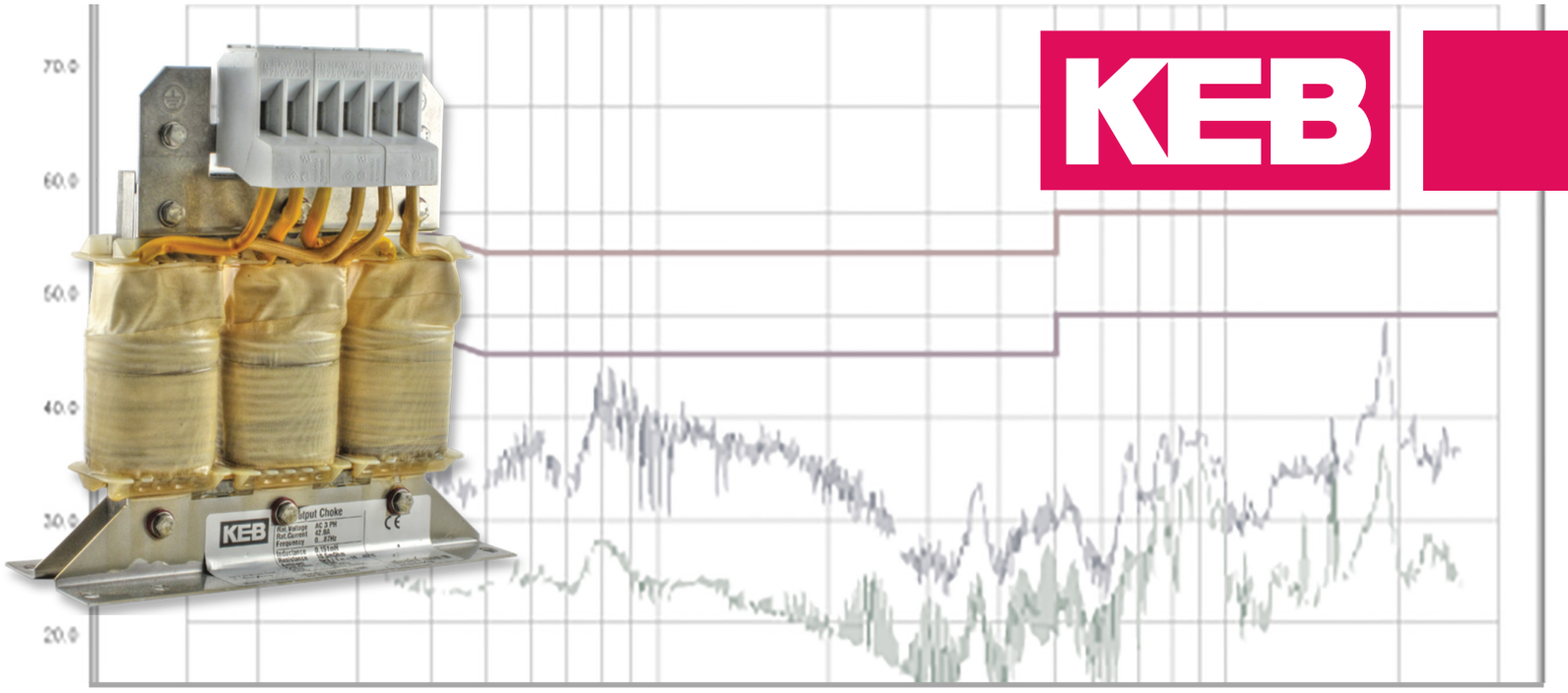


Protecting your investment with dV/dt filters from KEB America

By Jonathan Bullick

Using variable frequency drives – or VFDs – in industrial applications is a common and effective way to manage motion control tasks in a system. When planning the system integration, the engineers or consultants must take precautions where possible to prevent issues. One of these is high dV/dt or voltage rises which have the potential to damage expensive equipment.

This paper provides an explanation of the effects of high dV/dt created by VFDs and offers solutions to protect the installation's motor.

What are dV/dt spikes?

Most AC VFDs use a technology called pulse-width-modulation (PWM) to simulate a 3-phase AC sinusoidal voltage output. PWM operates by rapidly turning the drive's output insulated-gate bipolar transistors (IGBTs) on and off, thereby modulating the DC bus voltage of the drive. When the IGBT is closed, the voltage at the VFD's output terminals rises to that of the DC bus (Figure 1). The change in voltage is not instantaneous but actually ramps up to the DC bus level over a given time (TRISE). The rate at which the voltage increases is referred to as the dV/dt rise time and is a characteristic of the transistor design.

Motor cabling and reflected wave

The motor cabling between the drive and motor has a characteristic impedance which is dependent on the cable length and the physical properties of the cable material. The motor cabling acts as a transmission line and propagates the drive's output voltage to the motor. If the impedance of the motor and cabling are not matched, a wave reflection will occur at the motor load – this results in a voltage overshoot or "ringing" at the motor terminals and a reflected wave back to the drive (Figure 2). In a worst-case scenario, the reflected wave could be added to the fundamental waveform coming from the drive resulting in a significantly higher voltage at the motor terminals. Longer motor leads have larger impedances, ultimately increasing the voltage at the motor leads. For this reason, it is a best to mount the motor and drive as close together as possible.

Switching frequencies

Operating at higher switching frequencies is desirable in certain installation, like theatres or hospitals, because it reduces the audible noise made by the VFD while providing the motor with a higher quality current waveform which results in lower motor losses. When AC VFDs were first commercially applied, the transistors were typically cycled at a frequency around 2kHz. As technology improved, transistors with higher dV/dt rise times became available allowing operation at higher switching frequencies. Today, most drives operate at 8kHz switching frequency as standard with the option to run up to 16kHz when required by the application. It is important to note that higher switching frequencies require that

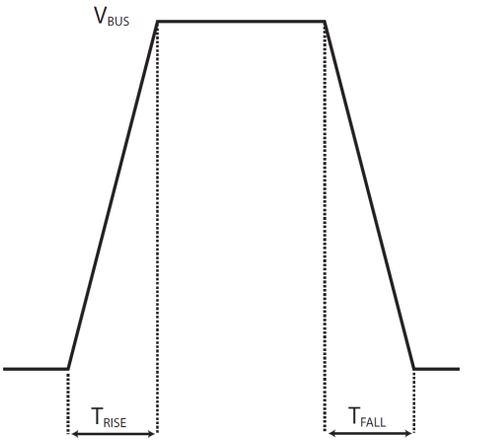


Figure 1 - Typical IGBT switching cycle

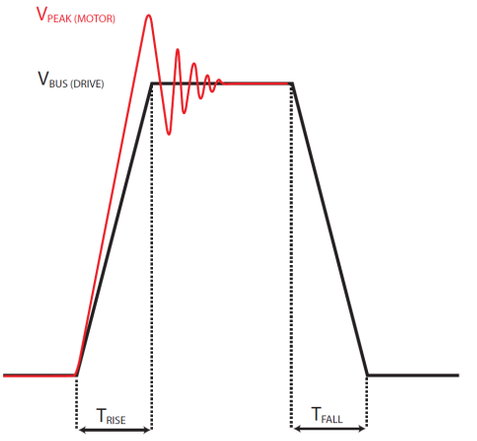


Figure 2 - Voltage ringing at motor

the transistors turn on/off more times over a given period of time, thereby exposing the motor to an increased number of high voltage peaks.

dV/dt effects on motor operating lifetime

In short, voltage peaks from high dV/dt break down a motor's insulation and shorten the motor's operating lifetime. Most 3-phase AC motors produced today are "inverter-rated" and utilize wire and insulation rated to withstand peak voltages of at least 1600V. Certain applications (480VAC, long motor leads, 16kHz switching, etc.) are more susceptible to dV/dt failure and will experience voltage spikes in excess of the motor insulation rating. However, even if the dV/dt spikes do not exceed the 1600V insulation rating, the repeated exposure to the spikes over the motor's lifetime will stress and weaken the insulation. Over time, the motor insulation system could break down resulting in a phase-phase or phase-ground short in the windings and a catastrophic motor failure. Because the drive's peak output voltage is directly related to the DC bus level, the dV/dt spikes will be larger in 480VAC installations compared to those in 230VAC installs. So extra precaution should be taken to mitigate the dV/dt spikes in 480VAC installations.

MRL applications

A motor failure is particularly problematic in machine-room-less (MRL) applications because the motor is located in the hoistway and is not easily accessible to be either rewound or replaced. A motor failure in an MRL application could be very costly to repair and cause significant downtime. Furthermore, MRL applications are especially susceptible to dV/dt spikes because frequently the motor cannot be located next to the drive and the application requires long cabling runs adding to the magnitude of the dV/dt voltage peaks.

dV/dt mitigation and filters

The first thing a system integrator may do to protect their motor from high dV/dt is to minimize the length of cable between the drive and the motor. Another option could be to reduce the carrier frequency of the drive but this is usually not desirable in some applications since it introduces audible noise. If neither of these options are possible, a consultant should consider specifying a dV/dt filter (or choke) which will decrease the dV/dt rise time and reduce the peak voltages at the motor.

The dV/dt filter is placed directly at the drive output and limits the rate of change of the voltage (dV/dt) to a level characteristic of the filter design. It is important that the filter is placed as close to the output of the drive as possible so the voltage peaks are not propagated through the motor cabling. Unless the motor and cabling impedances are matched, the standing wave reflection could still occur but the negative effects are dramatically minimized by the filtering of the dV/dt spikes.

Because the motor represents a significant portion of the overall cost of a motion control system, a best practice is to install a relatively inexpensive dV/dt filter on all installations. This protects the motor investment and ensures a full lifetime of operation.

KEB dV/dt filters

KEB has worked closely with the customers in the motion control industry for over 40 years. Our dV/dt filters offer high performance while being commercially cost-effective.

PM/MRL applications

It is important to note that the KEB dV/dt chokes are designed to have a low impedance in order to not skew the drive's internal motor model. Standard output inductor chokes having 2-3% impedance can greatly affect the motor performance resulting in reduced peak torque, difficulty in reaching contract speed at full load, and general motor control instability. As a rule of thumb, KEB recommends the use of a dV/dt filter for all MRL applications where the motor is located over 40 feet away from the drive.

KEB dV/dT filters help protect the motor insulation and increase operating lifetime by reducing the peak voltage levels seen by the motor and reducing motor heating in VFD applications. By making this small investment a system integrator can ensure efficient operation for the life of the application.

Features and benefits

Low inductance design

Does not skew the motor model in the drive;

Can be used with both PM and Induction motors

Operable up to 16kHz

Can be used with high switching frequencies

Minimal inertia loss

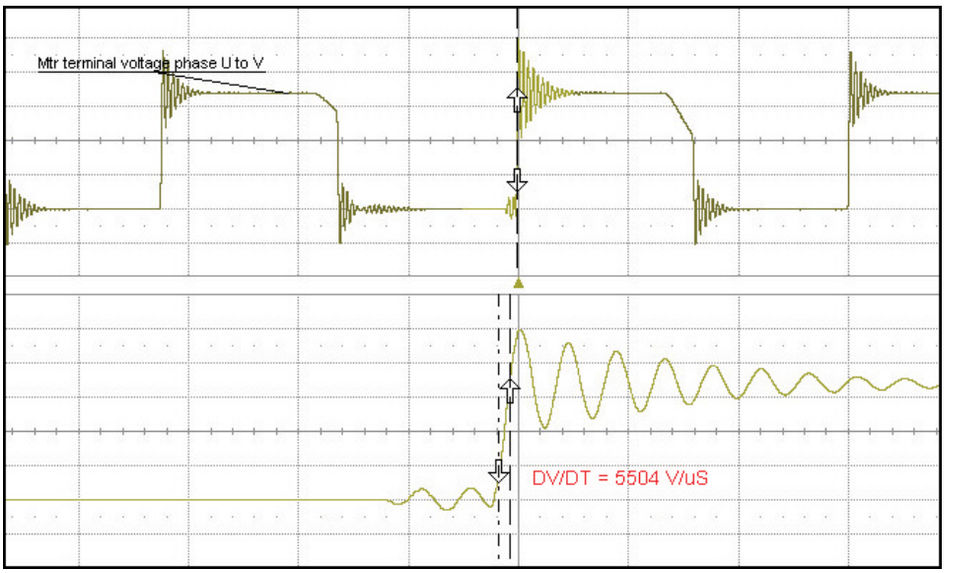
Efficient design with minimal power losses

Small footprint

Requires less cabinet space - Lower system cost

Reduced EMI

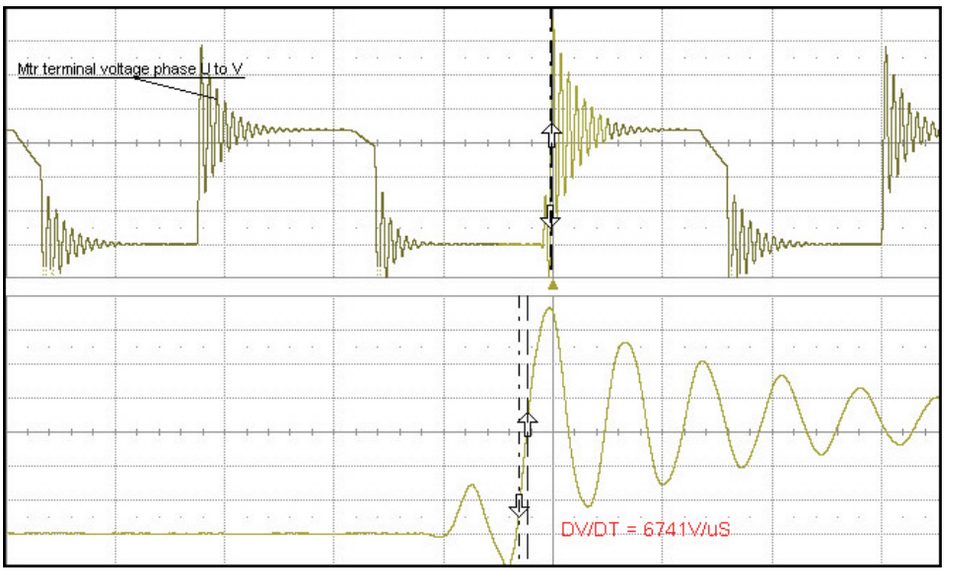
Limits radio frequency emissions (>250 kHz)



Increasing the drive-motor distance from 25 ft. to 75 ft. resulted in a 34% increase in the peak voltage seen at the motor.

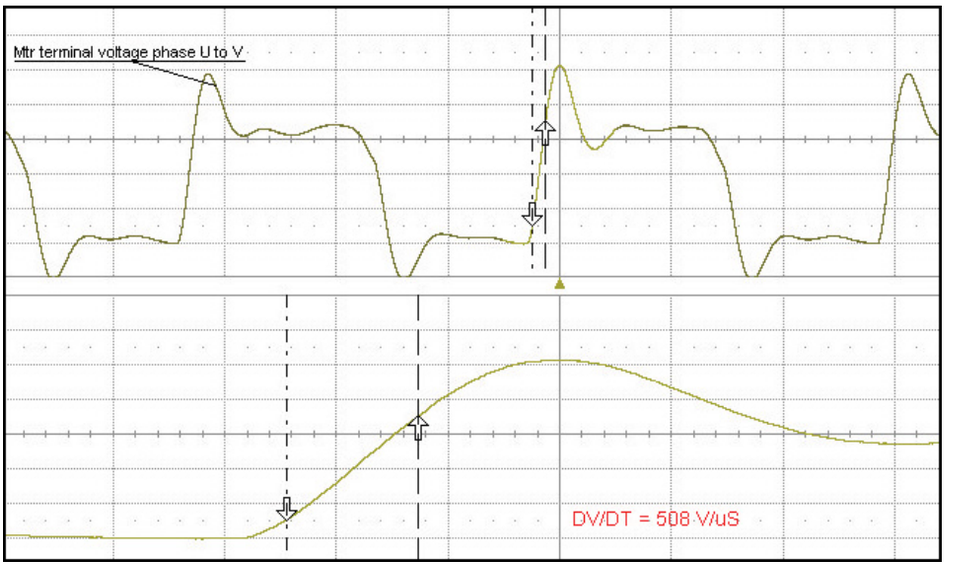
No choke at 25 ft

- *25 ft. shielded VFD cable*
- *No output choke*
- *dV/dt = 5504V/µs*
- *$V_{nominal}$ @ motor = 675V*
- *V_{peak} @ motor = 988V*



No choke at 75 ft

- *75 ft. shielded VFD cable*
- *No output choke*
- *dV/dt = 6741V/µs*
- *$V_{nominal}$ @ motor = 675V*
- *V_{peak} @ motor = 1326V*



Using a KEB dV/dt fi lter on the 75 ft. installation reduced the peak voltage at the motor by 28%

With choke at 75 ft

- *75 ft. shielded VFD cable*
- *KEB dV/dt choke (17Z1F04-1005)*
- *dV/dt = 508V/µs*
- *$V_{nominal}$ @ motor = 675V*
- *V_{peak} @ motor = 951V*

Frequently asked questions

Q. When do I require a dV/dt filter?

A. KEB strongly recommends the use of a dV/dt choke for all installations where the motor is located 40 ft. or more away from the drive. Using a dV/dt choke in closer installations is recommended but optional.

Q. Can I use the KEB dV/dt choke with other drives?

A. Yes. Because the KEB dV/dt chokes have a low inductance they shouldn't affect the drives ability to measure the motor parameters during an auto-tune or skew the internal motor model.

Q. Can I use a standard motor choke to mitigate high dV/dt on an application?

A. Not recommended. The high inductance and capacitive coupling found in these chokes will still result in high dV/dt while limiting the motor's peak torque during acceleration.

Q. Can I use the KEB dV/dt choke for either PM gearless or induction geared machines?

A. Yes. The KEB choke effectively limits the voltage transients in both applications and does not negatively affect the operation of either motor.

Q. Can I use the KEB dV/dt chokes for either 230V or 480V applications?

A. Yes. The chokes are designed to be used for voltages up to 550VAC.

Q. How much does a KEB dV/dt choke cost?

A. The dV/dt choke is typically 1 - 3% of the cost of the motor. This represents a small investment up front to prevent a costly repair or replacement at a later date.

About KEB America

KEB America is headquartered in Shakopee, Minnesota, a suburb outside of Minneapolis. The 86,000 sq. ft., ISO 9001:2015 facility has full design and manufacturing capabilities and is responsible for supporting the North American market. With more than 100 employees and growing KEB America provides top-tier service, repair, and field support for customers in the US, Canada, and Mexico.

The facility is home to R&D for mechanical and electrical products, as well as production of KEB's full mechanical product line. KEB America assembles the R6 and F5 lines of drives, and the full line of KEB integral gearmotors. Products produced and assembled on-site gives KEB America's customers the benefit of German engineering with responsive local support.

For more information on KEB America and our products please visit us online at kebamerica.com or email sales@kebamerica.com

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