Selecting Explosion-Proof Motors And Variable-Frequency Drive Controllers For Hazardous Environmental Applications

Introduction

Applying variable frequency power to explosion-proof motors in hazardous locations requires special considerations regarding UL 674, motor ratings and variable frequency drive characteristics to name a few. The attached paper (D-7154), originally published in Machine Design, highlights the issues important to the success of a XP motor operated on variable frequency drive power.

It is an appropriate paper for the VLS drive application note guide.
The proper application of variable-frequency drive controller power to AC induction motors can be difficult even in relatively simple applications. When using a variable-frequency controller, the non-pure sine wave output power causes additional motor heating primarily because of harmonics and below base speed operation. Add to these issues a hazardous environment requiring an explosion-proof (XP) motor, and the selection of a suitable, as well as efficient, motor and variable-frequency controller combination is complicated even further.

Hazardous locations are found in a wide range of industries, including petrochemical, textile, rubber making, agriculture, food processing and metalworking. The array of hazardous locations found in these industries has been defined by standards such as The National Electric Code (National Fire Prevention Association - NFPA 70). Refer to Figure 1.

Because standard constant-speed explosion-proof motors are not designed for use with variable-frequency controllers in these potentially explosive applications, it is necessary to understand how these controllers affect motor performance. UL® addresses this issue within its Hazardous Duty Motor Specification, UL 674, which defines the testing and marking that a motor manufacturer must adhere to in order to supply a “listed” motor package for hazardous environments, when powered by a variable-frequency controller.

The multitude of motors and controllers - as well as the ability to purchase each as a separate product - and the numerous hazardous application variables, make it extremely difficult to select the right explosion-proof motor/controller combination for hazardous applications.

**How Variable-Frequency Affects Motors**

Understanding the affects of variable-frequency on motors (whether the application is hazardous or non-hazardous) sheds some light on this complicated selection process. As with general-purpose locations, there are many benefits to using variable-frequency controllers in applications requiring explosion-proof motors. However, when variable-frequency power is applied to AC motors, it causes increased motor heating that must be considered.

Depending on the manufacturer and the type of variable-frequency controller, the input voltage and current waveform to the motor will be distorted by varying degrees. This distortion can be mathematically represented in terms of harmonics. The harmonics produced by drive controllers result from the conversion of the original “pure” sine wave to a variable-frequency output produced by the drive. Harmonic currents create no useful torque at the motor shaft. They actually produce additional heating in the motor.

Varying the speed of the motor shaft also affects a motor’s cooling capacity unless a separate constant-volume air supply is provided. The amount of air flow through or over the motor decreases as the inverter lowers the motor’s speed, decreasing the cooling capability of the motor. This decreased cooling capability, along with losses due to harmonics, combine to cause the motor to run hotter as its speed decreases.

The application in which the motor will perform must also be considered. Different load types have different effects on the heating of motors powered by variable-frequency sources. Constant torque, variable torque, and constant horsepower all create motor heat in different ways. Constant torque requires the same amount of torque throughout the application speed range, causing the motor to get hotter as its speed decreases. Variable torque is often used with centrifugal load, in which the load actually drops off faster than the motor’s speed, enabling the motor to run cooler (than it would at full-load, full speed) as its speed slows. However, the temperature rises again when the motor approaches stalled state. Constant horsepower enables the motor to run above its base speed; the torque goes down as the speed increases.

To complicate the issue further, different types of variable-frequency controllers, such as Variable Voltage Input (VVI), Current Source Input (CSI) and Pulse Width Modulated (PWM), have different output voltage and current waveforms, and thus vary in the amount of heat they impose on a motor. Underwriters Laboratories (UL) recognizes the complexity of these variables and provides a UL listing for motors that will be used in a hazardous atmosphere with variable-frequency controllers.
UL 674 and Hazardous Environments

UL requires motor manufacturers to complete an extensive series of tests to measure motor performance and temperature rise when powered by different types of drives and when used in different hazardous environments. UL must witness these tests in all combinations for which the motor manufacturer seeks a UL listing.

UL 674 defines the many requirements a hazardous-location motor must meet, including those it must meet when operated on inverter power. The standard states that the motor must perform “throughout the market frequency range and... be tested with each type of inverter with which the manufacturer specifies that the motor be used.” UL 674 also defines the marking required on a metal nameplate for a hazardous-location motor to be operated on inverter power.

To obtain the UL listing, the motor manufacturer must first submit to UL the speed/torque capabilities the manufacturer anticipates from the line of motors. UL also requires additional information such as the type of variable-frequency controller the motor will be used with (VVI, CSI, PWM, etc.); the motor’s voltage, frequency and speed ranges; duty, surface temperature code; and hazardous location classifications in which the motor will be approved. UL then selects the test requirements to verify the motors will perform as expected. Testing for variable-frequency motors in hazardous environments consists of tests to verify the surface temperature of the motor will not exceed the listed temperature code under all operating conditions throughout the speed range.

UL requires that the motor nameplate be marked to reflect its suitability for operation with an inverter. The specified speed range in hertz, the expected load type (e.g. constant torque, variable torque, or constant horsepower), as well as the hazardous location, Class, Group, temperature code (See Figure 2) and type of inverter (VVI, CSI, PWM) must be listed on the motor’s nameplate or the auxiliary UL nameplate. The UL nameplate identifies the hazardous environment. Applying a motor outside the specified limits on the nameplate is a violation of the UL label. Therefore, a motor not specifically labeled for variable-frequency use may not be applied to those applications.

Assuming the motor is already approved for sine wave explosion-proof duty and has undergone the rigorous testing of frames and thermostat capabilities, the tests for variable-frequencies focus on motor surface temperature and are divided into two main hazardous environment classifications:

- **Class I** - Locations with flammable gases or vapors in levels that may ignite or explode (Groups C and D)
- **Class II** - Locations with combustible dust (Groups E, F, and G)

See Figure 1 for complete UL and NEC Hazardous Area Class and Group classifications.

As Figure 1 illustrates, hazardous environments are determined by the type of flammable gas, vapor, dust or fiber in the area. Hazardous areas are typically identified by the insurance underwriters. However, the National Fire Prevention Association’s codes also provide guidelines for evaluating the environment.
Because of the vast differences among manufacturers’ variable-frequency controllers, as well as their affect on motors, these assumptions can lead users into trouble. For example, when using a 10 HP motor with a 10 HP controller - if applied over a wide speed range - the motor may overheat at lower speeds. Fortunately, few motors and controllers are ever applied to their non-hazardous environment, and are overheated for short periods of time, this may go undetected by the user. This is usually not the case for motors in hazardous locations. If misapplied, the thermostats will take the motor off-line. Also, any time a motor overheats, insulation life is decreased.

Therefore, extra care should be taken to properly match motors and controllers in hazardous environments. Exceeding a motor’s rated temperature at lower speeds, even for a short period of time, may cause the motor to become a hazard. The maximum surface temperature of the motor must remain below the auto-ignition temperature of the hazardous environment. Each remain beneath the limit. The temperature code defines the maximum motor surface temperature (See Figure 2).

By packaging a variable-frequency controller with a UL Listed motor, which meets the requirements of UL 674, the user has an installation that not only meets regulations, but provides the required nameplate speed torque range. In other words, the package meets the regulations, and does not compromise performance.

These standards cannot be met simply by installing thermostats in the motor windings that signal the controller, which feeds power to the motor, to shut down when the motor thermostats open. UL 674 test procedures specifically require that the thermostats be proven with the motor being tested. Factors such as thermostat location, temperature, tolerance and response time should be considered.

In fact, if a motor/controller package is not properly matched, the motor’s thermostat may simply trip because of its inability to perform the speed range function required, resulting in nuisance trips. You can begin to see the importance of properly matched motors and controllers when applied in hazardous environments. Nuisance tripping can lead to either very long, repeated start-ups.

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**Figure 2. NEC Temperature Codes**

<table>
<thead>
<tr>
<th>T Code</th>
<th>Max. Surface Temp.</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>450°C (842°F)</td>
<td></td>
</tr>
<tr>
<td>T2</td>
<td>300°C (572°F)</td>
<td></td>
</tr>
<tr>
<td>T2A</td>
<td>280°C (536°F)</td>
<td>Class I, Group D w/caut. label</td>
</tr>
<tr>
<td>T2B</td>
<td>260°C (500°F)</td>
<td>Class I, Group D w/thermals</td>
</tr>
<tr>
<td>T2C</td>
<td>230°C (446°F)</td>
<td>Class II, Groups E &amp; F</td>
</tr>
<tr>
<td>T2D</td>
<td>215°C (419°F)</td>
<td></td>
</tr>
<tr>
<td>T3</td>
<td>200°C (392°F)</td>
<td></td>
</tr>
<tr>
<td>T3A</td>
<td>180°C (356°F)</td>
<td></td>
</tr>
<tr>
<td>T3B</td>
<td>165°C (329°F)</td>
<td>Class II, Group G</td>
</tr>
<tr>
<td>T3C</td>
<td>160°C (320°F)</td>
<td>Class I, Group C</td>
</tr>
</tbody>
</table>

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Motors that are not listed for use with variable-frequency controllers, but UL listed for hazardous environments, are readily available off-the-shelf. Drives are readily available as well. Motor and drive packages are applied everyday to OEMs, distributors, manufacturers and end users. Many assumptions, however, and even erroneous “rules of thumb” are applied to the sizing of motors powered by variable-frequency controllers.
Though it is potentially dangerous and not recommended, it is nonetheless common practice to apply standard, totally-enclosed fan-cooled (TEFC) motors or, in some cases, open dripproof motors to a Division 2 environment. The key criteria for motors applied in a Division 2 motor include no sparking or arcing devices and the surface temperature of the motor must not exceed the maximum temperature allowed by the temperature code.

With the explosion-proof motor, the only surface exposed to the environment is the outside surface of the motor. The design of the motor is such that any explosion within the motor will be contained by the motor enclosure. However, with a Class 1, Division 2 motor, the internal surfaces (rotor, stator, space heaters, etc.) must not exceed the temperature code of the hazardous material. Fans must be made of non-sparking material and thermostats must be hermetically sealed.

In the case of motors applied on variable-frequency controllers, the actual internal temperature - especially the rotor temperature - can neither be accurately measured nor predicted. Nor can it be protected from exceeding the allowable temperature. If the drive or hazardous situations, should someone decide to bypass the thermostat. Overheating and nuisance tripping can also occur if the inverter is adjusted improperly.

Cautionary Label explosion-proof motors are also available for hazardous environments. These motors are used only in a Class I, Group D environment and do not require a thermostat. Their insulation system is designed to be the thermostat and will fail before the surface temperature of the motor reaches the hazardous environment limit. Nuisance tripping in this case means replacing the entire motor. Hence, care must be taken to ensure the inverter is not misadjusted and the motor/drive package is properly matched.

A Look at Division 2 Hazardous Environments
As shown in Figure 1, UL and NEC classifications include Class, Group and Division categories. Class groupings define the actual physical form of the combustible material; Groups further subdivide the classes. Divisions, however, define the degree of exposure to hazardous material.

- Division 1 - Location where hazardous material exists (always or periodically) during operating conditions.
- Division 2 - Location where hazardous material exists only in the case of a fault situation (leaky valve, burst pipe, faulty equipment).

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**Figure 3. Reliance Motor Nameplate and UL Listed Nameplate**

**Figure 4.**
is improperly adjusted, especially at the lower frequencies, motor
slip may increase. When this occurs, the bulk of the motor
heating occurs in the rotor. It is therefore recommended that
motors applied to variable-frequency for Division 2 applications
be fully-labeled explosion-proof Division 1 motors, thereby
eliminating the rotor as a potential heat source problem. The
Canadian Standards Association (CSA) provides a listing for
motors in Division 1 and 2 environments but currently doesn’t
recognize motors for use on variable-frequency power.

Conclusion
It is essential for users to recognize the importance of selecting
and installing properly matched motor/drive packages for
hazardous applications. Few manufacturers provide UL-approved
explosion-proof motors for use on variable-frequency controllers
in Division 1 Environments. None have UL approval for Division 2.
It is important to note that standard fixed-frequency explosion-
proof motors are not designed for use with all variable-speed
controllers. One should work with a manufacturer that complies
with UL 674 and understands the considerations to be weighed
and followed when using explosion-proof motors and variable-
frequency controllers in hazardous environments. Properly
matching drive controllers with motors for hazardous-duty
applications not only helps ensure meeting industry standards, it
also improves motor performance. To be UL approved for inverter
application, the motor nameplate must specify the type of inverter
for which the motor is suitable, the application characteristics
and the frequency range.

NOTE: This material is not intended to provide operational instructions. Appropriate
Reliance Electric Drives instruction manuals precautions should be studied prior to
installation, operation, or maintenance of equipment.