Adjustable-Speed Drives, Motors For Electric Compression > Cool facts about cooling large units

BY MANISH VERMA AND JAMES NANNEY

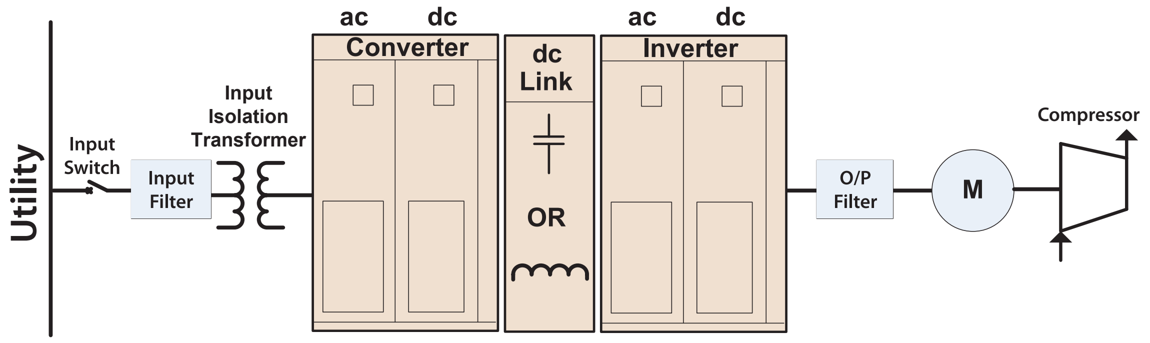

Figure 1. These are the basic building blocks of ASD system.

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The global oil and gas industry has experienced a large push for higher production capacity. At the same time, government and regulatory restrictions across many nations mandate that industrial installations reduce their carbon footprint.

In a typical petrochemical complex, compressors for oil, gas and refrigeration are the major consumers of energy. Historically, many compressors have been driven by gas turbines and engines. However, in recent years, electric motor ratings in the multimegawatt range have become common and economically competitive with turbines. As a result, some end users are selecting electric motors and adjustable-speed drives (ASDs) as compressor prime movers.

ASDs have the benefit of controlling the motor speed and torque that enables precise process control for plants or compressor stations. Small ASDs of 200 to 5000 hp (0.15 to 3.7 MW) are typically air-cooled. However ASDs that are larger than 5000 hp tend to be liquid cooled, since heat dissipation by air is cost prohibitive and not recommended.

In today's economic climate, project time lines have become shorter and more critical. During the engineering and procurement stage, concerns for ASD safety details, reliability, footprint, price, weight and delivery can overshadow the cooling system aspects of the ASD. Since cooling system issues are often seen as life-cycle issues, they may not be included in system evaluations with the same level of detail. This article will delineate the different types of ASD cooling systems, how heat rejection is accomplished and comparative selection points of selecting air-cooled versus liquid-cooled drives.

Sources of heat in an ASD system

Figure 1 shows the basic building blocks of an ASD and motor system. All building blocks shown below are not necessarily needed for all systems. Depending on the ASD topology and the manufacturer, some blocks will be required while some might not be required.

As shown in Figure 1, the four major sources of heat in an ASD are the input isolation transformer, converter, dc link and inverter. The heat contribution by the converter/inverter (rectifiers plus Power Bridge) is approximately 75% of the ASD system heat loss. Typically the ASD system itself is 96 to 97% efficient.

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

- The cooling system removes the heat from the power semiconductor devices in the inverter, converter, and from their auxiliary components.
- The cooling system maintains the overall ASD temperature for long system life.
- The cooling system, when optimized, allows the ASD to deliver its rated power, with the smallest equipment footprint.

By contrast, poorly designed or misapplied cooling systems can result in:

- Premature failure of the semiconductors.
- Risk of operating the ASD beyond thermal limits of the components.
- Leaks from substandard cooling

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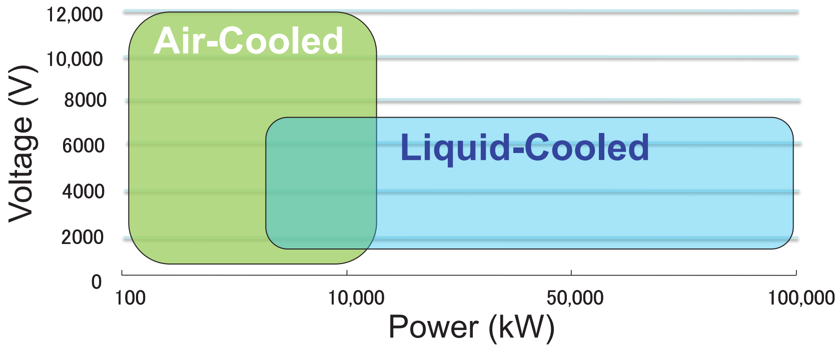


Figure 2. Power vs. voltage for air-/liquid-cooled ASDs.

system material selection (such as pipes, hoses, fittings, connections, etc.). This compromises personnel and equipment safety, long-term reliability, and operation.

At the present time, there are two methods of cooling an ASD. They are air-cooling and liquid-cooling. Depending on the ASD manufacturer, the power range of air-cooled and liquid-cooled may vary. Figure 2 shows a typical power range of air-cooled and liquid-cooled ASDs.

Air-cooled ASDs

Air-cooling of ASDs 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 ASDs use fans to force air through the ASD to dissipate heat. Figure 3 shows a front view of an air-cooled ASD.

Air cooling of ASDs is simpler than liquid cooling and has the following advantages:

- An air-cooled ASD cooling system is self-contained. There are no pumps, hoses, piping, filters, deionizers, or heat exchangers.
- When air-conditioner system repairs are needed, it is easier to find a knowledgeable HVAC service expert.
- When used for starting duty only, smaller air-cooled.
- ASDs can often be applied to large motors.

Corresponding disadvantages of air-cooled ASD include:

- Air-cooled units usually have a larger footprint compared to a similar size liquid-cooled ASD. This requires more space to house the ASD in an industrial control building.
- Since blower fans are used for cooling the ASD, the noise levels produced during operation can be high. Typical noise levels for medium voltage ASDs are 79 to 82 dB(A) measured at 3 feet (1 m).
- Keeping the ASD area clean, dry and free of dust is critical for uninterrupted service. Frequent air-filter checks and change outs are required.
- HVAC power requirements can be eight to nine times higher than the pumping power required for liquid-cooled ASDs. This must be considered when doing compete life cycle costing analysis.

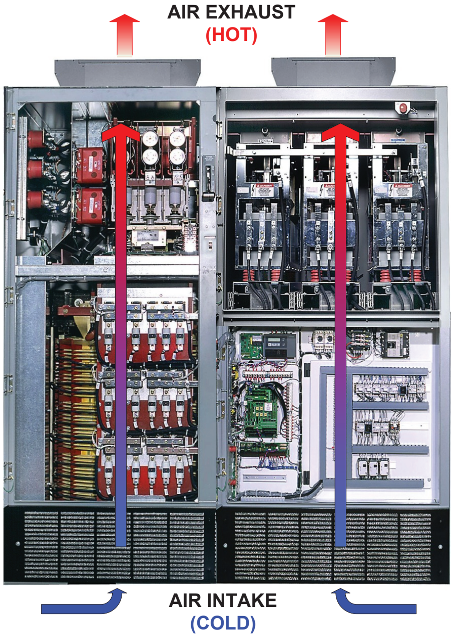


Figure 3. Typical air-cooled ASDs and air flow.

Major maintenance items on air-cooled ASDs include:

- Inspect and clean air filters. In most ASDs, this can be done during operation.
- Inspect and check torque on bolts at major bus bar and cable connections (can only be done at a shutdown time).
- Inspect and verify HVAC operation for proper cooling, internal buildup of dust or contaminants and other visible damage.
- Verify that the ASD location continues to maintain an atmosphere free from dust, moisture and humidity.

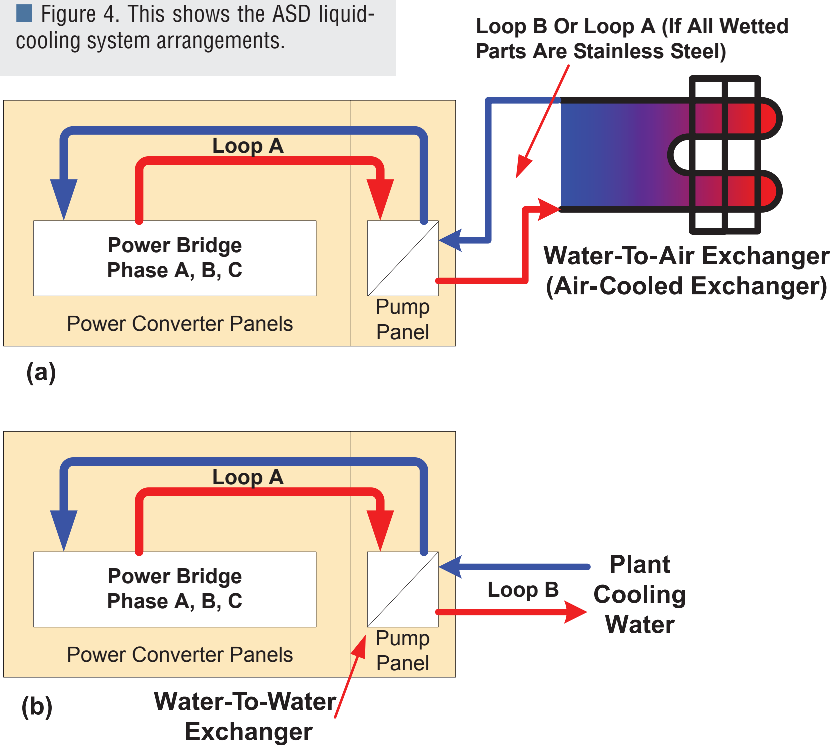
Liquid-cooled ASDs

The liquid cooling systems of liquid-cooled ASDs are more complex than their air-cooled ASD counterparts. Liquid-cooled systems are engineered specifically for the application, considering outdoor ambient temperature, cooling water availability, criticality of the driven process and the level of redundancy required. By nature, liquid-cooled ASD systems are applied to large, multimegawatt levels of motors and loads.

Liquid-cooled ASDs include a pump cooling panel that includes electronic controls, electrical pumps and mechanical equipment to move the liquid through the ASD. This pump cooling panel has a similar role as the industrial fans that draw air into and through air-cooled ASDs. The liquid used in most ASDs is either de-ionized water or a mixture of de-ionized water and glycol for low ambient temperature applications. The de-ionization 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.

There are two major configurations of ASD liquid-cooling systems and shown in Figure 4.

Figure 4. This shows the ASD liquid-cooling system arrangements.



• Liquid-cooled ASDs that have an internal liquid-to-liquid heat exchanger, as shown in Figure 4(a).

• Liquid-cooled ASDs that are outfitted with an outdoor liquid-to-air heat exchanger for heat dissipation, shown in Figure 4(b).

Figure 4 pictorially describes the two major arrangements of ASD liquid cooling systems. Here are some details:

• In the liquid-to-liquid system, Figure 4a, the cooling loop A is always a closed loop carrying de-ionized fluid internal to the ASD 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. Liquid-cooled ASDs that have an internal liquid-to-liquid heat exchanger as shown in Figure 4(a).

• In the liquid-to-air system, Figure 4b, the cooling loop A and the cooling loop B are actually one common loop carrying de-ionized 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 fluid leaves the industrial control building, it must be tolerant of all anticipated outdoor ambient temperatures, and may need to include glycol in a mixture with de-ionized water to inhibit freezing.

Cooling system arrangements

Liquid-cooled ASDs as shown in Figure 4a are fitted with an internal liquid-to-liquid heat exchanger. The two cooling loops in the system are: the ASD loop (Loop A) which is the de-ionized liquid loop, and the plant liquid loop (Loop B). A specific plant liquid ASD 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 the plant to provide high quality cooling liquid to the ASD at the required flow rate and temperature. They are best applied at plant sites where cooling liquid is also used to cool other parts of the process such as motors, vessels, and so forth. The ASD then efficiently uses the available cooling liquid supply.

As shown in Figure 4b, ASDs 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 ASD, making it a very attractive solution for remote ASDs that might be applied to gas-pipeline compressor stations or existing facilities with no available coolant liquid. High reliability is achieved by using redundant cooling fans and pumping systems, with long-life filters and de-ionizer that can be changed without shutting down the ASD.

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 an outdoor ambient temperature being cool enough to remove the heat efficiently and a low enough temperature for full rating. In practice, ambient temperatures of up to 104°F (40°C) can easily be accommodated by this type of system. High ambient temperatures common in some installations may require derating of the ASD, or even the use of chilled liquid from a refrigeration based system to cool the ASD and achieve full power output.

ASD cooling systems typically include the following equipment and instrumentation:

• Motor-driven pumps
• Control system
• Instrumentation and sensors for conductivity, temperature, pressure and flow
• Coolant reservoir
• Heat exchanger
• De-ionizer cartridge and filter
• Pipes, valves and actuators

Figures 5a and 5b show a typical liquid cooling system process and instrumentation diagram. 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 heat sinks at various points within the ASD. The heat sinks are in contact with the power semiconductors, diodes, resistors and other heat generating devices. As the ASD starts delivering power to

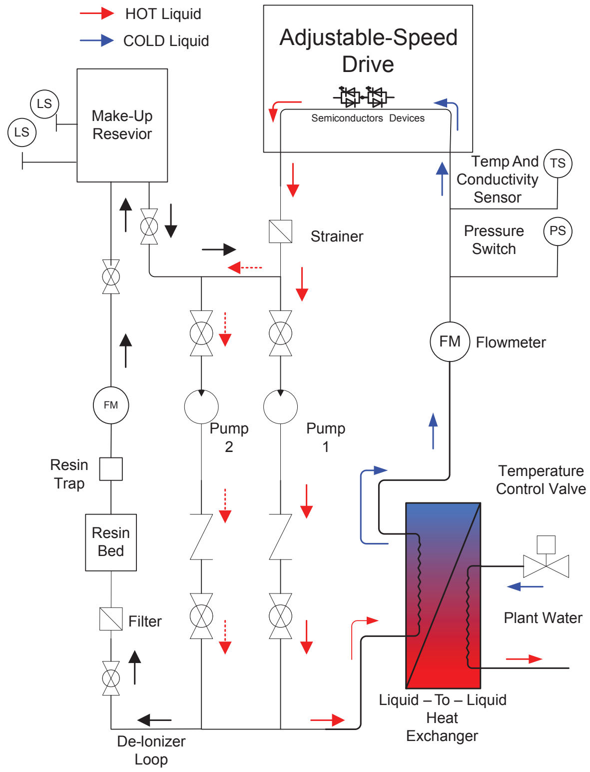


Figure 5a. ASD liquid-to-liquid cooling system.

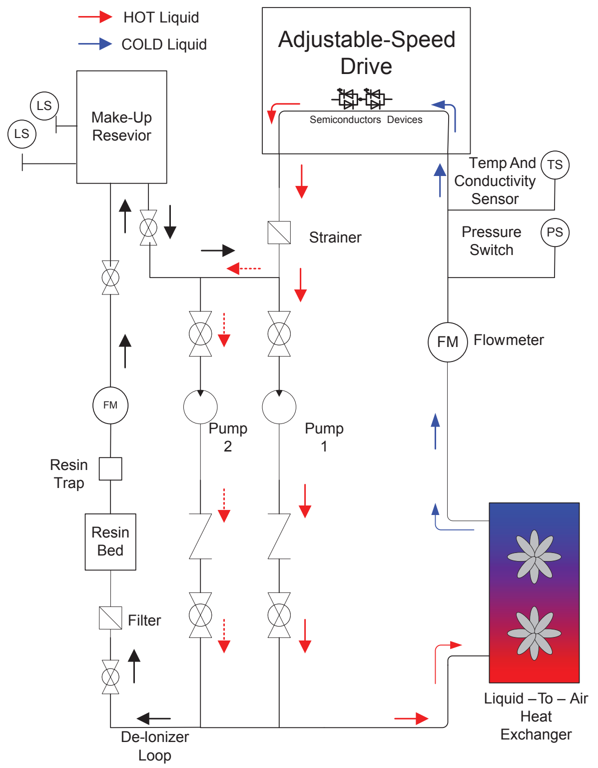


Figure 5b. This is the ASD liquid-to-air cooling system.

the motor, the power devices get hot. Their heat is transferred from the device to the heat sink and then to the liquid flowing through the pump. This hot liquid is pumped from the ASD and passes through the heat exchanger. Depending on the selection, heat from the hot liquid is either transferred to the plant cooling water, shown in Figure 5a, or to the air, shown in Figure 5b. The cooled liquid then flows back again to the ASD and the whole process is repeated again.

Since the ASD cooling-loop liquid must be de-ionized, a small amount of liquid is always passed through a de-ionizer DI-resin bed. This maintains the required ultralow conductivity of the water. Several parameters such as liquid temperature, conductivity and flow are monitored at all times.

Each pump shown in Figures 5a or 5b is sized for 100% full-load capacity. This enables the ASD 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. Figure 6 shows a typical cooling system pumping and control panel.

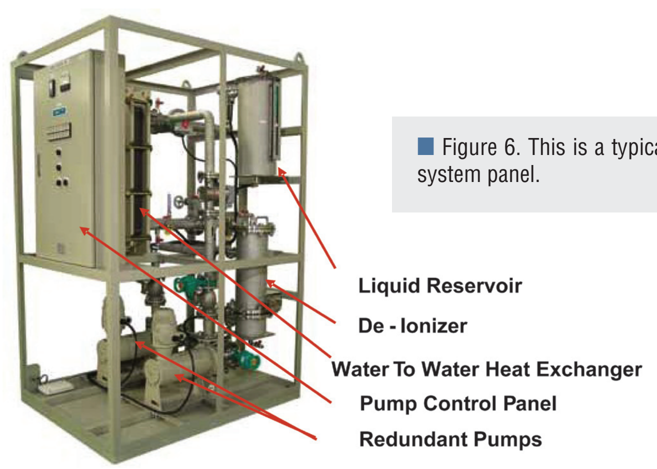


Figure 6. This is a typical cooling-system panel.

Typical liquid temperatures in the ASD are between 113° and 125°F (45° and 52°C) and flow rate ranging from 80 to 185 gal./min (300 to 700 L/min).

Advantages, disadvantages

As ASD power levels increase above 4700 hp (3.5 MW), liquid-cooled ASDs become more and more widely used and available. Key advantages of using a liquid-cooled system over air-cooled systems include the following:

- Liquid-cooled ASDs are designed to dissipate the high levels of heat, typical of large ASDs.
- A liquid-cooled ASD footprint is smaller per kilowatt of delivered power.
- Electrical houses are smaller, resulting in lower building and real estate costs.
- Electrical house noise levels are lower.
- Reduced exposure to airborne

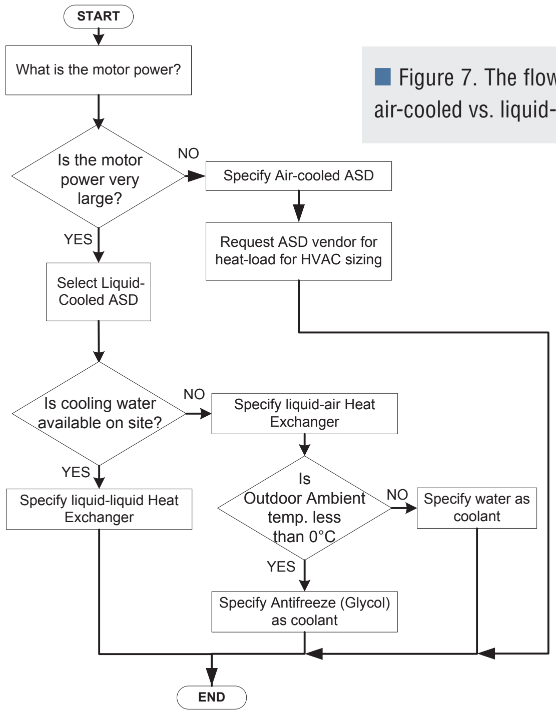


Figure 7. The flowchart on selecting air-cooled vs. liquid-cooled ASD.

based pollution gives higher environmental tolerance.

- HVAC costs are 80 to 90% lower compared to an air-cooled ASD of the same power output.
- Redundancy is often designed in both the pumping system and the fans.

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

- 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 d(B)A at 1 meter.
- Liquid temperature, resistivity and flow must be monitored and controlled at all times.
- Filter and de-ionizer cartridges typically need to be replaced every five years or when clogged. For some designs this can be done while the ASD is in operation.
- From 10 to 15% of the ASD heat loss is still dissipated into the electrical room, requiring a corresponding level of HVAC.

Selection based on output power

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

Figure 7 combines these elements into a decision-making flow chart to illustrate the ASD cooling system selection. While eventually it becomes impractical to build very large ASDs with air-cooling, a hard and fast number for ASD power is not used as a decision making point (first branch in the flowchart). Instead the term "very large" is used to represent the size of decision parameter. Individual user preference and changing technology affects this point, as was described earlier.

Selection effects on ASD footprint

ASD footprint and weight are an important consideration for oil and gas complexes. For onshore installations, real estate might be inexpensive and widely available. However, if ASDs are applied on offshore facilities such as floating units and platforms, then space is at a premium and the weight of the ASD is extremely critical. Figure 8 shows a footprint comparison for a 10,000 hp (7.5 MW) ASD.

Figure 8 compares examples of footprints of an indoor air-cooled ASD and a liquid-cooled ASD of corresponding power level with an external transformer. The air-cooled system indoor footprint is almost double the liquid-cooled footprint. Different technologies, topologies and different

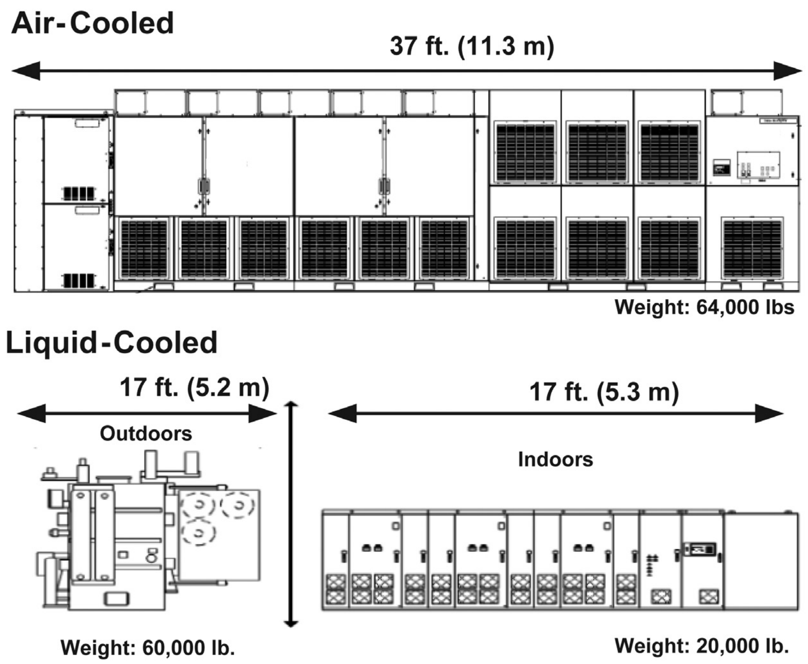


Figure 8. The footprint and weight of a 10,000 hp (7.5 MW) air-cooled and liquid-cooled, adjustable-speed drive.

manufacturers will give different ratios. However, liquid-cooled ASDs deliver more kW/sq.ft. for a given load rating.

The economic effect of a larger footprint will vary. If the ASD is installed in a new portable industrial control building, the cost for a cooled building for an integral transformer, air-cooled drive can be US$300 to 500/sq.ft. or more, including HVAC. The per-square foot cost is significantly less for liquid-cooled drives in the order of US$100 to 200/sq.ft. This is mainly due the savings in space due to compact liquid-cooled ASD.

ASD cooling system selection effects on HVAC and noise

Except for drives packaged for outdoor use, ASDs are designed for use in a temperature controlled environment. This makes HVAC sizing and reliability critical factors in evaluating air-cooled versus a liquid-cooled systems. Consider again the example of a 10,000 hp (7.5 MW) ASD in Figure 8.

For the air-cooled drive, with 96.5% efficiency, it is safe to use a realistic heat load of 4 hp (3 kW) of heat loss per 100 hp (74.6 kW) of motor output power. For the 7.5 MW example, 400 hp (300 kW) of heat will be dissipated. This translates to approximately 86 tons of HVAC rating required. HVAC noise adds to the noise generated by the VFD fans themselves.

Compare this to a liquid-cooled ASD where typically between 85 to 90% of the heat is removed via the heat exchanger with only 10 to 15% dissipated in the electrical building. For the example in Figure 8, with an external transformer, the total converter-inverter loss is 75% of the total or 300 hp (225 kW). The 10 to 15% remainder is between 30 to 45 hp (22.5 to 33.75 kW), which is dissipated in the control building via the HVAC system.

Since the ASD must have a climate controlled environment of 68° to 113°F (20° to 40°C) and 95% noncondensing humidity, varying from supplier to supplier, the reliability of the whole ASD system directly depends on the reliability of the HVAC.

Many ASD installations are specified with redundant HVAC equipment, requiring N+1 supply of cooling units. If one of the HVAC units is down for maintenance or repair, the ASD system can continue operation. This HVAC redundancy adds incremental cost.

Selection effects on costs

The up-front capital and installation costs associated with an ASD system are only part of the lifetime costs. When comparing an air-cooled versus liquid-cooled solution, it is important to look at the overall package rather than the initial costs only.

This includes real estate for installing the ASD, HVAC equipment installation and running costs, cabling, maintenance, downtime, availability, technician training, spare parts, and commissioning.

In conclusion, careful evaluation of each and every ASD application should be performed 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 before a final decision is made. CT2

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