Data Bulletin

Mounting Variable Frequency Drives in Electrical Enclosures Thermal Concerns

OVERVIEW

Variable frequency drives are available from manufacturers as enclosed engineered packages, as well as basic chassis components ready for customer packaging and integration into a custom control system. When an engineered package is purchased from a manufacturer, the thermal management engineering has already been done.

Most manufacturers' standard packages are designed for full load continuous operation in a 40°C (104°F) maximum ambient indoor environment. When creating your own enclosed variable frequency drives design, care must be taken to ensure that the variable frequency drives and associated electronic equipment will not overheat. The key to successful thermal management is to efficiently move heat from one location to another by effectively using the advantages of thermodynamics to overcome the disadvantages of thermodynamics.

There are several factors that must be considered to ensure a successful design. This paper will discuss the thermal management issues that should be considered when mounting Variable Frequency Drives in an electrical enclosure.

WHY VARIABLE FREQUENCY DRIVES THERMAL MANAGEMENT?

Many have asked, “Why is a variable frequency drive typically limited to a 40°C environment when other electronic equipment, like PLCs, are rated for 60°C?” Variable frequency drives use similar circuit board components as other electronic equipment. These components typically carry a 60°C rating. In a variable frequency drive design, the circuit boards are located near heat producing power semiconductor devices, such as diode rectifiers and transistor inverters. These devices produce significant amounts of heat that radiate near the circuit boards.

Therefore, in order to keep the temperature around the circuit boards at 60°C or less, the air surrounding the variable frequency drive and its heat sink must not exceed 40°C, or the variable frequency drives design rating. Operating electrical/electronic equipment above rated temperature will reduce the life of the equipment. Chemical processes accelerate by a factor of two for every 10°C increase in temperature.

Therefore, the rule in electronics is that the life expectancy of components will be cut in half for every 10 °C that they operate above their rated temperature.

$$40°C = 104°F$$
$$50°C = 122°F$$
$$60°C = 140°F$$
$$°F = °C \times 1.80 + 32$$
$$°C = °F - 32 \times 0.556$$

Figure 1: Temperature Conversion and Formula

NOTE: Some Square D variable frequency drive designs offer 50°C and 60°C ratings. Refer to the variable frequency drive's instruction bulletin for mounting, ventilating, and derating requirements.

SQUARE D
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TEMPERATURE RISE

Temperature rise is the difference between the internal temperature in an enclosure and the temperature of the outside ambient (surrounding) air. The total (worst case) temperature rise of a specific enclosed drive package in a specific environment will remain fixed.

Therefore, the internal temperature of the enclosure will vary as the temperature of the external ambient air varies. To determine the maximum internal enclosure temperature, the maximum temperature rise is added to the maximum ambient temperature. The resulting temperature must not exceed the rating of the variable frequency drives and other associated components; otherwise, premature failure will likely result.

There are many contributors to total temperature rise as well as many solutions to excessive temperature rise. Each of these will be discussed in detail.

$$\text{Temperature Rise} + \text{External Ambient Temperature}$$
$$= \text{Internal Cabinet Temperature}$$

Figure 2: Calculating Internal Cabinet Temperature

ENCLOSURE HEAT INPUT

The first step to calculating temperature rise is to determine the total heat contribution inside the enclosure. The heat dissipated by the variable frequency drive and associated components can be obtained from the instruction bulletin or the manufacturer.

Heat dissipation values are usually given in watts or BTU/hour. Convert BTU/hour data into watts and add all component values together to determine the total heat input within the enclosure.

$$\text{Watts} = \text{BTU/hr} \div 3.414$$
$$\text{BTU/hr} = \text{Watts} \times 3.414$$

Figure 3: Watts and BTU/hr Conversion

SURFACE AREA

The second step to calculating temperature rise is to determine the total usable surface area of the enclosure. The surface of the enclosure acts as a radiator to transfer heat from the inside to the outside (assuming the outside is cooler than the inside). The larger the surface area, the greater the heat transfer rate.

Total enclosure surface area is calculated by adding the area of all six surfaces. Usable enclosure surface area may be less than the total. If the back of the enclosure is against a wall, its radiation capability is greatly reduced, and should be omitted from the calculation. If there are no fans within the enclosure, the bottom surface is typically omitted since heat rises.

$$2\{(H \times W) + (H \times D) + W \times D)\}$$
$$\text{Square inches} \div 144 = \text{Square feet}$$

Figure 4: Calculating Total Surface Area in Square Inches

COMPONENT LAYOUT

Careful arrangement of components within an enclosure can reduce hot spots. Since heat rises, high heat generating components, such as the variable frequency drive, should be mounted near the bottom of the enclosure. Heat sensitive components should not be placed directly above the variable frequency drive.

Some variable frequency drive manufacturers offer kits to allow the variable frequency drives' heat sink to extend through the back of the enclosure, reducing the amount of heat radiated inside the enclosure. Observe the manufacturer's recommendations for orientation and clearance, and ensure free air flow around all vents.

NOTE: Square D uses thermal imaging technology and testing to determine the optimum component layout for its enclosed engineered variable frequency drives packages.

INITIAL CALCULATION

The third step is to make an initial temperature rise calculation to determine if convection cooling is adequate or if auxiliary cooling devices are required. Several methods are available that include mathematical calculations, use of curves/graphs, and computer modeling programs. The following method is contained in Square D Variable Frequency Drive instruction bulletins.

1. Determine the thermal resistance of the enclosure:

$$Rth = (Ti - To) \div P$$

Rth = Allowable Thermal Resistance of Enclosure

Ti = Maximum Internal Enclosure Temperature (°C)

To = Maximum External Ambient Temperature (°C)

P = Total Power Dissipated Inside Enclosure (Watts)

2. Determine the required usable surface area of the enclosure.

S = Required Usable Surface Area of Enclosure (Square inches)

K = Thermal Resistance per Square Inch of the Enclosure

(Typical value for painted metal is 300. Consult the enclosure manufacturer for K values.)

If the desired enclosure usable surface area is insufficient, use a larger enclosure or add an auxiliary cooling device.

NOTE: There are several methods of auxiliary cooling available; they range widely in effectiveness and cost. Your enclosure manufacturer can assist you in choosing the proper method and equipment.

ENVIRONMENTAL CONTROL

Environmental control may be required to prevent component overheating in an electrical enclosure. Some applications may also require measures to maintain a minimum temperature, reduce humidity, and prevent condensation. There are many devices and techniques available to control the environment inside an enclosure. Most of these are discussed below.

The following application information is required to properly select environmental control equipment to manage excess heat:

- Heat to be dissipated
- Maximum temperature expected outside the enclosure
- Maximum temperature allowed inside the enclosure
- Surface area of the enclosure

STIRRING FANS

Fans located inside the enclosure stir the air to distribute it more evenly around the surfaces, and reduce hot spots in the enclosure. Some variable frequency drives have built-in heat sink fans that provide this function. When adding additional fans, ensure that the airflow of the heat sink fan is not impeded.

FORCED VENTILATION

Forcing external ambient air through the enclosure with a fan system is a good solution in some environments. Filtering may be required to limit contamination from airborne particles. With forced ventilation, it may be possible to reduce the enclosure size. Adding forced ventilation may affect the enclosure NEMA or IP rating.

When designing forced ventilation fan systems, the following general guidelines should be observed:

- The air inlet should be located as far as possible from the air outlet.
- The air outlet should be at least as big as the air inlet, unless positive pressure is desired.
- When using more than one fan, all should be identical.
- Ensure that air flow is not restricted by other components.

HEAT EXCHANGERS

Heat exchangers provide a relatively low cost means of removing heat from an enclosure while maintaining the integrity of the enclosure. An internal fan moves the air inside the enclosure across a radiator, while an external fan moves the ambient air outside the enclosure across the other side of the radiator to extract the heat. This closed system design prevents ambient air contaminants from entering the enclosure.

NOTE: An air-to-air heat exchanger cannot reduce the internal enclosure temperature below the external ambient temperature.

AIR CONDITIONERS

The air conditioner is the only thermal management device that can reduce the internal enclosure temperature below the external ambient temperature. This is the most effective and the most costly thermal solution, but it may be required in some applications.

The air conditioner also removes humidity from the enclosure and keeps out ambient air contaminants. The excess heat (in watts) that must be removed from the enclosure can be converted into BTU/hour for proper sizing of the air conditioner.

Please refer to Figure 3.

Figure 5: Watts and BTU/hr Conversion

DRIVE OVER SIZING

In a variable frequency drives design, heat sinks, fans, shields, and component spacing are used to keep all components of the design within their maximum operational temperature. The variable frequency drives component or package is typically designed for continuous operation at rated load in a 40°C ambient environment.

Oversizing a variable frequency drive for the load allows it to operate below its maximum continuous output current rating. The lower output current allows the variable frequency drive to run cooler, which allows for a higher ambient temperature. Consult the variable frequency drives' manufacturer or instruction bulletin for derating information.

OUTDOOR APPLICATIONS

Outdoor applications introduce another set of thermal factors. The designer must consider direct sunlight, extreme ambient temperatures, and condensation. In order to design a reliable outdoor installation for electronic equipment, an "indoor" type of environment must be created.

The proper size and type of enclosure combined with various thermal management devices and techniques can create the proper environment. Such devices and techniques include: stirring fans, forced ventilation, heat exchangers, air conditioners, sun shields, shelters, paint color, strip heaters, derating, and component layout.

SOLAR CONTRIBUTION

In an unshaded outdoor environment, direct sunlight has a negative impact on total temperature rise. Paint color and sun shields are the most economical methods to reduce solar contribution. These methods are discussed in the following section.

PAINT COLOR

Properly choosing the finish of the enclosure can be an effective means of thermal management for outdoor applications in direct sunlight. The color and texture of the enclosure affect the amount of solar energy absorbed. According to a paper written by Hoffman Enclosures Inc., white is the best color, as illustrated in the chart below.

Table 1: Surface Color and Absorption

Surface Color	% Solar Energy Absorbing
White	14
Polished Aluminum	15
Light Grey	50
Dark Grey	95
Black	97

SUN SHIELDS

Sun shields are another effective method of thermal management for outdoor applications in direct sunlight. Most enclosure manufacturers offer low cost sun shields that attach to the top, back, or sides of the enclosure. The shield blocks the direct sunlight from striking the enclosure surface, and radiates the heat into the atmosphere.

Proper positioning of the enclosure and shields relative to the path of the sun is necessary to achieve the best results. Providing total shade by means of a shelter will eliminate much of the solar contribution, but solar energy reflected onto the enclosure from the foreground should be considered.

ALTITUDE

The density of the ambient air has an effect on its ability to conduct heat. The greater the altitude, the thinner the air, and the lower its heat conduction capability. The widely used industry variable frequency drives rating for maximum altitude is 3300 feet (1000 meters).

Above this altitude, the variable frequency drive's continuous output current may require derating. Consult the variable frequency drive's manufacturer or instruction bulletin for derating information.

HEATERS

It is difficult to think about adding heat inside an enclosure when so much effort is made to get the heat out. However, one must consider the low ambient temperature extremes as well.

If the internal temperature falls below the dew point, condensation may form, which could lead to equipment failure. If this condition is possible, then it is wise to install a thermostatically controlled heater, sized to maintain a minimum internal temperature during the lowest expected ambient temperature.

Another possible solution is to keep the electronics powered up when not in use. The minimum heat dissipation properties of the components may provide enough heat.

The following application information is required to size a heater:

- Heat generated by the electrical/electronic components within the enclosure
- Minimum temperature expected outside the enclosure
- Minimum allowable temperature inside the enclosure
- Surface area of the enclosure

CONCLUSION

When mounting variable frequency drives in electrical enclosures, attention must be given to thermal management in order to ensure maximum product life. The heat that a variable frequency drive produces can be accommodated in several ways. It is the responsibility of the system designer to establish the application criteria and implement a thermal solution that meets the physical and financial requirements of the project.

APPLICATION ASSISTANCE

Most enclosure manufacturers and distributors offer software tools, selection guides, and personal assistance to help you design a reliable installation. These tools and guides can usually be downloaded from their web sites.

The following sources of information are available for Square D variable frequency drives and soft-starts:

- Your Local Square D Sales Office
- Your Local Square D Distributor
- Square D Web Site - www.squared.com
- Square D Product Support Group - 919-266-8600

Square D Company
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www.SquareD.com

Bulletin No. 8800DB0102 April 2001.

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