# VFD Filters and Accessories for the Elevator Application

A review of methods to mitigate harmonic distortion in elevator systems

*by Eric Danner and KEB America*

## VFD Basics

Today, six-pulse Variable Frequency Drives (VFDs) are commonly used in traction elevator applications due to their reliability, premium ride quality, energy efficiency and cost effectiveness. Modern VFDs are designed with three main sections: the input rectifiers, DC bus capacitors and output Insulated-Gate Bipolar Transistors (IGBTs). The input rectifier stage takes the mainline Alternating Current (AC) three-phase power and rectifies it into Direct Current (DC) power. The input rectifiers on a VFD allow the current to pass through in one only direction, creating the DC bus. The DC bus consists of the rectified DC power in a large bank of capacitors.

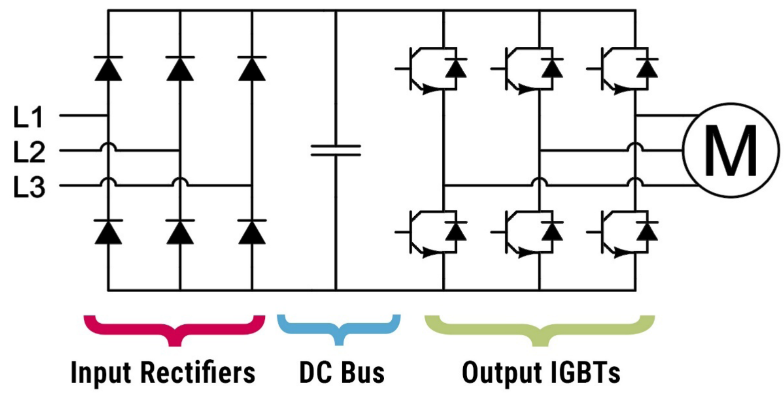


Figure 1: Basic topography of a six-pulse VFD

The voltage in the DC bus is approximately 1.41 x the AC line voltage. The input rectifier stage is passive, meaning if ripple occurs on the mainline, the DC bus will directly reflect these voltage disturbances. The capacitors in the DC bus help to filter this ripple and act as a reserve to power the motor. The third stage of a modern VFD is the output IGBTs. The output IGBTs turn on and off at very high frequencies (Typically 8- to 16- kHz for the elevator application) controlling the DC bus voltage to the motor. Output IGBTs can only be on or off. The modulation of the DC bus voltage by the VFD at controlled frequencies and magnitudes is called Pulse Width Modulation (PWM) and allows the VFD to output DC power in an emulated three-phase AC voltage sine wave that controls the speed and torque of the motor. The output IGBTs are bi-directional, meaning that current can flow in both directions from the DC bus. Current can flow to the motor while under load or back to the DC bus while the motor is in a regen state. PWM is the principle that allows VFDs to be used in the elevator application.

## VFDs Create Noise

Although PWM allows elevators to achieve premium ride quality, high efficiency and easier commissioning, the design inherently creates harmonic distortion. Harmonic distortion is caused by the VFDs six-pulse rectifiers when sending current to the motor. This is due to the

### Learning Objectives

After reading this article, you should know:

- ♦ The basics/three main parts of a six-pulse VFD
- ♦ The cause of harmonic distortion and which harmonic orders cause the most significant harmonics in elevator applications
- ♦ The multiple methods used to mitigate harmonic distortion and prolong the lifespan of equipment in the electrical and elevator system
- ♦ The cost versus performance of the system to determine the best method for the application at hand
- ♦ The difference between TDD and THDi, their uses and which is better for describing harmonic distortion over time in an elevator system

### Value:
### 1 contact hour (0.1 CEU)

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VFD powering the elevator motor having a non-linear load. Non-linear loads impedance and current draw changes during its AC electrical cycle. Examples of a non-linear load include elevator VFDs, computers, LED lights and televisions.

These devices differ from linear loads which have a steady impedance and draw a nearly perfect sinusoidal current from their voltage source. Examples of linear loads include resistors, inductors, capacitors or an AC induction motor operating at steady state operation from the AC mainline. The non-linear load input rectifier stage of a VFD draws non-sinusoidal current from the power supply. This irregular current draw results in harmonics of the fundamental frequency (e.g. 50 or 60 Hz), which acts on the systems impedances within a building electrical supply. A six-pulse VFD draws current harmonics at the fifth, seventh, 11th, 13th, etc., orders.

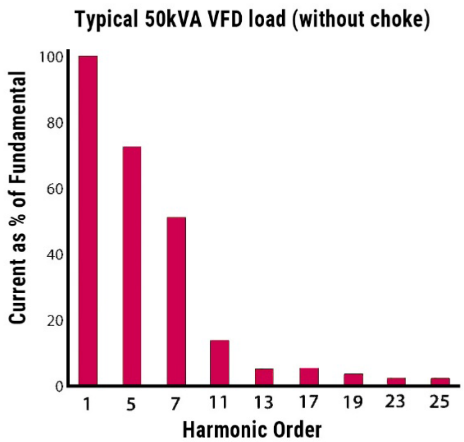


Figure 2: Current harmonics of a six-pulse VFD

Each harmonic current is a specific frequency *n* times the line frequency and has a magnitude dependent on load. For example, the first harmonic, also known as the fundamental frequency, will have a frequency of 60 Hz; the second harmonic will have a frequency of 120 Hz; the third 180 Hz; etc.

| Harmonic (*n*) | Frequency (Hz) |
|---|---|
| 0 | 0 (DC) |
| First (fundamental) | 60 |
| Second | 120 |
| Third | 180 |
| Fifth | 300 |
| ... | ... |
| 40th | 2,400 |

Figure 3: Harmonic orders and their corresponding frequency

The most significant harmonics in the elevator application occur at the fifth and seventh orders. As the order of the harmonics increases, the magnitude decreases. Higher current harmonics result in a greater Root-Mean-Square (RMS) current draw from the electrical system. When a system draws a significant amount of current harmonics relative to the power supply, voltage distortion on the supply occurs. This distortion, when significant enough, can cause other equipment on the same power system to malfunction and cause increased heating of the electrical components leading to earlier failure.

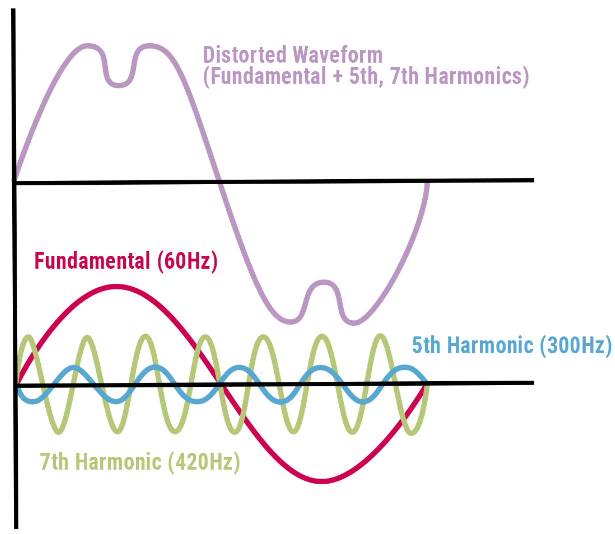


Figure 4: Depicts how adding the fifth and seventh harmonic to the fundamental frequency causes voltage distortion

## THDi vs. TDD

Harmonic distortion can be measured and is referred to as the Total Harmonic Distortion (THDi). THDi is the instantaneous ratio of the RMS value of the harmonics including distortion compared to the RMS value of the fundamental frequency, expressed as a percent. Since THDi is an instantaneous measurement, it will change with different elevator loading scenarios, making THDi more relevant for component manufacturers while sizing equipment to a rated current level.

For the elevator application, Total Demand Distortion (TDD) can be a more accurate representation of the electrical distortion in a system. TDD is the total RMS harmonic current distortion, in percent of the maximum demand load current (15- or 30- minute demand). Since TDD is a time-dependent average, it creates a more accurate description of the current harmonics affecting an elevator system.

The Institute of Electrical and Electronics Engineers (IEEE) 519-2022 sets the standards for building power systems total distortion at 8.0% THD at the point of common coupling (PCC). The PCC is the location where the utility companies' electrical system and the consumers' systems come together. For contractors in the elevator application, the PCC is often considered to be the mainline disconnect for the elevator controller, as the building's power is typically inaccessible to the elevator contractor. The theory is that, if the disconnect before the controller meets IEEE 519-2022, the elevator system cannot put the rest of the buildings power system out of compliance. If these standards are not met when specified, facilities often face penalties or connection limits from the utilities.

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## Power Factor

Another metric to consider in the elevator application is the power factor. The power factor represents the ratio between the power being put into useful work (active power) at the fundamental frequency and the total electrical power being transferred. A power factor of 1.00 is desired and indicates that all power being transferred is being consumed by the load. When significant harmonics are affecting the system, the power factor can quickly erode. When the power factor is very low in a system, oversizing electrical components is required to accommodate the reactive or harmonic non-useful power.

## 3% or 5% Line Choke

A 3% or 5% line choke or reactor is often the first and most cost-efficient way to reduce a VFD's harmonic distortion. The line choke is placed at the drives input and is recommended for all VFD applications. A passive line choke can reduce the THDi from ~80% to ~40%. This reduction in THDi can prevent nuisance voltage faults and premature damage to the VFD's DC bus capacitors. The use of a line reactor can double the DC bus capacitor's lifetime in the VFD. If an isolation transformer is used, a line reactor is not required.

Figure 5: Photo of line choke

## Harmonic Filters

Harmonic filters are an excellent way to further reduce harmonic distortion in an electrical system. They are commonly used in applications where sensitive electronics are on the same power system such as hospitals, airports or data centers. Harmonic filters' passive design does not require separate electronics to control and can accomplish a THDi of 8% when sized appropriately, putting the system in compliance with IEEE 519-2022 guidelines. Their design accomplishes this using calculated inductors and capacitors that allow the current at the fundamental frequency to pass through, but block current at higher harmonic orders. The core windings inside the harmonic filter are made of high-quality steel laminations and are engineered for the application.

Filters are designed for both 230V and 480V voltage classes and optimized for the fundamental frequency, either 50Hz or 60Hz for European and North American applications. Since current can pass in both directions through the harmonic filter, it can also be used with regenerative VFDs.

Harmonic filters are placed at the input of the VFD or the regen if equipped and are sized to the input current of the application. Many harmonic filters feature a 150% current overload capacity for 60 s, which protects against voltage and temporary load spikes. Proper sizing is critical for their effectiveness, as under sizing a filter to the current of the application will result in oversaturated cores. The oversaturated cores reduce the effectiveness of the harmonic filters and will likely put their performance out of IEEE 519-2022 specifications.

Additional considerations when sizing a harmonic filter are their ventilation and cooling. As the current flows through the filter, the core begins to heat up. If too much current overloads the core, it will become saturated, increasing its resistance and reducing its performance dramatically. It is critical that harmonic filters have the proper ventilation clearances and external airflow. On larger-sized harmonic filters, fans are incorporated into their design. For larger current applications, NEMA 1 enclosures are offered for more cost and space efficiency, allowing them to be installed outside of the controller panel. In these applications, multiple harmonic filters can be wired in parallel to accommodate the rated current.

When adequately sized and properly ventilated, harmonic filters can achieve a power factor of 0.99 to 1.00 and a THDi of 8% at rated load. Harmonic filters also protect the VFD and regen from line side disturbances or voltage transients. This reduces the temperature of the electrical components inside the VFD and extends the lifespan of the VFD. Studies show that the lifespan of the DC bus capacitors inside a VFD can be increased by 300% when a harmonic filter is used. When used with controllers whose required voltage matches the mainline, an isolation transformer is not needed as the harmonic performance of the filter greatly exceeds the isolation transformers. This can provide cost savings, as the harmonic filter is typically much less expensive than the isolation transformer.

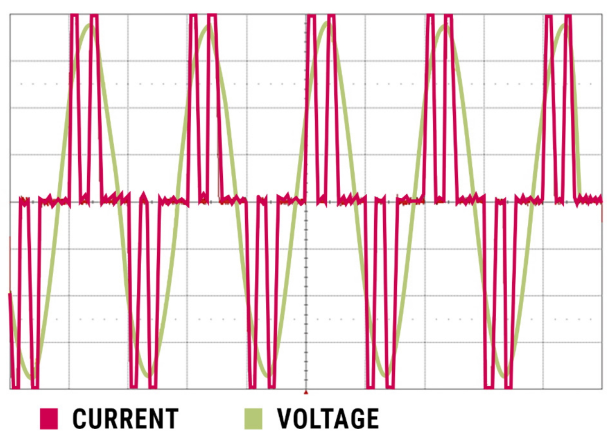



Figure 6: Voltage and current at the mainline without a line choke or harmonic filter

Figure 6 shows the voltage and current of an elevator mainline without the use of a line choke or harmonic filter. The incoming current peaks at five to 10 times the RMS value, resulting in a high ripple current through the DC bus. This ripple current can reduce the torque output of the motor and be detrimental to ride quality. Figure 7 shows the same mainline with a harmonic filter installed. With the harmonic filter, the line-side current is sinusoidal, and the peak current amplitude is reduced to only 1.4 times the RMS value. The voltage on the DC bus is also flattened, resulting in the DC bus capacitors seeing nearly zero ripple current. The significant reduction of the DC bus ripple current can extend the lifespan of the capacitors by three or more times and results in more predictable torque and ride quality.

Figure 7 shows the same mainline with a harmonic filter installed. With the harmonic filter, the line-side current is sinusoidal, and the peak current amplitude is reduced to only 1.4 times the RMS value. The voltage on the DC bus is also flattened, resulting in the DC bus capacitors seeing nearly zero ripple current. The significant reduction of the DC bus ripple current can extend the lifespan of the capacitors by three or more times and results in more predictable torque and ride quality.

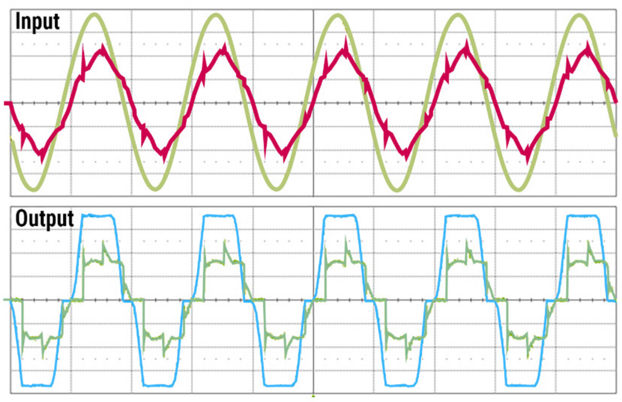



Figure 7: Voltage and current with the harmonic filter THDI<8%

## AIC

Harmonic filters are a cost-efficient solution to bring sensitive elevator applications into compliance with IEEE 519-2022 and prolong the lifespan of the system electronics. However, their passive design limits their THDi performance to their design's specific hardware components. If even higher harmonic performance is required, Active Infeed Converter (AIC) or Active Front End (AFE) technology may be utilized.

The AIC system provides the best harmonic performance and is comprised of two back-to-back VFDS. The first VFD synchronizes itself to the line voltage and actively rectifies the AC voltage into DC. This active rectifier stage uses an inductive capacitive filter to link to the AC line. The result is current flowing from the line in a nearly pure sine wave with low harmonic distortion; in many cases, it can be between 3-5% THDi. Using two sets of IGTBs inherently makes AIC technology regenerative. The power factor is regulated to a value of 1.00 at all load levels. Additionally, a high-quality Electromagnetic Interference (EMI) filter in front of the system is necessary, as the active rectifier creates a high level of common-mode EMI relative to earth ground. The second VFD functions as a motor drive and controls the motor, independent of the front-end stage.

Because the AIC uses PWM with a high-carrier frequency, the switching losses are higher compared to the block-style commutation of the regen unit. The PWM iron losses in the AIC filter are also higher compared to those in similarly sized harmonic filters. AIC systems can only be connected to a balanced three-phase wye, center-grounded electrical system; delta-connected systems are not permissible. Additionally, the phase voltages should be +/-5% with respect to each other. A transformer must be used in buildings having an older delta electrical system or if the phases are greatly unbalanced. An AIC exceeds the requirements of the IEEE 519 standard, but the added performance comes at a higher cost.

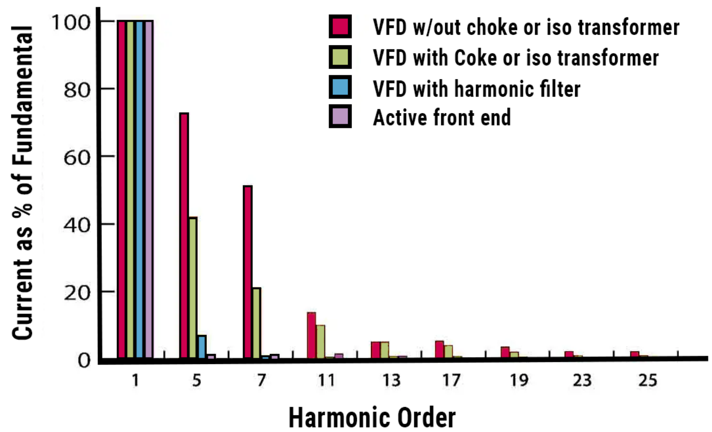



Figure 8: A comparison showing the percent of fundamental current at each harmonic order with various elevator VFD accessories

## EMI Filters

An EMI filter is a device installed before the input of the VFD. EMI Filters mitigate the effect of high-frequency electrical noise. EMI filters target high-frequency electrical noise (up to 30MHz), while harmonic filters address power harmonics at much lower frequencies. For the elevator application, which uses high output IGBT switching frequencies of 8kHz to 16kHz, heat builds up within the IGBTs.

When these high frequencies interact with stray capacitances in the electrical system, parasitic currents occur. These parasitic currents can disturb the power supply and other equipment on the same circuit while also increasing the temperature of the IGBTs within the drive unnecessarily. This extra heat is wasted energy and prematurely wears the VFD. The use of an EMI filter can reduce these parasitic currents, improving the longevity of the VFD and protecting other sensitive electronics within the connected power system. The EMI filter accomplishes this by draining the parasitic currents to the ground instead of conducting them back onto the supply current. For an EMI filter to work this way, proper grounding measures must be practiced. The earth ground is very important and provides a return path to drain the high-

Continued

frequency noise. In general, a low impedance path should be created, which allows the EMI noise to drain. For best grounding, the shortest possible ground is optimal. A flat braided ground strap is best as it provides a large surface area for connections and reduces impedance. Elevator applications without the use of an EMI filter and proper grounding can be susceptible to nuisance faults at the drive and controller.

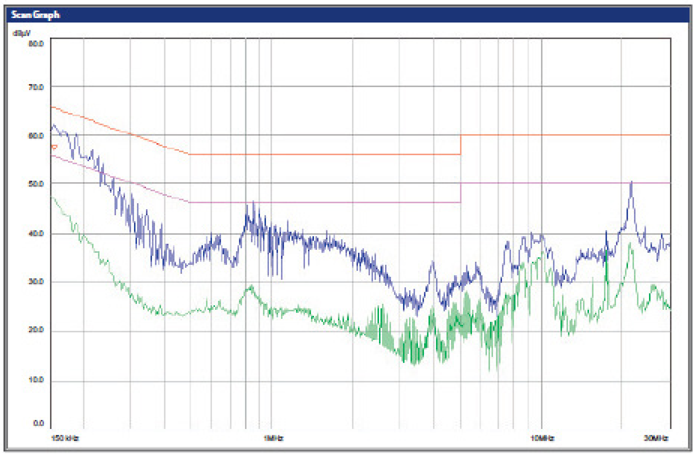



Figure 9: Noise reduction at high frequencies

## dV/dt Filters

On the output side of the VFD, electrical noise and distortion can occur, as well. A dV/dt choke is a passive inductor placed between the output of the VFD and the motor to mitigate these issues. When VFDs use PWM, the IGBTS in the drive turn on and off very quickly to control the speed and torque of the elevator motor. When the IGBT is closed, the voltage at the VFD output terminals rises to that of the drive's DC bus. The change in voltage is not instantaneous but actually ramps up to the DC bus level over a given time ($T_{rise}$). The rate at which the voltage increase is referred to as the dV/dt rise time and is a characteristic of the IGBT's design.

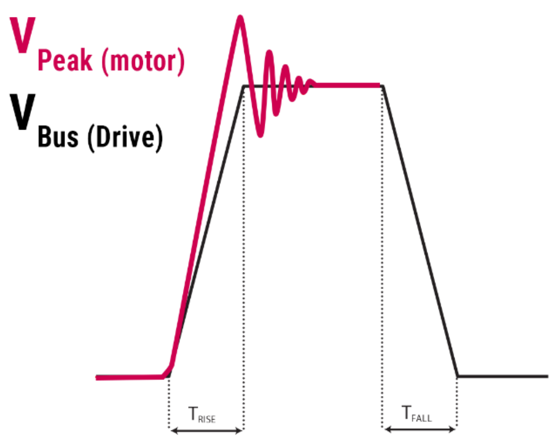
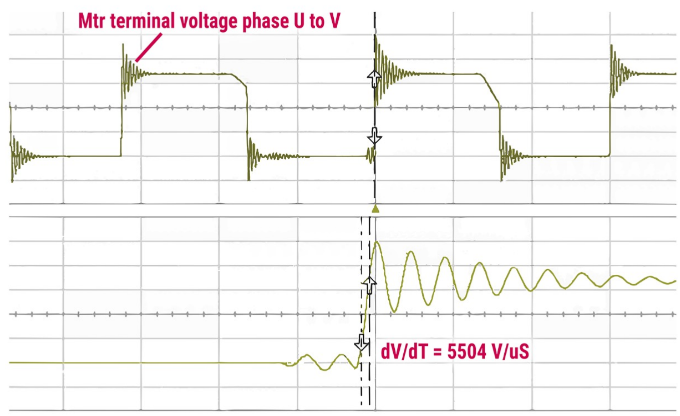



Figure 10: IGBT rise/fall time and peak motor voltage spike

In applications with long motor leads, the impedances in the motor leads can react with the PWM control from the VFD. The motor leads' impedances are determined by the length of the leads and their material. It is nearly impossible to match the impedances of the motor and motor leads. When the impedances between the motor leads and the motor do not match, the motor leads act as a transmission line and propagate the drive's output voltage to the motor. These wave reflections result in voltage overshoot at the motor while also sending a reflective wave back to the drive. If the reflected waves add to the fundamental waveform from the drive, the voltage delivered to the motor can dramatically increase. A dV/dt choke placed directly at the output of the VFD limits the rate of change of the voltage (dV/dt) to a level characteristic of the filter's design. The filter also reduces current ripples and rotor losses in the motor. Figure 11 shows a 480-V application with an idle DC bus of 675 V and 25-ft motor leads without the use of a dV/dt choke. The peak voltage received at the motor is 988 V. If the distance between the motor and the VFD is increased to 75 ft as in Figure 12, the max voltage at the motor terminals increases to almost 1,326 V.

This is almost two times the value of the VFD's DC bus! These repeated voltage spikes can have very damaging effects on the motor and can even result in ride quality issues if not corrected.



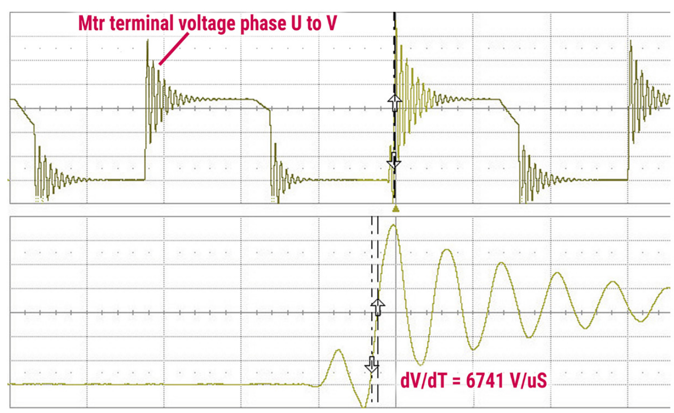




Figure 11: No choke, 25-ft leads. Peak motor voltage = 988 V
Figure 12: No choke, 75-ft leads. Peak motor voltage = 1,326 V

Today's modern 3-phase AC elevator motors are "inverter rated" and are designed for peak voltages of at least 1600 V; however, the repeated dV/dt spikes significantly stresses the windings and insulation inside the motor. In high switching frequency applications such as elevators operating with an output of 8 kHz to 16 kHz, this wear occurs much faster on the motor. Figure 13 shows a "protected motor" wired with a dV/dt choke in the same 480-V configuration as before. With the dV/

dt choke, the peak voltage from the VFD at the motor terminals is reduced to 951 V, a 40% reduction in the motor voltage! This reduction significantly protects the motor's windings and can improve ride quality.

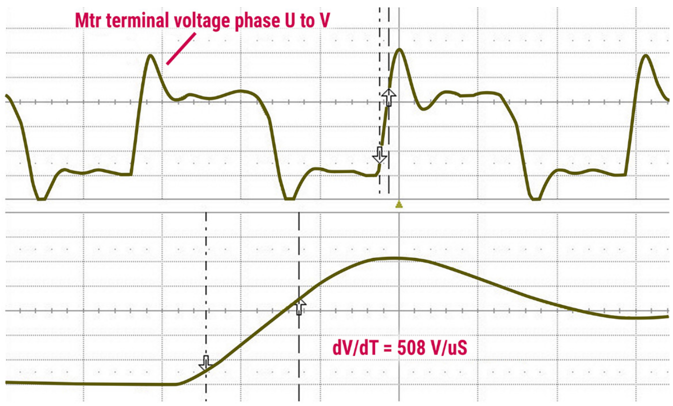



Figure 13: With dV/dt choke, 75-ft Leads. Peak motor voltage = 951 V. A 40% reduction in peak voltage.

dV/dt chokes are recommended for all VFD applications where the motor is located more than 40 ft away from the VFD. Using a dV/dt choke at shorter distances is recommended best practice, but optional. dV/dt chokes can be used with both permanent magnet and induction motors. The low inductance of the filters does not affect the VFD's ability to measure the motor resistances, inductance and dead time while learning the motor model or encoder position for permanent magnet motors. Chokes are available for voltages up to 550 VAC and are sized to the current of the application. dV/dt chokes are an excellent way to prolong the life of a motor and are typically a fraction of the cost to replace the motor.

## Ferrite Rings

The simplest and most cost-efficient way to mitigate electrical noise between a motor and a VFD is ferrite rings. Ferrite rings are passive inductors made from ceramic magnetic materials that help to filter out high-frequency noise. Ferrite rings are commonly used in any application where power transfer occurs. On your computer charger, the little plastic enclosure on both ends of the power supply are ferrite rings.

Figure 14: Multiple sizes of ferrite rings for VFD outputs

In the elevator application, PWM from the VFD and parasitic capacitances of the motor leads and motor creates unwanted high-frequency electrical currents. The ferrite rings' inductance increases the impedance between the VFD output and the cable filtering the high-frequency currents. The ferrite rings are placed at the output of the VFD with the motor leads running through them. Using ferrite rings can help rid the VFD and elevator controller of nuisance faults and prevent premature failure of motor bearings and motor windings due to parasitic currents.

## Conclusion – Comparison of Technologies

The modern elevator market demands clean and non-distorted power. There are many methods to mitigate harmonic distortion and prolong the lifespan of equipment in the electrical and elevator system. Line chokes, harmonic filters, AIC technology, EMI filters, dV/dt chokes and ferrite rings are all options with varying costs and performances to meet the system requirements of any application. Engineers and consultants must weigh the cost versus performance requirements of the system to determine the best equipment for the application. Navigating these requirements efficiently will result in long-lasting and safe high-performance elevators.

**Eric Danner** is an elevator VFD applications engineer at KEB America. He has been with the company for three years and enjoys working with customers to develop new products, troubleshoot challenging applications and conduct training on the KEB portfolio. Danner graduated from the University of St. Thomas with a BS in mechanical engineering. In his free time, he enjoys hockey, fishing, skiing and spending time outdoors.

## Learning-Reinforcement Questions

Use the below learning-reinforcement questions to study for the Continuing Education Assessment Exam available online at elevatorbooks.com or on p. 120 of this issue.

- What are the three main parts of a six-pulse VFD?
- What causes harmonic distortion and which harmonic orders cause the most significant harmonics in elevator applications?
- What methods are used to mitigate harmonic distortion and prolong the lifespan of equipment in electrical/elevator systems?
- How can engineers/consultants evaluate the cost versus performance of the system to determine the best method for the application at hand?
- What is the difference between TDD and THDi and which is better for describing harmonic distortion over time in an elevator system?

## Accounting of Time for Article

- Learning Objectives:
  30 Minutes – Page 104 - 106
- Accessories for the Elevator Application:
  30 Minutes – Page 106 – 109

# ELEVATOR WORLD Continuing Education Assessment Examination Questions

Read the article **"VFD Filters and Accessories for the Elevator Application"** (EW, July 2026, p. 104) and study the learning-reinforcement questions at the end of the article.

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1. The three main parts of a six-pulse variable frequency drive are:
   a. Input rectifiers, DC bus and output IGBTS
   b. Input rectifiers, encoder feedback module and output IGBTS
   c. Input IGBTS, DC bus and output rectifier

2. The most significant harmonics in the elevator application occur at which harmonic orders?
   a. first, second and third
   b. first, fifth and seventh
   c. first, fourth and eighth

3. Is TDD or THDi better for describing harmonic distortion over a period of time?
   a. TDD
   b. THDi

4. A dV/dt choke is recommended for applications where the motor and VFD are more than what distance apart?
   a. 20 ft
   b. 40 ft
   c. 75 ft

5. A power factor of 1.00 indicates...
   a. A very inefficient system where all power is wasted
   b. The load has no effect on the power system.
   c. All power is being transferred and is being consumed by the load.

6. Undersizing a harmonic filter to the current of the elevator application will result in?
   a. Oversaturated cores and overheating
   b. Poor harmonic performance
   c. All of the above

7. Which device has the best overall harmonic performance (achieves the lowest THDi)?
   a. Harmonic filter
   b. EMI filter
   c. AIC

8. EMI filters address frequencies at?
   a. High frequencies
   b. Low frequencies
   c. Neutral frequencies

9. Which of the following filters is placed at the output of the VFD?
   a. EMI filter
   b. Harmonic filter
   c. dV/dt choke

10. True or False? A transformer is always required for elevator applications with harmonic filters.
    a. True
    b. False

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Article title: **"VFD Filters and Accessories for the Elevator Application"** (EW, July 2026, p. 104)

Continuing-education credit: This article will earn you one contact hour (0.1 CEU) of elevator-industry continuing-education credit.

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