Literature:

There are many studies in literature that have dealt with different types of electric elevators driven by different control techniques. Rajaraman and Nagaraja 1984 [21] To achieve outstanding riding comfort and precise floor-leveling in medium-speed elevators operated by squirrel-cage induction motors, an electronic control system with speed feedback was introduced. Move less regulation of the elevator car's acceleration and deceleration was implemented using only two diodes and two thyristors, as well as a few modularized electronic circuit cards in the power control circuit, making it simpler and less expensive. To achieve floor leveling and smooth deceleration, a novel digital speed-reference circuit that uses programmable memory to generate the speed pattern based on the elevator car location was used. As compared to similar performance dc motor-driven elevators for car speeds up to 2 m/s, the electronic hardware allowed any fault to be easily traced to a specific card and was easier to maintain. Siikonen 1997 [22] described a new control that improves passenger service in a community of elevators. When allocating landing calls to the elevators, fuzzy logic and artificial intelligence were used in the regulation. From statistical forecasts, fuzzy logic was used to understand the traffic pattern and traffic peaks. The passenger traffic flow in the buildings was calculated in order to create statistical forecasts. The passenger traffic flow was learned day by day in the statistics, and the control adapts to the current traffic situation. Tanahashi 1997 [23] used a dynamic braking to control the elevator drive compared to well-known elevator control systems. A synchronous motor using permanent magnet was used as the lifting machine. This dynamic braking allows a compact design to be implemented into the structure of an electromagnetic brake to control, and reduce energy. Mutoh, et al. 1998 [24] Elevator performance can be improved by studying an induction motor driving controller. Three features are included in the controller. first, it has an energy-saving control that ensures the induction motor produces torque at maximum efficiency. Second, it can suppress elevator vertical vibrations while also conserving energy. Third, it ensures that elevators work well even when the source voltage is decreased due to a source side overload. Min Lee, et al. 1999 [25] proposed a new vertical vibration management technique based on car
acceleration feedback control for elevator ride quality improving, by adding an acceleration feedback compensator into a standard speed controller. Using a real acceleration signal as input, an algorithm was presented. A speed controller with an acceleration feedback controller is used in the proposed process. At the elevator test tower, experimental verification was carried out with a medium speed elevator system powered by an induction motor. The proposed vertical vibration controller's feasibility was illustrated by computer simulation and experimental performance.

Figure 1: Block diagram of proposed for vibration suppressing control [25].

Kulkarni, et al. 2000 [3] For AC gearless elevators, a comparison of regenerative and non-regenerative vector driven variable voltage variable frequency drives (VFDs) was presented. For each elevator control device, the study included a thorough analysis of energy consumption, line voltage and current harmonics, elevator machine room heat produced, input power factor, and peak demand. The input voltage and current waveforms for both regenerative and non-regenerative drives were shown to demonstrate the variable voltage variable frequency (VVVF) regenerative drive's clean power existence.

Kang and Sul 2000 [26] suggested a Vibration suppression technique for an elevator with an induction motor to improve ride comfort, using car acceleration feedback compensation. They created an extended full-order observer that calculates the lift car's velocity and vibration without the use of an expensive sensor on the car floor, and to improve ride quality by suppressing vertical vibration of the car using estimated state input compensation. Experiments were carried out at a 50-meter-high medium-speed elevator test tower to validate the proposed algorithm.

Al-Sharif, et al. 2001 [27] used dc VFDs in lift systems, discussed and analyzed outlines for their relative benefits and drawbacks. The DC-SCR drive, The Ward-Leonard DC system, the variable voltage AC system, and the VVVF system are examples of these drives. Three different methods and recent advances of braking were discussed in drive systems for lifts. Slim-disk permanent magnet synchronous motors are one of them (PMSMs), which have created machine rooms useless, in drive systems, the load and drive speed/torque curves were included and there Relationship to stability, to achieve a smooth journey, the reference curve was created and the speed curve of a lift system is profiled. This device achieved high levels of stopping accuracy and riding comfort.

Chung, et al. 2001 [28] presented a new standardized type of permanent magnet (PM) motor-driven gearless traction machine drive system for high-speed elevators in order to achieve a number of benefits, including increased efficiency, Miniaturization, improved convenience, and so on. A three-phase voltage-fed pulse width modulation (PWM) rectifier has also been adopted so that Dc bus voltage management, bidirectional power flow, and controllable power factor with reduced input current harmonics are possible. A resistance-capacitance (RC) terminator was installed on the motor side to ensure the system's reliability, for lowering dv/dt at the motor terminal and thus avoiding motor insulation failure Furthermore, other advanced features including reduction of audible noise and torque
A major necessity in elevators is to reduce force pulsations, suggested a Linear Switched Reluctance Motor (LSRM) for a ship elevator's main propulsion. A reasonable solution for this problem is typically a multi-phase excitation that is directed and uses one of the known Force Distribution Functions (FDF). The currently available FDFs were shown to be capable of reducing force pulsations but not of meeting the peak force command. As a result, control of speed and location no longer satisfy even the most basic performance requirements. To solve the problem created by the traditional FDF, a new FDF was proposed and presented. For speed and position control, a control system based on the proposed FDF was developed and integrated. The proposed LSRM with the new FDF has superior performance, according to extensive simulation results, and it was being that it would be appropriate for use in a ship elevator.

Li, et al. 2007 [29] developed a novel motion control method to reduce residual vibration and minimize jerk. This process makes use of a novel motion profile generation technique to smooth the acceleration profile as a consequence, the jerk profile is smoother without any abrupt corner. To, the difficulty of computation and relieve the motion controller's burden, for real-time motion profile generation and control, an embedded controller used a look-up table. With the help of a TI DSP controller, this method was implemented in a voice-coil driven linear stage. Lim 2007 [30] For a linear elevator prototype,
investigated linear switched reluctance motor (LSRM) drives as an alternative actuator. The elevator was given a control strategy that included four control loops, Control loops for current, velocity, force, and position feedback, to name a few. A novel force distribution function (FDF) for force control was proposed and compared to traditional FDFs with proportional plus integral (PI) controller. During the elevator’s elevation, descent, and halt operations, a trapezoidal velocity profile was added to monitor vertical travel position smoothly. This work also presented a novel current control method that eliminates the need for additional hardware to suppress measurement disturbances. The elimination of force ripple and acoustic noise was accomplished by refusing measurement disturbances. Because of its superior and stable current control performance. The proposed approach, it was thought, could be successfully extended to other motor drive systems to eliminate measurement errors while maintaining the same promising results without the need for additional hardware. Yu, et al 2007 [31] proposed a fuzzy logic controller (FLC) to be used in high-performance vector-controlled PMSM elevator drive system to improve the control of speed. A comparison was made between the proposed FLC and the traditional PI controller in terms of load torque and speed dynamic responses. Simulation and experimental results demonstrated that the proposed FLC was superior over the conventional PI in terms of speed responses. For high-performance elevator drive systems, this FLC may be a good match.

Lim and Krishnan 2007 [32] designed a one-tenth-scaled home elevator prototype. Current control and velocity control loops based on PI controller’s Dynamic simulations and experimental experiments have been used to study, hire, and validate the systems. The prototype was provided a trapezoidal velocity profile and that was applied to it to control the position smoothly when moving and stopping. Positioning feedback control loops to force control was also a good idea. The findings proved that LSRMs One of the leading contenders for linear elevator propulsion drives was. The prototype elevator has been tested at speeds ranging from 0.15 to 0.3 m/s and payloads of 23 and 32 kg. This elevator also has a simple design while still being capable of delivering the performance required for these applications.
Li, et al. 2010 [33] discussed the idea of using radial basis function (RBF) neural network for traditional PID algorithm for identifying control object in order to control an elevator movement, providing a Jacobian message which has been received to Back Propagation (BP) network. Then using the BP neural network’s arbitrary nonlinear expression capacity, tested the system to determine the best combination of PID control parameters, and, at long last, achieving the objective of fast and stable control. Meanwhile, simulation comparison was made to traditional PID controller on MATLAB and Simulink, and the result showed that the PID controller based on neural networks was faster in response and better in follow nature than the traditional PID controller was. Bojan, et al. 2011 [34] worked on finding solution for strong jerk occurs when electric elevator starts and stops via with a vector-controlled induction motor, control of a real gear-less electric elevator drive is possible. through The need to adjust the jerk was determined the trajectory of the position. Controller was made in the Malta/Simulink and showed that controller design meets the requirements completely. Smooth, accurate positioning, speed control, specific shape, and jerk value were achieved, thus obtaining a less torque stroke and a lower tracking error. Electromagnetic torque has a lower effect on mechanical systems due to its lower peak values and smooth form resonance sustainable oscillations, and it was tested through computer simulations.

Dursun and Fenercioğlu 2011 [35] The response of a fuzzy logic speed driven double-sided LSRM
with 12/8 pole, 3 step, 85V, 900 W power was simulated, the motor's PI and fuzzy logic velocity responses were compared. The friction in this system was reduced, as were the losses resulting from gear box power transfer, and the expense was reduced by eliminating the power transfer elements that were being used in excess. As a result, the motor was determined to be useful for high such as elevator load. On the other hand, because of their low cost and high quality, Fast rate force/volume, high starting force, precise position control, and quick response were also requested.

Rashid, et al. 2011 [36] For a four-car system, a fuzzy logic-based controller was used. elevator with a DC Geared motor was illustrated. A collection of fuzzy rules was also developed based on realistic considerations, with the goal of reducing energy used and waiting time. When a system was very complex due to a stochastic setting of traffic pattern, a fuzzy logic controller (FL) was used for analysis and design to make an approximate model. This research's experimental and simulation studies showed that the controller's efficiency in reducing energy used and waiting time was superior to the current device. Using instead of a microcontroller, a high-speed DSP board will optimize device efficiency.

Jung, et al. 2012 [37] A nine-phase PMSM drive device based on multiple voltage source inverters with three phases was presented. An ultrahigh-speed elevator's traction motor was developed using the nine-phase PMSM. The motor's mathematical model was simplified due to the symmetry of the structure. The drive system can be regulated using the simplified model and the d-q control theory. A traditional three-phase current control algorithm could be used to control the motor. Experimental results verified the validity that implementation of the simplified model and the motor's control mechanism. The results obtained while operating an elevator in an elevator test tower from the first to the 47th floor were presented in order to illustrate the drive system. The process was also fault-tolerant was also checked to see if the system's reliability had improved. It was concluded that the designed system and its controller were found to be efficient and reliable in terms of ensuring the elevators' desired operation.

Branko and Knežević 2012 [4] mentioned an electric elevator drive efficiency optimization algorithm. The elevator model included parameters from a real elevator with an induction motor drive (IMD). In Matlab/Simulink, the entire system was simulated with the designed performance optimization algorithm. Provided a substantial reduction in power loss, hybrid approach for performance optimization for a light load. It also has good dynamic efficiency with no loss of precision in the elevator car's location and
velocity. Although the elevator drive was implemented as a vector-controlled IMD, a similar performance optimization algorithm may be used for other types of elevator drives, such as PMSM drives, etc. A similar efficiency optimization algorithm can also be implemented to other control techniques in IMD, such as Direct Torque Control (DTC). Ford 2012 [5] implemented an elevator’s position-controlled electric drive. This work focused on expanding the addition of digital control systems and switching power supplies has increased the efficiency of electric drives, determining the parameters of a permanent-magnet DC motor, and designing a control system to guide the motor in the desired direction, as well as using computer simulations and experimental testing to test the system's performance. Before starting the design procedures for developing a cascaded control system, the tests to derive the motor parameters, as well as the principle behind the tests, were widely discussed. The use of a DC motor with a permanent magnet and position control to power an elevator was a success, and it worked as an example for those trying to use electric drives in a variety of mechanical systems.

Figure 9: Feedback control system of DC motor [5].

Kei, et al. 2012 [38] built a motion pattern generator for vertical elevator movements. A Standard S-Curve pattern generator was proposed to be used on a microcontroller-based device to enhance landing place accuracy. Changing the acceleration and jerk settings on an algorithm pattern allowed it to be easily optimized for different needs. The design provided very good performance and tracing ability to resist disturbance, as well as an increase in landing accuracy, according to both simulation and experiment results.

Figure 10: The elevator movement’s S-curve speed pattern [38]

Kim 2012 [19] suggested improving the problems of drive control system of rope-less elevator driven with linear synchronous motor (LSM), when developing prior to commercialization of rope-less elevator. The research focused on the advanced controller for rope-less elevator drive based on disturbance observer and examined the problem of traditional PI controller via a speed control test. The study showed that drive control techniques produced satisfactory results. This research also found a slew of other problems that would need to be tackled in the future in order to be widely adopted, such as sensor, high-performance controller, precision structures, and safety devices, to name a few. Georgiev and
Mirchevski 2012 [39] The energy efficiency of electric drives for vertical transportation was investigated using a hoisting system, and a variable-speed drive system. A device consisting of a PMSM as a three-phase Variable Voltage hoisting machine was modern elevator drives' most common solution, as an energy converter, an intermediate DC link was used with a Variable Frequency (VVF) converter. On a device like this, a series of energy consumption measurements were performed and analyzed. The value of in dynamic regimes, variable speed drives were being used to decrease electrical losses with the aid of power converters, as well as their effect on increasing distortion energy consumption, were both addressed. The total system's active reactive energy consumption and distortion energy were evaluated.

Hasan, et al. 2012 [40] presented an elevator energy saving algorithm that manipulates the system's speed and acceleration depending on the load and number of levels to be shifted. Furthermore, the algorithm produces a significant reduction in travel time as a result of such an optimal change in the speed value, resulting in improved efficiency with minimal energy consumption. The algorithm was put to the test under varied traffic conditions, with the results compared. Constant-speed elevators have been shown to reduce energy consumption and travel time significantly.

Mohammed and Shuraiji 2013 [13] presented new type of gear traction machine drive system with a permanent-magnet (PM) DC motor for mid-rise and mid-speed elevators. Some techniques were proposed to improve the elevator drive such as adding Trap filter to improve the drive performance. DC bus voltage management, Power flow in both directions and a controllable power factor with low input current harmonics were achieved using a 3-phase voltage-fed PWM rectifier. As a result, the PWM rectifier is an attractive choice for applications for mid-speed elevators. The application of the PMDC motor enabled many enhancements including the higher efficiency, the minimum jerk, and the greatest ride comfort.

Branko and Knežević 2013 [41] proposed an algorithm for improving elevator drive performance with controlled jerk. Theoretical study of power losses in elevator drives with induction motors and algorithm for parameter recognition in the loss model were presented based on Moore-Penrose pseudo inversion was presented. The elevator model included parameters from a real elevator with a drive. According to the findings of the theoretical study and simulations, the result showed that at a light load, the proposed approach for efficiency optimization resulted in a significant reduction in power loss and good dynamic performances without affecting elevator car location accuracy.

Shreelakshmi and Agarwal 2014 [6] worked on smoothening the speed profile in elevator systems to ensure comfort with a pre-defined non-instant jerk pattern. For the minimization of steady state losses, an optimized value of the torque generating portion of current (i.e. ids) was used. The proposed jerk pattern helps in smoothing the speed profile without increasing the travel time. The use of optimized ids values in the speed control loop also decreased steady state losses, the efficiency of the elevator system was improved by reducing steady state losses in the induction motor. MATLAB/Simulink was used to simulate the system. The proposed system provided improved ride quality and lower steady-state losses.
Mohaney, et al. 2015 [42] presented a novel and optimal elevator system modeling to achieve excellence in energy efficiency and low cost operation of elevators. In group elevator control, traffic control and time management have been major elements. Soft computing mechanisms were used to try to improve this situation. For optimal choice, an ANN and Fuzzy logic comparison was performed, and the proposed algorithm and hence program written in the Matlab environment for designing an economical and efficient elevator system were developed, with excellent results, capable of absolutely modeling any middle-level elevator. EGCS used soft computing techniques to solve the problem of traffic in high-rise commercial buildings, especially during peak hours. CRĂCIUN, et al. 2015 [34] presented a comparison of evolution of elevator kinematic Decelerating with constant speed decreased the peak value of acceleration, as shown in both cases of speed modeling, as well as the jerk's peak value. The transactional of the functioning cycle was also decrease. Since the constant speed step has been eliminated, there are less changes in acceleration and jerk during the deceleration period. As a result, the passengers in the elevator's cabin would be more comfortable. Lesser values of the inertia forces in that device result in a smoother variation of acceleration.; As a result, the mechanical components will be under less stressed. Deceleration using an asymmetrical S curve was also investigated in order to insure precision at cabin floor alignment.

A dynamic elevator installation model was presented by Esteban, et al. 2016 [44] for a PMSM controlled by a field oriented control regulator in the state space domain. The model included subsystems, both mechanical and electrical, as well as an a closed-loop system and an electrical machine field focused control to estimate key performance indicators for ride efficiency. Using a Kalman observer, you can achieve the necessary accuracy in an industrial application. It was estimated the friction forces. And the acceleration estimation could be improved. As an observer, only the regulator signals are used. inputs would allow for Adaptive additional challenges, such as active vibration control, will be implemented in the future had suggested a two-loop cascade controller to achieve smooth performance for elevators with linear induction motors.

To control the force ripple produced in elevator driven by linear switched reluctance motors (LSRMs), a new control model based on a minimum jerk model was proposed by Masoudi et al. 2016 [45]. This method works by controlling location, phase current, speed, and force in real time was applied on double sided four phase LSRM. In order to realize a good elevator motion quality, a speed profile was proposed based on a minimum jerk model. Also A new force distribution function is proposed that can distribute total force properly among the phases and considerably decrease the undesirable ripples of output force. Modeling and experimental findings in the elevator industry have been used to demonstrate performance.

A bidirectional Buck-Boost converter with active regenerative braking was installed to increase the overall performance of a modern building elevator by Xun, et al. 2016 [46]. The converter was wired in series with the inverter's DC bus. During regeneration, energy was stored in a series of super capacitors. As the elevator accelerated, it was transferred back to the DC-bus. A storage device control strategy using super capacitors was proposed. To ensure the correctness of the method used, the elevator system's simulation model has been developed. The results of the simulation show that the control
strategy, in traction elevators, it is possible to achieve regenerative energy recycling and reuse, which that
The study of energy-saving elevators is extremely important.

Abdelhameed 2016 [47] had suggested using a two-loop cascade controller and an S-curved speed
trajectory to get smooth output from a linear motor-driven elevator and to allow it to drive predetermined
position and speed trajectories at the same time. To control the elevator positioning and create a mover speed
trajectory, the cascade controller was modeled as a traditional PI controller and added to the external
control loop, where another PI controller was used to regulate the mover speed in the inner control loop.
Numerical simulations were used to verify the proposed scheme’s results. In addition, this analysis
included a comparison with the output obtained using the PID controller. As a result, the proposed
control system has met all of the system’s requirements. Knezevic, et al. 2017 [48] proposed a
synergistic solution based on jerk control and a band-stop filter upgrade to the speed controller, tuned
based on Gentzel algorithm and Kiefer, to regain lost ride comfort and speed control as a result of
vibration, for elevator mechatronic system (EMS). A unique generalized model was proposed to produce
the speed reference trajectory, which can be characterized by different shapes and amplitudes of jerk. The
proposed algorithm was implemented on a digital signal processor and implemented into the power drive
control algorithm. The proposed anti-resonant and jerk free control scheme for the EMS was a flexible
and effective solution applicable on all EMS types without modifications to the hardware. Only the
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time, the PDF controller had the best overall performance, disturbance rejection, parameter sensitivity, and control of the target velocity signal are all variables to consider. In addition, when compared to the PID controller, the PDF controller's architecture made for much easier tuning. Shreelakshmi and Agarwal 2017 [50] presented a new Loss minimization technique for elevators with induction motors (IMDES) to determine the most energy efficient velocity pattern. The total power losses in an induction motor are calculated using a differential equation to its rotor speed works as the objective function. The constraints were set in terms of speed and acceleration, which were based on passenger comfort. Since the speed and acceleration were state variables, the most optimum trajectory was determined by forming a suitable Hamiltonian function using Pontryagin's Minimum Principle. A combination of speed trajectory optimization and flux optimization techniques was proposed as the proposed technique. It will become more important and useful in the coming years as the need to efficiently use electric energy becomes increasingly crucial. Santo, et al. 2018 [51] A three-degree-of-freedom vertical transportation model with guide rail deformations was investigated for its horizontal dynamic nonlinear response. To improve passenger comfort, a state-dependent Ricatti Equation (SDRE)-based control strategy was proposed. To investigate the nonlinear behavior of the mathematical model used, numerical simulations were run. In addition, they used parametric errors and noise to measure the SDRE control technique's robustness. The SDRE control can protect the elevator component's integrity. It was possible to see that the magnitude of the acceleration was decreased, suggesting an improvement in passenger comfort during the elevator's motion. Arafà, et al. 2018 [52] A detailed implementation of a direct torque driven induction motor drive for elevator applications was presented. Elevators were distinguished with a need to develop torque at zero speed when the brake was released and with a need to operate at very low speed during acceleration and deceleration intervals of the traction cycle. These requirements cannot be compromised. Therefore, applying sensor-less techniques in elevator applications are quite challenging as most of these techniques exhibit low performance at zero and low speeds. Consequently, the majority of high-performance elevator drives were still equipped with speed sensors to maintain high performance under these conditions. The drive was controlled using the well-known space vector modulated direct control system (SVM-DTC). As the elevator drives were usually equipped with speed sensors, DTC equipped with speed sensor has a quite simple structure and it can offer high dynamic performance in terms of torque response time and speed tracking accuracy. MATLAB/SIMULINK was used to test the drive's performance and fine-tune the controller's parameters. The results show that the system operates well in both transient and steady-state environments.

Figure 15: SVM-DTC control scheme of SCIM [52].

Qin, et al. 2018 [53] had developed a 51-series chip-based elevator drive control, with an ideal speed curve in elevator operation. The transmission control mode of the system was selected to be VVVF technology. Changing the traction motor power supply's frequency and voltage, Sinusoidal pulse width modulation and single-chip microcomputer control technology (SPWM) technology were used. By comparing the deviation between the speed sensor's feedback value and the preset speed value, the microcomputer adjusts the elevator's speed and state. Changes in the parameters of the SPWM wave
were used to control the elevator's speed. The design offers cost savings, a machine structure that is smaller and simple to implement, control that is more easy and flexible, and a simpler, more stable, and more reliable system.

Because of the PMSM's high dynamic response and the elevator speed controller's limited bandwidth, if rotor flux linkage or station (static friction), or both, differ from predetermined values, traditional starting jerk control schemes result in increased starting jerk and increased starting energy. Further, since elevator systems have a low mechanical resonance frequency, classical disturbance observers (DOB) cannot have a large bandwidth, reducing their disturbance rejection capability. Due to the changing dynamics of friction and the dynamics of estimating rotor flux linkage at very low speeds, higher order and non-linear DOBs/controllers are difficult to design. A novel disturbance observer was suggested to deal with these issues by Rangarajan and Agarwal 2019 [54]. During start, this controls the speed of the stator flux connection rather than torque/current. The simulation results from MATLAB/SIMULINK supported the control scheme.

So and Chan 2020 [55] In the lift industry, a new direct torque control system had been introduced. The results in terms of start-up speed accuracy and rated speed activity, the consumption of power and energy had been investigated. Direct speed control, which uses less difficult circuitry and allows for more natural speed control, has been suggested, due to the lack of a proportional–integral controller, there is often a small steady-state error. Continuous integration is often used in successful direct torque (force) control to estimate magnetic fluxes, that will not apply to a saliency permanent magnet synchronous unit. In addition, a new idea for measuring magnetic flux linkages in real time was proposed. It should be noted that at this time, field-oriented control is superior. Direct force control and direct speed control can one day be more suitable for linear permanent magnet synchronous machine applications as technology advances.

The last update in this field was introduced by Othman et al.2021[56]. The researchers proposed a smooth transition pattern based on a minimum jerk profile to minimize the impact of this ripple on the elevator performance. The elevator cabin speed is controlled via a VFD, offline programmed with the best V/f pattern to get the best speed curve profile in order to get a smooth start and smooth stop for the elevator cabin and constant travel speed through the elevator floors with the least jerk possible. A three-floor elevator prototype driven by a locally designed and manufactured PMSLM to lift a 24kg payload. The result showed that using the driver leads to reduce the jerk by about 88% compared the that without using the driver. The proposed model achieved convincing results in terms of system control, responsiveness, speed, and smooth and comfortable transition between floors.

3. A Comparative Study:

Tables (1) – (5) below shows most important differences between previous studies in terms of efficiency, jerk, vibration, used speed control techniques, and system response:

| Authors | Algorithm used |
|---------|----------------|
| Branko & Knežević 2012 [4] | described an efficiency optimization algorithm for electric elevator drive. |
| Branko and Knežević 2013 [41] | had proposed an algorithm to get the efficiency optimization with a significant power loss reduction. |
| Shreelakshmi & Agarwal 2014 [6] | the efficiency was improved through minimization of steady state induction motor losses. |
| Xun, et al. 2016 [46]. | To improve overall performance, a bidirectional Buck-Boost converter was used to implement an active regenerative braking converter. |
| Chung, et al. 2001 [28] | They proposed a new type of gearless traction machine drive system that is standardized for high-speed elevators with a permanent magnet (PM). |
motor to improve performance.

Mohaney, et al. 2015 [42] Using soft computational modeling such as artificial neural networks (ANN) and fuzzy logic to achieve excellence in energy efficient

Table 2: Jerk control

| Authors | Control technique |
|---------|-------------------|
| Li, et al. 2007 [29] | Used a TI DSP controller to smooth the acceleration profile which results in a smoother jerk profile |
| Bojan, et al. 2011 [34] | A real electric elevator drive with no gears was controlled with an induction motor controlled by a vector to find solution for strong jerk occurring. |
| Kei, et al. 2012 [38] | A popular S-curve pattern generator has been proposed for use on microcontroller-based systems to improve landing accuracy position. An algorithm pattern was By modifying the acceleration and jerk controls, the match can be easily customized to meet a variety of needs. |
| Kei, et al. 2012 [38] | designed an S-curve algorithm such as a pattern generator specifically developed for use with microcontroller-based systems by changing the acceleration and jerk setting to improve landing accuracy position |
| Mohammed & Shuraiji 2013 [13] | presented drive system for a new type of gear traction machine with a PMDC motor to reduce the jerk to minimum value and get the greatest ride comfort. |
| Shreelakshmi & Agarwal 2014 [6] | worked on smoothening the speed profile in elevator systems to ensure comfort with a pre-defined non-instant jerk pattern. |
| Abdelhameed 2016 [47] | The cascade controller was designed as a standard PI controller and applied to the external The elevator's position was controlled by a control loop and generate a mover speed trajectory |
| Knezevic, et al. 2017 [48] | a synergistic solution based on jerk control was proposed and a band-stop filter upgrade to the speed controller, tuned based on Gentzel algorithm and Kiefer to regain speed control and lost ride comfort as a form of vibration in elevator mechatronic system. |
| Othman et al. 2021[56]. | proposed a smooth transition pattern based on a minimum jerk profile to minimize the impact of this ripple on the elevator performance, by using VFD driver. |

Table 3: Vibration control strategy

| Authors | Control technique |
|---------|-------------------|
| Min Lee, et al. 1999 [25]. | proposed a new vertical vibration management technique based on car acceleration feedback control for enhancing elevator ride efficiency. |
| Li, et al. 2007 [29] | used a new motion profile generation approach to smooth the acceleration profile, resulting in a smoother jerk profile without any abrupt corner to reduce vibration in the elevators by a TI DSP controller. |
| Esteban, et al. 2016 [44] | had proposed two-loop cascade controllers to obtain smooth performance for elevator combined with a LIM to control vibration in the future |
| Knezevic, et al. 2017 [48] | proposed a synergistic solution based on the jerk control and the upgrade of the speed controller with a band-stop filter to restore lost ride comfort and speed control caused by vibration. |
Table 4: Speed control technology

| Authors                   | Control technique                                                                 |
|---------------------------|------------------------------------------------------------------------------------|
| Min Lee, et al. 1999 [25] | The proposed method employed An acceleration feedback controller is included in the speed controller. |
| Al-Sharif, et al. 2001 [27]| used dc VFDs in lift systems to profile the speed curve to achieve a smooth journey.     |
| Lim et al. 2005 [18]      | used the LSRM with the FDF for speed and position control.                         |
| Yu, et al 2007 [31]       | proposed a fuzzy logic controller (FLC) to drive a PMSM to improve the speed control |
| Lim & Krishnan 2007 [32]  | A trapezoidal velocity profile was presented and implemented on a prototype to smoothly control the position while moving and stopping, as well as position feedback control loops to force control via PI controller. |
| Yajun, et al. 2008 [2]    | The MCU was employed to control By transmitting pulse signals to the stepper motor's drive with chip L298 you can control its speed and direction. |
| Li, et al. 2010 [33]      | used PID controller based on neural networks to access the goal of rapid and stable control. |
| Abdelhameed 2016 [47]    | A PI-PI algorithm based controller was used for tracking position and concurrent speed. To regulate the mover speed, another PI controller was introduced to the inner control loop. |
| Masoudi et al. 2016 [45] | A new control model based on a minimum jerk model was proposed. This system requires real-time control of position, speed, phase current, and force was applied on double sided four phase LSRM. |
| Knezevic, et al. 2017 [48]| The original method for band-stop filter tuning based on Gentzel algorithm and Kiefer was used to recover lost ride comfort and speed control as a result of vibration. |
| Mangera, et al. 2017 [49] | The use of a Pseudo Derivative Feedback (PDF) controller resulted in the best overall output in terms of rise time, elevator run time, settling time, sensitivity to parameter changes, disturbance rejection, and control of the desired velocity signal. |
|anto, et al. 2018 [53]    | The State Dependent Ricatti Equation (SDRE) was used to propose a control strategy, to improve the passenger comfort. |
| Rangarajan & Agarwal 2019[54]| A novel disturbance observer was proposed During start, this briefly controls the speed of the stator flux connection rather than torque/current. |

Table 5: Control technique used and system response

| Authors                 | Control technique                                                                 | Effectiveness                                                                 |
|-------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Rajaraman & Nagaraja 1984 [21]| using a novel digital speed-reference circuit that generates the speed pattern directly as a function of the elevator car location using programmable memory | achieve accurate floor level and a smooth deceleration.                        |
| Tanahashi 1997 [23]    | used a dynamic braking to control the elevator drive                               | A synchronous motor maintains its rated speed and accelerates the elevator in a sufficient margin. |
| Mutoh, et al. 1998 [24]| Studied an induction motor driving controller                                     | It can suppress vertical vibrations of elevators while performing energy saving control. |
| Kang and Sul 2000 [26] | For improved riding, proposed a vibration suppression method, comfort of an elevator driven by induction motor using car acceleration feedback compensation | To improve the riding comfort of an elevator driven by induction motor          |
| Al-Sharif, et al. 2001 [27]| Used dc VFDs in lift systems                                                       | This system achieved excellent standards of riding comfort and good stopping accuracy |
| Author(s) | Year | Description |
|-----------|------|-------------|
| Chung, et al. | 2001 | A voltage-fed 3-phase pulse PWM rectifier to greater comfort and higher efficiency |
| Lim et al. | 2005 | FDFs was proposed to speed and position control. |
| Li, et al. | 2007 | Used a TI DSP controller to smooth the acceleration profile which results in a smoother jerk profile |
| Lim | 2007 | A velocity profile with a trapezoidal shape was introduced during the descent and stopping of the elevator, smoothly controlling vertical travel position |
| Yu, et al. | 2007 | Proposed a fuzzy logic controller to improve the speed control |
| Lim and Krishnan | 2007 | PI controllers are used to control the position smoothly during moving and stopping |
| Bojan, et al. | 2008 | The electric elevator drive with no gears was controlled with an induction motor controlled by a vector to minimize the strong jerk |
| Jung, et al. | 2012 | The model mainly included MCU control module. The elevator was During acceleration and deceleration, the drive is smooth. |
| Branko & Knežević | 2012 | Designed an S-curve algorithm such as a pattern generator designed specifically for use with microcontroller-based systems by changing the acceleration and jerk setting |
| Kei, et al. | 2012 | To improve landing accuracy position |
| Kim | 2012 | Conventional PI controller through the speed control showed that drive control techniques achieved satisfactory results. |
| Georgiev &Mirchevski | 2012 | A VVVF converter was used with an intermediate Dc link and an encoder or resolver. To reduce electrical losses by help of power converters as well as their influence to increase the distortion energy consumption. |
| Hasan, et al. | 2012 | He introduced an algorithm that aims to conserve energy. It results in a decrease in energy usage and travel time of a large magnitude. |
| Shreelakshmi and Agarwal | 2014 | Worked on smoothening the speed profile in elevator systems to ensure comfort with a pre-defined non-instant jerk pattern. Proposed system providing an improved ride quality and lower steady-state losses. |
| Mohaney, et al. | 2015 | used soft computing techniques. It achieved at operating elevators in an energy-efficient and low-cost way. |
| CRĂCIUN, et al. | 2015 | Presented a comparison of evolution of elevator kinematic. As a result, the passengers in the elevator's cabin will feel more comfortable. |
| Esteban, et al. | 2016 | A PMSM controlled by a field oriented control regulator to obtain smooth performance for elevator. |
| Masoudi et al. | 2016 | A new control model based on a minimum jerk model was proposed. Depending on instantaneous control of position, phase current, speed, and force, the model was applied on double sided four phase LSRM. In order to realize a good elevator motion quality. |
| Xun, et al. | 2016 | A bidirectional Buck-Boost converter was used to implement an active The simulation results show that the control strategy would allow traction elevators to... |
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regenerative braking converter. recycle and reuse their regenerative energy.

Abdelhameed 2016 [47] Suggested applying an S-curved speed trajectory and two-loop cascade controllers were used. The proposed scheme's performance was measured using numerical simulations.

Mangera, et al. 2017 [49] using PDF controller When compared to the PID controller, the PDF controller architecture made for much easier tuning.

Arafa, et al. 2018 [52] The drive was controlled according to the well-known SVM-DTC scheme It can offer high dynamic performance in terms of torque response time and speed tracking accuracy

Qin, et al. 2018 [53] A single-chip microcomputer control technology and SPWM technology was used. Changes in the parameters of the SPWM wave were used to control the elevator's speed.

Rangarajan and Agarwal 2019 [54], A novel disturbance observer was suggested Because of the PMSM's high dynamic response and the elevator speed controller's limited bandwidth

So and Chan 2020 [55] a new direct torque control system had been introduced. investigated Direct speed control, which uses less difficult circuitry and allows for more natural speed control

Othmanet, et al. 2021[56]. Using VFD with best V/F pattern to control the speed of motor The proposed model achieved convincing results in terms of system control, responsiveness, speed, and smooth and comfortable transition between floors

4. Conclusions
In this paper, an overview has been introduced of using and application of variable speed drives in electric elevator systems, discussing both present systems and recent developments in the elevator field. Therefore, a required variable-speed design providing a smooth movement is required to get good ride comfort, good leveling accuracy, and a large number of start and stop operations. Some general concepts are discussed in in driving systems first, including load curves and driving speed/torque and their relationship to system stability; reference curve generation; speed curve profiling of the elevator system to achieve smooth transmission. A number of driving systems such as DC-SCR motor, Ward-Leonard DC motor, variable voltage, variable voltage variable frequency VVVF, etc. are discussed and analyzed that determine the relative advantages and disadvantages. A comprehensive comparison has been made for all previous studies presented in terms of elevator performance, response speed, vibration and jerk ratio, system stability, and efficiency. The latest study reached the manufacture of an elevator prototype driven by PMSLM loaded by 24kg.

The motor was controlled by VFD to get a smooth start and smooth stop for the elevator cabin and constant travel speed with the least jerk possible estimated about 88% compared the that without using the driver. It is preferable to the latest work on the application an online smart design of S-curve profile under any condition of load variation or any electrical or mechanical disturbance may happen in the system.

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