

## Whitepaper

# Audible Noise Reduction

### Introduction

Adjustable frequency drives are commonly installed today in commercial buildings to provide system control and cost savings in the heating, ventilating, and air conditioning (HVAC) systems. In buildings such as hospitals, schools and dormitories, office buildings and others, audible noise generated by electrical equipment can be a concern. An adjustable frequency drive may produce audible noise and induce noise in motors.

### Causes of audible noise

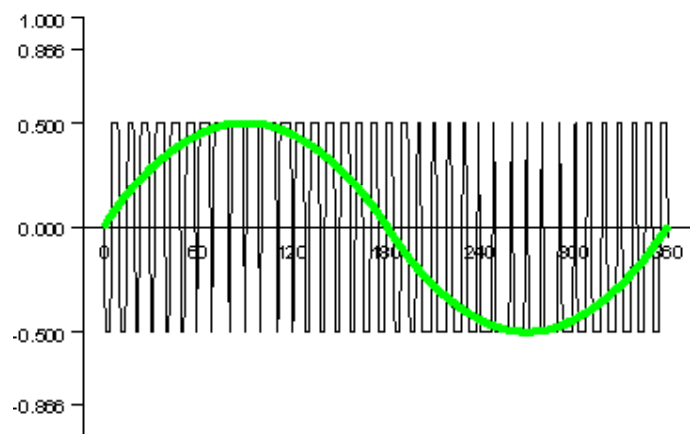
The most obvious difference between operating a motor from the AC line and from the output of an adjustable frequency drive is that the drive changes the frequency of the power supplied to the motor. The form of the frequency wave applied to the motor is the major cause of motor noise. Instead of being a simple sine wave, the voltage is more complex.

In drives with a pulse-width modulation (PWM) inverter, as in most modern drives, an inverter controls the voltage to the motor by sending a series of high-voltage pulses to the motor (see figure 1). Audible noise is generated by frequency distortion. The pulses may cause a resonance in the motor stator or cooling fins. The typical frequency of these pulses, called carrier frequency, is within the audible hearing range. This mechanical resonance causes the motor to act as an amplifier. The vibration can produce an annoying high-pitched tone.

In order to generate a variable frequency, most PWM controlled drives have a switching frequency of 2 to 6 kHz. This is within the range where the human ear is the most sensitive and where even low noise levels are usually detected. Since the noise is high frequency, most people find it very annoying. High frequency noises are difficult to mask and can be heard at some distance from the source.

Another source of noise is input power to the adjustable frequency drive. Generally, sounds cannot be heard when electricity passes through power wires. This is because there

Understanding the causes of audible noise is the first requirement in resolving its effects. The following will look at the factors that can generate audible noise in an adjustable frequency drive and the equipment connected to it. Also examined is the severity of the condition in various applications as well as solutions to limiting or eliminating audible noise concerns.



**Figure 1.** PWM voltage wave form

is very little material that can vibrate and the forces are not very strong. Transformers, on the other hand, can produce a noticeable hum because their coils concentrate the magnetic fields produced by the current.

Adding a filtering circuit on the input of an adjustable frequency drive to reduce electrical noise on the AC power line can increase audible noise. This is because the main device in such a filter is a large coil. The concentration of the magnetic fields, as in a transformer, can cause enough vibration in its windings to produce a noticeable noise.

The adjustable frequency drive itself is another possible source of audible noise. The changing currents through the drive result in changing magnetic fields. These magnetic fields can cause metallic objects to resonate, resulting in acoustic noise.

Acoustic noise from the AC power line, input line filters or the adjustable frequency drive is rarely a concern. The equipment is usually located in an isolated utility room. If the noise is objectionable, there are a number of possible remedies. It is likely that the wall or cabinet to which the filter or drive is mounted amplifies the noise. The sound can be dramatically reduced by using vibration isolators between the unit and the wall or by mounting the unit on a floor stand. In an extreme case, the manufacturer of the drive or the filter can be contacted to see if a quieter filter or other solution is available.

Audible noise generated in the motor, however, can be more significant and needs to be discussed in detail. The optimum solution would be to eliminate frequency pulse noise in the drive's output voltage but that is not possible without adding passive components in the output of the drive.

A second way to control audible noise is to change the switching frequency out of the sensitive range, by either moving it up or down. Lowering the switching frequency below the range allowed by the drive is not a good solution, since the current and voltage waveform would be distorted and the creation of a near sinusoidal waveform would be impossible. This means that the ability to control the motor would be reduced drastically. Raising the switching frequency is discussed below.

**Noise reduction techniques**

Four different motor noise reduction techniques will be compared:

1. Fixed high switching frequency
2. Random switching frequency
3. LC output filter
4. Automatic Switching Frequency Modulation

**Fixed high switching frequency**

A fixed high switching frequency in the range of 12-20 kHz is the traditional way of reducing acoustic noise in the motor. This high frequency sound is much harder for the human ear to detect and, unlike low frequency, has no significant impact on the waveform. This approach, however, has disadvantages. The primary ones are increases in:

- Electromagnetic Interference (EMI).
- Risk of motor insulation damage.
- Power losses which generate heat in the drive.
- Leakage currents if a larger EMI filter is used

Increased EMI may require a larger and more expensive EMI filter. This increases the cost of the drive and adds to leakage current. Leakage current may cause insulation problems in the motor and, moreover, can lead to electrical hazards.

High switching frequencies generate additional heating on the drive, which reduces the operational life of the drive or requires an oversized drive to be installed. Losses are a result of the distortion in the motor cables at high frequency. This means that if the drive was operating at a lower switching frequency, it would be able to operate the motor at lower energy cost or operate a larger motor. In the drive inverter, a switching frequency around 4 kHz ensures the lowest losses in the drive, and the overall efficiency is highest in the range from 2.0 to 4.5 kHz (see figure 2).

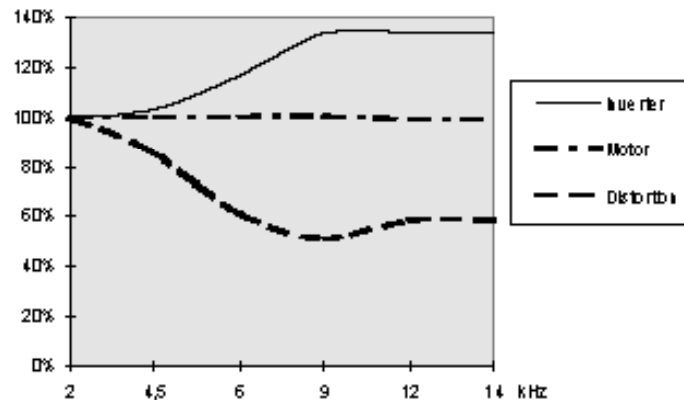


Figure 2. Indexed output losses

**Random switching frequency**

Random switching frequency is also known as “white noise.” The switching frequency is continuously changed within a band around a base switching frequency. This approach does not require derating of the drive. The major disadvantage of this technique is that the induced white noise makes the motor sound as if a bearing is failing. This sound is different from the fixed switching frequency, but may be just as annoying.

### LC filter

An LC filter can be mounted in the output of the drive. This filter generates a pure sine wave voltage. Since the distortion is eliminated, the noise induced to the motor is also eliminated. This means that the motor operation in general is improved, such that in most applications there is no difference between operating directly on line or operating with a drive.

An LC output filter approach to resolving motor noise has some drawbacks. Primarily, the LC filter itself can become a source of audible noise. The disadvantages include:

- Noise is not removed from the system, just moved to the LC filter instead.
- A voltage drop is introduced between the drive and the motor.
- Increased installation cost, because the LC filter must be mounted separately.

### Automatic switching frequency modulation

Automatic Switching Frequency Modulation (ASFM) is an advanced electronic feature in the VLT HVAC Drive. With ASFM, the carrier frequency is automatically adjusted up to a programmed maximum switching frequency whenever the motor is lightly loaded. When the motor load is high, the switching frequency is reduced to save energy.

A low carrier frequency (slow pulsing rate) causes noise in the motor, making a high carrier frequency preferable. A high carrier frequency, however, generates heat in the drive thereby limiting the amount of current available to the motor. ASFM regulates these conditions automatically to provide the highest carrier frequency without overheating the drive. By providing a regulated high carrier frequency, ASFM quiets motor operating noise at slow speeds, when audible noise control is critical, and produces full output power to the motor when the demand requires. Systems without ASFM can do one or the other, but not both. An important benefit is not needing to derate output at high load. ASFM adjusts the frequency based on motor current demand rather than motor speed to provide the best carrier frequency possible, matching both performance and noise control.

Pump and fan applications have a variable torque characteristic. Full drive output current and full carrier frequency is available until the load reaches 60%. (See figure 3 which represents 15-60 HP drives at 460 VAC and 5-30 HP at 208 VAC.) With the characteristics of variable torque, this means the fan or pump speed is roughly 75% to 80% of full speed

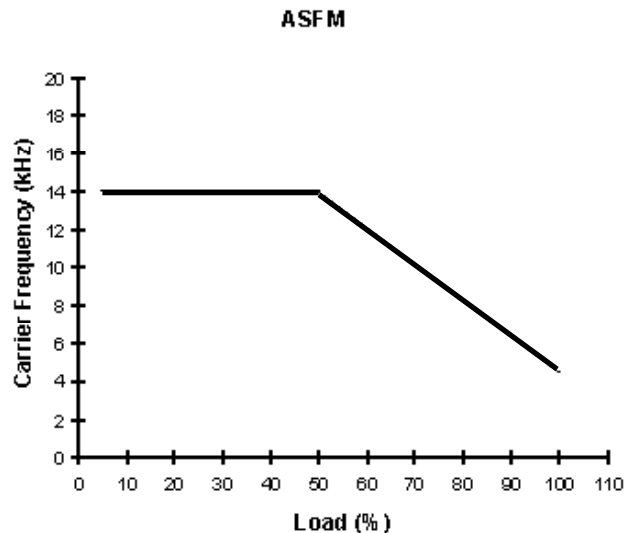


Figure 3. Variable torque characteristics.

before 60% load is reached. Therefore, a higher switching frequency is available at most times without having to oversize the drive, particularly under the important low load conditions where noise is a factor. In addition, most HVAC application motors are oversized for performance and system safety factors. This is because an oversized system can always be run at reduced load, while an undersized system simply cannot meet design requirements. The adjustable frequency drive, therefore, rarely operates near full output, greatly increasing the speed range where a high carrier frequency can be used.

The fact that the switching frequency is highest at low load means that electrical disturbance on the system is very limited compared to a fixed high switching frequency. EMI is also less than with a fixed high switching frequency, resulting in lower leakage current, and longer motor life. In addition, total electrical losses are reduced since power loss due to low frequency distortion in the motor cable is minimal. This has the additional benefit of lowering energy costs.

With ASFM, audible noise is still generated when the drive operates at high load. However, in most pump and fan applications, the normal ambient acoustic noise generated increases as the speed and load increase. The noise generated by the switching frequency is, therefore, usually disguised by the audible noise of the system.

**Motor Design Influences**

Noise generated in the motor by frequency resonance is dependant primarily on the motor design, materials and construction. Motor designs respond differently to harmonic currents. In a comparison of two motors, in one motor audible noise was lower at the switching frequency than at twice the switching frequency. For the other motor, the exact opposite was true. The difference between the two motors was the number and size of the cooling fins.

An air gap as small as possible between the stator and rotor, a characteristic of higher quality motors, also helps reduce the motor noise level.

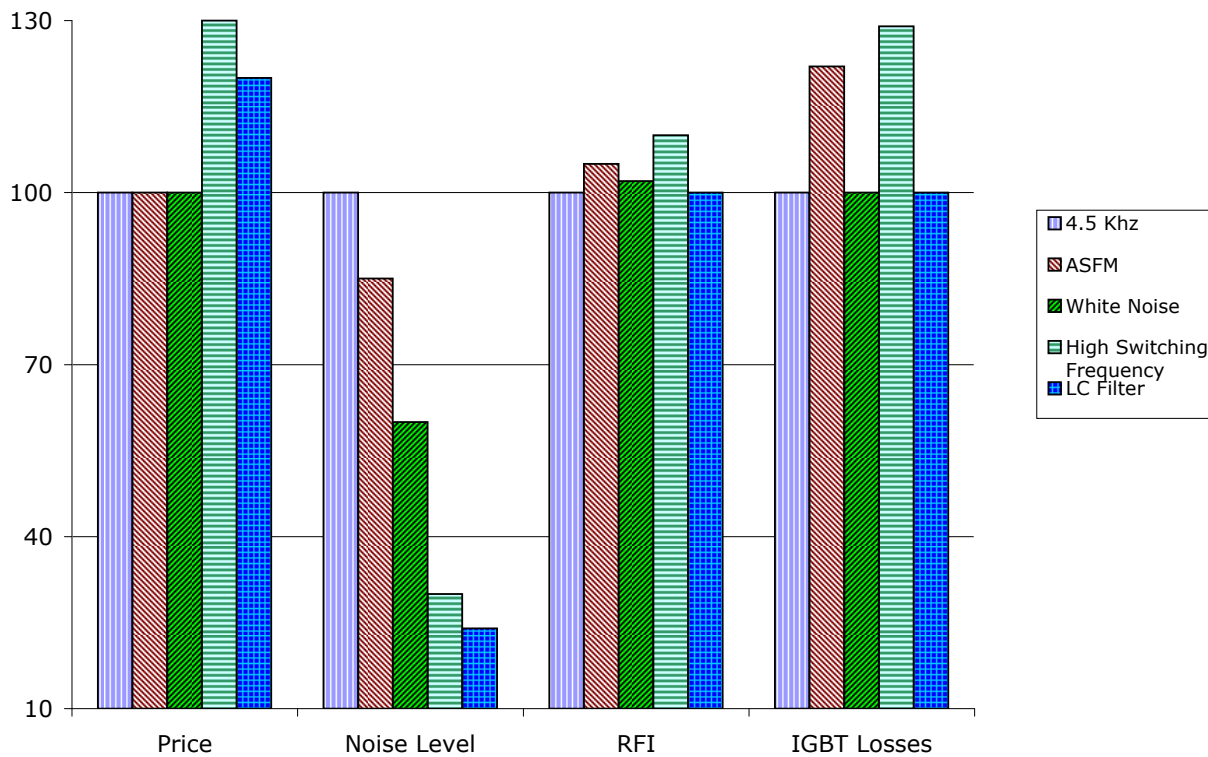
Tests of multiple motor brands and sizes has lead to the conclusion that no one motor manufacturer has the optimum design to reduce noise levels. Even the best motors vary with motor size. It is, therefore, not possible to generalize about motor noise.

**Noise Reduction Comparisons**

**Cost and benefits**

The diagram below compares the different techniques discussed.

**Comparison by Noise Reduction Techniques**



The LC filter and high switching frequency result in the greatest noise reduction. High switching frequency, however, causes not only an increase in the price of the drive when the drive is derated, it also increases electrical loss in the system and causes increased EMI. A major disadvantage of using the LC filter is increased price.

White noise significantly reduces drive induced motor noise, but induces other noise of its own just as problematic.

ASFM, a unique function of the VLT HVAC Drive, is usually the most cost effective solution.