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COOLING LARGE VARIABLE FREQUENCY DRIVES

Medium-voltage variable frequency drives (VFD) are available in power ranges from 200 to 100,000 kW. High efficiency over a wide speed range, ease of installation, low maintenance and other factors have contributed to increased application of VFDs. Small VFDs (200–5000 HP) are typically air-cooled. As power ratings increase above 5000 HP, liquid cooling is more common because air cooling is not as economical, and liquid cooling reduces the footprint of these higher power drives (see Figure 1).

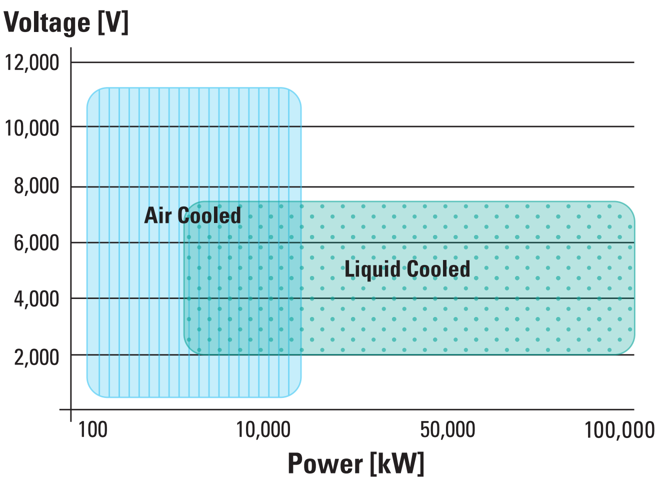

Figure 1. Power vs. voltage for air- and liquid-cooled VFDs

Sources of Heat in a VFD System

Figure 2 shows the basic building blocks of a VFD and motor system. All building blocks shown below are not necessarily needed for every system.

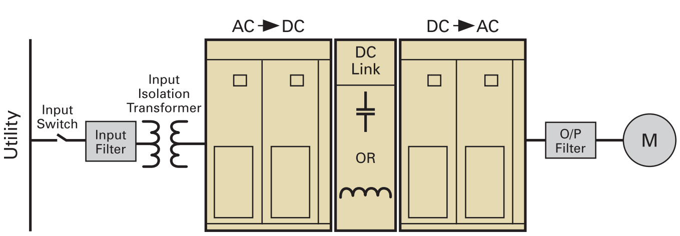

Figure 2. Basic building blocks of VFD system

As shown in Figure 2, the major sources of heat in a VFD are:

1. Input isolation transformer
2. AC-to-DC Converter
3. DC Link (energy storage)
4. DC-to-AC Inverter

The heat contribution by the converter and inverter sections is approximately 75% of the VFD system heat loss. Typically the VFD system itself is 96–97% efficient. The input isolation transformer is typically 98–99% efficient. VFDs that permit component splitting may offer more packaging and cooling alternatives — for example, being able to locate the input transformer separately (or outdoors) from the VFD.

Drive Cooling

In performing its critical operation, a well-selected VFD cooling system provides three major functions:

1. Reliably removes the heat from the power semiconductor devices in the inverter, converter, and from their auxiliary components.
2. Maintains the overall VFD temperature for long system life.
3. When optimized, allows the VFD to deliver rated power with the smallest equipment footprint.

At the present time, there are two methods of cooling a variable frequency drive, air cooling and liquid cooling.

Air-Cooled Variable Frequency Drive

VFD air-cooling works on the principle that heat transfers from hot devices and component surfaces to the mass of air flowing over or past them. Most air-cooled VFDs use fans to force air through the VFD to dissipate heat. Figure 3 shows a front view of an air-cooled VFD.

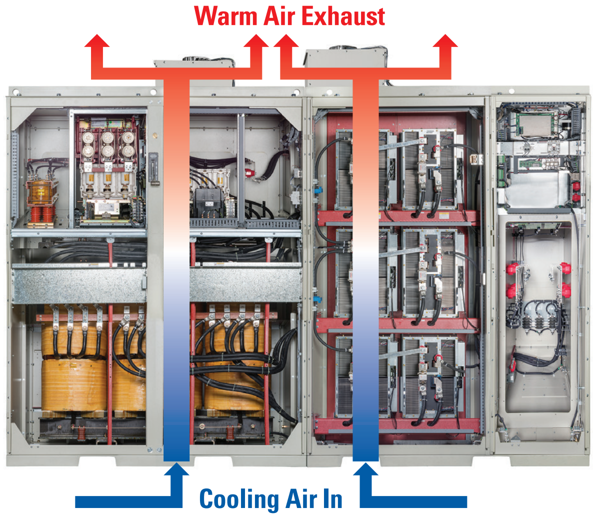

Figure 3. Typical air-cooled VFDs and air flow

Advantages
Air cooling of VFDs is simpler than liquid cooling and has the following advantages:
1. An air-cooled VFD cooling system is self-contained. There are no pumps, hoses, piping, filters, deionizers, or heat exchangers.
2. Servicing/support of the client's HVAC system is more readily available.
3. When applied for starting duty only, smaller VFDs can often be applied to large motors on a short time rating.

Disadvantages
Corresponding disadvantages of an air-cooled VFD include:
1. Air-cooled units usually have a larger footprint compared to a similar size liquid-cooled VFD.
2. Blower fans for cooling the VFD typically have noise levels of 79–82 dB(A) at 1 meter from drive.
3. The VFD area must be kept clean, dry and free of dust. Inspection and maintenance of air filters may be required.
4. HVAC power requirements for cooling the heated air rejected from the drive may be higher than the pumping power required for liquid-cooled VFDs. This should be considered when doing life cycle cost analysis.

Maintenance
Major maintenance items on air-cooled VFDs include:
1. Inspection and cleaning of air filters. In most VFDs, this can be done during operation.
2. Inspection and verification of the HVAC operation for proper cooling, dust or contaminants buildup, and other visible problems.
3. Verify that the VFD location continues to maintain an atmosphere free from dust, moisture and humidity.

Liquid-Cooled Variable Frequency Drive
Liquid-cooled VFD cooling systems are more complex than their air-cooled VFD counterparts. Liquid-cooled systems are engineered for the installation, considering temperature ambient(s), cooling water availability and redundancy level required.

Principles of Liquid-Cooling
Liquid-cooled VFDs include a pump cooling panel consisting of electronic controls, electrical pumps and mechanical equipment to move the liquid through the VFD. This pump cooling panel has a similar role as the industrial fans that draw air into and through air-cooled VFDs. The liquid used in most VFDs is either deionized water or a mixture of deionized water and glycol for low ambient temperature applications. The deionization is required to maintain a low electrical conductivity of the fluid, a requirement imposed by the high voltages that appear on the heat-producing components.

Liquid-Cooling Systems Configurations
There are two major configurations of VFD liquid cooling systems shown in Figure 4.
1. Liquid-cooled VFDs that have an internal liquid-to-liquid heat exchanger, Figure 4a.
2. Liquid-cooled VFDs that are outfitted with an outdoor liquid-to-air heat exchanger for heat dissipation, Figure 4b.

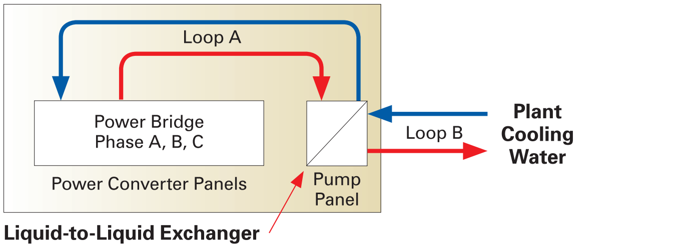

Figure 4a.

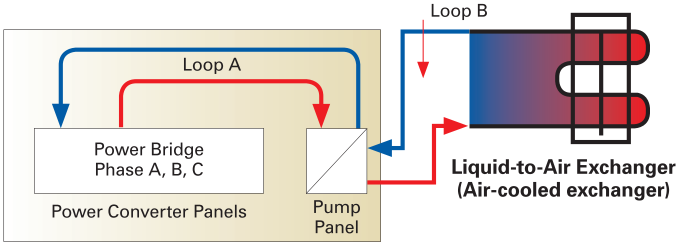

Figure 4b.

Figure 4. VFD liquid cooling system configurations

In the liquid-to-liquid system, Figure 4a, the cooling loop "A" is always a closed loop carrying deionized fluid internal to the VFD through a liquid-to-liquid heat exchanger. The second liquid cooling loop (Loop B) carries the plant cooling water, which takes away the heat picked up from the internal exchanger.

In the liquid-to-air system, Figure 4b, the cooling loop "A" and the cooling loop "B" are actually one common loop carrying deionized fluid. The fluid path passes through the hot drive parts, through the pump panel and out to the external liquid-to-air heat exchanger where it is cooled and returned. Because the heat exchanger is often located outdoors, the cooling fluid must be tolerant of the outdoor ambient temperatures. The fluid may need to include a glycol mixture with the water to inhibit freezing.

Cooling System Arrangement Details
Liquid-cooled VFDs as shown in Figure 4a are fitted with an internal liquid-to-liquid heat exchanger. The two cooling loops in the system are the VFD loop (Loop A), which is the deionized liquid loop, and the plant liquid loop (Loop B). A specific plant liquid

VFD inlet temperature range is required for optimum heat transfer by the cooling system. Liquid-to-liquid systems are less expensive than liquid-to-air systems and more compact. However, liquid-to-liquid systems do require facility cooling water to be brought to the VFD. They are best applied at sites where cooling water is also used to cool other plant processes.

As shown in Figure 4b, VFDs with liquid-to-air heat exchangers typically use outdoor radiator type forced air-cooled exchangers to transfer the heat from the liquid. This is a similar arrangement to a car radiator. One of the benefits is that no plant cooling liquid is required to cool the VFD, making it a very attractive solution for remote VFDs or facilities with no available cooling water. Liquid-to-air systems are more expensive than liquid-to-liquid designs. The higher costs include the exchanger itself, the space and mounting pad for the exchanger, piping and the ongoing expense of the fan operation. Operation depends on the outdoor ambient temperature being cool enough to transfer the heat efficiently. In practice, ambient temperatures of up to 40°C can easily be accommodated by this type of system — higher ambient temperatures may require de-rating of the VFD.

Liquid-Cooled VFD Components, System Details and Functions

VFD cooling systems typically include the following equipment and instrumentation:

1. Motor driven pumps
2. Control system with instrumentation and sensors for conductivity, temperature, pressure and flow
3. Coolant reservoir
4. Heat exchanger
5. Deionizer cartridge and filter
6. Pipes, valves, and actuators

Figures 5a and 5b show typical liquid cooling system process and instrumentation diagrams. This may vary from manufacturer to manufacturer, and even from drive to drive for a particular manufacturer. However, the general concept remains the same.

Liquid is passed through the components at various points within the drive that are in contact with the power semiconductors, diodes and other heat-generating devices. As the VFD delivers power, heat is transferred from the devices to the hot surfaces and then to the liquid flowing through the pump. Then this hot liquid is pumped from the VFD through the heat exchanger. Depending on the selection, heat from the hot liquid is either transferred to the plant cooling water as shown in Figure 5a, or to the air

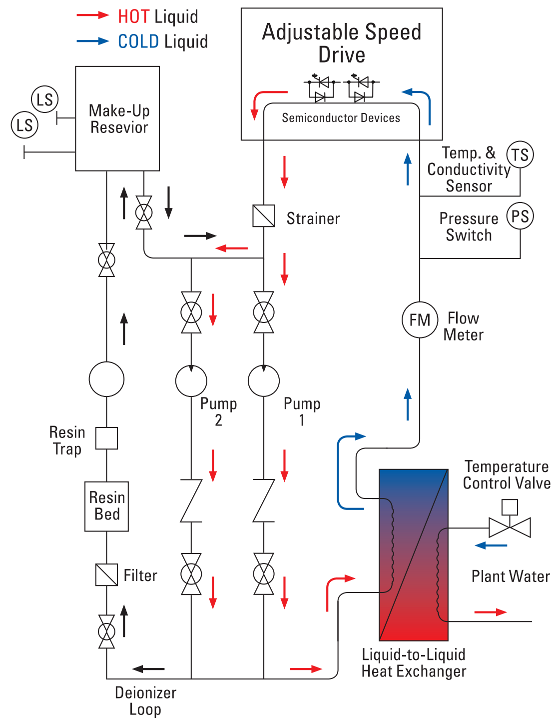

Figure 5a. VFD liquid-to-liquid cooling system

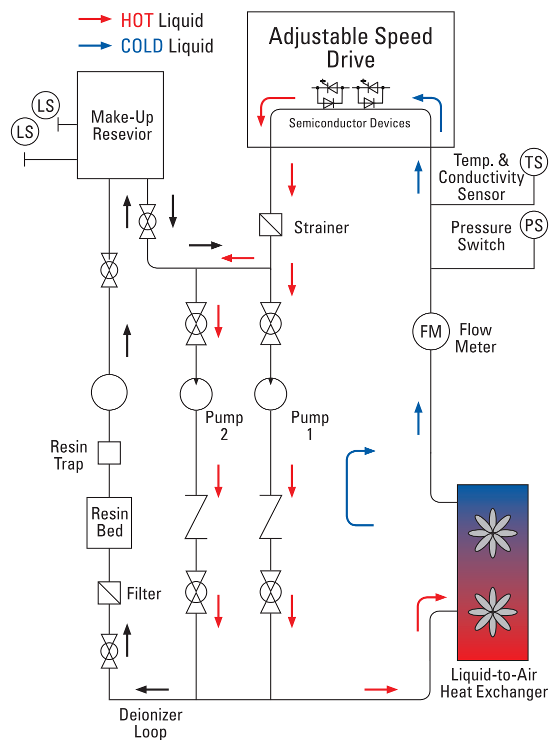

Figure 5b. VFD liquid-to-air cooling system

as shown in Figure 5b. The cooled liquid then flows back to the VFD and the whole process is repeated. Approximately 90% of the heat generated by the VFD is cooled by the liquid, and 10% of the heat is still transferred to the air.

Since the VFD cooling loop liquid must be deionized, a small amount of liquid is always passed through a deionizer DI-resin bed. This maintains the required ultra-low conductivity of the water. Several parameters such as liquid temperature, conductivity and flow are monitored at all times.

Each pump shown in Figures 5a and 5b is sized for 100% full load capacity, enabling the VFD to continue running even if one of the pumps is out of operation. The entire pumping process is managed by a programmable logic controller that is user configurable.

Typical liquid temperatures in the VFD are between 40°C and 52°C, and flow rate ranges from 100 to 700 liters/minute.

Advantages of Liquid-Cooled Systems

1. Liquid-cooled VFDs are designed to dissipate the high levels of heat typical of larger VFDs.
2. A liquid-cooled VFD footprint is smaller than equivalent air-cooled system per kilowatt of delivered power, resulting in lower building and real estate costs.
3. Reduced exposure to airborne pollution gives higher environmental tolerance.
4. HVAC costs are considerably lower compared to an air-cooled VFD of the same power output.

Disadvantages of Liquid-Cooled Systems

While the advantages with a liquid-cooled system often outweigh the disadvantages, there are some limitations:

1. For installations with an outdoor air-cooled heat-exchanger, fan noise can be high and may require sound barriers or special fans to mitigate the noise. Typical fan noise is about 85 dB(A) at 1 meter.
2. Liquid temperature, resistivity and flow must be monitored and controlled at all times.
3. Filter and deionizer cartridges typically need to be replaced every 5 years or when depleted.
4. 10–15% of the VFD heat loss is still dissipated into the electrical room, requiring a corresponding level of HVAC.

Maintenance

Important maintenance tasks on liquid-cooled VFDs include:

1. Inspect and replace the deionizer cartridge as needed. A resistivity meter in the cooling system normally provides advance indication the deionizer needs servicing.
2. Inspect pumps, cooling fans and motors.

Comparative Selection Points of Air-Cooled versus Liquid-Cooled VFDs

In every VFD application, the goal is to minimize initial cost, including installation, and to maximize process payback and energy savings. Knowing the environment in which the VFD will be located, motor power requirements, and the type of load to be driven are key items in accomplishing these goals.

Figure 6 combines these elements into a decision chart. Individual user preference and changing technology affect this selection, as was described earlier.

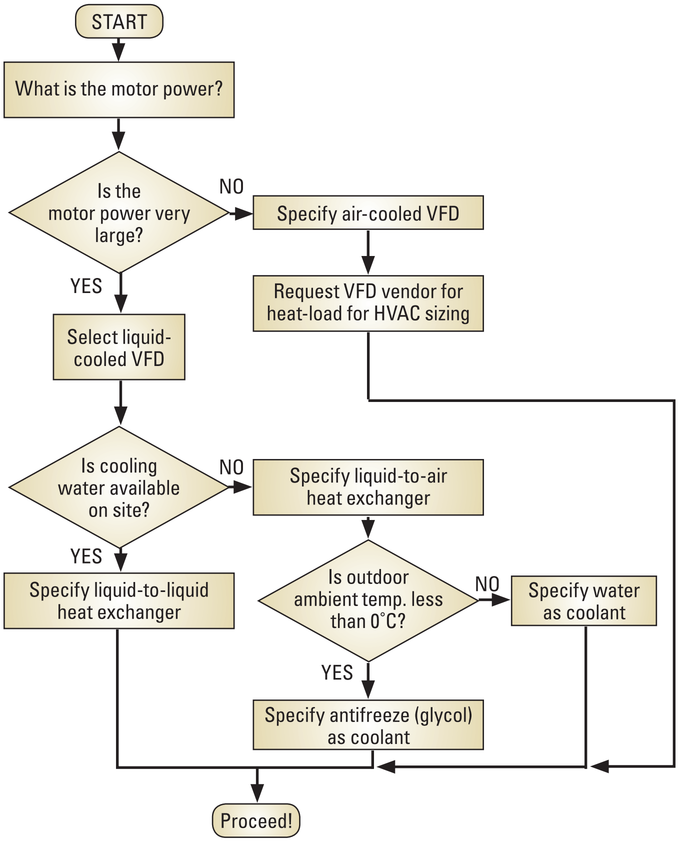

Figure 6. Flowchart on selecting air-cooled vs. liquid-cooled VFD

Conclusion

This article presented the details of VFD cooling systems and why they are a critical consideration during the engineering and design stages of a project. One of the key recommendations is that careful evaluation of each VFD application be made across a range of parameters such as safety, reliability, maintainability, and life cycle costs. This will allow the best decision of air versus liquid cooling.